AVALANCHE FORECASTING AT JACKSON HOLE SKI AREA

J. Simms

Introduction

The responsibility of hazard forecasting and stability evaluation for the Jackson Hole Ski area falls upon the U.S. Forest Service Snow Rangers assigned to the area. Although their forecasts are primarily for the ski area, several other agencies and groups benefit from their evaluations. Grand Teton National Park borders the ski area to the north and the Snow Rangers often assist the Park's back-country rangers when they request snowpack conditions. The Wyoming Highway Department is in daily contact with the Snow Rangers for evaluation of avalanche conditions along their highways, particularly the Teton Pass Highway, 13 km south of the ski area. The Snow Rangers also issue a general report of avalanche conditions relative to ski-touring, mountaineering or snow-mobiling.

Over a period of nine years, forecasting techniques and instrumentation have evolved into a sophisticated system of evaluating avalanche hazard on a day-to-day basis. Through good instrument-orientated forecasting, considerable savings may be made in man-hours and explosives, while maintaining a high level of safety to both the public and those involved in avalanche control.

Area Description

A description of the ski area is necessary in order for the reader to fully appreciate the methodology. The resort is located at the base of a large north-south running ridge at the southern end of the Teton range. The ski runs are generally located on east exposures, and are divided into three distinct service areas. Rendezvous Mountain (3182 m) is the highest point of the ski area and is served by a tramway 4 km long with a vertical rise of 1,300 m. Two and one-half km northeast along the ridge is a cirque known as Casper Bowl, at an elevation of 2,740 m. Two and one-half km further down the ridge is Apres Vous Peak, elevation 2,580 m. The Casper Bowl area and Apres Vous Peak are both served by chairlifts. The entire area encompasses 12 km^2.

The large vertical relief of the area creates three different weather zones: upper mountain, mid-mountain and lower mountain. The upper zone has a vertical relief of about 500 m; the middle zone 500 m, and the lower zone the remaining

300 m. Because of this great vertical relief, it is often impossible to even guess what is taking place at the mountain top level without instrumentation. It is not unusual to get 25 cm of snow at mid-level and none at the base. In an inversion situation, the temperature at the base might be -30°C, and at the mountain top, -10°C. Winds at the base might be light and variable; at the mountain top, 100 km/hr!

Instruments

It is obvious that, to reliably forecast avalanches at each of the three elevation zones, it is necessary to have instrumentation feeding information from each zone. The U.S. Forest Service Forecaster's Laboratory at the base of the mountain is the receiving and recording station for information from the various weather instruments on the mountain. Instrumentation sites have developed to utilize existing phone lines for telemetry. The basic equipment is now described in sequence, descending from top to bottom of the area (Fig. 1).

The upper mountain weather tower is located near the summit of Rendezvous Mountain. Mounted on this 10 m Rohn tower are a wind vane, a totalizing anemometer, and a gust anemometer. The tower is located below the mountain top in order to register winds of consequence to the majority of the slide paths of the "upper mountain". The wind vane transmits wind direction to an analog recorder in the forecasting lab. The analog recorder gives us a precise record of the wind direction and trends, which we find of considerably more value than the event recorder type of readout. The gust anemometer transmits information to the same recorder as the wind vane, thus gusts and direction may easily be correlated. The totalizing anemometer transmits to an event recorder, which registers the total wind passing the tower. By correlation with the wind vane, total wind from a particular direction can easily be determined. This parameter relative to snow available for transport is of particular importance to the forecaster. Each anemometer is derimed by a heater system consisting of a set of four 300 watt lights aimed at the whirling cups. All data is transmitted via phone lines leased from the telephone company.

Temperatures are measured with a thermistor located in a sheltered pine grove at 3,000 m, and transmitted via phone line to a Simpson recorder in the lab. A mechanical pyranograph is located in the vicinity of the upper telemetry thermistor and is used to monitor the solar radiation. We hope to utilize these readings to explain avalanche releases, which may be related to infrared input and release through terrestrial radiation.

Precipitation is measured at an upper study plot located at the base of Rendezvous Bowl (2,900 m). A total depth stake and interval boards are used to determine new snow depth and density as well as total snow depth and settlement. Snow study pits are also dug periodically at this undisturbed site. A heated precipitation gauge is located near tower #3 of the aerial tramway (2,750 m). An Alter-type windshield surrounds the gauge in an attempt to minimize errors due to distortion of airflow over the gauge. Unfortunately, these gauges have a rather poor record of giving realistic readings during periods of low precipitation intensity. We have observed snowfall amounting to 5 mm of water over a period of five hours without a single response from the gauge. We seem to have solved this by adding an overflow reservoir.

