APPLICATIONS OF SNOTEL DATA IN FORMULATING THE SOUTH-CENTRAL MONTANA AVALANCHE ADVISORY

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ABSTRACT

Since the winter of 1987-1988, the South-Central Montana Avalanche Advisory Group (SCMAA) has issued advisories weekly during the avalanche season. The area covered includes the Gallatin National Forest and the northern part of Yellowstone National Park. The advisory is developed utilizing input from both public and private sectors. It includes weather forecasts, recent snow accumulation from remotely telemetered meteorological sites, avalanche occurrences from both natural and controlled sources, snowpit analyses and backcountry user observations. The Soil Conservation Service (SCS) operates a remote snow telemetry system (SNOTEL) reporting daily readings of snow water content, rainfall and temperature. A few SNOTEL sites also report wind parameters. Utilizing the USFS Avalanche Handbook technique for indexing recent snow accumulation as a measure of snow loading, a snow loading index (SLI) is computed from increments measured at SNOTEL sites. The SLI is computed on the day of the advisory for every SNOTEL site within the area of coverage and upwind in the storm track. Analyses indicate that a relationship between SLI and frequency of slides exists for controlled slides at Bridger Bowl and Big Sky Ski Areas. However, least squares regression analyses fail to demonstrate a significant correlation. Regression analyses of snow pillow and snow board data do show a strong correlation supporting the use of SNOTEL butyl pillow data as an accurate and operational real time measure of snowpack accumulation. This demonstrates the necessity of utilizing all available sources of information and resources to provide an advisory for backcountry users that is as accurate and credible as possible.

BACKGROUND

In recent years, the recreational use of our mountainous backcountry has continued to increase due to the popularity of snowmobiling, cross-country skiing, and other winter activities. High powered snowmobiles, increased popularity in telemark cross-country skiing, the challenge of the unknown, and the quest for solitude have led more of these recreationists deeper into the backcountry and higher onto potential avalanche terrain.

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Snow avalanche accidents and fatalities have increased proportionately. Government agencies and other concerned groups have responded to this increased hazard by attempting to educate recreationists and provide current avalanche advisories. Ferguson et al. (1988), provides an explanation of how the Northwest Avalanche Center, Seattle, Washington operates. Avalanche centers of this type are currently in operation in Utah, Colorado and other areas throughout the west.

In Montana, December 1979, the U.S. Forest Service, Region 1, established an avalanche warning policy and designated coordinators for areas of jurisdiction (USFS 1979). As a result, the Northwest Montana Avalanche Warning System issued its first advisory December, 1979, and has operated to the present. Occasional avalanche advisories/warnings for the Bozeman, Montana area were issued throughout the years in conjunction with ongoing avalanche control work at Bridger Bowl and Big Sky Ski Areas near Bozeman.

Brown (1983) proposed the establishment of a Montana State Avalanche Forecasting Center with a two year trial period restricted roughly to the Gallatin National Forest. The need for an avalanche awareness program and advisory system on the Gallatin National Forest was throughly documented by Harris (1987). As a result, the South-Central Montana Avalanche Advisory System (SCMAA) was created. Cooperators include: Gallatin National Forest, Soil Conservation Service, Gallatin County Sheriffs Office, Gallatin County Civil Defense, Bridger Bowl and Big Sky Ski Areas, National Weather Service, Yellowstone National Park and Montana State University. Since the winter of 1987-1988, the SCMAA has issued advisories weekly during the avalanche season for the Gallatin National Forest and the northern part of Yellowstone National Park.

ADVISORY FORMULATION

The Gallatin National Forest and the northern Yellowstone Park area comprises roughly 15,500 square kilometers in south-central Montana near the Montana-Wyoming-Idaho Borders. The area has numerous mountain ranges and varies in elevation from 1500 m in the valley areas to over 3200 m at numerous peaks. Two alpine ski areas with avalanche control work performed by professional ski patrol are located in the Montana portion of the area. These areas are Bridger Bowl approximately 18 km north of Bozeman and Big Sky approximately 100 km south of Bozeman. The diverse topography of the area contributes to a complex interaction of meteorologic and orographic effects making avalanche advisory formulation a complex process.

