THE USE OF CLASSIFICATION TREES AS A TOOL FOR FORECASTING AVALANCHE ACTIVITY ON THE SEWARD HIGHWAY, ALASKA

Jordy Hendrikx[1*], Matt Murphy[2], Terry Onslow[2]
[1] Snow and Avalanche Laboratory, Montana State University, Bozeman, Montana, USA.
[2] Alaska Department of Transportation and Public Facilities Anchorage, AK, USA.

ABSTRACT: The Seward highway is located in coastal Alaska and is subject to an extreme maritime climate, with strong winds, and large storms that can bring several meters of snow to the start zones and total snow often exceeding 10m per year. The highway extends for 127 miles through steep glacially carved valleys, from Seward to Anchorage, Alaska. Along its route, from mileposts 18 to 107, avalanche paths threaten the road and in many cases these avalanches flow down from their starting zones in excess of 1000m above the road.

Using a classification tree approach, we examine almost 30 years of snowpack, weather and avalanche data. This suite of data contains more than 4500 individual avalanche events on over 100 paths, with 20 paths seeing regular activity. We use this wealth of data to train our statistical model. Using a statistically defendable tree, we are able to forecast avalanche days that affect the road, with a remarkably high level of accuracy of 93%, using only two parameters of 72 hour storm water and 24 hour high temperature. We then use these results from the Seward Highway to compare them directly to a similar study previously undertaken for the Milford Road in New Zealand, which despite being located almost 12,000km away and in the Southern Hemisphere, is in a similar climatic setting. Due to the similar methods used in this, and the previous Milford Road study, we are able to compare key metrics. We find that a drift parameter and the sum of water over a 48-72 hour period are important in both of these areas. We consider that theses parameters are the potential fundamental metrics for avalanche forecasting in these types of maritime climate. These can be used as another tool to assist forecasters in these environments, either dealing with succession, and or with the rigors of long seemingly never ending winters.

1. INTRODUCTION & BACKGROUND

This paper describes the analysis of meteorological variables using classification trees to determine, and potentially forecast, significant avalanche activity on the Seward highway, Alaska. The Seward highway is located in coastal Alaska and is subject to an extreme maritime climate, with strong winds, and large storms that can bring several meters of snow to the start zones and total snow often exceeding 10m per year. The highway extends for 127 miles through steep glacially carved valleys, from Seaward to Anchorage, Alaska (Figure 1). The first portion of the Seward Highway was completed in 1923, and the highway was finished on October 9, 1951. The road runs through the scenic Kenai Peninsula, Chugach National Forest, Turnagain Arm, and Kenai Mountains. Along its route, from mileposts 18 to 107, avalanche paths threaten the road and in many cases these avalanches flow down from their starting zones in excess of 1000m above the road. The Seward Highway Avalanche Program became a full-time active operation in 1983, after nearly 30 years of intermittent avalanche work starting in 1955. The Seward Highway was finished while Alaska was still a Territory and was managed by the Bureau of Public Roads. After statehood in 1959, management changed to the Alaska Department of Highways, and in 1977 the named was changed to the Alaska Department of Transportation and Public Facilities (AK DOT & PF).

**Corresponding author address:* Jordy Hendrikx, Snow and Avalanche Laboratory, Department of Earth Sciences, Montana State University, P.O. Box 173480, Bozeman, MT, USA 59717;
email: jordy.hendrikx@montana.edu

Early attempts to reduce the avalanche hazard between 1955-1969 included: building earthen mounds as avalanche breakers north of Girdwood, utilizing the U.S. Army for artillery support, and installing a ridgetop weather station above Turnagain Arm in 1959. During this first era of avalanche work on the Seward Highway, there were only 3 years (1959-1962) when full-time