For mid-mountain conditions, a telemetry thermistor is located at 2,600 m and temperatures here are transmitted to a Simpson recorder in the lab. The well-sheltered mid-mountain study plot at 2,520 m is the site of a propane heated snow gauge with telemetry to the lab, as well as a total depth stake and interval boards for determining depth, settlement, and water content of old and new snow. Occasional snow pits are also dug in this one-quarter acre undisturbed area. A Rohn tower on a windswept ridge at 2,400 m supports a gust anemometer which transmits gust information to a recorder in the lab.

A study plot at 1,940 m gives total depth, settlement interval snowfall information for the lower mountain.

<u>Avalanche Forecaster's Laboratory and Instruments</u>

All telemetried information is recorded at the Forecaster's Laboratory at the base of the mountain.

1. An Esterline-Angus event recorder records on a strip chart precipitation information as received from the two tipping rain gauges. The same instrument also records total wind.

2. An Esterline-Angus analogue recorder records wind direction as received from the wind vane and wind gusts as received from the generating Anemometer.

3. Two Simpson Recorders record the temperatures from the telemetried thermistors.

4. A Belfort Microbarograph records changes in atmospheric pressure.

5. An aircraft altimeter gives direct readings of atmospheric pressure.

6. A Bell System Teletypewriter is used to exchange information with the U.S. Weather Service in Cheyenne, Wyoming.

7. A Taylor Thermograph records temperatures at the base area.

8. A remote indicating wind system indicates wind direction and velocity at the base of the mountain.

All telemetry is by telephone lines on lease from the telephone company. An example of data for 22 March, 1975 is shown in Table 1.

Pre-Forecasting Procedures

At 6:00 a.m. the forecasters meet at the laboratory. All present and past 24-hr data is noted and recorded on a daily observation sheet (Table 1). Present wind, temperature, 24-hr precipitation, and general weather conditions are sent via teletype to Cheyenne weather service. In return, Cheyenne sends an 18-hr forecast for winds and temperatures aloft, an estimate of expected snowfall, present weather at Idaho Falls, Idaho and West Yellowstone, Montana, and other information considered pertinent, including estimated time of frontal passage.

By this time, the forecaster has decided whether or not the 105 mm recoilless rifle at the base should be fired. If so, the gunners are called and told to meet at the laboratory. (The way in which this decision was reached will be explained shortly.)

The forecaster then turns his attention to making his stability evaluation and hazard forecast. It must be understood that instruments alone cannot forecast avalanches. It is the forecaster's ability to interpret and correlate instrument readouts that enables him to fully utilize good data. It is relatively easy to make a general forecast such as high, moderate or low. The real art of forecasting is the ability to evaluate specific slopes. To do this one must use a combination of two methods of evaluation.

Subjective Analysis

Many experienced mountaineers, and most professional forecasters, are able to give an accurate stability evaluation of a particular slope without benefit of numerical values. In many cases, this is merely an empirical evaluation without regard to theory or factual evidence. Most forecasters are actually relying on their memories of similar situations (empiricism) in combination with a subconscious analysis of present contributing factors. A good forecaster has the seemingly innate ability to "feel" and "know" a particular slope. It is this feeling, rather than luck, which keeps many of us from being caught in avalanches.

The subjective analysis method is valid if the forecaster is actually at the slope in question or if the vertical drop is slight enough so that the observer actually knows what is happening in the starting zones.

Deductive Analysis

When simple subjective analysis is not practical, instrumentation is essentially the only recourse. The key to this type of evaluation is in utilizing the instrument data to enable the forecaster to mentally picture the situation and evaluate it as though he were on site and making a subjective evaluation.

As an example of the process of evaluation, consider the data available in Table 1, and, in addition, some general information which is as follows:

1. the mountain in general is covered by 2-4 cm sun-crust with stiff wind pack on northeast exposures.

2. when the snow started falling on (March 21st) it consisted of stellar crystals, spatial dendrites and irregular particles.

3. on March 21st, snow was forming a soft slab which was relatively fragile and not adhering to the old snow.

4. some sluffing of new snow was observed but only on very steep slopes subject to high intensity build-up by wind transported snow.

5. hasty snow pits two days ago indicate some temperature gradient crystals still present on northeast exposures above 3,000 m. Snowpack, in general, shows no temperature gradient but is generally cold averaging -10°C upper layers.

The forecaster can now make the following deductions:

a) a slab is probably present over majority of the mountain.

b) it is unlikely that crystal-type has changed throughout the storm. If anything, wind may have broken some of the stellar crystals into irregulars, thereby increasing slab probability.

c) due to high intensity of snowfall, coupled with optimum snow transport winds on upper mountain, many of the steeper slide paths may have run naturally shortly after midnight.

d) lower mountain winds were sufficient to transport snow and high probability of slab is present.

e) slab is probably in a very unstable condition because temperature still shows a rising trend and is unlikely to drop for several hours.

f) upper mountain winds may have been strong enough to scour slopes which would be loaded under lesser winds.

g) the slab is unlikely to be adhered to the old snow surface.

