FATAL AVALANCHE ACCIDENTS AND FORECASTED DANGER LEVELS: PATTERNS IN THE UNITED STATES, CANADA, SWITZERLAND AND FRANCE

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Abstract

Throughout the winter, avalanche forecasters issue bulletins to help the public and the managers of public facilities make avalanche safety decisions. These bulletins typically describe important snowpack features and current weather events before rating the avalanche danger on a scale of one through five. Although the character of avalanche conditions may vary between regions, the physical processes that form avalanches are universal. In addition, the methods used to forecast avalanche activity are similar throughout North America and Europe. We use the distribution of fatal avalanche accidents with respect to forecasted avalanche danger level to examine how effectively avalanche forecast groups communicate with the public and how consistent these groups are within countries and internationally. The results show that avalanche forecast groups are effectively communicating with the public when relatively benign or very dangerous conditions exist.

KEYWORDS: avalanche accidents, avalanche danger, avalanche forecasting

1. Introduction

People who make decisions for themselves or others about avalanche safety often get information from an avalanche forecasting group. This group might be focused on a well defined area, like a transportation corridor or skiing area, but usually they are providing information for a large geographic area and a diverse group of users. It is often difficult for the avalanche forecasting group to determine how useful their products are and how their various customers use the information. Quantitative verification of avalanche forecasts is difficult and often costly (Schweizer et al., 2003). We collected information on the distribution of fatal avalanche accidents with forecasted avalanche danger level to examine variations within North America and compare the distributions with data from France and Switzerland. Our intention is to provide insight into the consistency of avalanche bulletins and whether or not they help the public make sound avalanche safety decisions.

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Since we examine fatal accidents with respect to a forecasted danger level, it is impossible to separate the data from the avalanche danger scale. Avalanche danger scales are an important issue in avalanche forecasting as they are the primary tool we use to communicate with the public. The forecasting groups that participated in this study use one of two avalanche danger scales. Section 3 compares and contrasts the two scales.

2. Previous Work

Each country represented in this study collects information on fatal avalanche accidents, but the information is stored and disseminated differently. Descriptions of each accident are published in summary publications such as *The Snowy Torrents* (Logan and Atkins, 1996) or *Avalanche Accidents in Canada* (Jamieson and Geldsetzer, 1996), or in the annual reports of each forecasting group. These volumes may include the forecasted avalanche danger level for each accident but do not examine long-term trends or patterns in fatal accidents with respect to the forecasted avalanche danger.

McClung (2000) used data from fatal avalanche accidents in backcountry areas of Switzerland and France to examine the avalanche danger scale and forecast verification.

He used Bayesian methods to calculate probability mass functions for each danger level in a five level scale. His analysis concluded that fatal accidents are most likely to occur when the avalanche danger is rated Considerable (Level 3). The greatest increase in the likelihood of a fatal accident occurred between Moderate and Considerable (Levels 2 and 3), with only a slight increase from High to Extreme (Levels 4 and 5). One main conclusion of his work was that the High and Extreme levels could be combined to create an effective four-level scale.

Harvey (2002) examined 12 years of data from recreational accidents in Switzerland. The dataset included both fatal accidents and other destructive avalanches. He discussed patterns in avalanche dimensions, terrain characteristics and forecasted danger levels. Harvey concluded that at all danger levels, fatal avalanches are similar in size and occur in similar locations. He also concluded that the probability of triggering an avalanche increases with increasing slope angle and both the probability of triggering an avalanche and the number of potential trigger points decrease with forecasted danger level.

3. Avalanche Danger Scales

Avalanche danger is defined as the potential for avalanches to cause injury or death (Greene et al., 2004; Stucki et al., 2004). All the avalanche forecast centers included in this study use a five-level scale to rate the avalanche danger in their bulletins. Although the scales used in North America and Europe both contain the same number of levels, there are some notable differences in the definitions of each danger category.

3.1 <u>North American Avalanche Danger Scale</u>

The avalanche danger scale used in North America (Dennis and Moore, 1996) is

Table 1: English translation of the European Avalanche Danger Scale.

