

## **Contributory Factors To Avalanche Occurrence On Red Mountain Pass, San Juan Mountains, Southwest Colorado**

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### **Abstract**

Avalanche occurrence is a result of current and previous weather influences. Using 12 months (two six month seasons between 1971 and 1973) of avalanche and meteorological data collected from Red Mountain Pass in the San Juan Mountains, Southwest Colorado, daily avalanche frequency is plotted against seven possible contributory factors including: daily measurements of water equivalency of new snow, depth of new snow, depth of snow on the ground, wind speed and direction and maximum and minimum temperatures. New snow depth and water equivalency measurements, for a 24 hour period, were summed with the previous day's measurements and plotted against the single day's avalanche observations. We assumed any relationship between avalanche occurrence and precipitation to be cumulative and a 48 hour time period was arbitrarily chosen. Wind and temperature measurements at observation time were averaged with the previous day to factor in prior weather conditions that could influence avalanche occurrence. No distinction was made between natural or artificial avalanches.

Avalanche frequency generally increased with water equivalency of new snow, new snow depth, and depth of snow on the ground. Most of the avalanche days occurred when the 48 hour new snow water equivalency was below 0.5 inches (71%). Only 8% of the avalanche days occurred when the water equivalency was over one inch. Most avalanche days were when 48 hour new snow depth was between 0-10 inches (76%). There were 11 avalanche days with no new snow recorded (48 hour), including the three largest avalanche days that had 30, 38, and 40 avalanches on each day. Depth of snow on the ground (48 hour observation time average) was between 40 and 50 inches for every avalanche day with 16 or more avalanche occurrences.

Avalanche occurrence was strongly related to wind direction and speed. On 83% of the avalanche days average observation time azimuthal wind direction (for a 48 hour period) was between 180-360°, and 45% of the avalanche days showed a wind direction between 180-270°. Wind speeds for the same time period averaged 15-40 miles per hour and correspond to 60% of the avalanche days. The four months having the greatest avalanche frequency had average monthly wind speeds between 21 and 26 miles per hour.

No avalanches occurred when the average 48 hour observation time maximum temperature was below 15° F. All occurrences happened when average minimum temperatures (48 hour observation time average) were below 27° F.

In the Red Mountain Pass area, avalanche frequency is most strongly influenced by wind direction and speed with critical values being between 180-360° and 15-40 miles per hour respectively. Even though there was a general increase in avalanche occurrence with increases in new snow depth and water equivalency of new snow, the highest avalanche days occurred with no prior 48 hour precipitation.

The absence of avalanche activity when average maximum 48 hour temperatures were below 15° F is surprising. It is not known at this time the role air temperature plays in avalanche occurrence. It is possible that air temperature plays a more important physical role in avalanche occurrence than was previously thought. Alternatively, air temperature may only correlate with a more important controlling mechanism that is not apparent from this data.

## Introduction

Many or most avalanches are considered to be caused directly or indirectly by meteorological conditions (*e.g.* Williams, 1981; McClung and Schaerer, 1993). A study of meteorological influences on avalanche hazard for Kootenay Pass Highway in British Columbia by McClung, Tweedy and Weir (1993) found precipitation rate, total storm snow and new snow depth were the most significant weather factors leading to avalanche occurrence. These results are similar to those of Perla (1970) for the area near Alta, Utah. He found the avalanche probability on south facing slopes varied considerably with precipitation and wind direction, only slightly with temperature change and seems to have no definite relationship to wind speed and snow settlement. However, on other slopes avalanche occurrence was more directly related to precipitation (Perla, 1970).

In the Rogers Pass area of British Columbia, Canada Salway (1979) found that snow-pack depth, precipitation and relative humidity are the most important factors of contributory to avalanche occurrences.

In the San Juan mountains of Colorado, Williams (1981) found that warm southwest storms hit the range harder than storms from other directions and precipitation amount, intensity and duration are the prime factors in avalanche formation. Wind speed and direction were considered the second factors for avalanche formation and temperature may have an influence but it is hard to measure (Williams, 1981).

