GUIDELINES FOR FORECASTING SNOW AVALANCHES ON THE MILFORD ROAD, NEW ZEALAND

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ABSTRACT: We explore the use of rule-based systems as an operational tool for helping evaluate the avalanche hazard on the Milford Road, New Zealand. Climate in the region is strongly maritime; annual precipitation exceeds 7m (water equivalent) and winter storms often deposit 2-3 m of snow in the start zones. Winter rain-on-snow is common. Most of the hazard comes from direct-action avalanches. Here we exploit the wealth of local knowledge of personnel in the program, and the 20-year archive of avalanche and weather data, to establish observational thresholds that are conducive to avalanching. Observations indicate that the potential for avalanches reaching the road increases when the cumulative precipitation at East Homer gauge exceeds 60mm w.e. Of course caveats apply; we are extremely mindful of Ron Perla's rule of thumb: *The only rule of thumb in avalanche work is that there is no rule of thumb*.

KEYWORDS: Snow, avalanches, forecasting

1. INTRODUCTION

The Milford Road (SH-94) links TeAnau to Milford Sound on the southwest coast of New Zealand. The highway, which follows the valley floor, is in the runout zone of avalanches that start more than 1000 m higher (Fig. 1). It is often difficult for travelers to perceive the hazard, especially on days when the snowline is well above the highway. Average annual precipitation in the region exceeds 7 m (w.e.) and winter storm cycles often deposit 2-3 m of snow in the avalanche start zones. Most potentially hazardous avalanches are “direct-action” avalanches that release during or soon after storms. Rain is common, even during midwinter.

An avalanche program was initiated in 1984; the primary goal of the program is to minimize the hazard to workers and travelers on the highway. The hazard is managed by evacuating workers and travelers from avalanche runout zones during times when the avalanche potential is forecast to increase. Periods of high hazard are managed by closing the road until slope stability increases either naturally or by active control. Current practice for active control is to use explosives deployed by helicopter. Statistics indicate that on average, 36 avalanches (both natural and artificial) large enough to destroy a vehicle (size 2.5 and larger on the Milford scale) reach the road each year (Hendrikx and Owens, 2006). The East Homer avalanche path is the most active (6.9 potentially destructive avalanches per year), followed by Raspberry (4.6), Moir (4.1) and Sinks (3.9). Although statistical analyses of avalanche occurrence provide useful guidance for risk evaluation on highways (e.g. Hendrikx et al., 2006; Margreth et al., 2003), their use for daily operational avalanche forecasting is limited.

Figure 1: Aerial view of the Milford Highway. The highway traverses up the Hollyford valley, passes through the Homer tunnel into the Cleddau valley, which it follows to Milford Sound. The highway is threatened by avalanches from both sides of both valleys.

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Here we draw on more than 20 years of experience and observations and begin to establish a rule-based decision making system for forecasting snow avalanches on the Milford Road. The approach is inspired by the “obvious clues" method described by McGammon and Hageli (2006) for assessment of slope stability in the backcountry.

2. OBSERVATIONS

Observations and forecasting tools now available to forecasters include:

2.1 *Road-level observations*

Key road-level observations include avalanche activity, snow-line elevation, waterfall activity, weather, and road conditions.

Avalanche technicians record location (path and start zone) and time of avalanche activity, avalanche size, fracture line elevation and depth, distance of runout from road, length and depth of deposit on the road, and evidence of blast across the road (leaves, rocks on road, snow in trees). Avalanche activity on indicator paths that are not usually controlled is also recorded; Talbot Ramp and Talbot Face are often the first to release during winter storms. Monkey Creek often provides an indication during rain-on-snow instability. The avalanche atlas for the the Milford Road has been updated (Hendrikx and Owens, 2006). Snow-line elevation is important for determining the elevation of the rain/snow transition, necessary for estimating the altitudinal gradient of instability. Waterfall activity during rain or melt events provides direct information about snow stability; well established drain channels are thought to stabilize the snowpack because water is directed out of the snowpack and away from potential sliding layers. Caution is needed if waterfalls are not active during and following rain-on-snow events. Hazard increases significantly when snow and ice on the road causes traffic to slow, or stop and backup.

2.2 Weather and snowpack measurements

Hourly measurements of weather and snowpack properties are currently telemetered to TeAnau from a network of remote stations. Two stations are located at road level (East and West Homer), four are near start zones (Consolation, Belle, Cleddau, Crosscut, and Gates) and one (Rover) is a mobile unit. Hourly measurements include: precipitation, air temperature, wind speed and direction, air pressure, relative humidity, solar radiation, snow depth, snow temperature profiles, water outflow from beneath the snowpack, and snow creep.

