TEMPERATURE BASED FORECASTING OF A SPRINGTIME ARCTIC SNOWPACK

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Introduction

Until recently, avalanches involving arctic snowpacks have received little attention in publications. Man has had very little contact with the arctic snowpack until recent years with the advent of arctic exploration for oil and the subsequent development of oil-related facilities. This has considerably increased the incidence of avalanche encounters in arctic mountain ranges.

This paper describes an avalanche forecasting and control project conducted to allow oil pipeline maintenance crews to work on the Alaska pipeline during the spring melt/freeze cycle. The location of this project was the remote Brooks Range of northern Alaska, an area that develops unique avalanche characteristics because of extreme meteorological conditions. Because no previous work had been done under these conditions, new and innovative procedures had to be devised for forecasting and control.

Description of Terrain and Meteorological Conditions

Atigun Pass is located in the Brooks Range of northern Alaska at a latitude of 68° north and a longitude of 150° west. Valley floors lie at an altitude of 1,000 m. The Pass elevation is 1,450 m and peaks rise to slightly higher than 2,000 m. The approximately 1,000 m of land that lies between the valley floors and the peaks is typified by slopes in excess of a 30° incline with many gullies and ridges typical of fold sedimentary mountains. The climate is arctic/continental with light snowfalls, cold temperatures, and high winds which combine to form a snowpack predominated by depth hoar and overlain by wind-blown hard slab in terrain depressions.

Infrequently, avalanches arise from the deposit of new snow or wind-transported snow over a base of well-developed depth hoar. In the spring, warming temperatures introduce free water to the snowpack which eventually results in numerous full depth, wet, loose avalanches. Both these conditions - which can lead to snowpack instability - were observed.

The project goal was to provide avalanche forecasting and control to reduce the hazard to pipeline maintenance crews working in the Pass. A field trip during the arctic night of early January revealed an essentially stable snowpack made up of extremely hard, wind-blown snow overlying depth hoar. The mean temperature was below -40°C. Snow depths in the starting zones in January were generally less than 1 m. Another field trip was made in March and revealed essentially the same conditions. During the period of December 1, 1979 to April 15, 1980, only one significant avalanche cycle was observed. This occurred in December as a result of new snowfall. By April 15, a significant increase in total snow depth in the starting zones was noted.

Due to rising temperatures in the spring, it was felt that a fulltime observer was needed to prepare daily hazard evaluations and implement control activities when necessary. This was done from April 26 to June 1, 1980.

Instrumentation and Observations

Due to a relative lack of new snowfall and wind-transported old snow, once the melt cycle had begun, it was felt that primary forecasting input should be observation of snowpack temperatures. In addition to the normal range of meteorological observations necessary for forecasting, a series of snowpits was analyzed on different exposures on a regular basis. This provided spot checks of temperature and crystal structure to correlate with the primary input of snowpack temperatures which consisted of a set of thermistors arranged by number as shown in Figure 1. Figure 2 shows data for May 1980 as a function of depth for thermistors C6, C5, C7, and C4 from Figure 1.

Installation of the thermistor strings on April 23 was accomplished with a minimal disruption of thermal properties of the snow. Of particular interest at the onset was the question of whether warming would occur more rapidly through the depth hoar bordering the hard slab or through the hard slab itself. By May 3 the thermistor strings had revealed that the hard slab was warming faster than the base or perimeter of depth hoar. This was particularly important from a forecasting viewpoint because it meant the hard slab would not be undermined while it was still cold. During this period an excellent correlation between snowpit temperatures and the thermistor readings was observed. This gave added confidence in the use of the thermistor data. The snowpit studies also revealed the extent of free water content, although this was very limited until May 18, near the beginning of the summer-long arctic day.

From May 3 to May 18, when the first major avalanches occurred on south faces, the air and snowpack temperatures rose at approximately the same rate. Extensive sublimation was observed on steep south faces. This was demonstrated by the removal of the entire 0.3-0.6 m snowpack, except for the deeply drifted gullies, without a trace of runoff water. Most of the sublimated snow was depth hoar lying among rocks.

Snowpits of May 17 revealed that south facing slopes had become wet to a depth of 1 m. A check of the thermistors showed the temperature at 1 m to be -.4°C. Up to this point only four days had a high above 0°C with average temperature at -5°C. This was dramatic proof of the accumulated solar radiation brought on by the recent advent of continuous day. Control work on the afternoon of May 18 released full depth avalanches from all major south facing chutes under the project's jurisdiction.

