SPATIAL AND TIME SCALE EFFECTS IN CANADIAN AVALANCHE BULLETINS

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ABSTRACT: In the winters of 2004-05 and 2005-06, 235 local "nowcasts" of the avalanche danger at and below treeline in the Coast, Columbia and Rocky Mountains of western Canada were compared with the danger rating from the public avalanche bulletin for the region including the nowcast site. These bulletins are issued from three to seven times per week, and the forecast regions range from 100 km^2 to approximately 30,000 km^2. After identifying an observation bias and filtering the data to 192 cases, the local nowcasts agreed with the regional danger rating in approximately 57% to 64% of the cases in the Coast, Columbia and Rocky Mountains. The agreement rate was higher for small forecast regions than for larger regions. Many of the nowcasts could be compared with danger ratings published zero, one or two days previously. This allowed the effect of different lead times to be assessed. It appears that the danger rating for the larger regions with infrequent bulletins has the potential to be improved more by reducing the size of the forecast regions than by increasing the frequency of forecasts from three times per week to five or seven times per week.

KEYWORDS: avalanche forecasting, scale issue, spatial scale, temporal scale, avalanche danger

1. INTRODUCTION

One way of assessing a regional bulletin is to compare the forecast danger level with local observations, stability ratings or danger ratings (Schweizer et al., 2003). We used this approach to explore the effect of spatial and time scales on the *hit rate*, which is the rate of agreement between the danger ratings in regional forecasts and local ratings of the avalanche danger. These local ratings for the current day are on the scale of a small drainage or ski tour (about 10 km^2) and are referred to as *local nowcasts*.

This study is a spin-off from the Canadian Avalanche Association's Avalanche Decision-making Framework for Amateur Recreationists (ADFAR) project. The data were gathered for assessing the value of snowpack observations in areas covered by public bulletins (Jamieson and others, 2006). Jamieson and others (2005) provided the initial comparison of regional danger ratings with local danger ratings from the winter of 2005-06. This paper provides additional, more detailed analysis of data from the winters of 2004-05 and 2005-06.

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2. REGIONAL BULLETINS

Regional avalanche bulletins in western Canada typically include danger ratings and several short paragraphs of text. The text typically explains how the weather and snow conditions are contributing to the avalanche danger and discusses the avalanche danger in terms of the terrain. Most Canadian bulletins rate the avalanche danger separately for the alpine, tree-line (TL) and below treeline (BTL) areas. The danger from the regional bulletin (or forecast), D_{RF}, is rated as either Low (1), Moderate (2), Considerable (3), High (4) or Extreme (5). The classes of avalanche danger are consistent with those used in most of Europe and the United States (Canadian Avalanche Association, 2002, p. 76; Greene and others, 2004, p. 119). The numbers for the danger ratings are currently not used in Canadian bulletins, but are used in some European countries and in this study.

In western Canada, forecast regions vary widely in area as shown in Figure 1 and Table 1. The areas of the forecast region for the South and North Columbia Mountains each approximate 25,000 km^2. The South Coast forecast region covers about 29,000 km^2. Parks Canada's bulletin for the highway corridor through Glacier National Park (GNP) covers approximately 450 km^2, while the Banff-Yoho-Kootenay (BYK) bulletin covers approximately 8,000 km^2. The Whistler-Blackcomb ski patrol's backcountry avalanche advisory covers an area of approximately 100 km^2 and North Shore Avalanche Advisory Group's bulletin covers approximately 150 km^2. The three largest regions are approximately 250 times larger than the smallest region and 2,500 times larger than the scale of a ski tour (approximately 10 km^2) used for the local danger ratings.

The GNP bulletin is published each morning in the winter for the current day and for each of the following two days. The CAC bulletins are published in the afternoon usually three times per week, but occasionally more frequently and are typically valid for each of the following two or three days. The bulletin for the BYK region is published each afternoon for the following one or two days. These and other forecasts are summarized in Table 1.

