AN ANALYSIS OF FORECASTER ACCURACY IN PREDICTING AVALANCHE PROBLEM TYPE AND LIKELIHOOD IN SKI AREA OPERATIONAL HAZARD ASSESSMENTS

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ABSTRACT: Forecasting staff at Mt Rose Ski Tahoe have been utilizing the InfoEx International product to issue daily hazard assessments and record avalanche activity within ski resort terrain since 2019. In order to improve our forecasting process, we reviewed the past four seasons data to determine if operational AM Hazard Assessments were providing an accurate representation of observed conditions. Our aim was not only to quantify forecast accuracy, but to identify any steps within the Conceptual Model of Avalanche Hazard (CMAH) based process that were prone to error.

Utilizing hazard assessment and avalanche observation data recorded in InfoEx, we compared avalanche problem type, distribution, and sensitivity on AM and PM operational hazard assessment forms to determine the frequency which forecast avalanche problem, sensitivity, distribution, and likelihood differed from observed problems. We also analyzed days when widespread natural avalanche activity and remote triggering were observed to evaluate whether conditions were accurately described in the morning assessment.

Comparing AM with PM Hazard Assessments, adjustments were made to the avalanche problem type in 4% of total forecasts and sensitivity rating 13% of the time. A retrospective look at AM forecasts compared to results from avalanche mitigation work appears to demonstrate a tendency to describe more avalanche problems within the AM hazard assessment than are observed during the subsequent day. Major cycles of natural avalanche activity were well captured in the AM assessment, however, natural releases involving persistent slab problems were sometimes not anticipated.

Use of a CMAH based workflow process appears to provide an accurate method to anticipate hazard conditions within ski resort terrain. Ski resort operational data provides a robust data set for evaluating hazard assessment, as routine slope testing with explosives for operational objectives provides immediate feedback on forecast accuracy.

KEYWORDS: Avalanche Forecasting, Ski Resort Operations, Conceptual Model, InfoEx, Avalanche Problem Type, Avalanche Likelihood

1. INTRODUCTION

In 2019, avalanche forecasting at Mt Rose transitioned fully to the InfoEx International program and a hazard assessment process based on the Conceptual Model of Avalanche Hazard (CMAH). After several years of data collection and minor improvements to the workflow process, we aimed to find tools to more effectively evaluate the accuracy of avalanche hazard assessments and identify any common pitfalls within the process.

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Evaluating the accuracy of any avalanche forecast is challenged by potentially sparse data of avalanche observations from the forecast period (Champion et al, 2023). However, ski area operational objectives of opening terrain and mitigating risk necessitate frequent slope testing with explosives and ski cutting. This provides a relatively complete and unbiased dataset for evaluating the day's forecast.

The Conceptual Model of Avalanche Hazard (CMAH) provides a structure for evaluating the likelihood of avalanche activity based on avalanche distribution and sensitivity to triggers (Statham et al 2017). Feedback from

forecasters and route leaders suggested that anticipating avalanche problem sensitivity may be a challenge for a variety of reasons, including the temporal nature of this variable as well as the descriptive scale within CMAH. As any inaccuracies in sensitivity assessment will ultimately affect the process outputs of avalanche likelihood and the overall hazard rating, we wanted to determine if this was in fact a problematic step in the process.

2. BACKGROUND

Mt Rose Ski Tahoe operates on a combination of private and USFS lease land within the Carson Range of Western Nevada. The resort operating area is classified as Class A avalanche terrain and includes an approximately 200 acre area of complex terrain known as the Chutes. Routine avalanche mitigation work and hazard forecasting has occurred for this area for 20+ years and the resort has built a robust snow safety program. In 2019, the snow safety program transitioned all forecasting and avalanche recording observations to the InfoEx International program.

Forecasting staff at Mt Rose Ski Tahoe utilize the CMAH within a customized InfoEx International workflow to issue daily AM Avalanche Hazard Assessments for ski resort terrain and PM Nowcasts on days when avalanche mitigation work has been completed. AM Hazard assessments are typically completed prior to daily operations, and constitute a forecast of expected conditions for the next 24 hours. PM assessments are typically issued in early afternoon and follow a nowcast format, describing conditions as experienced during daily operations. Both AM and PM workflows describe the avalanche problem type using the nine avalanche problems described in CMAH (Statham et al 2017). Sensitivity is described using the four step scale, and distribution a three step scale; together this output determines likelihood. Avalanche size is described using the D-scale classification and an overall hazard rating is issued for resort terrain based on the North American Public Danger Scale (AAA, 2022).

Avalanche observations within ski area terrain are recorded and shared within the same InfoEx International database as daily hazard assessments. Results from artificial and natural triggers are recorded following SWAG guidelines (AAA 2022). All avalanche mitigation work is described whether or not avalanches result from mitigation efforts. Whenever possible, avalanche observations are linked to an avalanche problem type during the recording process, however, observations made during times of poor visibility and intentional triggers that do not produce associated avalanche activity are not linked to an avalanche problem.