The advisory is developed utilizing all available information sources from both the public and private sectors including real time National Weather Service (NWS) weather forecasts, recent snow accumulation from remotely telemetered SCS SNOTEL meteorological sites, information on avalanche occurrences from both natural and controlled sources, snowpit stability analyses and backcountry user observations.

During the advisory season, a teleconference call with all contributors is convened every Friday morning at 7:30 am (MST). Real time snow accumulation data and weather forecasts are combined with other pertinent data. An advisory is then formulated for the weekend.

Updates are formulated as needed for other periods when high avalanche potential exists. The advisory is made available to the public through the local newspaper, broadcast media, posted in outdoor supply stores and as a recorded telephone message at the Bozeman Ranger District Office of the Gallatin National Forest.

SNOTEL Data Application

The SCS operates a remote telemetry system called SNOTEL that reports snow water equivalent, total precipitation and current, maximum, minimum and average temperatures for the previous 24 hour period. A few SNOTEL sites also report wind speed and direction. All remote SNOTEL sites are interrogated daily at approximately 4:00 am (MST) year round. Additional interrogations can be conducted on demand. Any special reporting requirements can be programmed into the site's micro-processors. A typical SNOTEL remote site consists of snow, precipitation and temperature measuring devices and sensors, a shelter that houses the radio telemetry equipment and an antenna that also supports the solar panels used to keep the batteries charged. Transducers in the shelter house convert the weight of the snow and total precipitation into electrical readings that are then transmitted through the radio system.

The SNOTEL system utilizes the meteor burst communications technique which allows communications between two locations as much as 2000 km apart. Two master stations at Boise, Idaho, and Ogden, Utah, cover the 10 western states and control interrogation and data collection from the remote sites. The master stations feed the data to SNOTEL's Centralized Forecasting System (CFS) in Portland, Oregon, where it is then available to users via computer access. There are currently thirty-eight operational SNOTEL sites in the SCMAA area. The elevations of these sites range from 1975 m to 3042 m.

Prior to the Friday morning conference call, SNOTEL data from the specific sites is accessed to determine recent SWE accumulation, wind speed and direction and temperature measurements. This data is then analyzed to determine storm patterns, wind loading potential, elevational characteristics and snow loading index throughout the advisory area.

Snow Loading Index

Perla and Martinelli (1976) describe a numerical technique for totalling recent SWE accumulation utilizing decay coefficients representative of the stabilization effect of new snow loading over time.

This snow loading index (SLI) is calculated from SNOTEL data using the following equation:

$$SLI = W_0 + 0.6W_1 + 0.3W_2 + 0.1W_3$$

Where W_0 ,W_1 ,W_2 ... are the respective SWE's of the snowfall for the last 24 hours, yesterday, two days ago, three days ago, etc. These SLI's are calculated for each SNOTEL site and are reported to the advisory group. We are currently using the generalized coefficients as shown in the equation but these could be refined as more data is accumulated.