Historical records of avalanche occurrences collected from the twelve avalanche months between November 1971 and April 1973 were correlated with daily measurements of precipitation, maximum and minimum temperatures, wind speed and direction, water equivalency, depth of snow on the ground and depth of new snow to determine the meteorological effects on avalanche occurrence in the Red Mountain Pass area of the San Juan Mountains, southwest Colorado.

## **Geographic Setting**

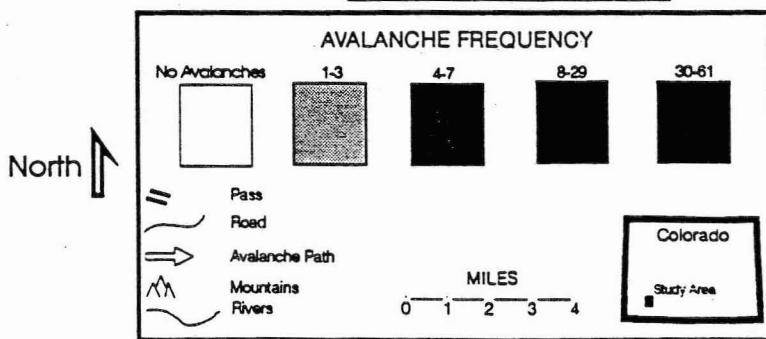
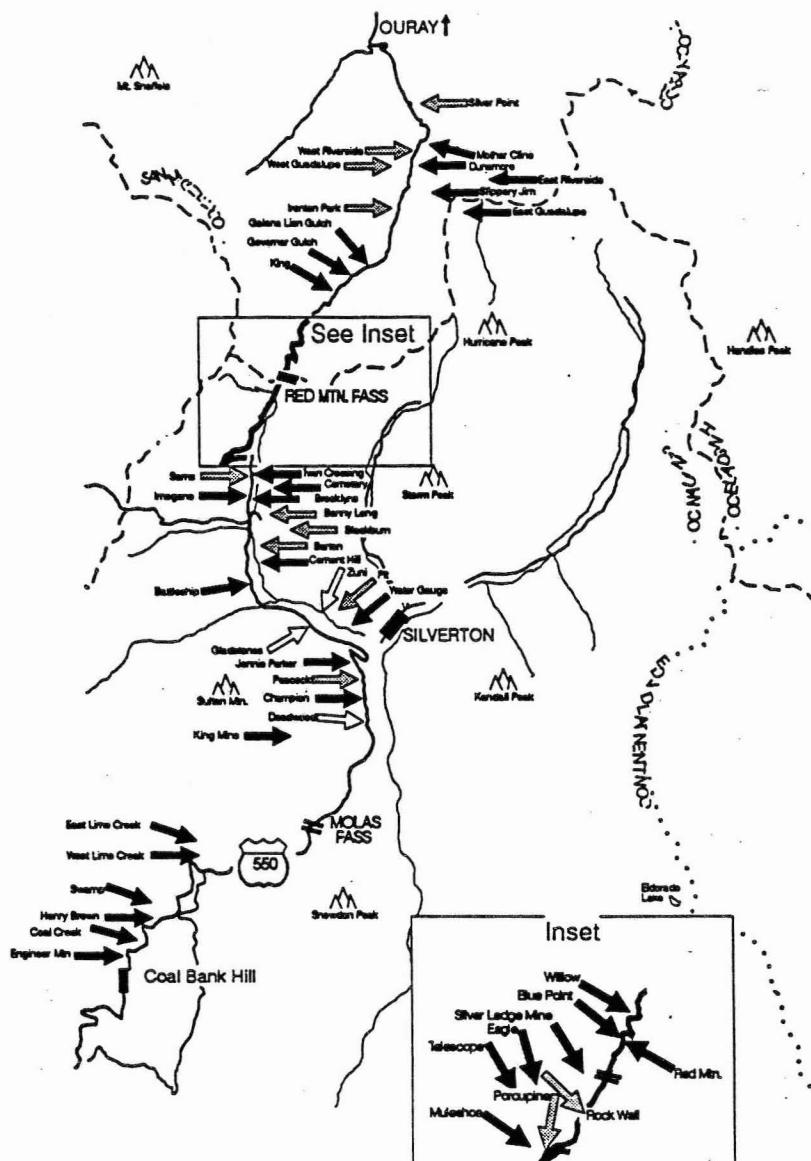
Avalanche starting zones in the Red Mountain Pass area (Figure 1) are above 3,000m in elevation, with many different slope aspects. There are 156 avalanche paths that threaten highways in the area. Those avalanche paths are located along the 58 km corridor adjacent to Highway 550 between Coal Bank Hill and the town of Ouray and the 14km of Colorado Highway 110. This area includes Molas Divide, the town of Silverton and Red Mountain Pass (Armstrong and Ives, 1976).

