SNOW AVALANCHE CLIMATE AND EXTREMES OF THE WESTERN UNITED STATES MOUNTAIN RANGES

Cary J. Mock[1], Karl W. Birkeland[2], Jacqueline J. Shinker[3], and Michelle Bergen[4]

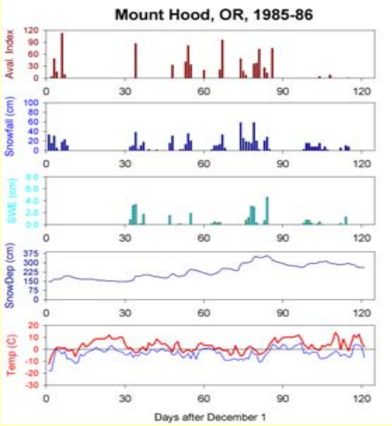
[1]Department of Geography, University of South Carolina, Columbia, SC 29208, United States, mockcj at sc.edu
[2]U.S. Forest Service National Avalanche Center, P.O. Box 130, Bozeman, MT 59771, United States, kbirkeland at fs.fed.us
[3]Department of Geography, University of Wyoming, Laramie, WY 82071, United States, jshinker at uwyo.edu
[4]Trimble Navigation Ltd, New Zealand, Christchurch, P.O. 8729, New Zealand, Michelle.Bergen at trimble.co.nz

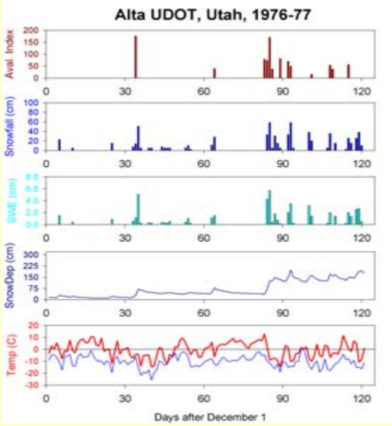
INTRODUCTION

The snow avalanche climate of the western United States has long been believed to encompass three major zones following a west-east gradient: coastal, intermountain, and continental (Mock and Kay 1992; Mock and Birkeland 2000). The coastal zone of the mountain ranges in the Pacific coast states and extending a bit into northern Idaho, is characterized by mild temperatures, abundant heavy snowfall, a high density snowcover, and a low temperature gradient in the snowpack. Conversely, the continental zone of the Rocky Mountains in Colorado, Wyoming, and parts of Montana is characterized by cold temperatures, less abundant snowfall, lower density snowcover, and a steeper temperature gradient. The intermountain zone of the northern Rocky Mountains of Montana, the Wasatch Range of Utah, the Blue Mountains of northeastern Oregon, and southwestern Colorado is intermediate in avalanche climate characteristics between coastal and continental. All of these climatic and snowpack differences are important since they determine the structure of the snowcover and the resultant character of the avalanches that each zone normally experiences. A thorough knowledge of prevailing avalanche climate also aids in the calculation of runout distances (e.g., Bergen 2002).

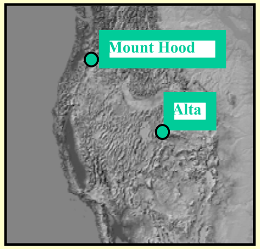
EXAMPLES OF AVALANCHE RESPONSES TO CLIMATE

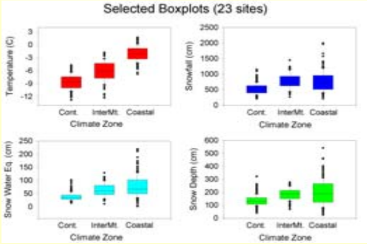
We discuss two examples of how avalanches respond to weather and climate during an extreme continental year (Alta, Utah, 1976-77) and an extreme coastal year (Mount Hood, OR, 1985-86). We developed a daily avalanche hazard index based on the size and frequency of avalanches from Westwide Network data, with an emphasis on potentially large damaging avalanches. We also constructed daily time series of the avalanche hazard index with several weather and snowpack variables. The situation for Mount Hood, Oregon in 1985-86 demonstrates extreme coastal climate characteristics. The relatively deep snowpack, and warm and low diurnal ranges of temperatures are evident. Temperature gradients within the snowpack are minimal, and therefore weak layers of faceted crystals are limited. Periods of significant avalanching are still evident, but avalanching typically occurs immediately following large and/or prolonged storms and usually involve only recent new snow. The 1976-77 season at Alta, Utah started out with a thin snowpack, abnormally cold temperatures, and relatively large differences between maximum and minimum temperatures. The temperature gradient in the snowpack exceeded 10°C/ m, and was associated with the formation of weak faceted crystals. Cool temperatures and a thin snowpack throughout the 1976-77 season ensured that weak layers remained prevalent in the snowpack, and even small storms are associated with relatively high avalanche activity, as measured by the avalanche index. Limited new snowfall is sufficient to overload old layer of fragile depth hoar, resulting in avalanching.





Top: Explosive released avalanche at Snow Basin Ski area in Utah. Bottom: Chris Lundy inspecting the crown face of a large wet slab avalanche in Glacier National Park, Montana.