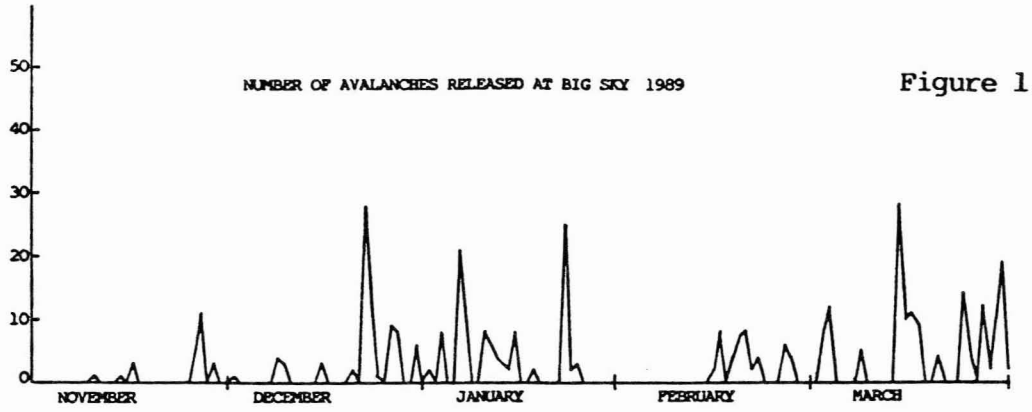
The daily SLI data during the snow season can be compared to avalanche occurrences, where available, to determine which sites show the best relationships. Analyses can be used to compare these relationships and their significance. Figure 1 graphically compares the number of avalanches released at Big Sky during the course of daily avalanche control routes against the daily SLI computed from SWE increments measured at the Lone Mountain snow pillow located near the top of the ski area. Figure 2 compares similar data from Bridger Bowl and the Bridger Bowl snow pillow which is located near the top of the ski area. The dashed line on each lower graph delineates the approximate SLI level where graphical peaks appear to coincide with regularity. Below this line the relationship becomes irregular. Linear regression analyses of all data from both locations failed to demonstrate a significant relationship at the 95 percent significance level using the t test on slope between SLI and the number of avalanche occurrences.

Since information on backcountry avalanche activity is sporadic to non-existent, our analysis was limited to recorded avalanche occurrences from regular control work at the two ski areas. Size and number of avalanche releases in the uncontrolled backcountry environment may differ greatly from the ski areas. In addition, throughout the season, the number of avalanches released on a particular day may not have been a valid measure of the avalanche potential in uncontrolled areas.

Figures 3 and 4 present the 1990 SLI data from SNOTEL sites in the vicinity of both the Lone Mountain and Bridger Bowl pillow sites. In most cases, similarities exist from site to site and are indicative of major widespread storm systems that encompassed these areas. However, there are occasional periods that show localized effects which would ordinarily go unnoticed without the benefit of daily telemetered SNOTEL data from the various sites in the advisory area.

SNOW WATER EQUIVALENT DATA

Most snow water equivalent data is now being obtained from snow pillows constructed of nylon-reinforced butyl or hypalon material and are about 3 m in diameter and filled with about 400 l of antifreeze solution. As snow accumulates on the pillows, it exerts pressure on the solution equal to the snow water equivalent. Before butyl/hypalon snow sensors were standard, snow water equivalent was measured with stainless steel snow pillows. Recent studies have shown that stainless steel snow pillows may have some problems measuring short term increases in snow water equivalent and total water equivalent (Farnes 1990).


NUMBER OF AVALANCHES RELEASED AT BIG SKY 1989
50
40
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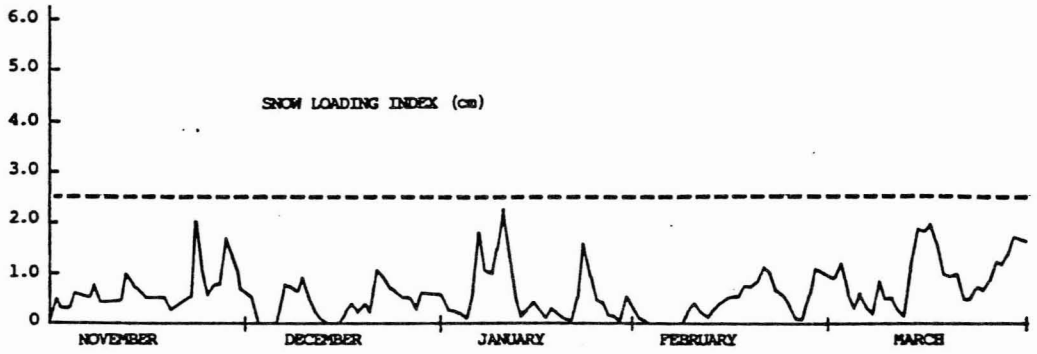
10
0
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH

Figure 1.


