TEMPERATURE INVERSIONS AND AVALANCHE CHARACTER IN THE CENTRAL WASATCH: A STATION BASED ANALYSIS

Haley Brenkmann[1]

1 Salt Lake Community College, Salt Lake City, Utah

ABSTRACT:

Atmospheric temperature inversions form under clear, calm, high-pressure conditions and are shaped by both synoptic weather and local topography. We tested whether inversion strength relates to snowpack and avalanche conditions using 3,777 avalanche observations from Little and Big Cottonwood Canyons (1996–2025), alongside mountain temperature records from the Brighton SNOTEL station (8,790 ft; 2,679 m) and Snowbird SNOTEL station (9,170 ft; 2,795 m), and lower-elevation temperature observations from Hawthorne (4,285 ft; 1,306 m), Rose Park (4,249 ft; 1,295 m), and Salt Lake City International Airport (4,227 ft; 1,288 m). Together, these stations span approximately 4,900 ft (1,500 m) of elevation and allowed us to compare valley and mountain temperatures and characterize the strength and occurrence of temperature inversions across the Salt Lake Valley–Central Wasatch elevation gradient.

Strong-inversion days had higher storm water equivalent, narrower avalanche crowns, and a different mix of avalanche problem types ($p < 0.001$ for all). PM2.5 concentrations were nearly twice as high on strong-inversion days (16.8 vs. 8.8 μg/m³, $p \approx 2\times10^{-45}$), confirming the measure as a valid valley-scale signal. Strong inversions did not increase avalanche frequency: daily counts were actually lower (3.30 vs. 4.46, $p = 0.0027$). Persistent-weak-layer avalanches were not associated with stronger inversions on the day they occurred. However, the strongest inversion anomalies occurred approximately 2–3 weeks before these avalanches. This timing is consistent with inversions creating cold, stable conditions favorable for surface-hoar formation, followed by burial of that weak layer during subsequent snowfall and eventual avalanche release.

Overall, these results suggest that temperature inversions are more closely associated with snowpack development and avalanche characteristics than with an immediate increase in avalanche activity. The delayed relationship between strong inversions and persistent-weak-layer avalanches is particularly important, indicating that inversion periods may help identify atmospheric conditions favorable for weak-layer development weeks before avalanche release. Rather than serving as a direct predictor of avalanche frequency, inversion strength may therefore provide useful context for understanding how periods of cold, stable weather influence the evolution of persistent avalanche problems in the Central Wasatch.

KEYWORDS**:** temperature inversion; avalanche; snowpack; Wasatch; SNOTEL; cold-air pooling

1. INTRODUCTION

Temperature inversions are a common feature of winter weather in the Salt Lake Valley and Central Wasatch. During an inversion, colder air becomes trapped at lower elevations while warmer air remains above, producing a temperature structure opposite the typical decrease in temperature with elevation. The complex topography of the Wasatch can strengthen cold-air pooling and create substantial temperature differences between valley and mountain environments.

Although inversions are often discussed in relation to valley air quality, their potential relationship with mountain snowpack development is less clear. Extended periods of clear skies, weak winds, and cold temperatures can alter the snow surface and favor the formation or preservation of weak snow, including surface hoar and near-surface faceted crystals. If these layers are subsequently buried by snowfall, they can persist within the snowpack and contribute to persistent weak-layer avalanche problems. This suggests that the influence of an inversion may occur well before an avalanche release rather than appearing as a same-day relationship.

https://doi.org/10.15788/1790098896

The Central Wasatch provides an opportunity to examine this relationship because long-term weather observations span a large elevation gradient between the Salt Lake Valley and surrounding mountains, while extensive avalanche records are available for Little and Big Cottonwood Canyons. Comparing temperatures between valley stations at Hawthorne, Rose Park, and Salt Lake City International Airport and higher-elevation stations at Brighton and Snowbird allows inversion conditions to be evaluated alongside documented avalanche activity.

This study investigates whether the strength and timing of valley-to-mountain temperature inversions are associated with subsequent snowpack and avalanche characteristics in the Central Wasatch. Particular attention is given to persistent-weak-layer avalanches and whether inversion conditions preceding these events differ from those occurring on the day of avalanche release. By examining both immediate and lagged relationships, this study evaluates whether inversions may provide useful atmospheric context for understanding the development of persistent avalanche problems.