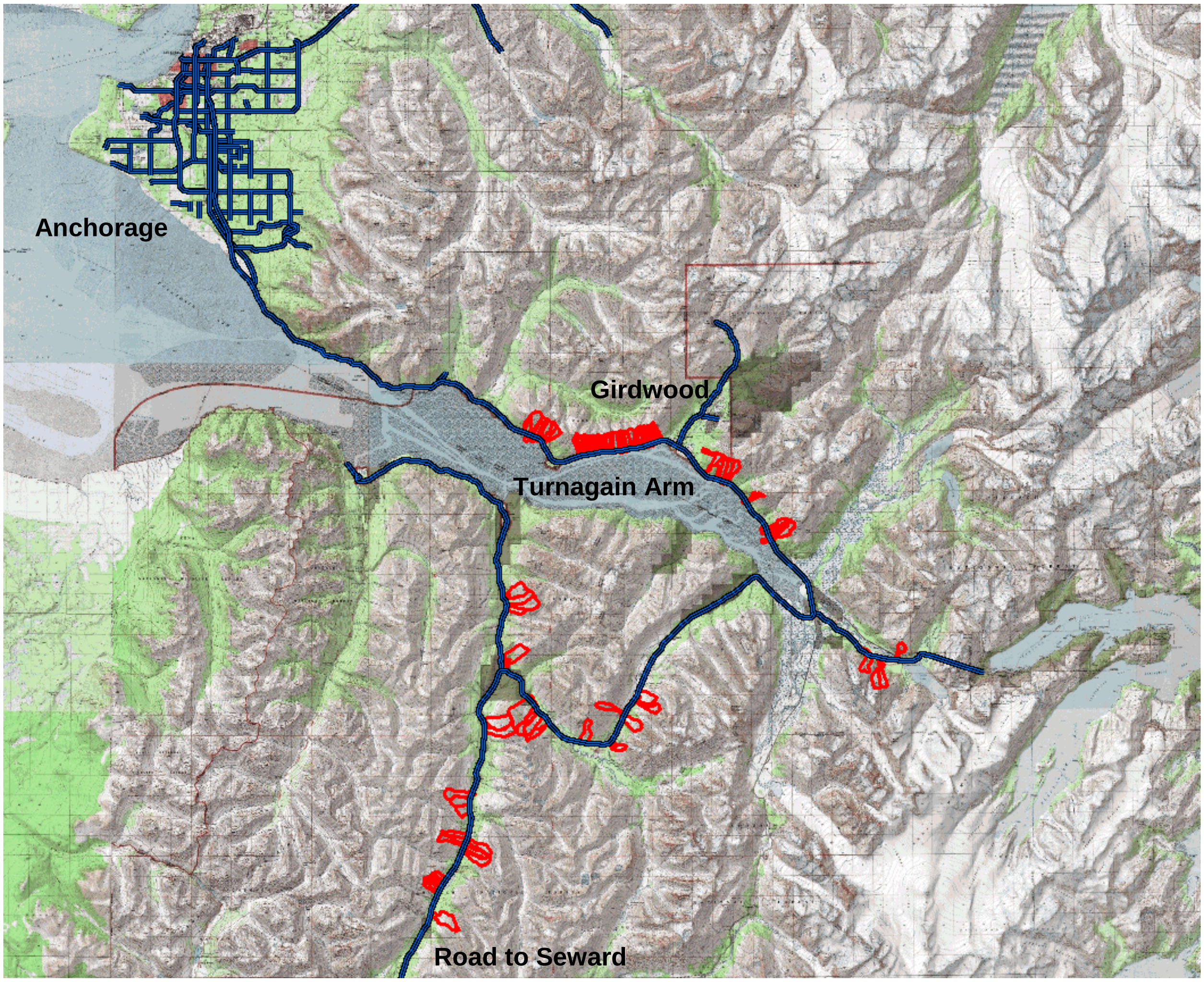

Figure 1: Location map showing the Seward highway (shown in blue), that connects Anchorage with Seward, Alaska, USA. The main avalanche paths are shown as the red polygons on the map. Key places of interest are labeled.

personal had the primary duties of avalanche observations and forecasting (Hamre, 1979). Problems with rime and inaccessible terrain made alpine weather and snowpack observations stations difficult and unreliable, so most of the data came from lower elevation weather stations and road patrols.

The U.S. Army proved to be very cooperative during these early years, but there were certain limitations making it difficult for the Department of Highways to have immediate access to artillery for avalanche work. After 1969, The Department of Highways entered an agreement with the United States Forest Service (USFS) to lease a 75mm recoilless rifle from the U.S. Army for highway avalanche control work. Between 1969-1975, USFS personnel fired this weapon for the Department of Highways, but similar to the Army, there were problems with immediate access to artillery.