Danger Level	Snowpack stability	Avalanche triggering probability
LOW	The snowpack is generally well bonded and stable.	Triggering is generally possible only with high additional loads[2] on very few steep extreme slopes[4]. Only sluffs and small natural[6] avalanches are possible.
MODERATE	The snowpack is only moderately well bonded on some[1] steep[3] slopes, otherwise it is generally well bonded.	Triggering is particularly possible with high additional loads[2], mainly on the steep[3] slopes indicated in the bulletin. Large sized natural[6] avalanches not expected.
CONSIDERABLE	The snowpack is moderately to weakly bonded on many[1] steep[3] slopes.	Triggering is possible, sometimes even with low additional loads[2] mainly on the steep[3] slopes indicated in the bulletin. In certain conditions, a few medium and occasionally large sized natural[6] avalanches are possible.
HIGH	The snowpack is weakly bonded on most[1] steep slopes.	Triggering is probable even with low additional loads[2] on many steep[3] slopes. In certain conditions, frequent medium and also increasingly large sized natural[6] avalanches are expected.
EXTREME	The snowpack is generally weakly bonded and largely unstable.	Numerous large natural[6] avalanches are expected, even on moderately steep terrain.

[1] Generally described in more detail in the avalanche bulletin (e.g. altitude, slope aspect, type of terrain, etc.).
[2] Additional load:
high - e.g. group of skiers without spacing, snowmobile/groomer, avalanche blasting
low - e.g. single skier, snowboarder, snowshoeer.
[3] Steep slopes: slopes with an incline of approximately more than 30 degrees.
[4] Steep extreme slopes: those which are particularly unfavourable in terms of the incline, terrain profile, proximity to ridge, smoothness of underlying ground surface.
[5] Aspect: compass bearing directly down the slope.
[6] Natural: Without human assistance.
Exposed: especially exposed to danger

Table 2: Selected differences between the North American and European Avalanche Danger Scales.

Danger Level	North American	European
LOW	Isolated area of instability.	The snowpack is generally…**stable**.
MODERATE	Unstable slabs possible on steep terrain. Natural avalanches unlikely.	Triggering…possible with high additional loads... Large natural avalanches not expected.
CONSIDERABLE	Human triggered avalanches **probable**.	Triggering is **possible,** sometimes even with low additional loads...
HIGH	Natural and human triggered avalanches likely. Unstable slopes likely on a variety of aspects and slope angles.	Triggering is probable even with low additional loads on **many** steep slopes. In **certain conditions**, frequent medium and also increasingly large sized natural avalanches are expected. Snowpack is weakly bonded in most places.
EXTREME	Extremely unstable slabs certain…Large destructive avalanches possible. Widespread natural **or** human triggered avalanches certain.	Numerous large natural avalanches are expected even on moderately steep slopes.

based on the probability of triggering an avalanche. Each avalanche danger level is defined by the probability that a natural and human trigged avalanche will occur. The five levels also include some information on where avalanches could be triggered and give a recommendation to backcountry travelers of what they can do to minimize the risk. The scale was developed as a tool to communicate variations in avalanche danger to people involved in backcountry recreation. This scale is not typically used by programs that forecast for transportation corridors, municipal areas or mechanized skiing.

3.2 European Avalanche Danger Scale

The European Avalanche Danger Scale (Meister, 1994) considers snow stability, avalanche frequency, avalanche size and the probability of triggering an avalanche (Table 1). Each danger level definition discusses the amount of bonding within the snowpack, the size and number of avalanches, and the potential for natural and human triggered avalanches. The spatial extent of snow stability and the load required to produce an avalanche are also included in some of the danger level definitions. The scale was developed to communicate avalanche danger to the general public, managers of towns and transportation corridors, as well as recreationalists.

3.3 Combining North American and European Avalanche Danger Ratings

The North American and European avalanche danger scales each use five levels to describe a continuum of avalanche conditions. Although in some respects the scales are quite similar, within each definition there are notable differences (Table 2). The European scale includes more parameters than the North American scale, but both scales are based on a progression of avalanche frequency, and they also both rely heavily on how easy it will be to trigger an avalanche. Despite their differences, we believe that generally the levels in both scales are used to describe similar conditions. For the purpose of this investigation we consider each of the five levels to be equivalent.

4. Data and Methods

We collected data on avalanche fatalities and the corresponding forecasted avalanche danger level from France, Switzerland, Canada and the United States. These data cover the time period from the fall of 1996 through the spring of 2006. All recreational, occupational and residential fatalities are included in the dataset. We made every attempt to determine the danger level forecasted for the area, elevation and slope angle where the accident occurred. We also collected frequency data of the forecasted avalanche danger to normalize the avalanche fatality distributions.

4.1 United States

Avalanche bulletins in the United States are issued by both government and private organizations. These entities issue forecasts on a variety of time periods ranging from daily to weekly. We collected data on avalanche fatalities that occurred within the forecast area of any avalanche center in the U.S.

During the established time period over 200 people were killed in snow avalanches within the United States. Three criteria were used to decide if an accident should be included in the dataset for this study. First, the avalanche bulletin had to be issued within 24 hours of the accident. Second, the avalanche bulletin had to be publicly available. Third, the avalanche accident had to be within the forecast area of the avalanche centers.