6.0
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SNOW LOADING INDEX (cm)
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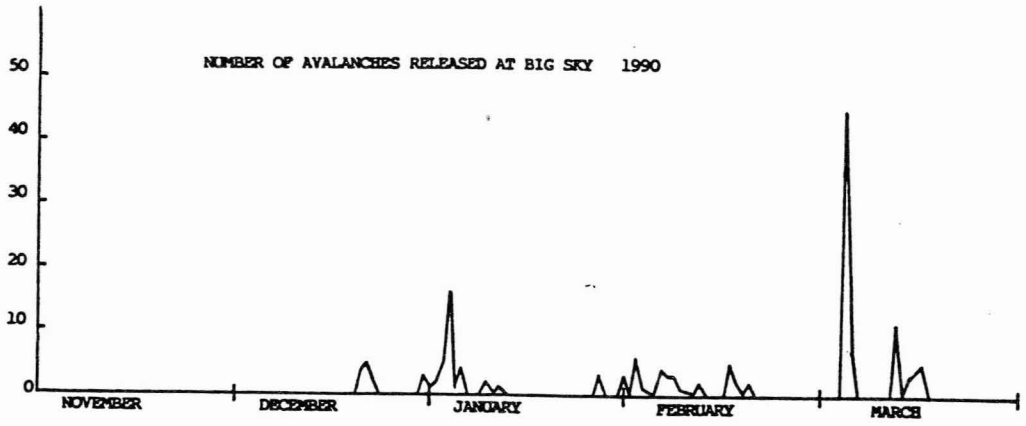
JANUARY
FEBRUARY
MARCH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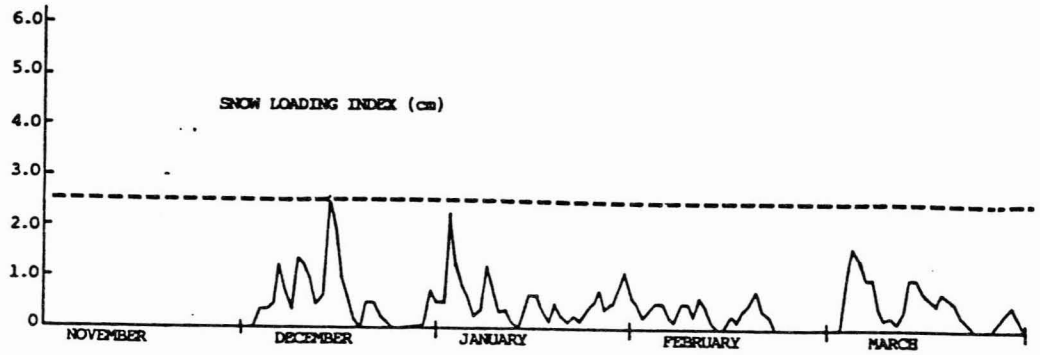
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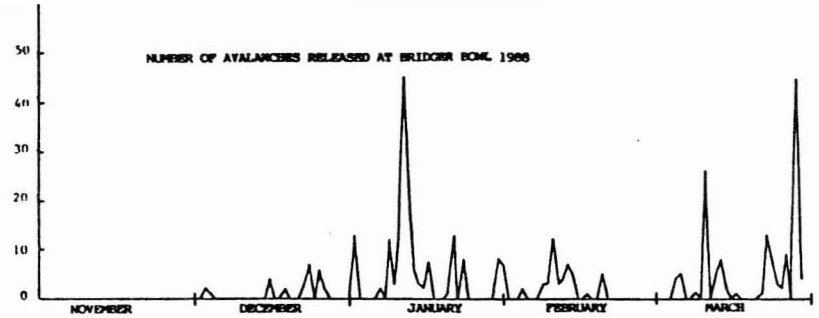
Figure 2.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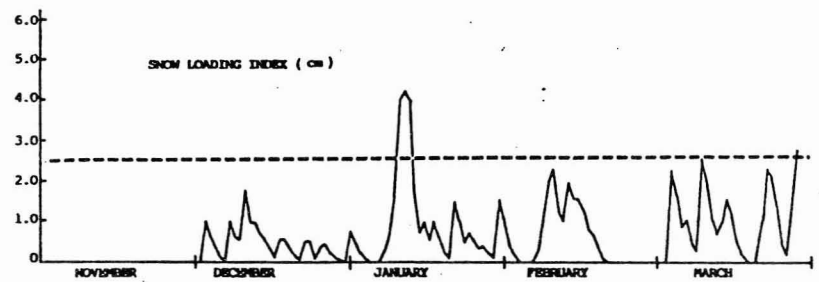