In 1976, the Department of Highways acquired a 105mm recoilless rifle leased from the U.S. Army. This weapon was fired by Department of Highways personnel, which improved the previous problems of accessibility experienced under the Army and USFS. Between 1976-1983, blind fire data was established allowing AK DOT & PF to shoot during storms and at night, which did not occur in the earlier artillery operations. These capabilities greatly improved the effectiveness of avalanche artillery operations.

Since 1983, the Seward Highway Avalanche Program (SHAP) has been staffed full-time by two personnel dedicated to avalanche work while local foremen and equipment operators have been trained to fire the artillery in support of the avalanche program. Therefore, the most detailed and complete avalanche and weather observations have been taken from 1983-present. The primary weather station for the SHAP was established in the Girdwood Department of Transportation yard in 1983, where daily measurements are taken manually and by instrumentation. Rime and difficult access has been a continuing problem for ridge top weather stations above the highway along Turnagain Arm, but Alyeska Resort and The Chugach National Forest Avalanche Information Center have had better success with higher elevation meteorological data. The Girdwood Department of Transportation yard weather station data, is the primary weather station utilized by SHAP for making avalanche decisions.

Since 1999, a couple of significant changes have occurred for SHAP due to the transition from the 105mm recoilless rifle to the M101A1 105mm howitzer, and the realignment of the highway north of Girdwood. Prior to 1999, the most active avalanche area on the Seward Highway (in regards to frequency of avalanches that hit the road with debris) was the section between Girdwood and Bird (mileposts 99-90). After 1999, a new road alignment and the construction of catchment dams have greatly reduced medium sized avalanche occurrences from hitting the highway in that section. Large and fast moving avalanches are still a threat to this section of road.

We now have over 28 years of snow pack, weather and avalanche data (1984-2012) from the Seward Highway. This suite of data contains more than 4500 individual avalanche events on over 100 paths, with 20 paths seeing regular activity. We use this wealth of data to train our statistical avalanche model. Avalanche forecasting using a wide variety of statistical models, e.g. Correlation analysis (Perla, 1970); Multivaritate discriminant function analysis (Bois et al., 1975; Fö hn et al., 1977); Nearest neighbours (Buser, 1983); Expert systems (Schweizer and Fö hn, 1996; Classification and regression trees (Davis et al., 1999); and cross validated classification trees (Hendrikx et al., 2005). For this study we elected to use cross validated classifications trees as successfully recently used by Hendrikx et al., (2005) and Peitzsch et al., (2012). This technique was used as it provides a clearer and often more easily understood interpretations of complex interactions than other model constructions (Davis et al., 1999), which makes them ideal for operational forecasting. A full discussion of classification and regression trees is given by Breiman et al. (1993). We also used this approach to allow for direct comparison to the resulted from the Milford Road in New Zealand (Hendrikx et al., 2005). Despite the Milford Road being located almost 12,000km away, and in the Southern Hemisphere, it is located in a similar climatic and avalanche setting as the Seward highway.

The main objective of this study was therefore to identify the meteorological variables responsible for significant avalanching in the extreme maritime climate of the Seward Highway in Alaska. Specifically, our main aim was to create a forecasting classification tree using remotely measured meteorological variables as predictors of a significant avalanche activity. A secondary aim was to compare and contrast these key metric and indicators to those presented for the Milford Road (Hendrikx et al., 2005), to assess if any are universal in these types of extreme maritime snow and avalanche climates.

2. METHODS

To enable the use of classification trees we first defined a significant period of avalanche activity as an “avalanche day”. For the purposed of this work, we only wanted to consider the bigger avalanche events, that where significant from an operational forecasting perspective. To achieve this, we considered only the events that had run at least 90% of their path length, where 100% represents the road way. This definition is similar to the avalanche day definition as used by Hendrikx et al., (2005) where they considered only events ≥2.5 in the Canadian size class, or the sum of sizes ≥10. Using this 90% threshold, we generated 552 unique avalanche days. Almost all avalanche days had more than one event.