For the comparison of normalized distributions we only used data from the CAIC. This comparison required counts of both avalanche fatalities and the total number of times each danger level was used in a bulletin, and the CAIC is the only avalanche center in the U.S. that collected these data over the given time period.

4.2 Canada

The Canadian dataset covers the period from November 1996 through July 2006. The dataset includes all regions within Canada where an avalanche fatality occurred and a corresponding avalanche danger rating was publicly available. Thirty-seven fatalities were not included because there was no avalanche bulletin available at the time or for the area.

Avalanche bulletin data was collected from the Canadian Avalanche Center (CAC), Parks Canada (PC), and Kananaskis Country (KC). Within these organizations, 11 distinct forecast areas exist. There are three other organizations within Canada producing avalanche bulletins; two of these (Whistler/ Blackcomb and Vancouver North Shore) have overlapping forecast areas with Canadian Avalanche Center areas. Center d'avalanche de la Haute-Gaspésie is located in Quebec. There have been no fatal accidents in this region while the program has been in operation.

Parks Canada produces daily avalanche bulletins, while the Canadian Avalanche Center and Kananaskis Country publish 3-5 bulletins per week, per area. Avalanche danger ratings in Canada are applied to three elevation bands: alpine, treeline, and below treeline. The elevation band of each accident was interpreted using local knowledge and accident reports. For example, when an avalanche runs 1000 meters it may cross several elevation bands and the assigned danger rating will depend on the location where the victim was caught or struck from above. The danger rating for each fatality was based on avalanche bulletin information that was current at the time of the accident.

Forecast frequency data was only available from the Canadian Avalanche Center. Therefore the fatality day used in the normalized distribution does not include data from Parks Canada or Kananaskis Country.

4.3 Switzerland

The Swiss dataset includes all known avalanche fatalities that occurred between the fall of 1996 and the spring of 2006. Within this dataset there are no recreational snowmobiling accidents as this activity is widely prohibited in the Alps. The people killed during a Low or Moderate danger were all involved in recreational activities. At higher danger levels, in addition to recreational activity, people were killed while driving, walking on paths or residing in buildings. Non-recreational fatalities most often occurred during periods of High avalanche danger.

The Swiss Alps are divided into about 100 forecast areas. The forecasts are issued by the Avalanche Warning Group at the Swiss Federal Institute for Snow and Avalanche Research (SLF) and typically include the degree of danger (one out of five) as well as a description of the most dangerous areas. About 5% of the bulletins during this period did not include a danger level and some (12.6%) of the avalanche fatalities occurred on days with no forecast. We did not include either case in the dataset.

During the winter of 1996/97 avalanche bulletins were not yet issued on a daily basis. In most cases, however, the forecasted danger level for the area where fatal accidents happened was documented. In two cases with 5 fatalities in 1996/97 the danger level was uncertain. These accidents are not included in the dataset.

The Swiss dataset may be misleading at High and Extreme danger levels. This aspect of the data is due to one accident where 12 people were killed in 1999. The avalanche danger was forecasted as High, but later verified as Extreme. Without this accident there were 13 people killed during High danger and 2 people killed during Extreme danger. When this accident is included under the *forecasted* danger level the numbers change to 25 for High and 2 for Extreme. The inclusion of this accident, which occurred during an under-forecasted event, into the High rather than Extreme bin drastically changes the distribution.

4.4 *France*

The French dataset represents the period from December 1996 through June 2006, and includes all regions within France where an avalanche fatality occurred and a corresponding avalanche danger rating was available. The source of the information on avalanche accidents is the annual report of the ANENA (Association Nationale pour l'Etude de la Neige et des Avalanches). Fifty fatalities were not included because they occurred in an area or time period when no avalanche bulletin was available.

The French Alps, Pyrénées and Corsica are divided in 34 forecast regions. Avalanche bulletin are issued daily by 9 local meteorological centres from Météo-France in the afternoon. It includes a brief description of the weather forecast for the day after and a more precise description of the snow stability, avalanche type and most dangerous areas. One degree of danger is also included for each forecast region, sometimes two degrees in case of different situations with altitude or time evolution. We include all the forecasted danger levels in this dataset.