2.3 Weather forecasts

Reliable twice-daily forecasts of local weather (frontal passage, winds, hourly precipitation at East Homer and air temperature at Mt Belle) from the New Zealand meteorological service are critical for managing the hazard. The weather forecasts are now generally good especially when forecast models agree; problems arise when results from the three forecast models diverge (pers comm., avalanche technicians, 2006). Updated weather forecasts from the meteorological service when synoptic conditions change significantly are now a mandatory for operational avalanche forecasting.

2.4 Results from active control

The main objective of control work is to eliminate deep instabilities in the snowpack. Explosives are used to clean out start zones and pockets of potential deep instability that did not release naturally during a storm cycle. Eliminating deep instabilities is key for forecasting the response of the snowpack to the next storm. Bomb placement and avalanche activity is logged and archived.

2.5 Snow pits and fracture-line profiles

Standard measurements (layer stratigraphy, density, temperature, moisture content, shear stress and strength) from snow pits and fracture line profiles in avalanche start zones provide information about current snow stability at a particular location. The observations provide a basis for extrapolating conditions over the region and for predicting how the snowpack will respond to future possible changes. Snow-profile observation guidelines for the Milford road have been adapted from the New Zealand guidelines. Profiles are recorded using SnowPro software. In 2001, a hut was erected at Crosscut between the start zone of two paths. The hut has enabled avalanche technicians to observe snow and weather conditions in the vicinity of start zones during storms. An important immediate observation from Crosscut was that cold, low-density snow is likely to blow away; in general, less snow is deposited in start zones during cold storms than is predicted by the East Homer gauge.

3. OBVIOUS CLUES

The avalanche potential along the Milford Road is particularly high during storms of intense precipitation when the loading from new precipitation increases faster than the snowpack can strengthen. Key questions include:

1. Is an avalanche likely to reach the road now? If so, what are the consequences? Will it blast or deposit debris on the road? Will it be sufficient to immobilize or slow traffic?
2. What conditions will cause an avalanche to reach the road in the future? Forecasts of the hazard at least 4-6 hours ahead are needed to allow time to evacuate travelers from their destination at Milford Sound.

Some of the clues and questions asked by avalanche technicians as an aid to forecasting the hazard include:

3.1 <u>Avalanche activity in past 24 hours</u>

1. *Have avalanches affected the road?*
   Yes - high hazard
2. *Have any indicator paths (Talbot Ramp, Talbot Face, Monkey Creek) released?*
   Yes - high hazard

3.2 <u>Road conditions</u>

3. *Is there currently snow on the road?*
   Yes - increased hazard
4. *Is snow on the road in the forecast? How much?*
   Yes - increased hazard.

3.3 <u>Weather and snow conditions</u>

5. *Total precipitation since last control work?*
   Yes - increasing hazard when
   > 50 mm w.e. at East Homer gauge.
6. *Is precipitation in the forecast*?
   Yes - increasing hazard when cumulative storm and forecast precipitation is > 50 mm w.e.
7. *Rain-on-snow?*
   First rain on new snow?
   Yes - be prepared for immediate avalanche activity if the snowpack is tender; otherwise avalanches may be delayed for up to 48 hours or more. Hazard remains high.

   Waterfalls active?
   - evidence of drainage of water out of the snowpack; decreasing hazard.

   Water flowing through lysimeter?
   - drainage; decreasing hazard.

   Snowpack isothermal, drain channels established?
   - decreasing hazard.

4. THRESHOLDS

As a first step to quantify the precipitation thresholds used for hazard forecasting we have examined avalanche and storm statistics for three years: (2000 - 2002). We identified 52 storms (defined when total precipitation at East Homer gauge is greater than 50 mm w.e.) over the three-year period. Avalanches occurred (defined when three size 2.0 or one size 2.5 avalanche released) during 24 of the 52 storms studied. We used the Mann-Whitney U test (Mann and Whitney, 1947) to assess whether observations during avalanche-producing storms were significantly different from those during non-avalanche storms. Of variables tested, those that indicate significantly different ($p \leq 0.05$) distributions are:

1. snow depth at Belle (Belle_HS)
2. maximum precipitation rate at East Homer gauge (max p/r)
3. maximum cumulative 3-hr precipitation at East Homer (3-hr ppt)
4. maximum cumulative 6-hr precipitation at East Homer (6-hr ppt)
5. maximum cumulative 12-hr precipitation at East Homer (12-hr ppt)
6. maximum cumulative 24-hr precipitation at East Homer (24-hr ppt)
7. maximum cumulative 48-hr precipitation at East Homer (48-hr ppt)
8. maximum cumulative 72-hr precipitation at East Homer (72-hr ppt)
9. cumulative storm precipitation at East Homer (storm ppt)
10. Snowfall at elevations greater than 1700m (discriminated by temperature at 1700m at Belle and precipitation at East Homer (snow>1700)
11. Snowfall over previous 72 hrs (Snow - 72hrs)
12. Storm snowfall (storm snow)