We then generated an almost equal number of non-avalanche days. These were randomly selected days in the same time period as the avalanche days (i.e. the same number of days in each month and each year as the avalanche days). The number of non-avalanche days was not exactly equal to the number of avalanche days, as some randomly generated non-avalanche days while not avalanche days as per the definition, did still have avalanche activity, so were excluded.

This process resulted in 387 random non-avalanche days. These non-avalanche days were expressly selected from the same time periods, as the avalanche days to ensure for robust testing and analysis. For example, it would not be reasonable to just pick days at the start or end of each season and then compare these to the avalanche days; that would be too easy to statistically discriminate, and more critically is not very useful from a forecasting perspective.

This process resulted in a final analysis data set containing a total of 939 avalanche and non-avalanche days. For each of these days, we generated a series of meteorological metrics from the nearby weather station (Girdwood Department of Transportation yard) (Table 1).

Table 1: 32 direct, accumulated and derived meteorological parameters used in the analysis that were obtained from the variables collected at Girdwood Department of Transportation yard weather station.

Parameter	Variable Name	Time Period
Average high temperature	AvHigh_XX	24,48,72
Average low temperature	AvLow_XX	24,48,72
Average new snow depth	AvSnow_XX	24,48,72
Sum of new snow depth	SUMSnow_XX	24,48,72
Average water	AvWater_XX	24,48,72
Sum of water	SUMWater_XX	24,48,72
Density at time of avalanche	Density_00	At time of event
Sum of rain for 72 hours prior	SUMRain_72	72
Value of storm water total for the last 72 hours	StormWater_72	72
Value of storm depth total for the last 72 hours	StormDepth_72	72
Average wind speed	AvSpeed_XX	24,48,72
Direction for the 24 hours prior	Dir_24	24
Drift index = Ave wind speed * water	Drift_XX	24,48,72
Drift index3 = (Ave wind speed)3 * water	Drift3_XX	24,48,72

Where, XX in the symbols refers to the time period (24, 48 or 72 hours) that the variable is calculated over, prior to the day of avalanche occurrence.

To enable direct comparison, this list of variables is explicitly similar to those used by Hendrikx et al., (2005) for the Milford road. However a few new variables have been added. In particular, we have added a new snow drift index “Drift index3”. This is similar to the drift index used by Hendrikx et al., (2005) but rather than just finding the product of the average wind speed and the amount of water over a given period (24,48 and 72) we use the cube of the average wind speed. This new drift index is in line with the work by Pomeroy (1989) and is more realistic given our understanding of snow transport by the wind.

Using these data, we then plotted simple box and whisker plots to examine if there were any obvious difference between these meteorological parameters for avalanche and non-avalanche days. We also undertook a simple non parametric statistical analysis, the Kolmogorov-Smirnov two-sample test (Conover, 1999), to compare avalanche days with non-avalanche days. Finally, we also examined these data using a Classification Tree (CART) analysis. The method, stopping conditions, and the cross validation technique are identical to those as outlined by Hendrikx et al., (2005).

3. RESULTS

The non-parametric Kolmogorov-Smirnov two-sample test indicated that many of these meteorological parameters are different for avalanche days when compared to non-avalanche days (Table 2). Of the parameters that were statistically significant, most of the parameters were significant at the $p < 0.001$ level. Only wind direction was not significant at this level, but was still significant at the $P < 0.025$ level. We also tested the date field and found that this was not significantly different using this test. This confirmed that the avalanche and non-avalanche days were being selected from the same time period (as described in the methods section).

Our first 10 fold cross validated classification tree (Tree 8) used an equal misclassification costs of one, which means that the analysis is not penalized for false negatives any differently to obtaining false positives. This tree, using only four parameters; the 24 hour drift parameter, the 24 hour high temperature, the sum of 48 hours of water, and the storm depth for 72 hours, managed to obtain an overall predictive score of 73% with

681 of the 939 avalanche and non-avalanche days correctly predicted (Figure 2 and Table 3). However, this tree obtain a higher probability of detection for an avalanche day at 79% with 434 of the 552 avalanche days correctly predicted.

Table 2: Kolmogorov-Smirnov two-sample test comparing avalanche days with non-avalanche days. Shaded rows indicate tests were significant at the $p < 0.025$ level. Variable names are described in Table 1.