2. DATA AND METHODS

2.1 Avalanche dataset

The avalanche dataset initially contained 4,958 event records from Little and Big Cottonwood Canyons in the Central Wasatch, Utah, spanning 26 December 1996 through 16 October 2025. After removing 728 exact duplicate records and consolidating 329 otherwise identical records containing different storm water equivalent (SWE) values by averaging the duplicate SWE measurements, 3,777 unique avalanche events remained for analysis.

The dataset included avalanche date, location, avalanche characteristics, storm SWE, and, where available, avalanche problem type. Avalanche records were matched with meteorological observations by calendar date.

2.2 Valley and mountain temperature data

Temperature observations were collected from five stations spanning approximately 4,900 ft (1,500 m) of elevation between the Salt Lake Valley and Central Wasatch. Mountain temperatures were obtained from the Brighton SNOTEL station (site 366; 8,790 ft; 2,679 m) and Snowbird SNOTEL station (site 766; 9,170 ft; 2,795 m). Valley temperatures were obtained from Hawthorne (4,285 ft; 1,306 m), Rose Park (4,249 ft; 1,295 m), and Salt Lake City International Airport (4,227 ft; 1,288 m). Using multiple stations at both elevations provided a broader representation of regional temperature structure and reduced reliance on conditions at any single site.

Station observations were matched by calendar date, and inversion strength was characterized from the temperature contrast between the lower-elevation valley stations and higher-elevation mountain stations. Under typical atmospheric conditions, air temperature decreases with elevation. Inversion conditions occur when this vertical temperature gradient weakens or reverses, leaving relatively colder air at lower elevations and warmer air above.

Because the normal temperature relationship between individual stations varies seasonally and can also be affected by station siting and local topography, inversion strength was evaluated relative to the typical monthly valley-to-mountain temperature relationship rather than from a simple warmer-versus-colder threshold. This approach reduced the influence of seasonal and site-specific differences and allowed unusually strong temperature reversals to be distinguished from the normal background temperature gradient.

2.3 Avalanche-dataset temperature fields

The avalanche database contained additional temperature fields separate from the independent weather-station observations. Cross-checking these values showed that some duplicated Brighton daily temperature rather than representing independent measurements at individual avalanche locations.

These fields were excluded from the analysis to avoid circularity. Inversion calculations instead relied on independently obtained valley and mountain weather-station observations.

2.4 PM2.5 validation

Daily PM2.5 observations from the Hawthorne and Rose Park monitoring stations were used as an independent indicator of atmospheric stagnation in the Salt Lake Valley. Winter inversions and cold-air pools suppress vertical mixing, allowing particulate matter to accumulate near the valley floor.

PM2.5 concentrations were compared across inversion-strength categories to determine whether stronger temperature-defined inversions corresponded with greater valley stagnation. Because wildfire smoke can elevate summer PM2.5 independently of inversions, winter conditions were also evaluated separately. PM2.5 was treated as supporting evidence of atmospheric stagnation rather than as a direct measurement of inversion strength.

2.5 Daily avalanche activity

A separate day-level avalanche record was used to examine whether avalanche activity varied with inversion strength. Daily avalanche counts were matched with the inversion record by calendar date.

Because this dataset contains only dates with at least one recorded avalanche, the analysis evaluates the number of avalanches occurring on active avalanche days. It cannot determine whether inversion conditions affect the probability of an avalanche occurring on any given day.

2.6 Lagged inversion conditions before persistent-weak-layer avalanches

The atmospheric conditions associated with inversions may influence persistent weak layers well before avalanche release. Clear skies, weak winds, and radiational cooling can favor the formation or preservation of weak surface snow, including surface hoar and near-surface facets. Once buried, these layers may persist for days to weeks before contributing to avalanche release.

To investigate this lagged relationship, avalanche events with identified problem types were matched to the inversion record by date. For each event, inversion strength was evaluated during the 3, 7, 14, and 21 days preceding the avalanche. The strongest inversion signal within each period was calculated, and persistent-weak-layer avalanches were compared with other avalanche types using Mann–Whitney U tests. This approach tested whether persistent-weak-layer avalanches were systematically preceded by stronger inversion conditions rather than being associated only with inversion conditions on the day of release.