The study area is characterized by varied relief and decreased forest cover due to mining. Many of the avalanche starting zones in this area are located above treeline which lies at 3,600m. The Rocky Mountains are known for their continental winter climate consisting of frequent light to moderate snowfalls interspersed with long dry periods. There is also great annual climatic variability combined with relatively low latitude (Armstrong and Ives, 1976).

Snow data was collected south of Red Mountain Pass and East of Highway 550 until 1984. After 1984, the snow data was collected immediately southeast of this area at the St. Paul Lodge. Wind data was measured at an elevation of 12,325 feet.

AVALANCHE PATHS AND THEIR FREQUENCIES ON RED MOUNTAIN PASS  
 SAN JUAN MOUNTAINS, SOUTHWEST COLORADO  
 1971-1972 AND 1972-1973 SEASONS

Data Supplied By: The Colorado Avalanche Information Center



Map By: Sally Thompson

## **Methods**

Two avalanche seasons, November 1971 to March 1972 and November 1972 to April 1973 were extracted from the total record set and used for this study because these years had the most complete weather records. Observations were recorded once every 2 hours. These were high avalanche seasons. Together the 71-72 and 72-73 seasons had 55% of all avalanches recorded during the seventeen seasons that had records between the years 1952 and 1971. An avalanche day was defined by the occurrence of at least one slide of any magnitude along Highway 550. Total avalanche occurrences were plotted against: 1) 48 hour observation time average fastest wind speed, 2) 48 hour observation time average wind direction, 3) average 48 hour maximum and minimum temperatures, 4) 48 hour sum of depths for new snow and 5) 48 hour sum of new snow water equivalency and 6) average depth of snow on the ground for a 48 hour section of time.

## **Results and Discussion**

There was a general, but not linear, increase in avalanche occurrence with increases in water equivalence for new snow and new snow depth (Figure 2). Only 8% of avalanche days occurred when 8 hour water equivalency was above 1 inch, while 71% of avalanche days occurred when the 48 hour new snow water equivalency was < .5 inches. When the 48 hour new snow water equivalency was zero, there were 8% of the avalanche days.

When new snow depth was between 0 -10 inches, 76% of avalanches days occurred, including all days having more than 16 occurrences (Figure 3). Only 2% of recorded avalanche days occurred when new snow depth was over 20 inches. In the four months with the most avalanche occurrences (December 1971, November 1972, December 1972 and March 1973) the average water equivalency of new snow was much higher than the eight other months studied, as was average snow depth.

Days with the most avalanche occurrences were recorded when depth of snow on the ground for an avalanche day was between 40 and 50 inches (Figure 4). The greatest number of avalanche days, 43%, occurred when depth of snow on the ground was between 60-80 inches. Avalanche occurrence was relatively constant when the snow depth was greater than 40 inches. Only 6% of total avalanches during these two seasons were recorded when total snow depth was below 40 inches.