Table 1: Summary of data for comparing local nowcast with regional forecasts

Number of cases	**Sites for local nowcasts**	**Forecast region** (Fig. 1)	**Source of regional forecast**	**Forecast area[b] (km^2)**	**Forecast frequency (forecasts/week)**
10	Whistler Backcountry	Whistler Backcountry (Coast Mtns.)	Whistler-Blackcomb Ski Patrol	100 (small)	7 (daily)
18 (14[a])	North Shore	North Shore (Coast Mtns.)	North Shore Avalanche Advisory Group	150 (small)	approx 3 times per week[c] intermittent
34	Near Duffey Lake Road or Coquihalla Pass	South Coast (Coast Mtns.)	Canadian Avalanche Centre (CAC)	29,000 (large)	3[c]
9	North Purcell Mountains	South Columbia Mountains	Canadian Avalanche Centre (CAC)	25,000 (large)	3[c]
56	Cariboos near Blue River, BC	North Columbia Mountains	Canadian Avalanche Centre (CAC)	24,000 (large)	3[c]
41	Highway corridor in Glacier National Park	Highway corridor in Glacier National Park (Columbia Mtns.)	Parks Canada	450 (small)	7 (daily)
67 (28[a])	Banff, Yoho and Kootenay National Parks	Banff, Yoho and Kootenay National Parks (Rocky Mtns.)	Parks Canada	8,000 (medium)	7 (daily)

[a] Reduced number of cases after excluding cases in which the observations were made in a study plot and the observation team included a forecaster who wrote the current bulletin. See Section 4.2.
[b] Approximate area of snowy regions with mountains or hills estimated from maps.
[c] Additional bulletins published during holidays and as updates are required.

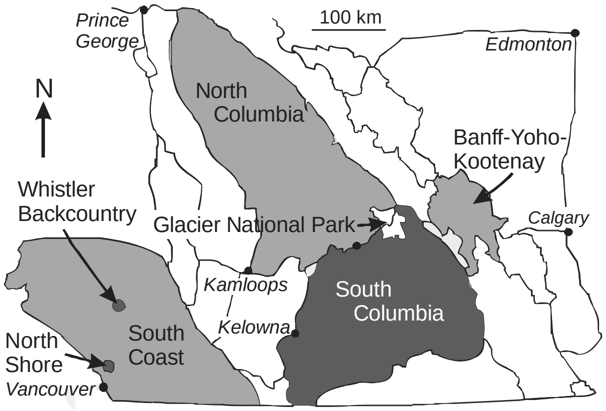

Figure 1. Map of southwestern Canada showing the seven forecast regions in which observations were made for local danger ratings. A map showing these and other forecast regions in western Canada is available at www.avalanche.ca.

Many of the large forecast regions in western Canada are larger than in the United States as indicated by the medians and third quartiles shown in Figure 2.

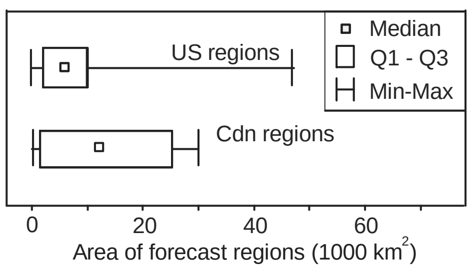

Figure 2. Distribution of areas of 15 forecast regions in western Canada and 25 in the United States. The areas are approximate.

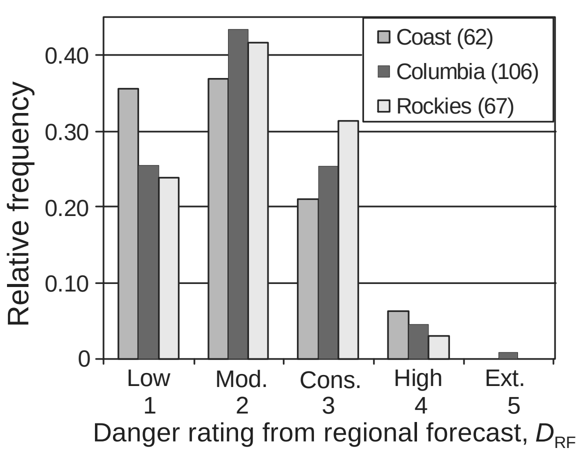

Figure 3. Relative frequency of the danger ratings from regional forecasts that corresponded with the local nowcasts in the three mountain ranges.

The relative frequency of the various regional danger ratings that were paired with nowcasts are shown in Figure 3. There were many more low and moderate ratings than high or extreme ratings, which can influence the distribution of differences between the regional and local rating discussed in Section 4.1.