It is obvious that a highly unstable condition is present on the entire mountain and that a full control morning is called for. The previous afternoon, the forecaster knew that a major storm was moving in and had told the ski patrol dispatcher to alert the gun crews to the probability of having to fire and to call an early morning for the ski patrol in general. On days when it is expected that heavy control work will be necessary, the ski patrol comes to work one-half hour early in order to give themselves time to complete avalanche control duties prior to normal opening hour. Since the forecaster expects instability on major lower slopes, he has called the 105 mm gunners to report to the lab. He now decides which shots should be fired, mostly on the basis of which areas cannot be controlled by hand-charge teams. Most of this area is of low-intermittent hazard and no activity is actually expected or forecast.

The forecaster now prepares an evaluation for each slide path. He records his forecasts e.g., "Corbett's Couloir: Soft slab less than one meter", and then notes later what actually happened, e.g., "fractures, but no release". We have found that it is not easy to make specific forecasts for individual slide paths, but it enables us to check our accuracy and thereby improves our forecasting.

Specific Evaluations

Rendezvous Bowl. The forecaster knows that Rendezvous Bowl is a heavily-skied large bowl near the top of the mountain and feels quite secure in his belief that there is little chance for a major slide. High southwest winds tend to create a hard slab on the bowl above the starting zone. He will recommend that the bowl be controlled, but his forecast will not call for an undue amount of explosives.

Far Drift. The Far Drift slide path is a narrow path at the southwest edge of Rendezvous Bowl. Due to a row of trees this path will have a large buildup (>1 m) on top of a sturdy suncrust. Chances are good (80%) that control will get a soft slab >1 m. If this path fails to release, a temperature gradient crystal layer will probably form above the suncrust and the slope will be cause for concern over the next several days when release is again probable.

Dean's Slide. The Dean's Slide path is an active early-season path, but at this time of year, the underlying snowpack is stable and, although hard slab rolls to 1 m depth will be found, some surface fracturing is all that is likely to happen.

Hanging Rock. The Hanging Rock is one of those "Old Faithful" slide paths that will definitely slide as a hard slab. This slide path is very unlikely to run naturally, so the forecaster is almost 100% certain of his evaluation.

Mud Slide. The Mud Slide is an area of high intermittent pockets and small faces. Most of the pockets will probably run as soft slabs less than 1 m thick. These pockets are prone to run naturally as sluffs and are unlikely to build to substantial proportions under present conditions.

John Deere. A very high probability of hard slabs about 1 m thick is forecast for this area. This is very unlikely to have run naturally because this path builds as a large stiff roll above a cliff and snow falling below the roll sluffs off, rather than building and creating a pulling force on the roll. (Similar to Hanging Rock.)

Laramie Cliffs. Laramie Cliffs is a high intermittent hazard, probably one of the most active paths on the mountain. Chances are that natural activity took place around midnight under high precipitation intensity conditions. Since then, a hard slab has probably built and will run readily.