Figure 2

**Number Of Avalanches Vs. Water Equivalency Of  
New Snow For Day And Day Prior**

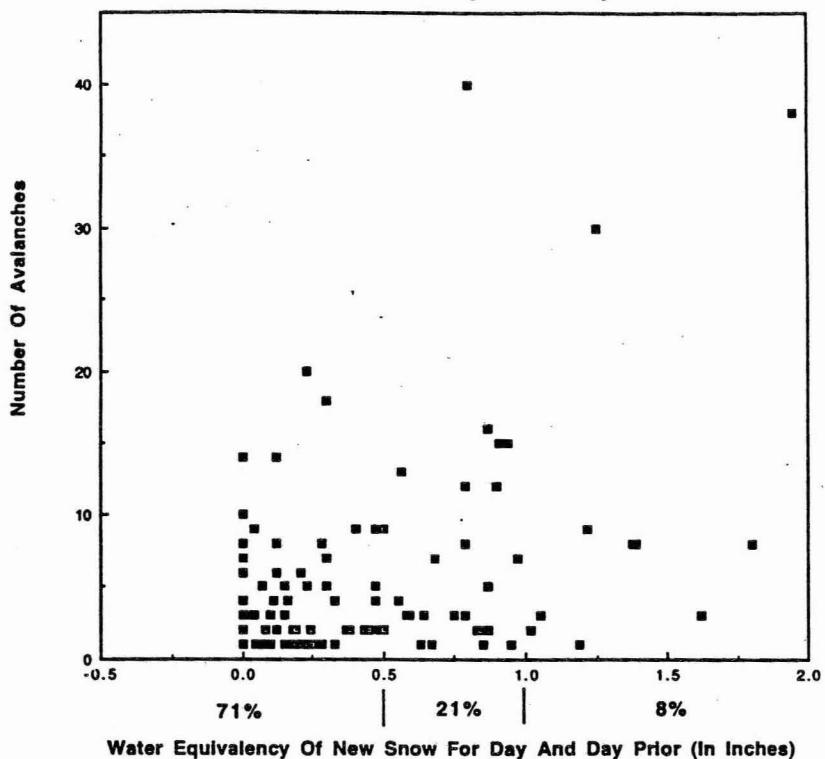
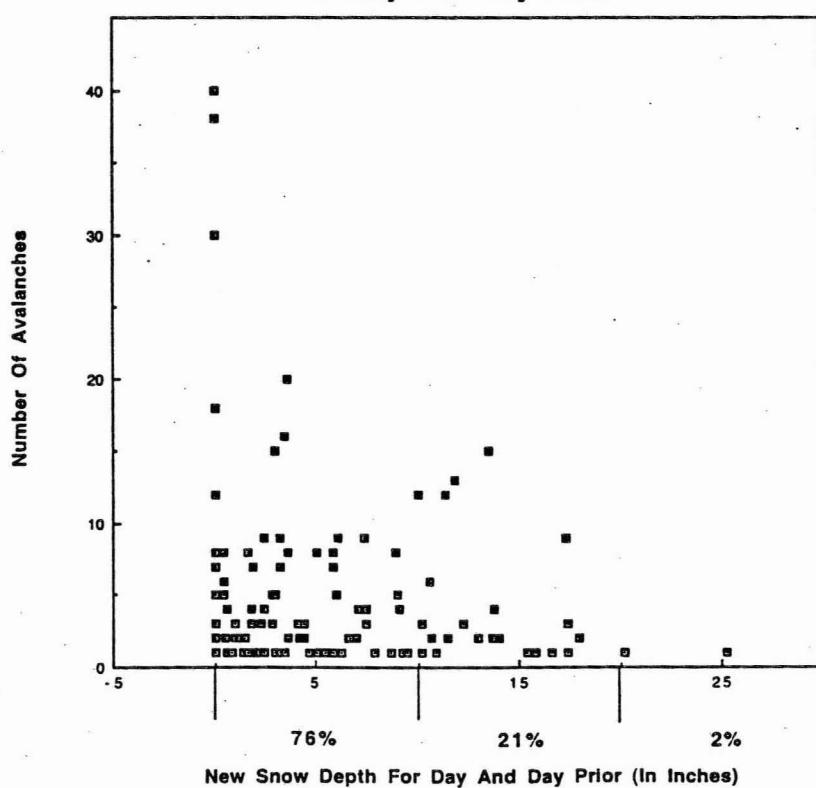


Figure 3

**Number of Avalanches Vs. New Snow Depth  
For Day And Day Prior**



Most avalanche days (83%) occurred with azimuthal wind directions between 180-360°. There were 38% of the avalanche days with a westerly wind direction and 45% of avalanche days had a southwesterly direction (Figure 5). All avalanche days with over 16 avalanche occurrences had a wind direction from the southwest. In the four months with the most avalanche occurrences the wind direction averages were all southwesterly.

Wind speeds between 20 and 40 miles per hour (Figure 6) correlate with 60% of the avalanche days. Only 7% of avalanche days had wind speeds greater than 40 miles per hour. The four largest avalanche months all recorded average wind speeds between 21 and 26 miles per hour. All avalanche days that had 20 or more avalanches had wind speeds between 36 and 41 miles per hour.