From May 18 to May 22 a cold period intervened causing a drop in temperature at the high layers of the snowpack. Base temperatures continued a grdual warming trend.

After May 22 each day's high was above 0°C, and the nights were above 0°C from May 24 to May 27. This rapidly wrmed the entire snowpack to 0°C. On May 26 and 27 some thermistors showed an increase of more than 4°C from the 25th to the 26th. Of particular note at this stage was the persistence of isolated nodes of colder snow (-3°C to -4°C) surrounded by snow at 0°C. Problems in releasing isolated pockets with explosives were noted, in spite of the generally unstable nature of the snowpack. It is possible that these pockets were not yet isothermal.

Avalanche control on May 26 led to medium-sized, isolated releases. When all thermistors had reached 0°C on May 28, control work released full depth avalanches from east and west exposures in virtually all gullies. It seems likely that the isolated cold spots which helped stabilize the snowpack before May 28 were rapidly warmed by continuous radiation and high temperatures during the 24-hour arctic day. Inspection of thermistor data had revealed the isolated cold pockets several days before May 28, a phenomenon that would be hard to quantify using conventional snowpit techniques.

Contributory Factor Analysis and Unusual Features of Avalanches

The sun never rises from November 15 to January 25 and never sets from May 15 to July 25.

Temperatures average -40°C from December 1 to March 1 and -20°C from March 1 to April 15. This long period of cold in a region with a shallow snowpack causes the land mass to cool to a significant depth. During January, the soil temperature at .5 m deep was -18°C illustrating the effect the cold has. The land mass therefore acts as a cold sink, trapping and holding the extreme cold of winter long into spring. The air warms rapidly with the onset of long days, and the ground cannot lose its stored cold as quickly through the insulating snowpack. The result is that the ground level often remains frozen when the snowpack has become isothermal. Percolated water then has a tendency to run along the ground/snowpack interface and undermine the entire snowpack.

Precipitation is generally light, although the crest of the Arctic Divide at Atigun Pass receives more than surrounding areas. Average annual precipitation is estimated at 700 mm; approximately half of this is in the form of snow. New snowfalls rarely exceed 25 cm.

During the spring warm-up, an arctic front develops between the warm air provided by the heating of interior Alaska and the cold air mass over the polar regions. This arctic front is gradually pushed north from the Brooks Range at the average rate of 10-15 km per day. After the arctic front has passed to the north, a period of approximately one week of melt bares the tundra. Once this is done the warming of this brown surface helps to accelerate the warming of the air mass. This process was very obvious from the increase in heat waves off the tundra after snow melted.

Approximately 40 km south of Atigun Pass is the northern limit of the boreal forest. From here to the north there is almost no vegetation that grows more than 0.1 m above the ground. The North Slope of the Brooks Range is a flat plain for 300 km north to the frozen Arctic Ocean. During the winter, northerly arctic outflow winds blow continuously across the snow-covered plain. We speculate that, to a certain degree, this plain acts as a fetch zone for the entire Brooks Range. The lack of terrain irregularities on the North Slope would tend to favour wind transport of snow into the Brooks Range. Terrain irregularities there act as catchments for this wind-transported snow.

Slush Flow Avalanches

While this project emphasized involvement with recognized avalanche paths which affected personnel safety, the presence of gullies subject to slush flow avalanches sparked a keen interest. Within the observation area there were several of these gullies that could affect personnel safety. In general, these slush flow prone gullies average 10° to 15° and do not exceed 20° slope incline in the starting zone. They invariably contain a deep (2 m to 5 m) uniform, hard slab snowpack. Six slush flows were recorded in observations and hundreds occurred outside of observation. None of the flows was recorded in motion. Virtually all major, low angle gullies had slush flow avalanches. Observations in the track indicated a speed possibly as high as 25 m/s. Factors contributing to this would be channelized flow, uniform ground surface, and well-lubricated flowing mass. In addition to the deep snowpack that becomes involved, gouging action entrains a high percentage of scree - in some cases as much as 40% of the volume is debris. This involvement of scree could significantly increase the impact pressure of a slush flow.