In most cases the people killed were involved in recreational activities but some people were killed while walking on paths or residing in buildings. These accidents most often occurred during periods of High avalanche danger due to heavy snow falls. For the Extreme danger level, only 3 fatal accidents occurred during the studied period and the large number of avalanche fatalities is mainly due to one accident where 12 people were killed in their house in February 1999. Only one person was killed in the majority of the avalanche accidents that involved

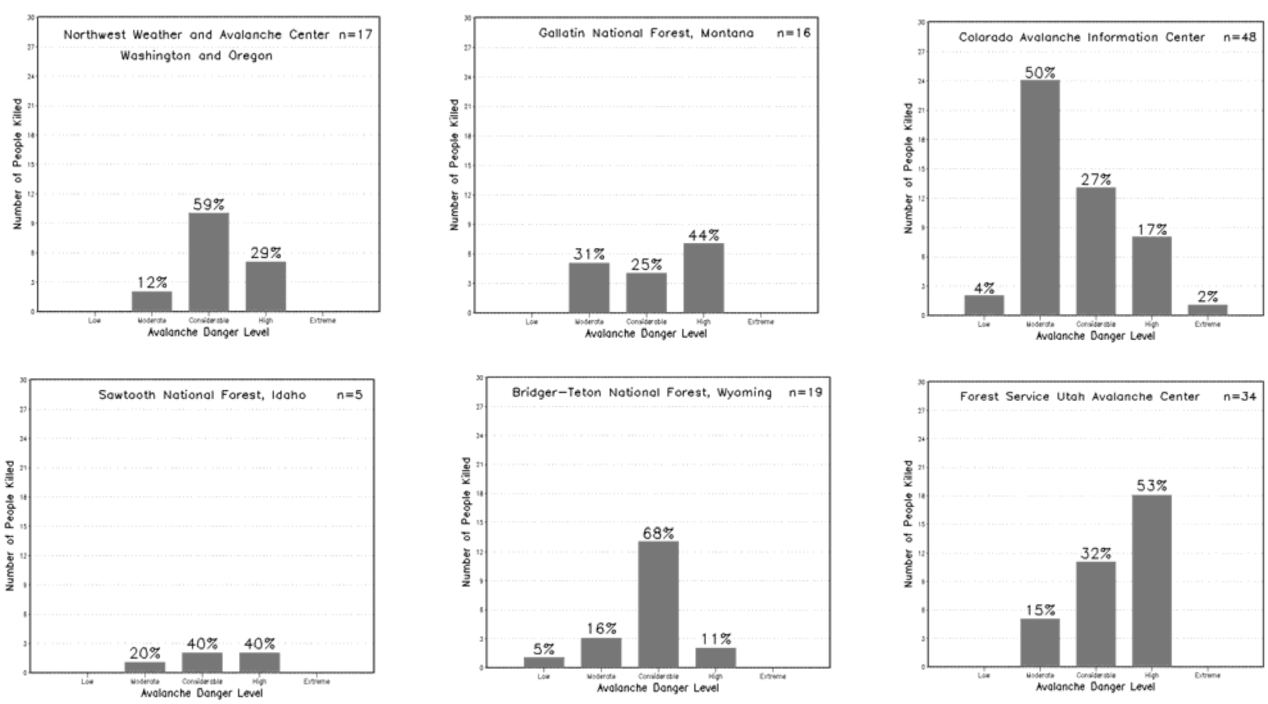

Figure 1: Regional distribution of fatalities by forecasted danger level in the United States. Avalanche centers with five or more fatalities in their forecast area between the summer of 1996 and summer of 2006 are displayed.

people in recreational activities. The most terrible accident occurred in January 1998 where 11 young people were killed when they snowshoed up a slope.

The number of people killed by year in avalanche accidents in France varies from 16 to 50 during the study period. More fatal accidents occurred when the danger level was considerable than high, though this trend has changed for the last two winters.

4.5 Statistical Comparison

To statistically test for differences between the distribution of fatal accidents and forecasted danger level, we use the non-parametric Fisher Exact test (Daniel, 1990). The Fisher Exact test determines, with respect to a tolerance value (α), if there are non-random associations between categorical values. By simultaneously testing a series of categorical values we can test if the distributions are from the same population. We chose $p < 0.05$ for our level of significance, so we consider a $p < 0.05$ to be good evidence that the distributions are different, while higher values of p suggest the populations are not significantly different.

To compare the different distributions, we conducted paired tests on all of the data sets. For tests that require comparisons of multiple data sets, we applied the Bonferroni correction to the α-value (Miller, 1991). The Bonferroni correction reduces the α-value by the number of data sets being compared. Thus if we compare data sets from the United States to those from Canada, Switzerland and France an α-value of 0.05 is reduced to 0.017.