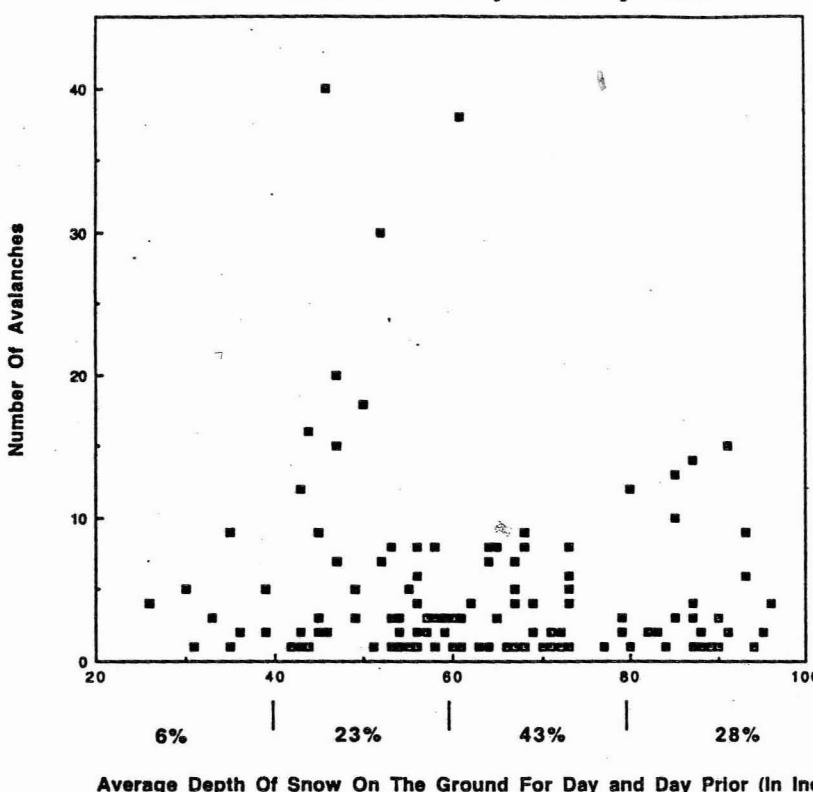
Probability of avalanche occurrence has no definite relationship to the 24 hour observation time average maximum temperature (Figure 7). It is significant that no avalanches occurred when the 24 hour maximum temperature was below 15° F. The average maximum temperatures for the four months with the most avalanche occurrences were between 21 and 29°F which is lower than most of the other months studied.

A slightly stronger relationship between average minimum temperature and avalanche occurrence was found with 87% of the avalanche days occurring when minimum temperatures ranged between 1 and 21°F (Figure 8). Also occurring in this range are the avalanche days with the most number of avalanches per day. Only 3% of the avalanche days occurred when the average minimum temperature was greater than 20° F. It is important to note that all days with avalanche occurrences had average minimum temperatures below 25°. The four largest months have average minimum temperatures within 5 degrees of each other, 4-9° F.