Variable Name	**Time period**
AvHigh_XX	24,48,72
AvLow_XX	24,48,72
AvSnow_XX	24,48,72
SUMSnow_XX	24,48,72
AvWater_XX	24,48,72
SUMWater_XX	24,48,72
Density_00	At time of event
SUMRain_72	72
StormWater_72	72
StormDepth_72	72
AvSpeed_XX	24,48,72
Dir_24	24
Drift_XX	24,48,72
Drift3_XX	24,48,72

Where, XX in the symbols refers to the time period (24, 48 or 72 hours) that the variable is calculated over, prior to the day of avalanche occurrence.

However when we consider Tree 8, the 118 false negative days are potentially more significant, or at least more dangerous, for operational purposes than the 140 false alarm or false positive cases. To lower the number of false negative cases, we changed the misclassification cost to penalize the analysis more for incorrectly classifying observed avalanche days as non-avalanche days (false negatives). To achieve this, we introduced a misclassification cost of two for false negatives and maintained a misclassification cost of one for false positives. This new tree (Tree 8*), using only two parameters; 72 hour storm water and 24 hour high temperature, managed to obtain an overall predictive score of 68% with 642 of the 939 avalanche and non-avalanche days correctly predicted (Figure 3 and Table 4). However, this tree obtain a much higher probability of detection for an avalanche day at 93% with 516 of the 552 avalanche days correctly predicted.

Table 3: Classification matrix for Tree 8, with observed cases in columns and the predicted cases in rows. This tree uses equal misclassification costs of one for any incorrect classification, and has an overall accuracy of 73%, while avalanche days are better predicted at 79%. The shaded cells show the correctly classified days. N=939.

		Observed	
		Avalanche day	Non-avalanche day
Predicted	Avalanche day	434	140
	Non-avalanche day	118	247

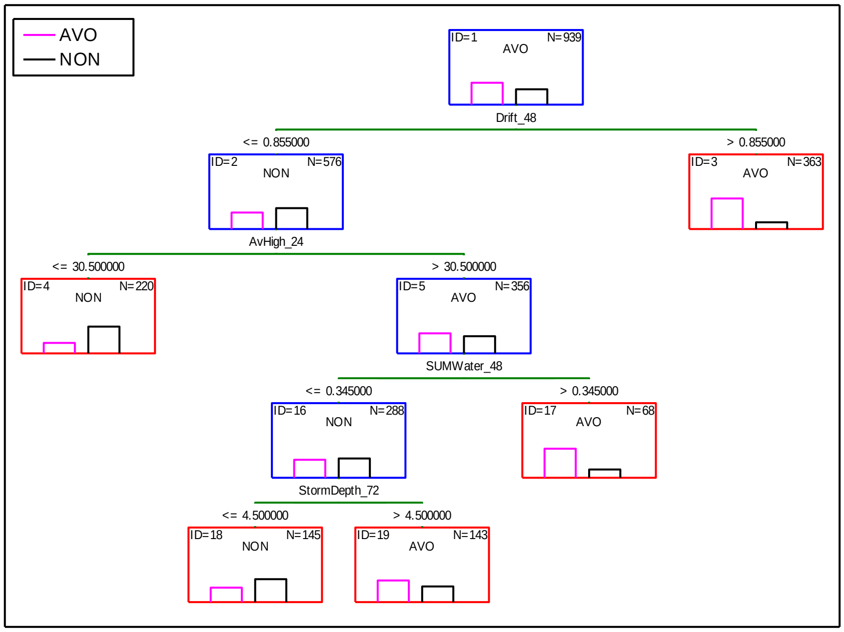

Figure 2: Avalanche day classification tree analysis following 10 fold cross validation showing Tree 8. Tree 8 is calculated using equal misclassification costs of one for any incorrect classification, and has an overall accuracy of 73%, while avalanche days are better predicted at 79%. Variable names used are as in Table 2.