Of further note is that the system of snowpack temperature data gathering developed for this project could possibly lead to accurate prediction of slush flow avalanches. The highest intensity of this type of avalanche was observed on the day (May 26, 1980) when most of the thermistors had reached 0°C. The presence of localized colder snowpacks was then observed in several slush flow areas by leftover remnants of cold "dams" in the gullies. Perhaps water backing up behind these dams plays a key role in formation. It is also possible that the presence of frozen ground at the bottom of the gullies, as noted earlier, plays some role. More research on slush flows will be necessary in the future to understand the physical processes involved. This will likely happen as industry moves into the arctic.

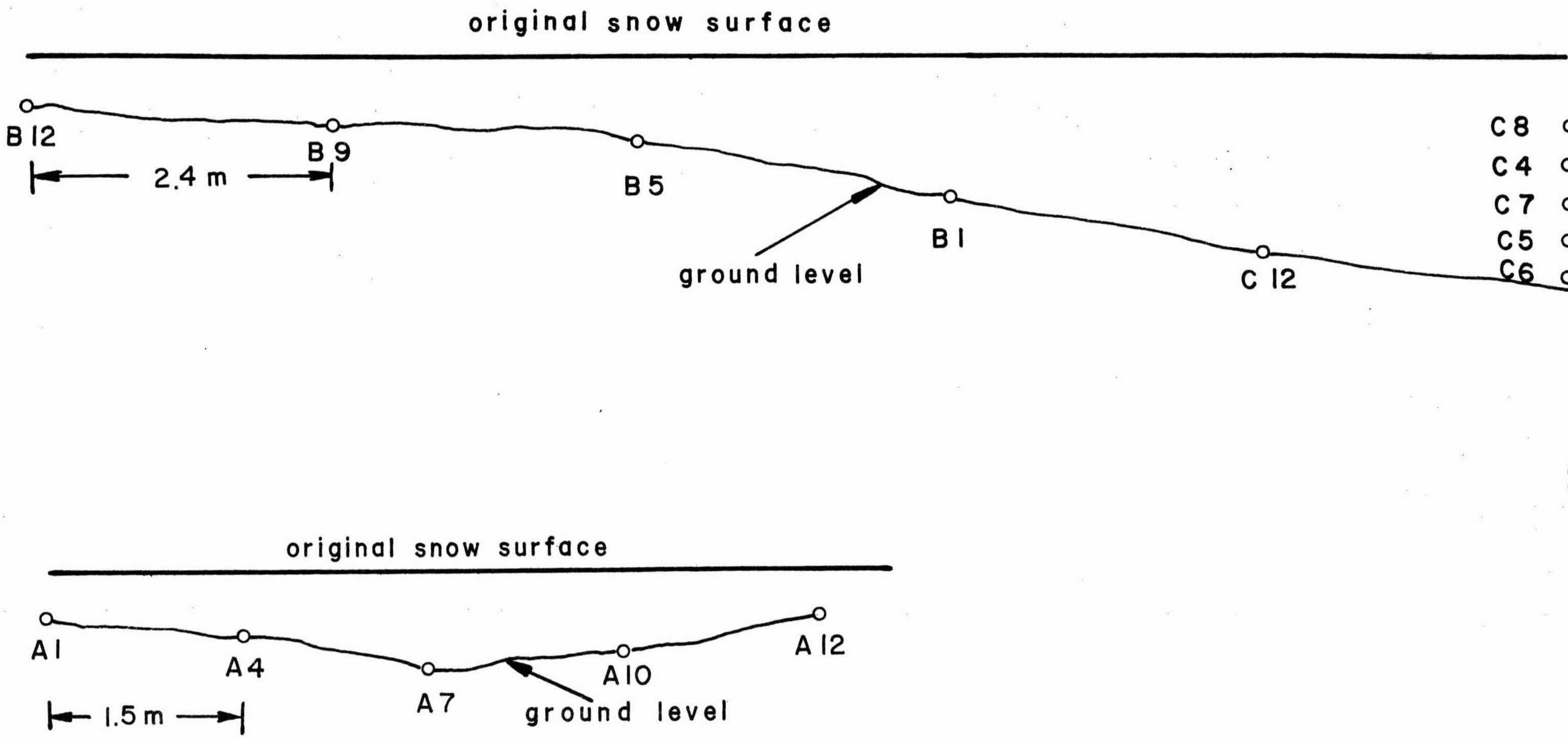

Figure 1. The array of thermistor strings installed to monitor snowpack temperatures. The grid defines the spacing of the thermistors in relation to each other and the original snow surface. These were installed on a southwest exposure similar in aspect, angle, and elevation to a slope which constituted the major hazard to the pipeline work site.