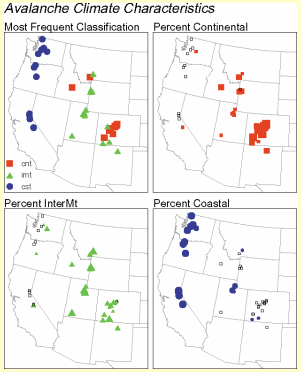


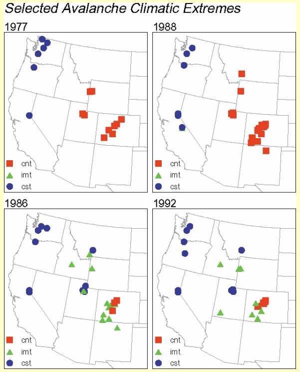


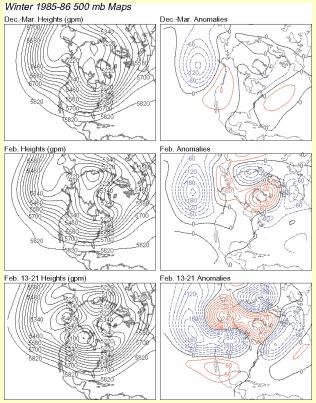
REGIONALIZATION OF AVALANCHE CLIMATE

We examined 48 stations with climatic and snowpack data from the Westwide Network, including two stations in Alaska to provide additional “climate space” in analyzing the variability of avalanche climate. Record lengths are not always continuous, varying from 2 to 57 years during the 1946-2004 time period. We analyzed daily data for December-March. Six snow climate variables were chosen: minimum temperature, maximum temperature, total snow depth, daily snowfall, daily snow water equivalent, and daily rainfall. Well-known criteria of defining thresholds and ranges of snow avalanche climatic variables provide the basis for classifying coastal, intermountain, and continental conditions. For further details on data and methods, please refer to Mock and Birkeland (2000).

We calculated the percentage of winters for each site that is classified as a particular avalanche climate, and mapped the results to summarize the major spatial patterns of avalanche climate characteristics over the West. Sites in the Pacific mountain ranges illustrate high percentages of coastal classifications, with rare classifications of intermountain and continental for some coastal interior stations. Almost all of the sites in Colorado have the highest percentages for continental classifications, with some moderate percentages of intermountain classifications. All of the Utah and Wyoming sites, and Bridger Bowl, Montana show highest percentages as intermountain. Northern Utah sites tend to receive more frequent coastal years as compared to continental years. Continental extremes tend to be more frequent northward in the intermountain zone, with Big Sky, Montana and Sun Valley, Idaho exhibiting fairly frequent continental classifications.

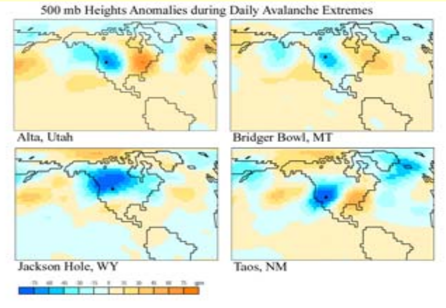






EXTREME AVALANCHE EVENTS

The avalanche climate classification for individual winters reveal two prominent coastal extremes (1985-86 and 1991-92), and two prominent continental extremes (1976-77 and 1987-88). A particularly severe avalanche cycle occurred in February 1986 in conjunction with the extreme coastal winter, which was associated with some extreme avalanche runout distances (Birkeland and Mock 2001). The Dec.-Mar. 500 mb heights reveal negative anomalies, centered in the northeastern Pacific Ocean associated with the coastal winter. This anomaly pattern is also evident for February 1986, which corresponds to increased southwesterly flow over most of the West. The 500 mb height pattern for February 13-21, 1986 also shows a similar pattern but differs some by indicating a blocking pattern over the eastern Pacific. Snowfall, high snow water equivalent, and abnormally high temperatures at Westwide Network sites were associated with this blocking pattern. Although this pattern with upper-level divergence along the eastern side of the jetstream is a common one for widespread avalanching, our investigations of extreme avalanche events elsewhere reveal that the superimposition of topography greatly affects how synoptic patterns govern avalanche activity at particular sites. Illustrating some synoptic examples, increased northwesterly flow is important for Bridger Bowl, Montana and Alta, Utah; and stronger westerly flow for Jackson Hole, Wyoming (Birkeland et al. 2001).



REFERENCES CITED

Bergen, M.L. 2002. Avalanche runout prediction using geographic techniques. M.S. Thesis. Department of Geography, University of South Carolina. Columbia, SC.

Birkeland, K.W. and C.J. Mock. 2001. The major avalanche cycle of February 1986 in the western United States. *Natural Hazards* **24**: 75-95.

Birkeland, K.W., Mock. C.J., and J.J. Shinker. 2001. Avalanche extremes and atmospheric circulation patterns. *Annals of Glaciology* **32**: 135-140.

Mock, C.J. and K.W. Birkeland. 2000. Snow avalanche climatology of the western United States Mountain Ranges. *Bulletin of the American Meteorological Society* **81**: 2367-2392.

Mock, C.J. and P.A. Kay. 1992. Avalanche climatology of the western United States with an emphasis on Alta, Utah. *The Professional Geographer* **44**: 307-318.