A. NO Avalanches (28 storms) **Percentiles**

	mean	median	St dev.	min	max	25%	50%	75%
Belle_HS	1.99	1.9	0.98	0	4.1	1.3	1.9	2.3
max p/r	8.36	8.35	2.78	4.8	17.3	6	8.35	9.65
3-hr ppt	20.2	20.5	5.97	10	34.6	14.3	20.5	23.8
6-hr ppt	33.9	32	10.1	18	58.5	24.5	32	41.8
12-hr ppt	52	49	17.3	26	86	38.3	49	70.5
24-hr ppt	71.5	60	28.3	31	142	54	60	90.4
48-hr ppt	96.9	89	38.5	51	181	65.5	89	115
72-hr ppt	116	106	53.2	52	283	73	106	127
storm ppt	111	93	62.2	50	297	66.3	93	122
snow>1700	5.9	6	3.81	0	13	4.25	6	8.75
snow-72hrs	16.8	7	21	0	73	2.25	7	27.5
storm snow	55.2	45.1	45.2	0	148	13.3	45.1	95.5

B. YES Avalanches (24 storms) **Percentiles**

	mean	median	St dev.	min	max	25%	50%	75%
Belle_HS	2.74	2.7	0.89	1.19	4.3	2	2.7	3.38
max p/r	11.3	10.6	4.43	4.6	21.2	8	10.6	13.5
3-hr ppt	26.6	27	9.29	10.2	46	18.5	27	35.3
6-hr ppt	44.6	46.5	16.8	14	76	30.3	46.5	56
12-hr ppt	71.4	68.5	27.4	22.7	125	52	68.5	93.3
24-hr ppt	108	108	42.5	34.9	211	76.3	108	130
48-hr ppt	148	143	55.7	62.3	282	95.3	143	191
72-hr ppt	179	174	66.2	69.9	335	120	174	234
storm ppt	193	167	110	65.9	523	116	167	266
snow>1700	9.58	8.5	3.66	5	21	8	8.5	11.5
snow-72hrs	41.5	21	48.9	3	208	6	21	61.5
storm snow	126	114	61.1	18	249	84.8	114	163

Table 1: Comparison of statistics for storms with and without avalanches.

5. DISCUSSION AND CONCLUSIONS

The Mann-Whitney U test yields a comparison of the median values of variables for avalanche/no-avalanche storms. Although the probability that the medians are different exceeds 95%, results shown in Table 1 indicate large overlap in the distributions; comparison of median values has limited value as a forecasting tool.

However, inspection of the tails of the distributions yields some hope. For example, the minimum snow depth at Belle for an avalanche-producing storm is 1.19 m. The percentile of non-avalanche-producing storms that does not meet this requirement is ~20%; that is, five or six of the 28 non-avalanche-producing storms could be predicted from the total snow depth at Belle. Examination of the statistics of precipitation totals yields additional insight. Table 1B shows that at least 60 mm of precipitation in 48 hrs is necessary to cause avalanching. Table 1A shows that the percentile of non-avalanche producing storms with less than 60 mm over a 48-hr period is ~15%; that is 4 or five of the non-avalanche producing storms could be predicted from the 48-hr precipitation. In other words, of the 52 storms analyzed, using these two discriminators we can have confidence that about ten of them would not have produced avalanches (provided that the same storm was not discriminated by both thresholds). Of course this also means that we would have miss-predicted the outcome of eighteen storms that did not produce avalanches.

Caution is needed interpreting these preliminary results. So far we have examined just a small subset of the available storm data. More analyses are planned and we expect to gain confidence in results as we examine more storm cycles. Interesting though, is that the 60-mm threshold for avalanching on the Milford Road that has emerged from the statistics for these storms is similar to the 50-mm threshold that is often used by experienced forecasters (unless some other observation indicates otherwise).

Our results indicate that comparison of the tails of distributions is likely more useful than comparing median values. Statistical comparison of the shape as well as the median of distributions (Kolmogorov-Smirnov or K-S test), and determination of the probability of extreme values using Gumbel or log-Weibell statistics may prove valuable.

Of course for avalanche forecasting during storm cycles there is no substitute for continual monitoring of key indicators. Key indicators include avalanche activity, snowline elevation, distribution of accumulation in start zones. evolution of drain channels during rain-on-snow events, including waterfall activity …… We anticipate that rules and indicators will continue to evolve as we assimilate more observations; we are extremely mindful of Ron Perla's rule of thumb: *The only rule of thumb in avalanche work is that there is no rule of thumb*.

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