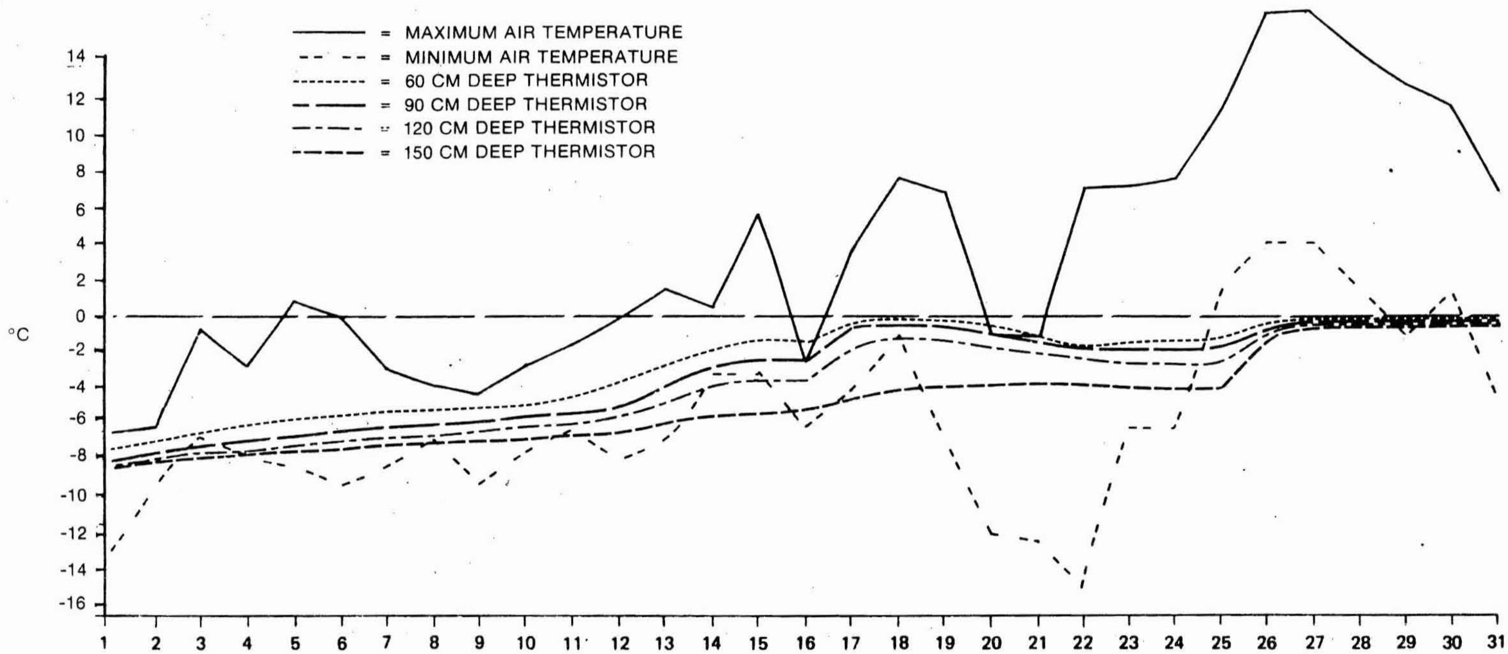

Figure 2. Graph of the air and snowpack temperatures during May 1980 for thermistors C6, C5, C7 and C4 depicted in Figure 1. The gradual rise of air temperatures until May 15 was reflected in an even rise in snowpack temperatures. When the air temperature rose considerably during May 17 to 19, the near surface snowpack temperatures responded quickly, but the near ground thermistors continued their gradual rise. During the cold period May 18 to 21, the near surface temperatures dropped considerably while the near ground temperatures continued a slow rise. As the low temperature of the day climbed above freezing, the snowpack reacted all the way to the ground by a sudden rise to 0°C which was reflected by the development of a full depth avalanche cycle as well as numerous slush flow avalanches.