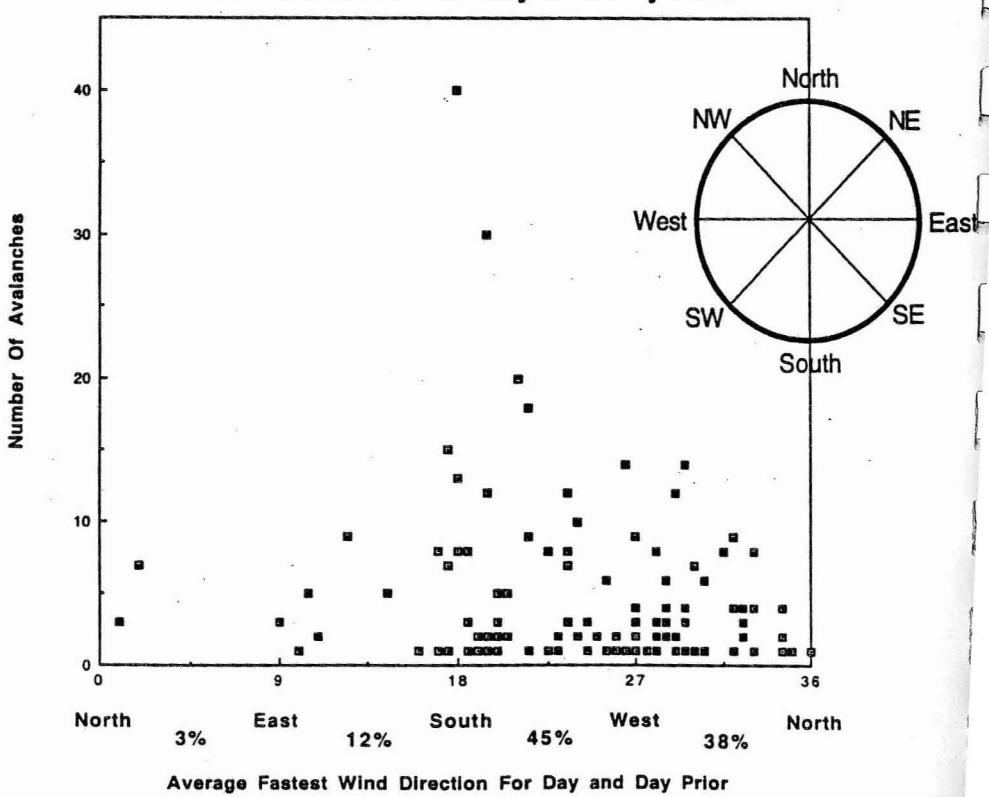
These observations show a general increase in avalanche occurrence with increases in water equivalence for new snow and new snow depth. A similar relationship was observed by Perla (1970) in the Wasatch Mountains near Alta, Utah. In a study of the same area, McClung *et al.* (1993) also found that new snow depth and water equivalence for new snow were primary variables in avalanche occurrence.

Avalanche occurrence was relatively constant when the snow depth was greater than 40 inches. This suggests that a critical amount of snow must accumulate before avalanches occur. Salway also found that depth of snow on

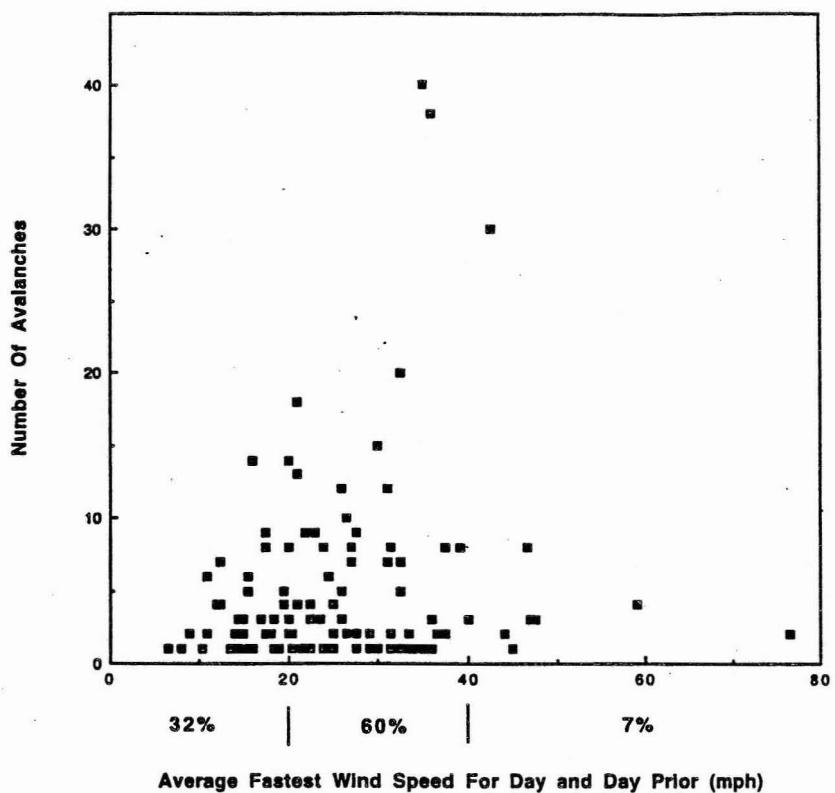
**Figure 4**  
**Number Of Avalanches Vs. Average Depth Of Snow  
On The Ground For Day and Day Prior**