5. Discussion

5.1 Regional Differences within North America

The avalanche forecast centers in North American cover areas that are diverse in topography, snow climate and population. Figure 1 shows regional variations in the distribution of people killed at each danger level in the United States. Colorado and Utah have the largest number of fatal accidents, but the distribution of these accidents through the danger scale is very different. There is a pronounced right-skew to the data from Utah, while the data from Colorado is skewed to the left. In all regions, fatal accidents are concentrated in the Moderate, Considerable and High categories, but there is no consistent pattern within these three categories across the different regions. The results of the Fisher Exact test (Table 3) suggests that the data from the Forest Service Utah Avalanche Center (FSUAC) and Colorado Avalanche Information Center are from different populations. However, there is evidence that all the other data sets compared in Table 3 have non-random associations ($p<0.013$). Since all of these data sets are quite small ($n<50$) the results are not conclusive. The FSUAC and CAIC are the two largest data sets of the group. By visual examination it appears that all of the regional distributions (Figure 1) are quite different from the national distribution in Figure 3.

Significant regional differences also exist in Canada (Figure 2). In areas covered by Parks Canada (PC) and the Canadian Avalanche Center (CAC), most fatal accidents occur when the danger is rated Considerable. However in Kananaskis Country (KC) the maxima occur in the Low and High categories, though this region only has 9 fatalities. The results of the Fisher Exact test (Table 4) shows no evidence that the data sets are from the same population. However, both the PC and KC data sets are quite small.

5.2 International Differences in Fatality Rate by Danger Rating

In all of the countries examined in this study, most fatal accidents occur when the avalanche danger is rated Considerable (Figure 3). This peak is most pronounced in Switzerland. The greatest increase in fatal accidents also occurs between Moderate and Considerable in Canada and France, but between Low and Moderate in the U.S. and Switzerland. In Switzerland, more people are killed at Low and

Table 3: Fisher Exact test results for the different U.S. avalanche centers.

	Bridger-Teton NF(WY)	Colorado Aval. Info. Cntr	Gallatin NF (MT)	NW Aval. Cntr (WA & OR)	Utah Aval. Cntr
Bridger-Teton NF(WY)	-	0.02	0.02	0.51	0.01
Colorado Aval. Info. Cntr	0.02	-	0.22	0.03	< 0.01
Gallatin NF (MT)	0.02	0.22	-	0.17	0.41
NW Aval. Cntr (WA & OR)	0.51	0.03	0.17	-	0.21
Utah Aval. Cntr	< 0.01	< 0.01	0.41	0.21	-

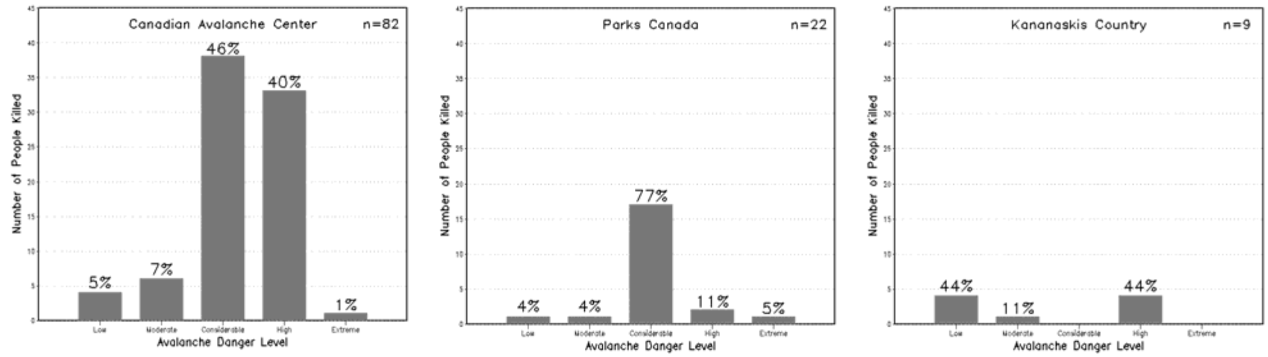

Figure 2: Regional distribution of fatalities by forecasted danger level in Canada. (These are just place holders until I paste in charts that look like the rest).

Moderate than High and Extreme. In the U.S. most deaths occur during the middle three danger levels (Moderate, Considerable and High), with a relatively even distribution between these three levels. In Canada and France most fatal accidents occur during periods of Considerable and High avalanche danger with very few occurring at Low, Moderate or Extreme. The Fisher Exact test (Table 5) suggest that all of the distributions are from different populations.