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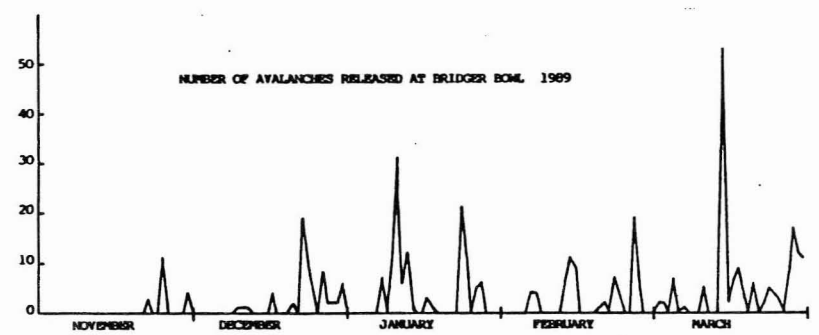
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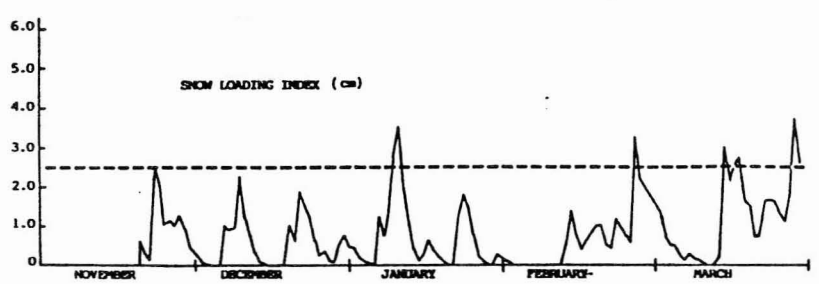
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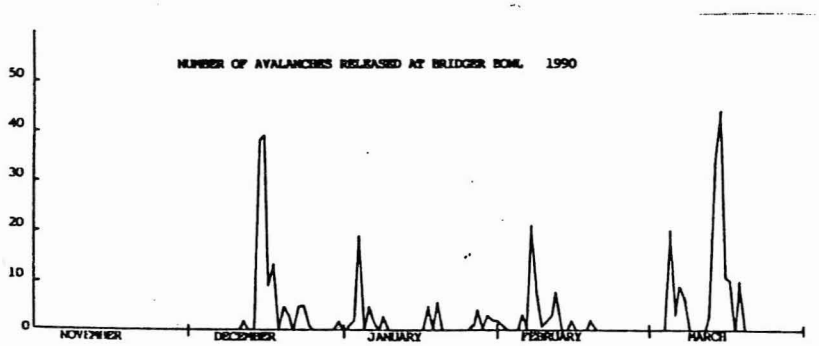
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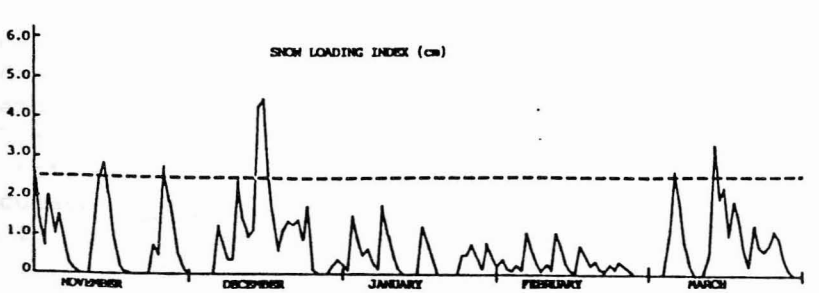
SNOW LOADING INDEX (cm)
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Figure 3. Snow Loading Index (cm) Lone Mountain and Surrounding SNOTEL sites-1990