3. FIELD METHODS: PRODUCING THE LOCAL NOWCAST

Field teams of two or three skilled observers produced the local nowcasts for this study between 12 January 2005 and 14 April 2005 and between 15 December 2005 and 19 April 2006. Their observations in the North and South Columbia and Glacier National Park were made during the winters of 2004-05 and 2005-06, whereas the observations in other ranges were made only in the winter of 2005-06. On each observation day, the observation team selected a sheltered site at or below tree-line. Usually on touring skis in teams of two or three, they traveled to the site and observed a detailed snow profile, at least two compression tests, noting the appearance of any fractures (Johnson and Birkeland, 2002; Greene and others, 2004, p. 36-37; van Herwijnen and Jamieson, 2005), and often a rutschblock test, noting the amount of the block that released (Schweizer and Wiesinger, 2001). The team made observations of avalanches and other less formal, but often valuable, observations of snow stability while traveling to and from the site. Also, they had access to weather, snowpack and avalanche observations from the hosting operation and from neighboring avalanche safety programs. Using *all* available information, a *danger rating for the drainage and the current day*, called the "local nowcast", D_{LN}, was selected by consensus for tree-line and or below tree-line—provided this could be done with confidence. Although field staff were aware of the regional danger ratings on some days, local field observations strongly influenced the local nowcast, as explained in Section 4.1. On most days, ratings were recorded for both treeline and below tree-line, yielding two cases per observation day. In the North and South Columbia regions, the field teams typically had less experience than avalanche forecasters; however, this likely did not affect the ratings which required little extrapolation over time or space, and were reached by consensus between at least two people. During the discussions leading to the local nowcast, a systematic difference in ratings between those with more and less experience was not apparent.

In this study, the local nowcast is the reference danger rating to which the regional rating is compared. The local nowcast and the regional forecast danger rating are expected to differ in many cases because regional forecasters are extrapolating over time and over areas much larger than the scale of the local nowcast.

4. RESULTS

4.1 Comparing regional danger with local danger

Occasionally, the regional forecast or the local nowcast for treeline or below treeline involved more than one rating, e.g. “moderate with areas of considerable”. To simplify the analysis—and not because we question the relevance of such ratings—these two-level ratings were excluded. In some cases, especially in the spring, the regional forecast or the local nowcast varied during the day, e.g. moderate increasing to considerable in the afternoon. In these cases, the maximum danger rating was used for the comparison.

The local nowcasts were paired with regional danger ratings as shown in Table 1. In all but eight cases we used the most recent regional forecast available to recreationists *in the morning*. In Glacier National Park, we used the bulletin prepared on the morning of each observation day. In forecast regions in which the bulletin was published in the afternoon, we used the most recent afternoon bulletin published one or more days previously. However, there were eight cases in the North Shore forecast region for which the only applicable bulletin was published in the afternoon on the day of the nowcast observation. These eight cases were included to maximize the number of comparisons for small forecast areas.

For each nowcast paired with a regional danger rating, the difference ΔD was calculated by subtracting the number of the local danger rating D_{LN} from the number of the danger rating from the regional forecast D_{RF}.

$$\Delta D = D_{RF} - D_{LN} \qquad (1)$$

A positive difference indicates that the regional danger rating was higher than the local nowcast, and negative difference indicates that the regional danger rating was lower than the local nowcast. The distributions of the differences are plotted in Figure 4 for each of the three mountain ranges. Cases in which the difference is zero, $\Delta D = 0$, are called hits and the relative frequency of hits is the hit rate h (Wilks, 1995, p. 240).

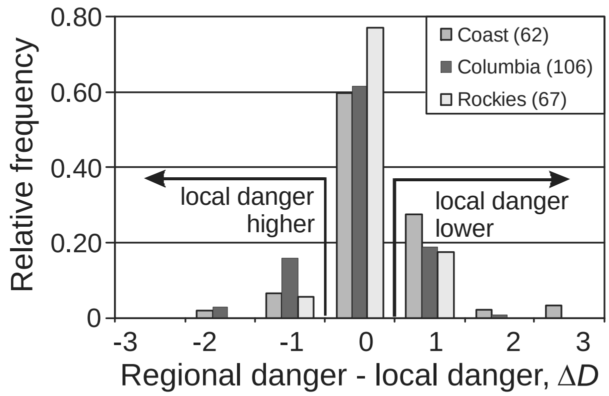

Figure 4. Relative frequency of the differences between the danger rating from the regional forecast (D_{RF}) and from the local nowcast (D_{LN}) for the Coast Mountains, Columbia Mountains and Rocky Mountains