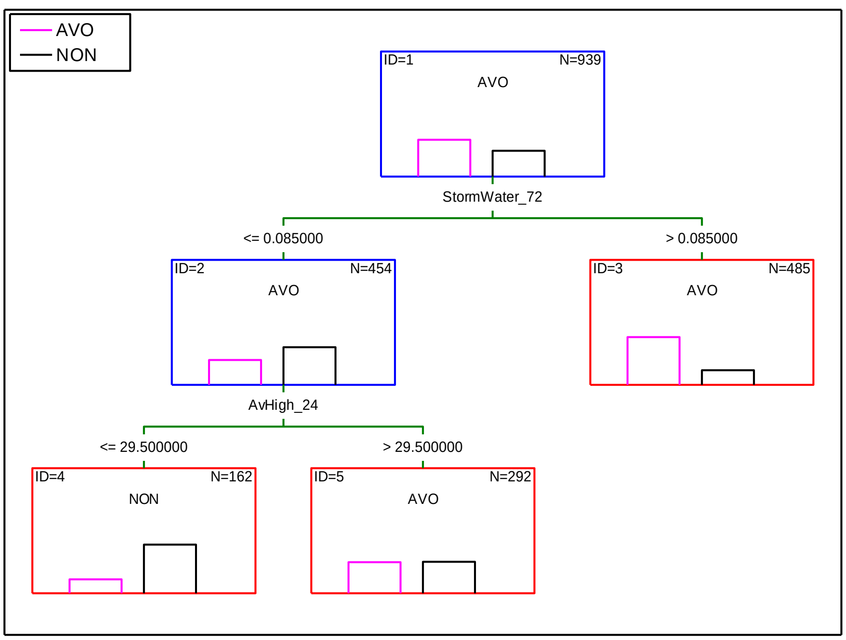

Figure 3: Avalanche day classification tree analysis following 10 fold cross validation showing Tree 8*. Tree 8* is calculated using a misclassification costs of two for false negatives and one for false positives, and has an overall accuracy of 68%, while avalanche days are much better predicted at 93%. Variable names used are as in Table 2.

Table 4: Classification matrix for Tree 8*, with observed cases in columns and the predicted cases in rows. This tree uses a misclassification costs of two for false negatives and one for false positives and has an overall accuracy of 68%, while avalanche days are much better predicted at 93%. The shaded cells show the correctly classified days. N=939.

		Observed	
		Avalanche day	Non-avalanche day
Predicted	Avalanche day	516	261
	Non-avalanche day	36	126

4. DISCUSSION & CONCLUSIONS

Our 10 fold cross validated classification tree results in statistically high correct classification rates. These rates are very encouraging, should the method be as conservative as suggested by Breiman et al. (1993). Peitzsch et al., (2012) also demonstrated this conservative nature of the cross validation technique, when they used a 10 fold cross validated classification tree outside of the training dataset with strong results for one season on the Going to the Sun Road, Montana, USA.

When we consider both trees presented here (Tree 8 and Tree 8*), we note that the average high temperature for the last 24 hours (AvHigh_24) is seen as a key split in both trees (Figure 2 and 3). This is encouraging as it shows that model is relatively stable and that the same parameters show up even with different misclassification costs are used. We also note that both trees, while using different parameters do consider the 48 or 72 hour water equivalence as a key metric to discriminate between avalanche and non-avalanche days. For Tree 8 this is represented by the parameter Drift_48, (the combined average wind speed and water for the prior 48 hours). For Tree 8* this is represented by the parameter Stormwater_72 (the 72 hours storm water total). From a forecasting perspective, this is reassuring and consistent with current practices, as a threshold of 0.75 inches (19 mm) of snow water equivalence over a 24 hour period is often used as a guideline for avalanche activity.

With respect to the utility of these trees for operational forecasting, we argue that it is the ability of a model to be able to predict avalanche days, rather than non-avalanche days well that is a more important measure for any potential operational model. Therefore, Tree 8* while having a higher rate of false positives, would be the more suitable, and more conservative tree, for use in operational forecasting. It also clearly reinforces the importance of wind and precipitation in this maritime avalanche climate, which as discussed by Shulski and Wendler (2007) is typical for this area of coastal Alaska.