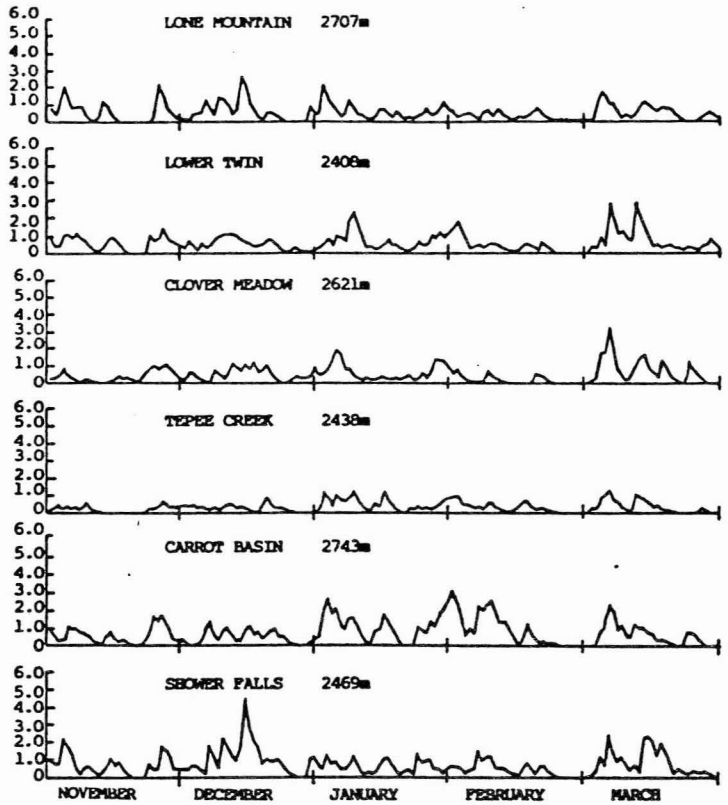
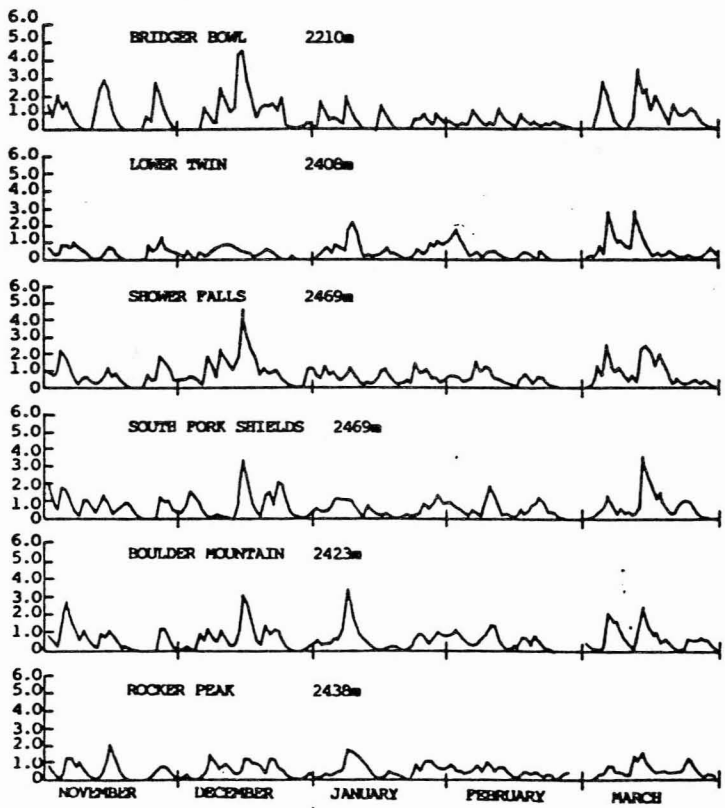