3. RESULTS

3.1 Snowpack and avalanche characteristics by inversion strength

Strong-inversion days were associated with significant differences in several snowpack and avalanche characteristics (Tables 1–2; Figures 1–2). Storm water equivalent (SWE) was higher during strong-inversion conditions than during weak/reverse conditions (18.1 vs. 14.5; Mann–Whitney U, $p < 0.001$). Avalanche crown widths were also significantly narrower during strong inversions (114.0 vs. 184.1 ft, $p < 0.001$). Crown depth did not differ significantly between groups (19.2 vs. 19.8 in., $p = 0.438$).

Avalanche problem type also varied with inversion strength. New Snow avalanches represented 23.8% of events during strong inversions compared with 39.6% during weak/reverse conditions, whereas Wet Snow avalanches represented 20.5% and 4.5%, respectively. Wind Drifted Snow occurred at similar frequencies (24.1% vs. 23.0%), and Persistent Weak Layer avalanches showed relatively little same-day difference between groups (25.6% vs. 29.7%).

Table 1. Avalanche problem type as a percentage of matched events by inversion strength.

Avalanche Problem	Strong Inversion (%)	Weak/Reverse (%)
Persistent Weak Layer	25.6	29.7
Wind Drifted Snow	24.1	23.0
New Snow	23.8	39.6
Wet Snow	20.5	4.5
Gliding Snow	4.6	2.1
Cornice Triggered/Fall/Cornice	1.4	1.0

Table 2. Snowpack and avalanche characteristics by inversion strength.

Metric	Strong Inversion Mean	Weak/Reverse Mean	Mann–Whitney p
SWE	18.1	14.5	< 0.001
Crown Width (ft)	114.0	184.1	< 0.001
Crown Depth (in.)	19.2	19.8	0.438

Figure 2. Storm water equivalent and avalanche crown width by inversion strength.

3.2 Valley PM2.5 and inversion conditions

Valley PM2.5 concentrations were positively associated with inversion strength, particularly during winter. Across the full overlapping record, the relationship was modest ($r = 0.24$) and strengthened when restricted to November–February ($r = 0.29$).

During winter, strong-inversion days had nearly twice the mean PM2.5 concentration of weak/reverse days (16.8 vs. 8.8 μg/m³; Mann–Whitney U, $p \approx 2 \times 10^{-45}$). This relationship supports the temperature-based inversion classification as an indicator of atmospheric stagnation in the Salt Lake Valley. Outside winter, differences were substantially smaller, consistent with additional influences on warm-season PM2.5, including wildfire smoke.

Table 3. Winter valley PM2.5 concentrations by inversion strength.

Inversion Group	Mean PM2.5 (μg/m³)	n
Strong Inversion	16.8	442
Weak/Reverse	8.8	443

3.3 Daily avalanche activity

Inversion strength was not associated with increased avalanche activity. Among the 1,044 avalanche-active days with matched inversion data, inversion strength and daily avalanche count showed a small negative correlation ($r = -0.10$, $p = 0.0009$).

Strong-inversion days averaged 3.30 recorded avalanches per active day compared with 4.46 during weak/reverse conditions (Mann–Whitney U, $p = 0.0027$; Table 4; Figure 4). Because this dataset contains only days with at least one recorded avalanche, these results describe avalanche volume on active days and do not measure the probability of an avalanche occurring on any given calendar day.

Table 4. Daily avalanche activity by inversion strength.

Inversion Group	Mean Avalanches per Active Day	Total Avalanches	Number of Days
Strong Inversion	3.30	811	246
Weak/Reverse	4.46	1,227	275

3.4 Lagged inversion conditions before Persistent Weak Layer avalanches

Persistent Weak Layer (PWL) avalanches showed a substantially different relationship with inversion strength when antecedent conditions were considered. During the three days immediately preceding release, PWL avalanches had a lower peak inversion anomaly than other avalanche types (0.57 vs. 1.00; $p = 2.6 \times 10^{-13}$). This difference decreased at seven days and reversed at longer lag periods.

Within the 14-day window, PWL avalanches were preceded by stronger peak inversion anomalies than other avalanche types (4.20 vs. 3.67; $p = 2.1 \times 10^{-8}$). The difference was greatest over the 21-day window, when PWL avalanches had a mean peak anomaly of 5.31 compared with 4.30 for all other avalanche types ($p = 2.6 \times 10^{-37}$).

These results indicate that PWL avalanches were not associated with particularly strong inversions immediately before release. Instead, stronger inversion conditions occurred approximately two to three weeks beforehand, consistent with a delayed relationship between atmospheric conditions favorable for weak-layer formation or preservation and subsequent avalanche release.

