LOOKING TO THE FUTURE: PREDICTIONS OF CLIMATE CHANGE EFFECTS ON AVALANCHES BY NORTH AMERICAN PRACTITIONERS

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ABSTRACT: Meteorological data provide a well-defined record of historic climates and climatic trends. Snow avalanche activity, in contrast, has complex contributing factors and is not readily assessed in relation to climate change. Research on climate change effects on avalanche activity is limited, and conclusions vary by region and over time. If current climate warming trends persist or accelerate, the implications for snow avalanche activity could be significant for snow safety professionals, affecting industry, commerce, recreation, transportation and housing.

Recognizing the difficulties of objectively assessing regional effects of climate change on avalanches, we sought opinions, observations and predictions from experienced snow-avalanche practitioners in the U.S. and Canada. Survey questions addressed avalanche types, frequencies, sizes, snowpack structure, length of the avalanche season and changes in forests. Some observations and predictions were consistent for all climate zones, including observed and predicted increases in wet and glide avalanches, and reduced avalanches at low-mid elevations. Observed and predicted forest effects varied with latitude and regional climate. Overall, the survey results indicate clear trends for many avalanche parameters due to climate change. The aggregate observed and predicted magnitudes of change over the next 20 to 30 years were described as “slight.”

While none of us can foresee the future, our combined experience can further our understanding of potential effects of climate change on avalanches. This will facilitate improved planning, infrastructure investments and guide future observations related to climate change and snow avalanches.

KEYWORDS: climate change, snow avalanches, North America.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) has reported that since the 1950s “warming of the climate system is unequivocal” and that “the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.” (IPCC, AR5, 2014). The potential and likely impacts of climate change on snow avalanches is complicated by the many contributing factors, including snow structure, precipitation types and intensities, changes in forests, atmospheric circulation patterns and others.

Weather and climate data in North America are widely available and generally consistent and reliable for scientific study. Avalanche records, in contrast, are much more limited, subjective and incomplete. The highest quality avalanche records tend to be affected by evolving mitigation programs. These limitations led the authors to a social scientific approach to studying this topic. We believe that combined observations of trends and projections can improve understanding needed for planning purposes.

Avalanche practitioners’ careers are on a multi-decade scale, similar to observed climate changes. Avalanche observations greatly exceed the recorded descriptions and measurements of avalanche events. We believe that the cumulative knowledge of many practitioners might be instructive, and possibly superior to individual knowledge for any complex issue.

2. PREVIOUS WORK

A study of long-term avalanche records in the Davos region of Switzerland, by Schneebeli, et. al., (1997) found no systematic trends or periodicity in extreme avalanches and concluded that extreme weather and related severe avalanche periods had remained stable during the past 97 years. More recently, a Swiss study by Pielmeier, et.al, (2013) found that the proportion of wet snow avalanches and full-depth glide avalanche activity during mid-winter season increased from 1952 to 2013. Naaim and Eckert (2016) looked at 30

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years of avalanche activity in France and concluded that run-outs and frequencies have decreased, and that the proportion of avalanches with powder component has decreased. In Austria, Zeidler and Stoll (2016) concluded that wet snow avalanches will become more frequent, low-mid elevations will see a decrease in avalanche activity, upper elevations might see an increase in activity, and overall snow stability will increase due to warming. A study by Laute and Beylich, (2018) in western Norway, where 120 years of avalanche records exist, found that the current trend of warmer, wetter winters may lead to a generally higher snow-avalanche frequency in February and March. They also predict an increase in wet avalanches and slush flows.

In North America, Bellaire, et.al. (2013) studied weather and avalanche data at Rogers Pass in Canada. The mean annual air temperature at two weather stations has increased over the last three decades. The warming was expected to cause early season rain crusts that facilitate deep weak layers and deep slab avalanches later in the season. Significant trends of avalanche activity could not be found. Lazar and Williams (2008) used global and regional climate models to predict the onset of wet avalanche activity at Aspen Mountain in Colorado, USA. Their results indicated that wet avalanches at upper elevations are likely to begin 2 to 19 days earlier by 2030 and 16 to 45 days earlier by 2100, depending on greenhouse gas emissions scenarios.

Publications indicate that interest in climate change and avalanches is increasing, especially in Europe. However, in North America, studies are fewer and findings suggest the need for additional work.

