Cold Regions Science and Technology 97 (2014) 113–120

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Classification trees as a tool for operational avalanche forecasting on the Seward Highway, Alaska

Jordy Hendrikx [a,*], Matt Murphy [b], Terry Onslow [b]

[a] Snow and Avalanche Laboratory, Montana State University, Bozeman, MT, USA
[b] Alaska Department of Transportation and Public Facilities, Anchorage, AK, USA

ARTICLE INFO

Article history:
Received 5 November 2012
Received in revised form 14 August 2013
Accepted 17 August 2013

Keywords:
Avalanche forecasting
Maritime climate
Classification trees

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 in the start zones often exceeding 10 m per year. The highway extends for over 200 km through steep glacially carved valleys, from Seward to Anchorage, Alaska. Along its route, from mileposts 18 (29 km) to 107 (171 km), avalanche paths threaten the road and in many cases these avalanches flow down from their starting zones in excess of 1000 m above the road.

Using a classification tree, we examined 28 years (1983–2011) of snowpack, weather and avalanche data. This suite of data contained more than 4500 individual avalanche events on over 100 paths, with 20 paths seeing regular activity. We used this wealth of data to train our classification tree model for days with significant avalanche activity. We tested trees with both equal and unequal misclassifications costs. The equal tree using only three parameters; the sum of 72 h of water, the 24 h high temperature, and the 72 h average high temperature, managed to obtain a probability of detection of 0.77 with 422 of the 545 avalanche days correctly predicted. The unequal tree using only two parameters; the sum of 72 h of water and 24 h high temperature, managed to obtain a probability of detection of 0.94 with 510 of the 545 avalanche days correctly predicted, but at the expense of a high false alarm rate. Testing these trees in a hindcast mode outside of their training period results in a drop in the model performance metrics considered. However when used in a forecasting mode in an operational setting no further reduction in model performance is observed. We conclude with a demonstration and test of a simple approach to use these trees in an operational avalanche forecasting program. We show how these trees have been used in a combined approach as a tool to assist avalanche forecasters with reasonable success.

1. Introduction and background

This paper describes the analysis of meteorological variables using classification trees to determine and 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 10 m per year. The highway extends for over 200 km through steep glacially carved valleys, from Seward to Anchorage, Alaska (Fig. 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 (29 km) to 107 (171 km), avalanche paths threaten the road and in many cases these avalanches flow down from their starting zones in excess of 1000 m 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).

Early attempts (between 1955 and 1969) to reduce the avalanche hazard 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. During this first era of avalanche work on the Seward Highway, there were only 3 years (1959–1962) of full-time observations and forecasting (Hamre, 1979). Problems with rime and inaccessible terrain made alpine weather and snowpack observation 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

* Corresponding author at: Snow and Avalanche Laboratory, Department of Earth Sciences, Montana State University, P.O. Box 173480, Bozeman, MT, USA 59717; Tel.: +1 406 994 6918; fax: +1 406 994 6923.
E-mail address: Jordy.hendrikx@montana.edu (J. Hendrikx).

0165-232X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.coldregions.2013.08.009