5.3 International Differences in Danger Rating Frequency

It is difficult to draw any conclusions about the number of fatal accidents at each danger level without knowing how often each danger level is used. Figure 4 shows the number of times each danger level was used in products issued by the CAIC, CAC, SLF and MF forecasting groups. Moderate is the most common danger level at all four offices. The CAIC and SLF distributions are quite similar even though the total number of forecasts differs by more than a factor of 40. The pattern of a maximum at Moderate and second peak in Considerable is also clear in the CAC and MF frequency data. However, by proportion MF and the CAC use Considerable much more often than either the SLF or CAIC.

5.4 Normalized Fatality Rate by Danger Rating Distributions

We normalized each accident frequency distribution by dividing it by the danger level frequency data. Our intention was to remove any biases in the accident distributions that were due to systematic differences in snow climate or forecast culture. The normalized distributions are quite similar through the first four danger categories, but the CAIC's value for Extreme is much larger than those from the other groups (Figure 5). This is most likely due to both the low number of forecasts and fatalities at this danger level. The results from the Fisher Exact test for the normalized distributions were the same as the International Comparison (p values not shown). When the Extreme category is included in the analysis there is evidence that all of the normalized distributions are different. However, when Extreme is excluded from the analysis (Table 6) the data from the United States is different from all but the Swiss data ($p < 0.017$). The test suggests that rest of the distributions are from the same population.

6. Conclusions

The purpose of this study is to examine when fatal avalanche accidents occur in relation to the forecasted danger level. We believe that this type of investigation can lend some insight into how we use avalanche danger scales to communicate with the public and how the public uses bulletins to make avalanche safety decisions. The number of human avalanche involvements may be a better metric for

Table 4: Fisher Exact test results for Comparisons between different Canadian avalanche centers.

	Canadian Avalanche Center	Parks Can.	Kananaskis Country
Canadian Avalanche Center	-	0.02	< 0.01
Parks Canada	0.02	-	< 0.01
Kananaskis Country	< 0.01	< 0.01	-