In some cases the field teams had read the regional bulletin before traveling to the site of the local observations. The relatively low hit rate, which is most evident for the Coast Mountains and Columbia Mountains (Figure 4), indicates that the local nowcasts were strongly influenced by their local observations. This potential bias is further assessed in Section 4.2

There are at least two reasons why there are more positive differences than negative differences in all ranges as shown in Figure 4. First, forecasters—especially when forecasting for large areas—may “err on the side of caution” or focus on the sub-regions with higher danger as a result of the uncertainty associated with forecasting over large areas and up to three days in advance. Second, regional danger rating was Low (Figure 3) much more often than it was Extreme, and for Low ratings, a negative difference cannot occur. We doubt that the increased frequency of positive differences is due to the observation teams underestimating the avalanche danger.

Although the danger rating in bulletins is central to this study, the text part of the bulletin can also be relevant to the local avalanche danger. For example, three differences of -2 occurred on 22 March 2005 (TL and BTL) and 23 March 2005 (TL) in the Cariboo Mountains. For each of these three cases, the text part of the bulletin for the North Columbias stated “Some areas (notably the northern Cariboos) got more snow than expected over the weekend (up to 35 cm at 1900 metres)”, providing more detailed information for parts of the region. There were a total of 23 cases in which the text part of the bulletin for medium or large areas identified the sub-region of the local nowcast as having conditions favourable to higher or lower danger. When these were excluded (Figure 5), the hit rate rose from 0.63 (n = 166) to 0.68 (n = 143). Notably, the two differences of +3 were excluded since the text part of the bulletin identified the area of the nowcast as likely to have less snow from the coming storm and therefore lower danger. When reviewing these and other cases, we also noticed that some of the miss-hits were due to incorrect weather forecasts, which comprise one source of uncertainty in avalanche forecasts. These examples and Figure 5 highlight the value of the text part of bulletins. Nevertheless, these data are included in the following analyses which focus only on the danger rating.

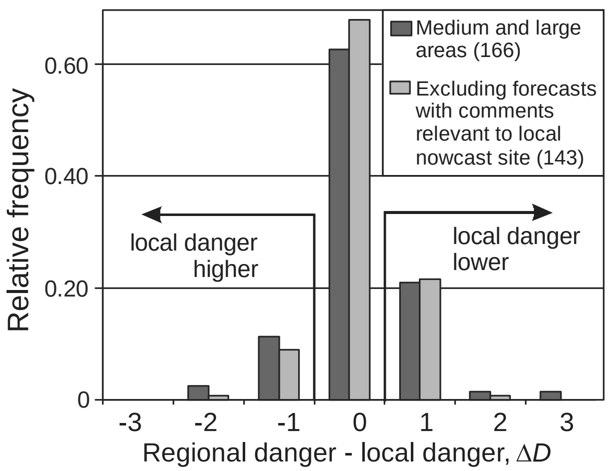

Figure 5. Relative frequency of difference between the danger rating from the regional forecast (D_{RF}) and the local nowcast (D_{LN}) for large and medium areas. These frequencies are plotted including and excluding the forecasts with comments relevant to the sub-region where the nowcast observations were made.

<u>*4.2 Why is the hit rate higher in the Rocky Mountains?*</u>

In the Rocky Mountains, the hit rate was 0.76 compared to approximately 0.61 in the Coast and Columbia Mountains. The Coast and Columbia involve some cases in which $\Delta D = \pm 2$ or $\Delta D = 3$ whereas there were no such cases in which the Rocky Mountains. All the data for the Rocky Mountains were from the Banff Yoho Kootenay (BYK) forecast region where the forecast (lead) times were often shorter and the forecast area was generally smaller than in the Coast or Columbia Mountains. These effects are analyzed in Sections 4.3 and 4.4. However, there are two other characteristics of the BYK nowcasts that are different from other regions:

- all the local nowcasts were prepared by the forecast team, usually including the person who had written the current bulletin, and
- in 58% of the cases, the snowpack observations for the local nowcasts were made in study plots.