Table 5. Peak inversion-strength anomaly in fixed periods preceding Persistent Weak Layer avalanches compared with all other avalanche types.

Window Before Avalanche	Persistent Weak Layer Mean	All Other Types Mean	Mann–Whitney p
3 days	0.57	1.00	2.6×10^{-13}
7 days	2.45	2.58	1.3×10^{-4}
14 days	4.20	3.67	2.1×10^{-8}
21 days	5.31	4.30	2.6×10^{-37}

4. DISCUSSION

The results indicate that temperature inversions are associated with measurable differences in snowpack and avalanche characteristics, but not with increased same-day avalanche activity. Strong-inversion days had higher storm water equivalent (SWE), narrower avalanche crowns, and a different distribution of avalanche problem types. These relationships suggest that inversion strength reflects broader atmospheric conditions influencing the mountain snowpack rather than acting as a direct cause of instability. This interpretation is consistent with Rupp et al. (2020), who showed that inversion development reflects interactions among synoptic weather, topography, and local surface processes.

The valley observations provide additional support for the inversion classification. By comparing lower-elevation temperatures from Hawthorne, Rose Park, and Salt Lake City International Airport with mountain observations from Brighton and Snowbird, the analysis captures temperature structure across a much larger elevation gradient than a comparison between the two mountain stations alone. Higher winter PM2.5 concentrations during strong-inversion conditions provide an additional, independent indication of atmospheric stagnation and cold-air pooling in the Salt Lake Valley. PM2.5 does not directly measure inversion strength, but its association with the temperature classification supports the interpretation that the identified periods represent meaningful valley-scale atmospheric conditions.

Same-day avalanche activity showed a different pattern. Strong-inversion days averaged fewer avalanches per active day than weak/reverse days (3.30 vs. 4.46), and Persistent Weak Layer (PWL) avalanches were not more common during strong inversions. These findings provide no evidence that stronger inversions correspond to greater immediate avalanche activity. Instead, the associations with SWE, crown width, and avalanche problem type suggest that inversion conditions are more closely related to the environmental setting and snowpack state than to same-day instability. Because the analysis is observational, these relationships should not be interpreted as evidence that inversions directly produce the observed snowpack differences.

The lagged analysis provides the strongest evidence for a relationship between inversions and persistent avalanche problems. PWL avalanches were preceded by relatively weak inversion conditions during the three days immediately before release but stronger inversion anomalies during the preceding 14–21 days. This temporal pattern is consistent with a sequence in which clear, stable weather favors the formation or preservation of weak surface snow, followed by a transition to stormier conditions that buries and loads the weak layer before eventual avalanche release. The analysis does not identify the weak layer directly and therefore cannot establish surface hoar as the mechanism. However, the timing supports the broader hypothesis that inversion-associated weather may be relevant to weak-layer development weeks before an avalanche occurs.

The association between strong inversions and narrower avalanche crowns remains unexplained. Inversion strength may covary with other factors that influence avalanche size, including storm characteristics, terrain, aspect, wind exposure, or the spatial continuity of weak layers. Differences in observation and reporting may also contribute to the pattern. Without controlling for these variables, inversion strength cannot be interpreted as the cause of narrower crowns. Future work incorporating terrain, aspect, wind, weak-layer observations, and individual storm cycles could help determine whether this relationship represents a physical snowpack response or an artifact of the observational record.

Overall, the results support viewing temperature inversions as an atmospheric context for snowpack evolution rather than as a direct indicator of avalanche occurrence. Their potential value appears greatest at longer lead times, particularly for identifying periods that may favor the development or preservation of persistent weak layers before those layers are buried and become an avalanche problem.

5. LIMITATIONS

Several limitations should be considered when interpreting these results.