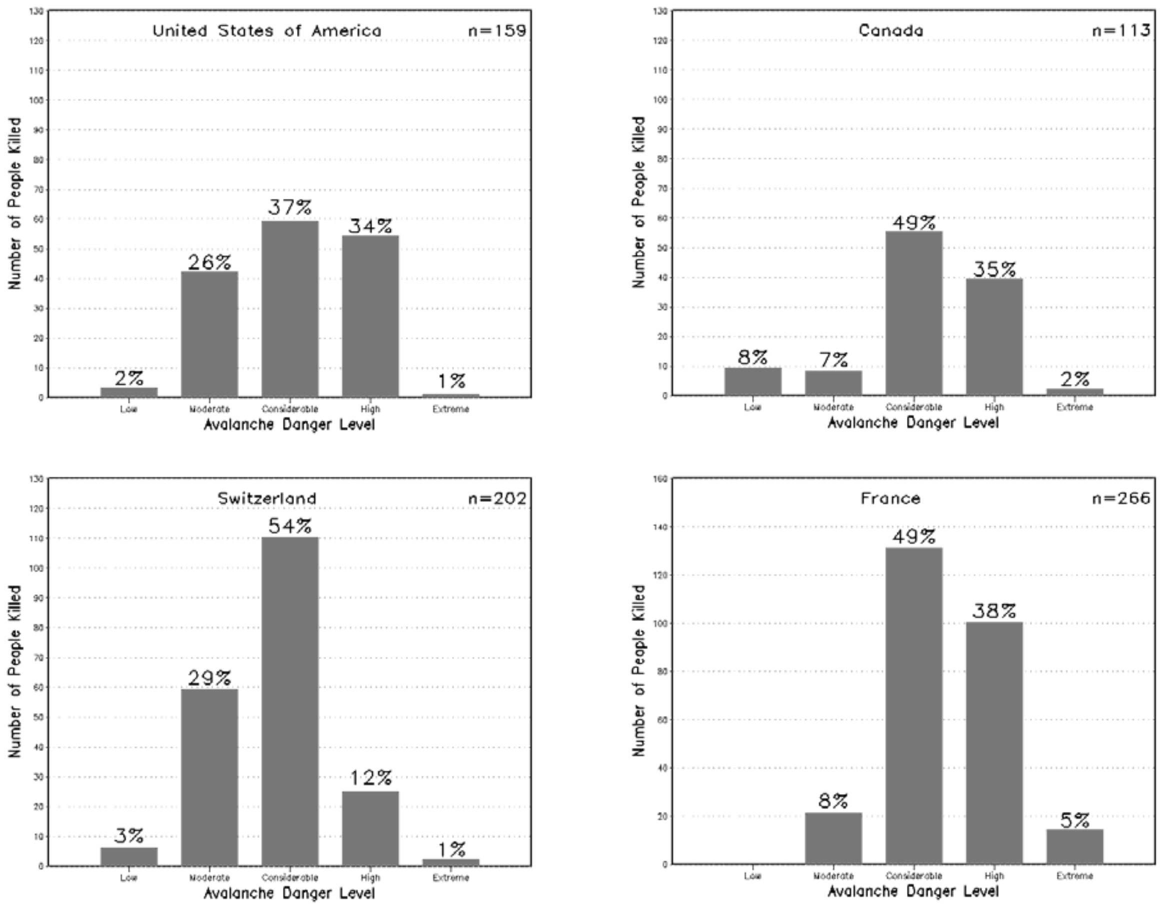

Figure 3: Number of fatal avalanche accidents at each avalanche danger level.

avalanche safety decisions. However, avalanche involvement data is always incomplete and in parts of North America it is so incomplete that any analysis would be almost meaningless.

The distribution of fatal accidents through the avalanche danger scale shows that in general, we are effectively communicating with the public. Less than 20% of fatal accidents occur during periods of Low avalanche danger when avalanche can only be triggered in isolated areas or with a large force. Public warnings are generally heeded as no more than 10% of fatal accidents occur when the avalanche danger is Extreme. When the Extreme category is excluded, the normalized distributions from the MF, CAC and SLF are statistically similar and the CAIC is similar to the SLF. Thus there is some level of consistency in how international groups use avalanche danger scales to communicate with the public. As more avalanche centers collect forecast frequency data, we will be better equipped to compare the regional distributions.

Avalanche danger is strongly influenced by topography, recent weather patterns and snow climate. Forecasted danger levels are influenced by these same factors as well as human interpretation or “forecast culture”. Clearly some of the differences are due to different snow climates and probably real differences in avalanche danger. However, if all forecasters used the danger scale identically and the public used the bulletins in a similar fashion to make decisions about avalanches, we should see similar distributions fatal accidents in each country and region. Thus there are real cultural differences in how the danger level is being forecasted and used. Unfortunately we cannot separate the human and physical influences within this dataset.

In this study we considered the two

Table 5: Fisher Exact test results for different countries.