3. METHODS

3.1 Participants

Surveys were sent to 240 North American avalanche practitioners via an email list compiled from sources including ISSW authors, regional avalanche centers, departments of transportation, ski and snowboard resorts, regional avalanche workshops contributors and others. The list was naturally and intentionally skewed towards 20-plus years of experience. Sixteen percent of participants were from Canada. The response rate was 22 percent for 53 total responses. Figure 1 illustrates the sample demographics.

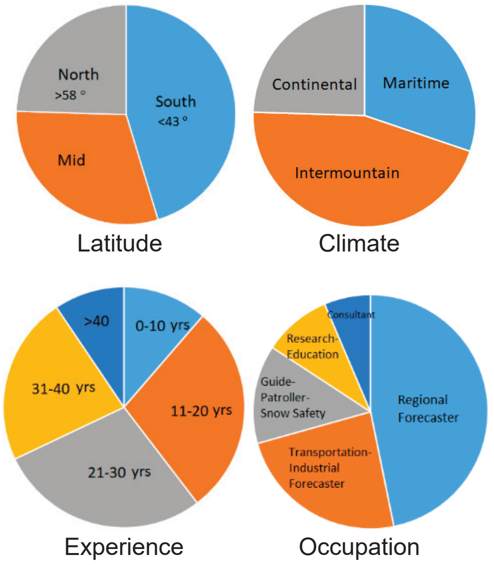

Figure 1: Demographics of Participants.

3.2 Materials

The survey had 24 questions about career observations, future predictions and respondent's region, experience and profession. Topics included observed and predicted changes in wet, glide and dry avalanches; changes to low-mid and upper elevation avalanches; and impacts of forest changes and snowpack stability. The survey responses were made anonymous using Survey Monkey's online service. Responses were coded to allow statistical comparisons among regions, experience levels, professions, as well as aggregated groups and overall responses. Table 1 shows the numeric codes for responses.

Table 1: Numeric coding for responses

1	2	3	4	5
significant	slight	No change	slight	significant
decrease			increase	

4. RESULTS

One Sample t tests with alpha set at 0.05 were used to determine if average responses about observed and predicted changes in avalanche behavior were significantly above or below the midpoint of the scale (3) that represented "no change."

Figure 2 shows respondents reported observed increases in wet, glide, and upper elevation avalanches as well as increased change in snowpack stability (all p<.05). No statistically significant changes were observed for dry, low-mid elevation avalanches, runout length or impacts of forest changes. Participants predicted significant increases for wet, glide and upper elevation avalanches, and increases in snowpack stability/structure. Decreases were predicted in dry and low-mid elevation avalanches (both p<0.02). No overall change was predicted for runout lengths or impacts of forest changes (all p>0.10).

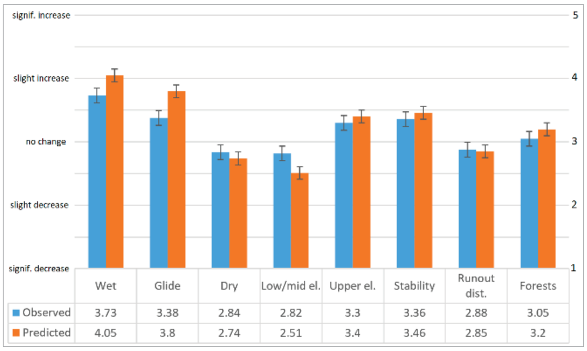

Figure 2: Observed and predicted increases or decreases in avalanche types and properties.

Differences between observed changes and predicted changes were examined using paired t tests with alpha set at 0.05. For wet, and glide avalanches, predicted increases were significantly greater than observed (p=.006 and .01, respectively). For low-mid elevation avalanches, predicted changes were in the direction of decreased activity, although the larger variability in responses about low-mid elevation avalanche behavior indicates greater disagreement between individual responses to those questions (p=.03). No differences were found between observed and predicted responses for dry avalanche behavior, upper elevations, structure or runout lengths (all p>.10).

Pearson Correlation Coefficients were calculated to examine the impact of years of experience on the observations and predictions of participants. Interestingly, none of our responses were significantly correlated to years in the profession. The only correlation that approached significance suggests that those with fewer years of experience reported a stronger increase in observed wet avalanches (r= -.27, p=.06; all other p>.10).