When we compare these results to those presented by Hendrikx et al., (2005) for the Milford Road, we note that for the Seward highway we have slightly lower rates of overall accuracy. For instance, the equal misclassification cost 10 fold cross validated classification tree for the Milford Road had an overall accuracy of 85% (compared with 73%). While the tree using differing misclassification costs for the Milford Road had an overall accuracy of 78% (compared with 68%). However, for the Seward Highway we have much higher success with forecasting avalanche days when we use our Tree8* with the high misclassification cost for the false negatives (i.e. 93% for the Seward Highway compared to 86% for the Milford Road).

When we compare the key parameters used for the classification trees for both roads, we observe some clear commonalities. For the Milford Road the main variables to discriminate between avalanche days and non-avalanche days were the average wind speed for a 72 hour period, and a wind drift parameter that combined wind speed and summed precipitation over 72 hours (Hendrikx et al., 2005). Clearly the drift parameter, which was used in both studies, and the sum of water over a 48-72 hour period are important in both of these areas. The average high temperature, while of importance to the Seward highway was not as important for the Milford Road. Given the similarities in the overall climates of these two regions, the results are maybe not too surprising. However, the closeness of these parameters indicate that there are key parameters that are transferable from operation to operation, within similar climatic regions. The exact threshold that should be used for each of these parameters is obviously dependent on the particular operation and the size / threshold of event that the program wishes to mitigate against. However, we consider that the parameters of wind drift and accumulated water equivalence over a 48-72 hour period are the fundamental metrics for avalanche forecasting in these types of maritime climate.

ACKNOWLEDGEMENTS

We would like to thank the Alaska Department of Transportation and Public Facilities, and all the people that have worked on the Seward Highway. Without their observations and ongoing efforts this work would not have been possible.

REFERENCES

Bois, P., Obled, C., Good, W., 1975. Multivariate data analysis as a tool for day-to-day avalanche forecast. Proceedings of the International Symposium on Snow Mechanics, Grindelwald, Switzerland, vol. 114. I.A.H.S. Publication, pp. 391–403.

Breiman, L., Friedman, J.H., Olshen, R.A., Stone, C.J., 1993. Classification and Regression Trees. Chapman and Hall, New York, USA. 358 pp.

Buser, O., 1983. Avalanche forecast with the method of nearest neighbours: an interactive approach. Cold Regions Science and Technology 8 (2), 155–163.

Conover, W.J., (1999). Practical Nonparametric Statistics (3rd Edition). Wiley, USA. 592pp.

Davis, R.E., Elder, K., Howlett, D., Bouzaglou, E., 1999. Relating storm and weather factors to dry slab avalanche activity at Alta, Utah, and Mammoth Mountain, California, using classification and regression trees. Cold Regions Science and Technology 30 (1–3), 79– 89.

Fö hn, P., Good, W., Bois, P., Obled, C., 1977. Evaluation and comparison of statistical and conventional methods of forecasting avalanche hazard. Journal of Glaciology 19 (81), 375–387

Hamre, D., 1979. Seward highway avalanche safety plan. Report prepared by Alcan Avalanche Services for the Alaska Department of Transportation and Public Facilities; Central Region, Maintenance & Operations and Graphics Section.

Hendrikx, J., Owens, I., Carran, W. and Carran, A., 2005. Avalanche activity in an extreme maritime climate: The application of classification trees for forecasting. Cold Regions Science and Technology, 43, 104-116. DOI: 10.1016/j.coldregions.2005.05.006

Peitzsch, E.H., Hendrikx, J., Fagre, D.B., and Reardon, B., 2012. Characterizing wet slab and glide avalanche occurrence along the Going-to-the-Sun Road, Glacier National Park, Montana, USA. Cold Regions Science and Technology, 78, 73–81. DOI: 10.1016/j.coldregions.2012.01.012

Perla, R.I., 1970. On contributory factors in avalanche hazard evaluation. Canadian Geotechnical Journal 7 (4), 414– 419.

Pomeroy, J. W., 1989. A process-based model of snow drifting. Annals of Glaciology, 13, 237–240.

Schweizer, J., Fö hn, P.M., 1996. Avalanche forecasting an expert system approach. Journal of Glaciology 42 (141), 318– 332.

Shulski, M., and Wendler, G., 2007. Climate of Alaska. University of Alaska Press, USA. 208pp.