Figure 4. Snow Loading Index (cm) Bridger Bowl and Surrounding SNOTEL sites-1990



Field experience with butyl/hypalon pillow data by the SCS has proven them to be a reliable snow sensor that provides accurate incremental data. For comparative purposes, two years cumulative butyl snow pillow data from the SCS installation at Big Sky Ski Area was correlated against SWE measurements obtained using a snowboard and density calculations in close proximity.

Figure 5 graphically demonstrates the relationship between cumulative butyl snow pillow SWE and SWE from snowboard and density calculations provided by Big Sky Ski Area for 1989 and 1990. Linear regression analyses of both years demonstrates a significant relationship using a hypothesis test on slope and the t test statistic at the 99 percent significance level. These relationships indicate that many malfunctions associated with snow pillow data that have been documented in the literature (Marriott and Moore, 1984; Beaumont, 1965; Tarble, 1968; Farnes, 1990) may have been improved by the use of butyl/hypalon snow pillow sensors and/or more accurate snow board measurements. Additionally, the use of telemetered SNOTEL data allows the benefit of comparing incremental SWE data against other sites in the area as well as a precipitation channel to verify daily increases. Consequently, we feel SNOTEL snow pillow data in combination with other supporting data sources provides a very useful tool to measure the component of incremental snow deposition in the overall avalanche hazard equation. However, many other factors must obviously be accounted for including: snowpack metamorphosis, temperature influences, slope, wind effects, etc. Formulating an avalanche advisory based solely on recent incremental snow accumulation and SLI calculations would be a dangerous over simplification.