Location of the nearest avalanche center was used to categorize location of respondents in two ways. Locations were divided into three latitude regions with the mid-latitude ranging from about 43 to 58 degrees north. Climate type was also grouped into maritime, intermountain and continental. One-way ANOVAs with alpha set at .05 were used to examine the effects of both latitude and climate type on responses. Sample sizes did not allow for a two-way ANOVA looking for interaction effects of these variables.

Latitude significantly influenced results about effects of forest changes with high latitude expecting less impact of forest, and south latitudes areas expecting higher impacts (p=.004) and low-mid range observed changes, with southern latitudes observing more change (p=.01). No other significant differences were found in responses between these regions (all p>.05).

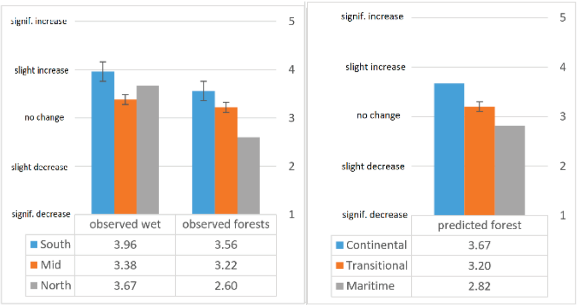

Figure 3: Latitude and Climate Zone observations and predictions for wet avalanches and forest effects.

Differences were found in the predicted, but not observed, climate type responses about impacts of forests, with the most impact predicted by continental respondents (p=.04). No other statistically significant differences were found between the responses from those in different climate types (all p>.10).

5. DISCUSSION

This study was intended as an initial effort to gain insight into effects of climate change on avalanches in North America. It was targeted to a relatively small group of persons selected for their experience and knowledge. The resulting small sample size is an inherent limitation of the study and results. We suspect, but could not confirm significant regional climate differences.

Despite the sample size limits, it is interesting to see that some observations and predictions are consistent across all North American climate zones. Specifically, we should expect more wet avalanches, and more glide avalanches.

Forest effects on avalanches are complicated due to opposing effects of warming-enhanced growth versus forest loss due to fires and insect-caused mortality. Our framing of the question forced respondents to determine a net effect. Written comments suggested slight forest density gains in maritime climates and density losses in continental climates. A similar weak trend is suggested for latitude with northern zones predicted to have slight increases in forests, while southern zones experience slight net losses in forests that may increase avalanche activity. This issue deserves additional study.

The issue of more frequent extreme events, greater variability and greater uncertainty came up in many comments. This possibility might also be reflected in predictions for an increase in avalanche activity at upper elevations. Responses suggest possible explanations; such as increases in wetter warmer storms while persistent weak layers remain present or less affected by climate change. The implications of more frequent extreme avalanches for hazard zoning and exposed resources could be important.

The results indicating that low-mid elevation avalanches have decreased slightly and are predicted to decrease across all zones is consistent with general warming. Unlike the predictions for upper elevations, avalanche hazards could decrease for lower elevation avalanche paths.

Comments by respondents provided fascinating anecdotal evidence that deserves consideration. Many forecasters stated that their jobs are becoming more difficult due to changing conditions in the last decade or two. The following are from 40-plus year veterans:

“Over the past several decades the norms of weather in mountain ranges in Canada have lost relevance, increasing uncertainty for mountain professional who rely on local knowledge.” (Banff)

“All my rules for weather and avalanche forecasting have changed in the last 10-15 years; weather patterns now are completely different … persistent weak layers and associated instability have increased due to wilder swings in weather.” (South Central Alaska)

“Every winter's weather is different. These weather differences vary enough to mask slow climate warming trends.” (Southwest Montana)

A survey is not a substitute for physical data on weather and avalanches. Collecting such data requires resources and expertise. While resources are always limited, the quality, consistency and sharing of avalanche data continue to improve. That work should continue and is essential to improved understanding of avalanches in a changing climate.

The results of this study should be used to stimulate thought and discussion about trends and future conditions. Change is ongoing, but the rate, magnitude, factor weighting, variability and geography of changes are complex. The task of forecasting the future is difficult, but must be done in order to plan and invest in efficient and effective avalanche mitigation measures.

6. ACKNOWLEDGEMENT

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