We consider the possible effect of study plots first and then the residual effect of observer bias by bulletin writers second. In Figure 6, the distribution of ΔD is plotted separately for cases in which the local nowcast was based on study plot observations and on roving (non study plot) observations. For the study plot cases, the hit rate is 0.85 (n = 39) and for the roving cases the hit rate is 0.64 (n = 28). We consider this to be indicative of a bias: when forecast teams involving a person who wrote the bulletin based their local nowcast on the study plot observations, their hit rate was inordinately high.

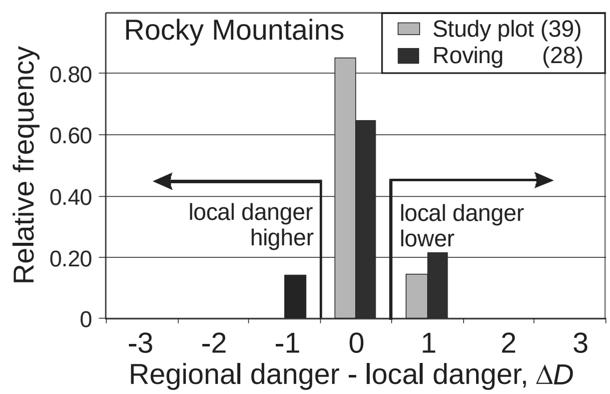

Figure 6. Relative frequency of differences between the danger ratings from the regional forecast and local nowcast for the Banff Yoko Kootenay forecast region. Frequencies for the nowcasts based on observations made in study plots are plotted separately from those for nowcasts based on roving observations.

After excluding the cases from the BYK region in which the snowpack observations were in a study plot, the hit rate for teams including bulletin writers is 0.64 (n = 25) and 0.67 for the remaining cases (n = 3). The latter sample is too small for a valid comparison but at least there is no evidence that bulletin writers have a substantially different hit rate than bulletin readers when making nowcasts based on roving observations. In the North Shore forecast region of the Coast Range, there were four other cases (all hits) in which the observation team included a person who wrote the bulletin and the observations were made in a study plot. These were also excluded from subsequent analyses. For the remaining cases, the hit rate in the Coast and Columbia Ranges is 0.59 (n = 46) when nowcasts were based on study plot observations and 0.60 (n = 118) for roving observations so there is no evidence of a residual study plot bias. The distribution of ΔD by range for the reduced dataset (n = 192) is plotted in Figure 7.

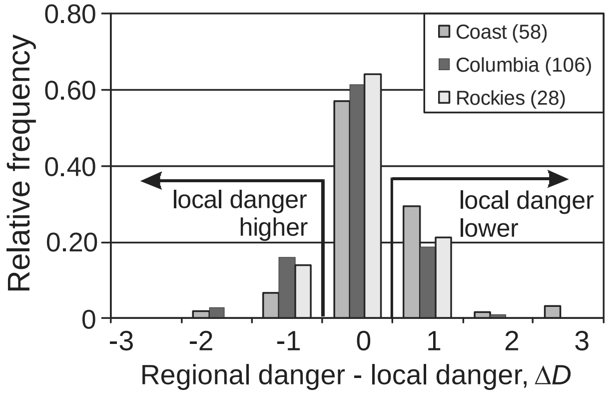

Figure 7. Relative frequency of the difference between the danger rating from the regional forecast and the local nowcast, after filtering the forecaster-study-plot bias. The relative frequencies for the Columbia Mountains are unchanged from Figure 4.

The higher hit rate in the Rockies (0.64) may be due to shorter lead time and smaller forecast area compared to the South Coast or North and South Columbia regions. These effects are evaluated in Sections 4.3 and 4.4.

4.3. Effect of spatial scale on hit rate

By grouping the forecast regions into small, medium and large as indicated in Table 1, the effect of spatial scale on the distributions is shown in Figure 8. The hit rate decreases from small (0.69), to medium (0.64) and to large areas (0.54). At all three area scales, the local avalanche danger is rated lower than in the regional forecast ($\Delta D > 0$) more often than the local danger is rated higher than the regional danger ($\Delta D < 0$). However, this graph is based on the regional danger rating in the first bulletin available to recreationists, and the lead times vary for these forecasts.

The median lead time L for the small, medium and large forecast area is zero, one and two days, respectively. The interaction between the time scale effect and the area scale effect is considered in the next section.