Conclusion

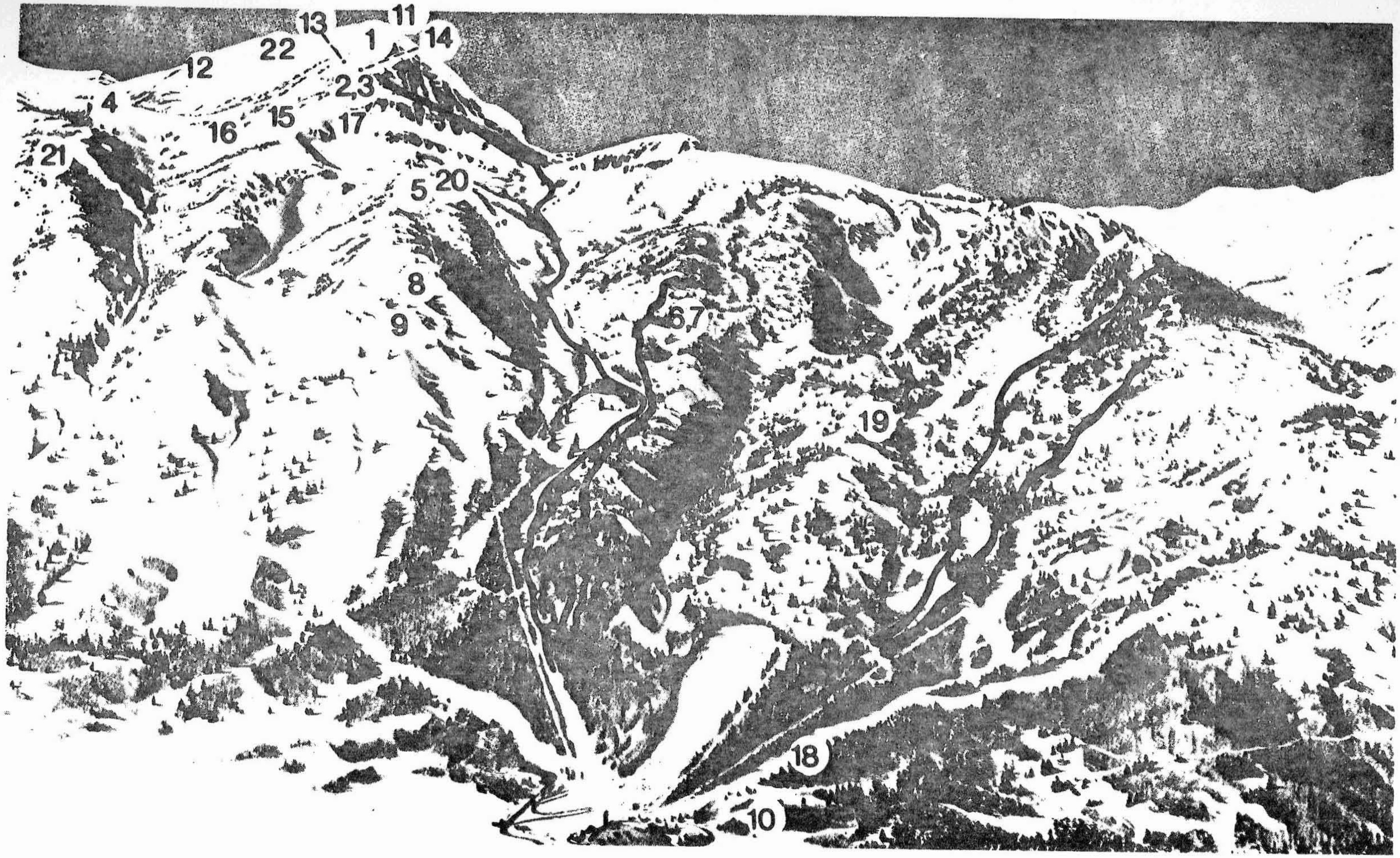
Preparing this paper has been a revelation, of sorts, as trying to enumerate the steps taken during a forecasting session is difficult at best. I am sure that there are some subconscious processes I am not aware of and perhaps never will be. A small sluff here, settlement there, cracking below a cliff, are all data to be remembered and used, if necessary, rejected, if immaterial. The important thing is to maintain a constant awareness of the mountain in question.

TABLE 1

Example of Data Received at Jackson Forecast Laboratory, March 22, 1975

	Upper Study Plot	Midway Study Plot	Lower Study Plot
Temp. (0600)	- 8°C	-5°C	-1°C
Temp. (24 hr. max.)	- 4°C	-3°C	-1°C
Temps. (24 hr. min.)	-12°C	-9°C	-8°C
Wind dir. and sp. (0600)	290/31 km/hr	200/18 km/hr	-
Wind (24 hr. total)	732 km	426 km	-
Wind (last 12 hrs.)	378 km	266 km	-
Wind (high hr.)	270/39 (07-0800)	200/31 (01-0200)	-
New Snow (24 hr.)	30 cm	25 cm	18 cm
Total Depth	274 cm	262 cm	124 cm
Gauge Precip. (24 hr.)	17 mm	17 mm	-
Gauge Precip. (12 hr.)	14 mm	12 mm	-
Gauge Precip. (high hr.)	2 mm (22-2300)	3 mm (05-0600)	-
Snow Surfaces	Slab/Suncrust/Windpack		

Weather forecast: Moderate to heavy snow today, diminishing by evening. Frontal passage early morning. High winds aloft.



Basic Wind Tower	1	Rendezvous Bowl	22
Mechanical Pyranograph	2	Far Drift	12
Upper Thermistor	3	Dean's Slide	13
Upper Study Plot	4	Hanging Rock	14
Upper Tipping Rain Gage	5	Mud Slide	15
Middle Tipping Rain Gage	6	John Deere	16
Middle Study Plot	7	Laramie Cliffs	17
Mid Mt. Thermistor	8	Gun # 1	18
Colter Ridge Anemometer	9	Gun # 2	19
Rendezvous Peak	11	Gun # 3	20
Forecaster's Laboratory	10	Gun # 4	21

FIGURE 1 JACKSON HOLE SKI AREA: INSTRUMENTS, MAJOR AVALANCHE ZONES, AND GUN EMPLACEMENTS