3. METHODS

Operational records of hazard assessment and avalanche activity from 2019-2024 were queried and exported in CSV format from the InfoEx database. Three methods were utilized to evaluate the accuracy of AM Hazard assessments.

3.1 *Comparison of AM and PM Assessments*

From 2021-2024, a total of 118 PM Nowcasts and 283 AM Hazard Assessments were recorded. AM Hazard Assessments were compared to the PM Nowcast on all 118 days when a PM assessment was completed. Differences in avalanche problem type, sensitivity, and distribution were identified. Although an important part of the hazard assessment process, avalanche size was not compared due to the tendency of forecasters to describe a size range within the AM assessment.

3.2 *Analysis of Natural Avalanche Activity*

The avalanche observation dataset was queried for dates where natural avalanche activity and/or remote triggering were reported. The AM Hazard Assessment was reviewed for each date to verify if the morning forecast described a sensitivity and likelihood where natural avalanches would be expected to occur. Days where avalanche problems were forecast as ‘touchy’ or ‘reactive’ were considered to be an accurate estimation of conditions, while days where problems were described as ‘stubborn’ or ‘unreactive’ yet natural activity occurred were labeled as outliers.

3.3 *Nowcast based on Control Results*

Twenty days from 2019-2024 where avalanche mitigation work was completed were randomly selected for analysis. Utilizing the avalanche activity recorded during those dates, current members of the snow safety team retroactively produced a shortened version of a PM Nowcast including avalanche problem type, sensitivity,

distribution, likelihood, size, as well as assigning a danger rating. PM Nowcasts were compared to the original AM Hazard Assessment for that date. Differences in avalanche problem type, sensitivity, and distribution were recorded.

4. RESULTS

4.1 *Comparison of AM and PM Assessments*

Several trends were noted in the comparison of AM to PM Hazard Assessments as forecasting staff updated avalanche problem type and sensitivity based on conditions observed during avalanche mitigation work. Avalanche problem types were added or removed and problem sensitivity and therefore likelihood was updated on PM assessments based on conditions.

Avalanche problem type was changed on 10% of PM assessments. This represented 4% of total forecasts issued for 2021-2024. The problem sensitivity was modified on 30% of PM forms or 13% of total forecasts. Avalanche problem distribution was updated on 3% of PM forms and 1% of total forecasts.

Several trends emerge when modifications to the PM assessment are broken down by avalanche problem type (fig 1). Storm slab and wind slab are the most frequently forecast avalanche problems followed by persistent slab. Storm slab problems were most frequently added or removed from the PM assessment, while wind slab problems were rarely added or removed. Although wind slab problems were rarely modified, this problem saw the most adjustments to sensitivity rating, followed by storm slab and persistent slab. Problem sensitivity was increased and decreased with similar frequency.

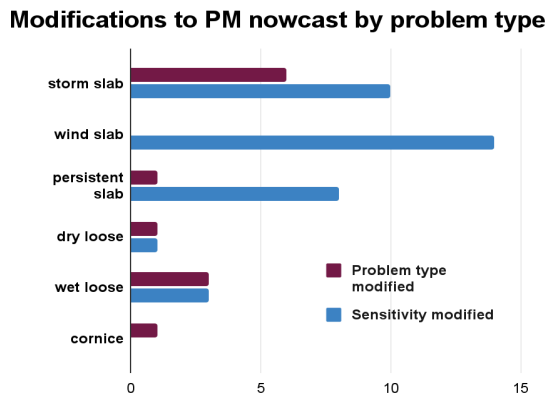

Fig 1. Number of days where modifications to problem type and sensitivity were made on PM Nowcast

4.2 *Analysis of Natural Avalanche Activity*

Natural activity was well described during major cycles, and we did not find a single instance of unanticipated natural avalanche activity during a major storm event between 2019-2024. Two natural and one remote triggered persistent slab release were observed on dates when this problem was forecast as 'stubborn' or 'unreactive.'

4.3 *Nowcast based on Control Results*

PM Nowcasts generated by reviewing only the day's avalanche control work and observations deviated more significantly from the previous AM assessments. Avalanche problem type was modified on 75% of the 20 PM forms completed. In all but one instance, PM assessments eliminated one or more of the multiple avalanche problems originally forecast for that day. This was observed with both new snow problems (storm slab and wind slab) and with persistent slab problems. Avalanche problem sensitivity was modified on 50% of the PM forms (Fig 2).

This may be evidence of a tendency for forecasters to describe more avalanche problem types than are ultimately observed during that day. However, this may also be a major shortcoming of this hindsight based approach to evaluating forecast accuracy. By only looking at the active avalanche problems for the day, rather than the larger picture of weather and snowpack, problems described as being 'unlikely' or 'possible' will not not be recognized if no avalanches are triggered on these layers, even though these layers may still represent a significant concern.