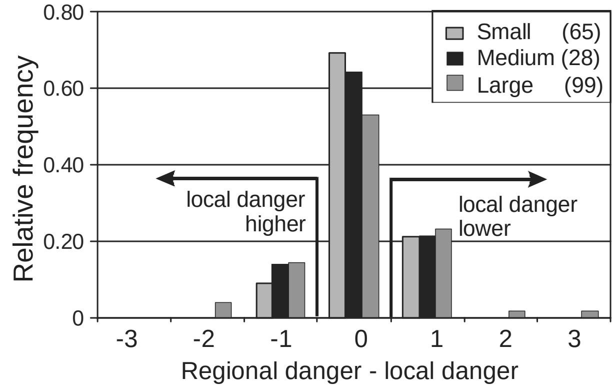

Figure 8. Relative frequency of the difference in danger ratings from the regional forecast and the local nowcast for small, medium and large forecast areas.

4.4. Time and spatial scale effects

Many of the local danger ratings can be compared with the danger ratings from more than one regional forecast. For example, in Glacier National Park the danger rating for a given day was published that morning, on the two previous mornings. To increase the dataset for analyzing time scale effects, we also compared the local danger rating with the rating from the regional forecast published on the afternoon of the local nowcast. Using all data for various lead times, the hit rate for small, medium and large forecast areas is shown in Table 2. For lead times of two, one and zero days, the hit rate for large forecast areas increases from h_2 = 0.50 to h_1 = 0.51 to h_0 = 0.54. For lead times of two, one and zero days, the hit rate for medium forecast areas increases from h_2 = 0.63 to h_1 = 0.64 to h_0 = 0.73, although the hit rate for a two day lead time is based on a very small sample (n = 8). For lead times of two, one and zero days, the hit rate for small forecast areas increases from h_2 = 0.63 to h_1 = 0.71 to h_0 = 0.71. The hit rates for lead times of zero, one and two days, excluding the one based on only eight cases, are shown in Figure 9.

Table 2. Hit rate for various forecast areas and lead times			
Area of forecast regions	Lead time, L (days)		
	0	1	2
Large (N., S. Columbia, S. Coast)	0.54 [a] (27/50)	0.51 (23/45)	0.50 (18/36)
Medium (BYK)	0.73 [a] (19/26)	0.64 (18/28)	0.63 [b] (5/8)
Small (GNP, North Shore, Whistler Backcountry)	0.71 (36/51)	0.71 (36/51)	0.63 (24/38)

[a] The bulletin was published in the afternoon of the nowcast day and therefore not available to recreationists.
[b] Insufficient sample size for analysis.

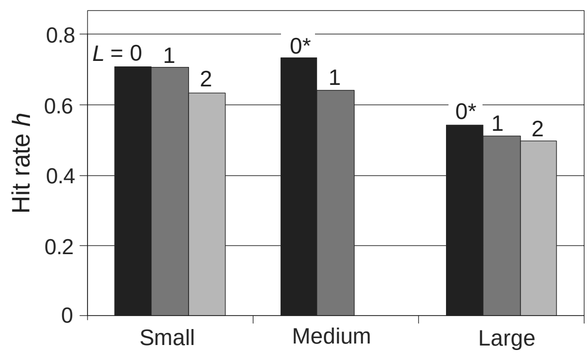

Figure 9. Relative frequency of the hit rate for small forecast areas, medium areas (Banff Yoho Kootenay) and large areas (North and South Columbia regions and South Coast). The lead time, L, in days is shown above the bars. The asterisk for same day forecasts indicates the bulletin was always or often published in the afternoon of the nowcast day and therefore not available to recreationists. The relative frequencies for medium forecast areas with two day lead times are not shown because of small sample size.

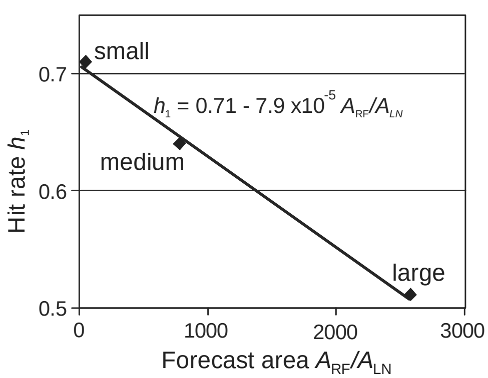

Figure 10. Hit rate for one day lead time, h_1, vs forecast area A for the small, medium and large forecast areas identified in Table 3.