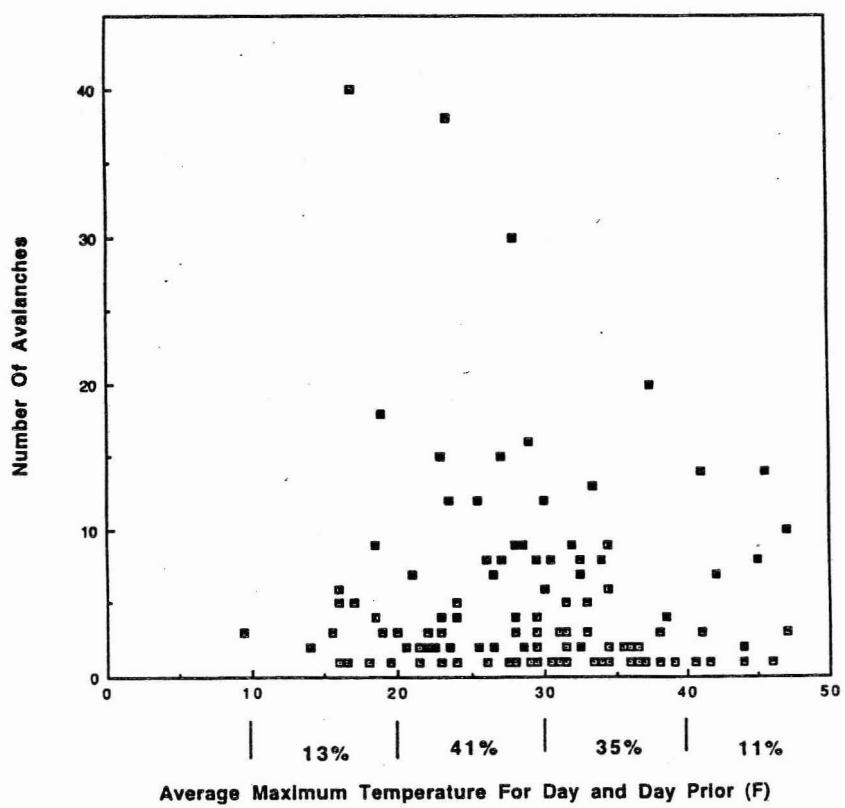
**Figure 5**  
**Number Of Avalanches Vs. Average Fastest  
Wind Direction For Day And Day Prior**



**Figure 6**  
**Number Of Avalanches Vs. Average Fastest Wind Speed For Day and Day Prior**



**Figure 7**  
**Number Of Avalanches Vs. Average Maximum Temperature For Day and Day Prior (F)**



the ground was the most highly correlated variable to avalanche activity in his study done on the Rogers Pass area of British Columbia, Canada (1979).

On Red Mountain Pass, avalanche activity is highly correlated with wind direction. A significant proportion, 60%, of the avalanche days had wind speeds between 20 and 40 miles per hour. This is in contrast to the work done by Salway in the Rogers Pass area (1979) who considered wind speed to be a secondary variable in avalanche occurrence. In the area surrounding Alta, Perla (1970) suggests that wind direction is a stronger factor than wind speed for avalanche occurrences. However, Williams (1981) considers precipitation to be the main factor in avalanche formation and that wind speed and direction are the "follow up" ingredients. He believes it is difficult to separate the individual contributions made by precipitation and wind.

The finding that 11 avalanche days occurred when there was no prior 48 hour precipitation and that 72% of avalanche days occurred with less than a 0.5<sup>+</sup> 48 hour water equivalence, suggests that new snow fall is not the primary factor for avalanche occurrence in the Red Mountain Pass area. Wind speed and direction are perhaps more critical than total precipitation. It is interesting that no avalanches occurred when the 24 hour maximum temperature was below 15°F.