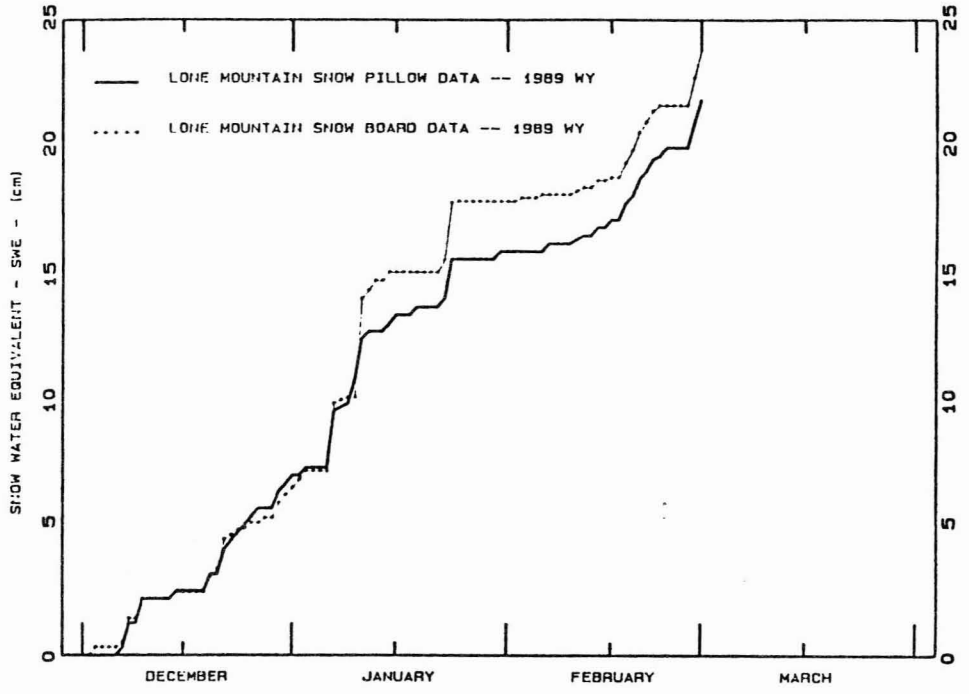
SUMMARY

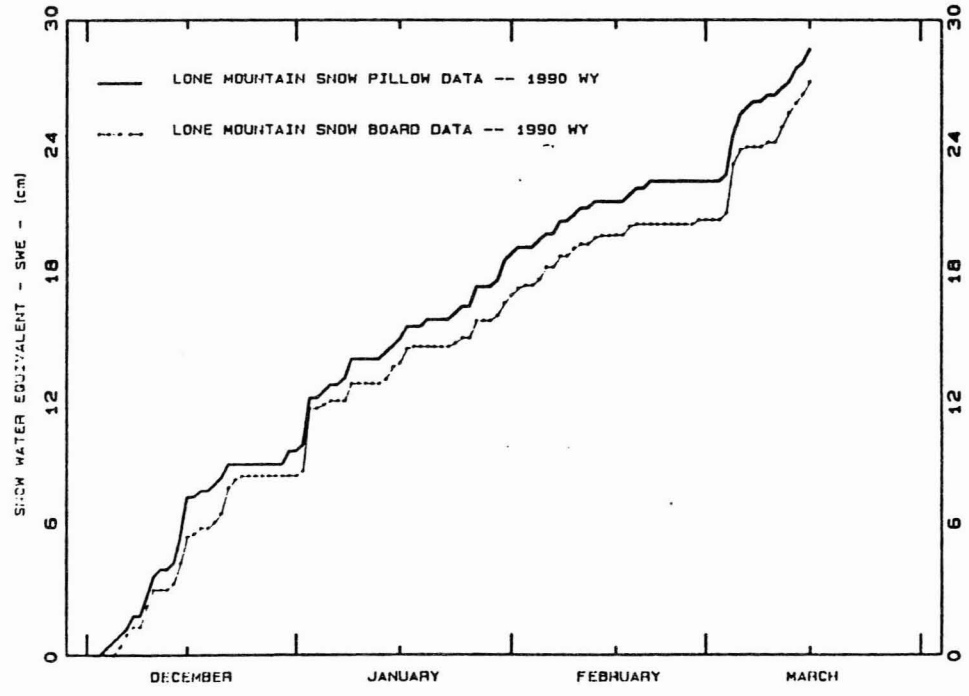
Daily SWE measurements from SNOTEL sites throughout the SCMAA area provide a useful and current measure of recent snow accumulation in areas where manual observation data is normally not available. Wind data from remote sites with wind sensors can give insights into storm tracks and the potential for wind transportation and wind loading area orientation. Changes in temperature data can be used to help identify additional stress being placed on snow in avalanche prone areas.

The science of compiling and interpreting snowpack and stability data and formulating avalanche advisory information is complex. Many variables must be taken into account and sometimes there are data shortages. When the avalanche advisory is extended over a large area with complex characteristics as contrasted against limited areas such as ski areas, care must be taken to assure that the advisory accurately describes current conditions.

Expansion of the SCMAA data acquistion network, an improved advisory dissemination proceedure, increased awareness and better feedback and documentation of avalanche occurrences to establish relationships will be invaluable towards improving future advisories. Until the science can be greatly refined, public agencies, by necessity, cannot accurately forecast avalanche hazard over large areas but must be relegated to formulating advisories that avalanche conditions may exist.

Figure 5. Comparison of Snow Water Equivalent from Lone Mountain Snow Pillow and Big Sky Ski Area Snow Board





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