The hit rate for lead time of 1 day, h_1, for small (weighted average A_{RF} = 330 km^2), medium (A_{RF} = 8,000 km^2) and large forecast areas (weighted average approximately A_{RF} = 54,000 km^2) is shown in Table 2 and Figure 10. Smaller forecast areas show an increased hit rate. With only three points to consider, we make the simplest assumption about the trend and show the linear regression line

$$h_1 = 0.71 - 7.9 \times 10^{-5} A_{RF}/A_{LN} \qquad (2)$$

where A_{LN} = 10 km^2 is the nominal area of the local nowcast.

5. DISCUSSION: INCREASING THE HIT RATE FOR LARGE FORECAST AREAS

In this section, we cautiously compare the potential increase in the hit rate due to a reduction in area with the potential increase due to a decrease in lead time as a result of increased frequency of bulletins. The hit rate for 1 day lead time, h_1, for the medium forecast area (BYK) is 0.13 higher than for large forecast areas (Figure 10). Averaging the improvement in the hit rate for large areas (over two to zero days) and for medium areas (over one to zero day) yields Δh_1 = 0.054 d^{-1}. This is close to the overall average of 0.048 d^{-1} when the small forecast areas are included. This suggests that changing from a large forecast area to a medium area would result in a greater improvement than by decreasing the lead time by one day, or roughly increasing the bulletin frequency from three times per week to daily. According to Eq. 2, decreasing the forecast area by 30% from large (roughly 25,500 km^2) could increase the hit rate to 0.56 which is comparable to a one day reduction in the lead time. This is only a rough calculation based on limited data and an assumed linear effect of the spatial scale.

Reducing the area of a large forecast region into sub-regions with comparable heterogeneity would not improve the hit rate. Alternatively, subdividing a large forecast region with heterogeneous avalanche climate into sub-regions with reduced heterogeneity could potentially yield a substantial improvement in hit rate. Of course, any subdivided region must also have adequate reporting stations for avalanche, snowpack and weather data. The study by Haegeli and McClung (2003) may prove useful in subdividing the regions in the Columbia Mountains.

While this study documents the potential improvement in the hit rate for more frequent bulletins and for smaller forecast regions it does not consider the costs associated with more frequent bulletins or with an increased number of bulletins due to subdividing forecast regions.

6. SUMMARY

Teams of two to three field observers made total of 235 ratings of the avalanche danger for the current day on the scale of a small drainage or ski tour (local nowcasts) in seven different avalanche forecast regions in the Coast, Columbia and Rocky Mountain ranges of western Canada. Forty-three ratings were rejected because of a bias towards the danger rating in the regional forecast when the team of observers included a forecaster and the observations were made in a regular study plot.

The integer values of danger ratings from the regional forecasts were compared with the danger rating from the local nowcast by calculating the difference. In all forecast regions, relative frequency of zero differences (agreement rate or hit rate) exceeded the non-zero differences, indicating that regional danger ratings are useful, at least as initial estimates of the drainage scale avalanche danger on a given day. The regional danger ratings can be considered spatial averages.

There were more positive differences, indicative of conservative regional ratings, than negative differences.

Some avalanche bulletins are published daily and available in the morning to recreationists entering the backcountry. Others are published with lead times of one to three days before they are superseded by the next bulletin. The hit rate increased by an average of about 0.05 as the lead time decreased by a day.

The hit rate was higher for smaller forecast regions than for larger forecast regions. In particular, the hit rate for a medium forecast area (8,000 km^2) was 0.13 higher than for large forecast areas (weighted average 25,500 km^2). Consequently, the hit rate for large forecast regions can potentially be improved more by reducing the forecast area than by increasing the frequency from three times per week to five or seven times per week. Subdividing a forecast region will only improve the hit rate if the subdivided regions have less heterogeneity than the original larger region and there are sufficient sources of weather, snowpack and avalanche data in the subdivided regions. However, when the text part of the bulletin was considered for large and medium forecast areas, the hit rate increased by 0.05. This shows the potential for some large forecast areas to be effectively subdivided.

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