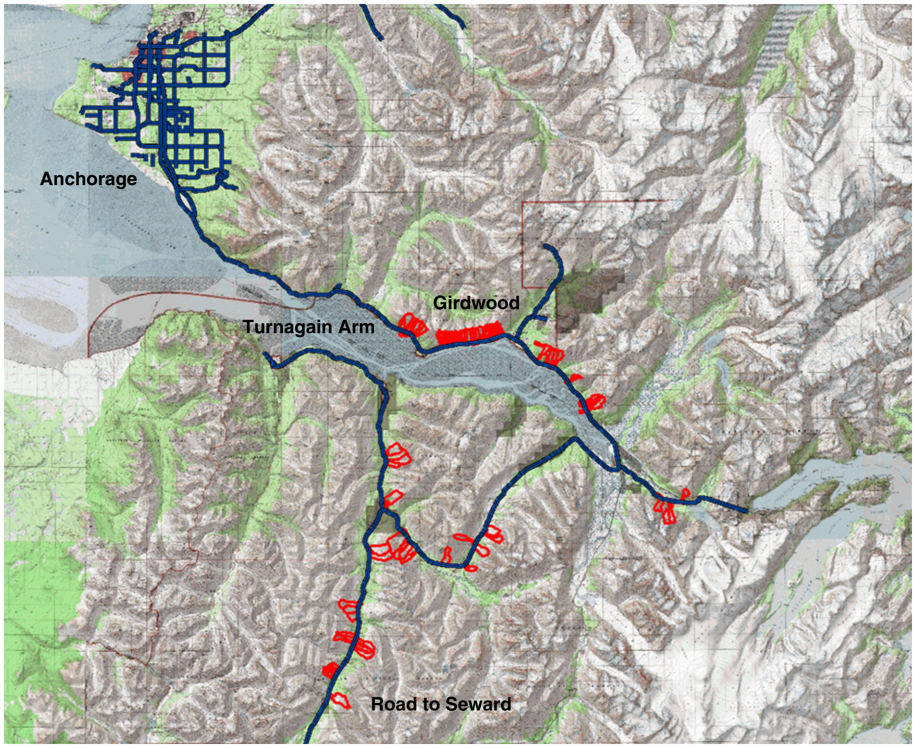

Fig. 1. Location map showing the Seward Highway (shown in blue), that connects Anchorage with Seward, Alaska, USA. The main avalanche paths are shown as the red polygons on the map. Key places of interest are labeled.

avalanche work. After 1969, the Department of Highways entered an agreement with the United States Forest Service (USFS) to lease a 75 mm recoilless rifle from the U.S. Army for highway avalanche control work. Between 1969 and 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 105 mm recoilless rifle leased from the U.S. Army. This weapon was fired by the Department of Highways personnel, which improved the previous problems of accessibility experienced under the Army and USFS. Between 1976 and 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 to present. Rime and difficult access have been a continuing problem for ridgetop weather stations above the highway along Turnagain Arm. For this reason, 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. The Girdwood Department of Transportation yard weather station data is the primary weather station utilized by SHAP for making avalanche decisions. A summary of the snow fall, snow water equivalence and number of avalanche days (as defined as a day with one or more events that have run at least 90% of their path length, where 100% represents the road way) in this period is presented in Fig. 2. Avalanche forecasting is primarily undertaken from the road level, with meteorological data from the low elevation (road level) of the Girdwood Department of Transportation yard weather station. Additional observations are also used from a high level weather station which has intermittent data due to the nature of the snow climate resulting in heavy riming. Field observations from the start zone are also an important aspect of this program and are taken when needed, as conditions allow. Given the nature of the snowpack and avalanches, most of the avalanche activity is observed during, or shortly after storms. However, these avalanches do not release solely in the new snow, and are known to step down to deeper weak layers developed earlier in the season. Therefore, the focus of the forecasting is to determine not only if avalanches might occur, but also how large they might be with a given additional load.

We now have 30 years of robust snow pack, weather and avalanche data (1983–2013) 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 28 years of this (1983–2011) to train our statistical avalanche model. The main objectives of this study are 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 and test a forecasting classification tree using remotely measured meteorological variables as predictors of significant avalanche activity and to test this in an operational forecasting setting, i.e. outside of the initial training data set, using data from the 2011–12 and 2012–13 seasons.

2. Methods

Statistical avalanche forecasting has been undertaken using a wide variety of approaches, e.g. correlation analysis (Perla, 1970); multivariate discriminant function analysis (Bois et al., 1975; Föhn et al., 1977); nearest neighbors (Buser, 1983); expert systems (Schweizer and Föhn, 1996); classification and regression trees (Davis et al., 1999); and cross validated classification trees (Hendrikx et al., 2005; Peitzsch et al., 2012a). For this study we first reviewed the relationship between the meteorological data and avalanche days using a univariate analysis using the non-parametric Kolmogorov–Smirnov two-sample test. Following this, we then elected to use cross validated classifications trees as used by Hendrikx et al. (2005) and Peitzsch et al. (2012a).