- **Station representativeness:** Inversion strength was derived from temperature observations spanning the Salt Lake Valley and higher-elevation Central Wasatch. Although the use of Hawthorne, Rose Park, Salt Lake City International Airport, Brighton, and Snowbird provides a broader elevation gradient, individual stations are still influenced by local topography, exposure, land cover, and instrument siting. Station temperatures may therefore differ from conditions at specific avalanche locations.
- **Temporal rather than spatial matching:** Avalanche events were matched to meteorological observations by date rather than by individual avalanche path. Local temperature, wind, radiation, and snow conditions may have varied considerably within Little and Big Cottonwood Canyons on the same day.
- **PM2.5 is supporting evidence, not a direct inversion measurement:** Elevated winter PM2.5 is consistent with atmospheric stagnation and cold-air pooling, but pollutant concentrations are also influenced by emissions, transport, and other meteorological factors. PM2.5 therefore provides independent supporting evidence for inversion conditions rather than a direct measurement of inversion strength.
- **Observational relationships do not establish causation:** The associations between inversion strength, SWE, avalanche characteristics, and problem type may reflect common synoptic or local environmental conditions. The analysis cannot establish that inversions directly caused the observed snowpack or avalanche differences.
- **Important environmental variables were unavailable:** The dataset did not consistently include solar radiation, cloud cover, wind exposure, canopy cover, or avalanche-path aspect. These factors can influence both local temperature structure and snow-surface processes and could contribute to the observed relationships.
- **Crown-width relationship is exploratory:** The association between stronger inversions and narrower avalanche crowns was statistically significant but does not yet have an established physical explanation. Additional analysis controlling for terrain, avalanche type, storm conditions, and reporting practices is needed before interpreting this relationship mechanistically.
- **No zero-avalanche baseline:** The daily avalanche-count dataset contains only days with at least one recorded avalanche. Consequently, the analysis evaluates avalanche volume on active days rather than whether inversion conditions affect the probability of avalanche occurrence. A complete daily record including zero-avalanche days would be required to test occurrence probability.
- **Lagged Persistent Weak Layer relationship does not identify the weak-layer mechanism:** The stronger inversion signal 14–21 days before Persistent Weak Layer avalanches is consistent with atmospheric conditions that may favor weak-layer formation or preservation, including surface hoar or near-surface faceting. However, snow-pit or weak-layer observations were not linked directly to individual avalanche events, so the analysis cannot determine which weak layer was present or demonstrate that inversion conditions caused its formation.

Overall, these limitations mean the results should be interpreted as evidence of statistical relationships between inversion conditions and avalanche-related variables rather than as proof of a direct causal connection.

6. CONCLUSIONS

Using temperature observations spanning the Salt Lake Valley and Central Wasatch, this study found that inversion strength was associated with measurable differences in snowpack and avalanche characteristics. Strong-inversion days had higher storm water equivalent, narrower avalanche crowns, and a different distribution of avalanche problem types. Higher winter PM2.5 concentrations during strong inversions provided additional evidence that the temperature-based classification captured periods of valley-scale atmospheric stagnation.

Strong inversions were not associated with greater same-day avalanche activity. Avalanche counts were lower on strong-inversion days, and Persistent Weak Layer avalanches showed no meaningful same-day association with stronger inversions. Instead, the strongest relationship emerged at longer lead times: Persistent Weak Layer avalanches were preceded by stronger inversion conditions approximately 2–3 weeks before release. This timing is consistent with stable weather contributing to the formation or preservation of weak surface snow that is subsequently buried and loaded, although the specific weak-layer mechanism could not be confirmed.

Overall, temperature inversions appear to provide greater insight into the atmospheric conditions associated with snowpack evolution than into immediate avalanche occurrence. Their potential forecasting relevance may therefore lie in recognizing periods favorable for persistent weak-layer development or preservation rather than predicting same-day avalanche activity. The relationship between inversion strength and narrower avalanche crowns remains unexplained and provides an additional direction for future research.

REFERENCES

McClung, D. M. and P. A. Schaerer, 2006. *The Avalanche Handbook*, 3rd ed., The Mountaineers, 347 pp. (pp. 345–359).

Rupp, D. E., Shafer, S. L., Daly, C., Jones, J. A., and Frey, S. J. K., 2020. Temperature gradients and inversions in a forested Cascade Range basin: Synoptic- to local-scale controls. *J. Geophys. Res. Atmos.*, 125, e2020JD032686, https://doi.org/10.1029/2020JD032686.

U.S. Environmental Protection Agency, 2026. Air Quality System (AQS) Data Mart: Daily PM2.5 Concentration and AQI, Hawthorne and Rose Park monitoring sites, Salt Lake County, Utah. https://www.epa.gov/aqs.

USDA Natural Resources Conservation Service, 2026. SNOTEL Site Information: Brighton (366) and Snowbird (766), Utah. National Water and Climate Center, https://wcc.sc.egov.usda.gov/nwcc/.