	CA	CH	USA	FR
CA	-	*< 0.01*	*< 0.01*	
CH	*< 0.01*	-	*< 0.01*	<0.01
USA	*< 0.01*	*< 0.01*	-	<0.01
FR	<0.01	<0.01	<0.01	-

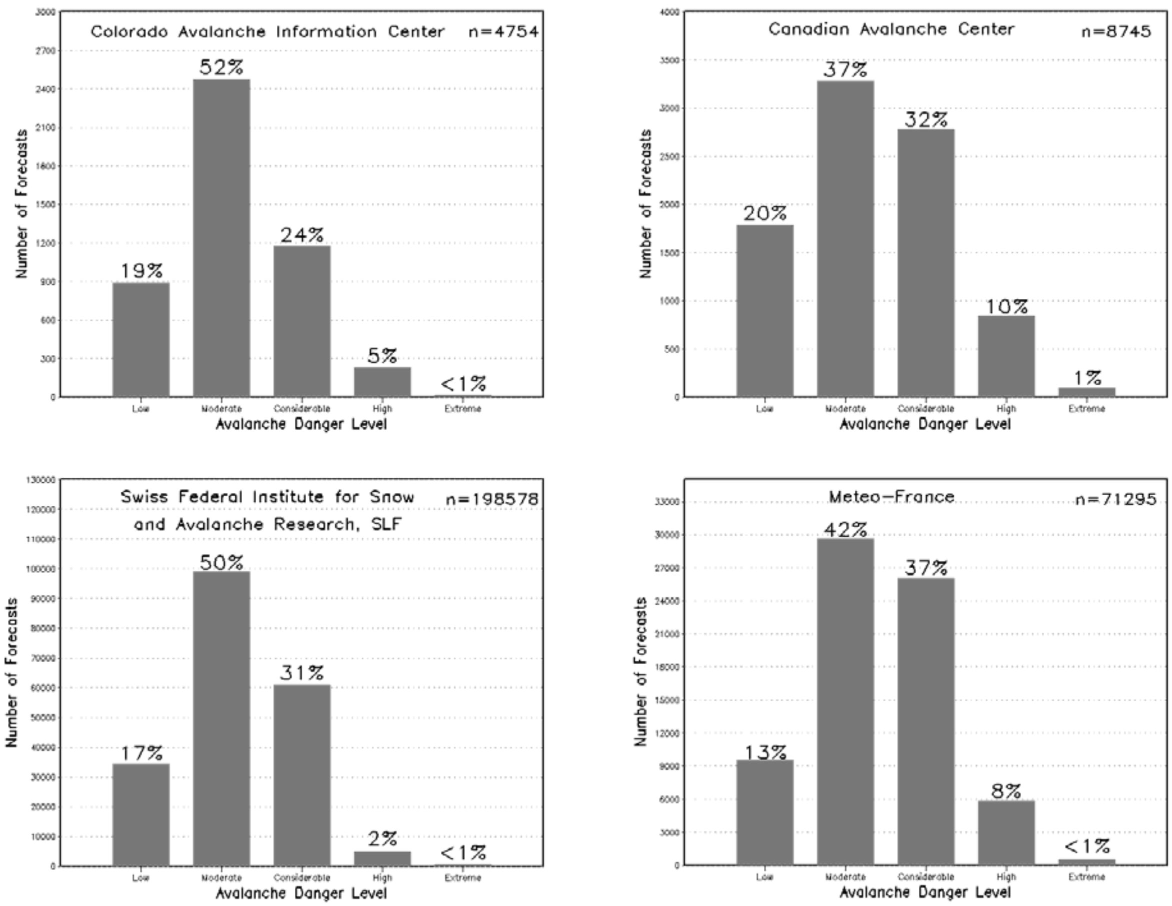

Figure 4: The forecasted danger level frequency.

avalanche danger scales to be equivalent. This is certainly a limitation of our analysis, but selecting the danger level in either scale is partially a subjective process. The regional distribution of fatal accidents suggests that the variation in how the two scales are used is as significant as the difference between the two scales. The most important commonality between the two scales may be that they both divide the continuum of avalanche danger into five levels.

A standardized method for determining and communicating avalanche danger might benefit both the public and professional avalanche community. However, avalanche forecasting relies heavily on the experience of the forecaster as well as their ability to interpret quantitative data analyses. LaChapelle (1980) showed that a group of forecasters could generate similar forecasts for given conditions by using different methods and emphasizing different data. Given the current state of avalanche forecasting it may be best to rely on a diverse and skilled forecasting group to determine the avalanche danger (McClung, 2002).

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Table 7: Fisher Exact test results for the normalized data, with Extreme removed, from different countries.

	CAC	SLF	CAIC	MF
CAC (CA)	-	0.25	< 0.01	0.02
SLF (CH)	0.25	-	0.18	0.03
CAIC (USA)	< 0.01	0.18	-	< 0.01
MF (FR)	0.02	0.03	< 0.01	-

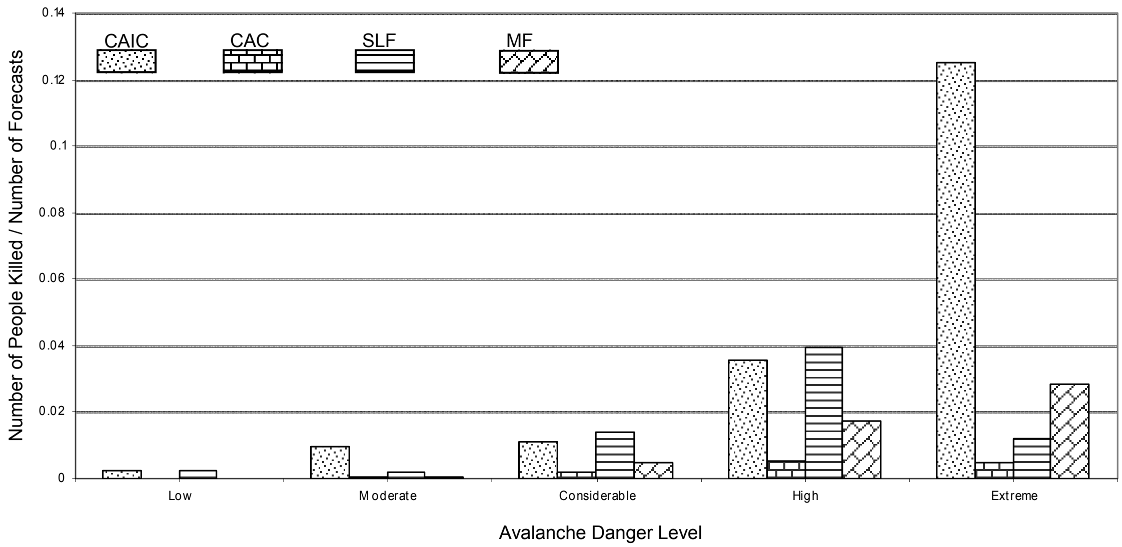

Figure 5: Normalized avalanche fatality distributions.

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