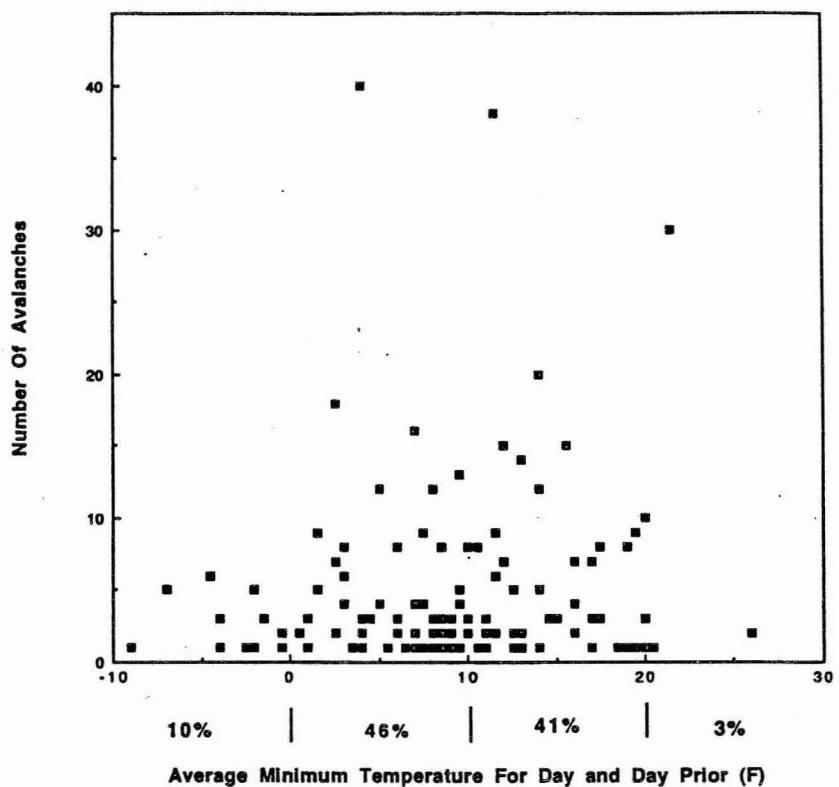
Most avalanche days, 87%, had 48 hour minimum temperatures ranging between 1 and 21°F. Williams (1981) states that temperature has an influence on avalanche occurrence, but it is hard to measure the effect because temperature determines the type of snow crystal formation and what type of precipitation falls which can also influence avalanche occurrence.

It is possible that air temperature plays a more important physical role in avalanche occurrence than previously thought. However, air temperature may only correlate with a controlling mechanism that is not apparent from this data.

## CONCLUSIONS

In the Red Mountain Pass area, wind speed and direction are the meteorological factors that have the strongest influence on avalanche occurrence. However, avalanche occurrence is a complex combination of meteorological, terrain and snowpack factors. Values of the meteorological factors that are "critical" to avalanche occurrence on Red Mountain Pass are summarized in Table 1. These values may be useful forecasting guidelines for avalanche potential in the Red Mountain Pass area. A strong wind influence toward avalanche occurrence in the Red Mountain Pass area is further supported by the observation

**Figure 8**  
**Number Of Avalanches Vs. Average Minimum  
 Temperature For Day and Day Prior (F)**



**Table 1**  
**Critical Weather Related Parameters For Avalanche  
 Occurrence On Red Mountain Pass, Southwest Colorado**

based on weather and avalanche records for two winter seasons  
 1971-1972 and 1972-1973

|                                     |              |
|-------------------------------------|--------------|
| 48 Hour New Snow Water Equivalency  | 0-1.0 inch   |
| 48 Hour New Snow Depth              | 0-10 inches  |
| Average Wind Direction              | 180-270 (SW) |
| Average Wind Speed                  | 15-40 mph    |
| 48 Hour Average Maximum Temperature | 21-29 F      |
| 48 Hour Average Minimum Temperature | 1.0-21 F     |

#### Other Significant Observations

- There were 11 avalanche days with no new snow (48 hr.) recorded including the three largest avalanche days
- Only 2% of the avalanche days occurred when 48 hour new snow depth was over 20 inches

that the highest avalanche frequency days had no prior 48 hour precipitation accumulation. Red Mountain Pass fits the continental climate avalanche profile where high avalanche potential can exist between periods of precipitation due to the availability of loose snow that can be transported into avalanche starting zones.

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