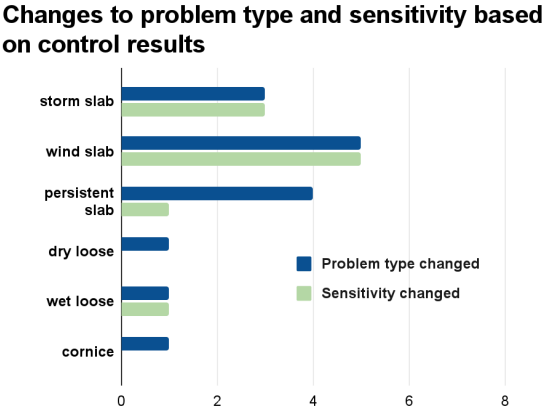

Fig 2. Number of changes made to problem type and sensitivity after analysis of control results

5. CONCLUSIONS

Analysis of four seasons worth of hazard assessment and avalanche observation data has illuminated both strengths and potential limitations to the operational hazard assessment process. AM Hazard Assessments created using a CMAH based workflow in InfoEx appear to provide an accurate forecast of conditions in order to meet operational objectives.

Forecasters were able to reliably identify the anticipated avalanche problem type and distribution of these problems. Natural avalanche activity was predicted accurately during storm cycles, however persistent slab releases proved more challenging to predict. This serves as a reminder to include extra margins when dealing with this problem.

The completion of a PM Nowcast after each day of avalanche mitigation work provides not only an important step in the data collection and review process, but also serves as a learning tool for snow safety staff. PM Nowcasts appear to be the most effective and reliable way to provide both short-term and long-range evaluation of forecast efficacy.

Review of both AM/PM Assessments and Avalanche Control results showed a tendency of forecasters to describe avalanche problems that were ultimately not observed during the day. This likely reflects uncertainty and an abundance of caution, particularly during data sparse periods such as large storm cycles, but may ultimately create confusing messaging during operational meetings. While there may be some advantages to describing new snow problems of storm slab and wind slab separately within the hazard assessment process, there appear to remain some operational challenges of separating these problems by both forecasters and observers.

Due to time constraints of this study, we were unable to examine the relationship between uncertainty and forecast accuracy. Although forecasters assign a confidence rating to each AM assessment and are able to graphically represent uncertainty within the CMAH workflow, we were unable to evaluate any possible impacts higher levels of uncertainty had on forecast accuracy.

Of the components of CMAH, avalanche problem sensitivity was the most challenging aspect for forecasters to anticipate. There may be several possible explanations as to why this component poses difficulty. Sensitivity of an avalanche problem varies on a temporal scale which may not be in optimal alignment with avalanche mitigation efforts or the 24 hour forecasting period. Therefore, we may not be able to accurately observe and describe the actual sensitivity of a given problem. Although CMAH provides guidance for describing avalanche sensitivity based on size and type of trigger, this information is most relevant to the forecaster making observations of avalanche activity as it is occuring. Determining the anticipated sensitivity of an avalanche problem when forecasting future avalanche hazard requires the forecaster's judgment and expertise and may be a potential source of human error.

Data within this study was limited to one operation and snow climate, and one four year period of data collection. The forecast area was limited to ski resort terrain, and forecasters had the advantage of terrain familiarity and an extensive avalanche history within this terrain to draw from. Although six different individuals contributed to forecasting efforts over this time frame, we may still be observing examples of individual biases and interpretation of avalanche hazard definitions (Horton et al, 2023). Although ski resort mitigation work provides a relatively complete data set for evaluating forecast accuracy, weather, visibility, staff safety, and road conditions often pose limitations on both the amount of mitigation work completed and the ability to make complete observations.

No data set is perfect, however ski area operations and the InfoEx platform provide a robust set of data for evaluating the forecasting and hazard assessment process. Future research looking at larger data sets from multiple operations and snow climates could help us better understand human processes of hazard evaluation as well as helping to clarify and build more consistent standards for describing risk.

Although the CMAH workflow process is expected to produce an output that can be linked to a hazard rating system, a well established connection between CMAH descriptions and the widely used North American Public Danger Scale is still lacking. This gap appears to be an entry point for forecaster judgment and bias (Horton et al 2023). It is also a potential source of confusion for both public messaging and in

avalanche education, particularly of newer professionals. In future research, we hope to investigate how forecaster application of the North American Public Danger Scale aligns with observed avalanche activity in resort terrain. Ultimately, use of both backcountry forecasting and ski resort operational data could help build that connection.

ACKNOWLEDGEMENTS:

Portions of this research were completed over the course of forecasting work at Mt Rose Ski Tahoe. This project would not have been possible without the dedication and expertise of the entire patrol and snow safety staff at Mt Rose.

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