AVALANCHE NEWS

CANADIAN AVALANCHE ASSOCIATION

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In This Issue:

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INFORMATION ABOUT AVALANCHE CONDITIONS IS AVAILABLE:
BULLETINS ARE ISSUED MONDAY & THURSDAY MORNINGS
ADDITIONAL UPDATES ARE MADE WHEN CONDITIONS CHANGE RAPIDLY

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CALL THE PERSONAL COMPUTER BULLETIN BOARD: 1-604-837-4893 (8N1 to 9600baud)
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The deadline for the next issue is May 31, 1994. Material may be sent to the Canadian Avalanche Centre in Revelstoke in a variety of formats. Hard copy, Fax, ASCII, or WP5.1 are required for text. Diagrams, charts, & figures may be submitted as .WMF (preferred), .CGM (preferred), .WPG, .TIF, or .PIC files. Files can be sent on disk or to the PC BBS.

Notice of Meetings

Notice of Annual General Meeting
The AGM of The Canadian Avalanche Association will be held in Penticton, B.C. at the Sandman Inn on May 4-5, 1994.

The Technical Meeting will take place in the morning of May 4th while the Business Meeting will take place in the afternoon.

Please note that these meetings are open to CAA members and invited guests only and notices of pending special resolutions will be sent to members in advance of the business meeting

Anyone who wishes to make a presentation at the Technical Meeting should contact Jim Bay or Alan Dennis at the Canadian Avalanche Centre in Revelstoke. The deadline is April 15th. Phone (604) 837-2435. Fax (604) 837-4624

Notice of Public Meeting
After a great response at the 93 Spring meetings we are looking forward to the 2nd Annual Public Session of the Canadian Avalanche Association Spring meeting where topics of interest to the general public will be presented.

Date: May 5, 1994
Time: 0830 - 1600
Location: Sandman Inn, Pentiction, B.C.

Anyone interested in making an avalanche related presentation of commercial, research, recreational, or industrial interest is welcome to submit their proposal to the Canadian Avalanche Centre (CAC) in Revelstoke. There will be facilities available for commercial/trade show exhibits. If you wish to display your services or products please contact the CAC. Address your inquiries/proposals to Jim Bay or Alan Dennis at the following address. *Please note* that this deadline is also April 15, 1994.

Canadian Avalanche Centre
Box 2759
Revelstoke, BC
V0E 2S0
phone (604) 837-2435
fax (604) 837-4624

An evening session of climbing will take place at Skaha Bluffs; suitable attire required.

Avalanche Control Incident Reports

In the past few years the Canadian and the American Avalanche Control communities have expressed concern over the lack of cross border information transfer and dissemination. This is primarily in regard to incidents where avalanche control circumstance may cause a safety hazard. Examples are:

- a particular procedure which has created a safety hazard; or,
- material flaws in a control device, like material disintegration due to extreme cold or unacceptably poor propellant ignition.

In an effort to ensure safety in the operations of North American avalanche control programs the Canadian Avalanche Association and the American Association of Avalanche Professionals have set up a procedure for distributing information when a safety hazard has been identified. If you experience or become aware of an avalanche control situation which is a safety hazard please forward the appropriate information to:

Canadian Avalanche Centre
Box 2759, Revelstoke, BC, V0E 2S0
Phone (604) 837-2435
Fax 837-4624.

This information will then be forwarded to the American Avalanche Community.

Computer Based Artificial Intelligence as an aid to BC MoTH's Avalanche Forecasters

Peter Weir, P. Geo., Research Officer, Snow Avalanche Programs, MoTH, Victoria and
Dr. David McClung, P. Geo., Depts. of Geography and Civil Engineering, UBC, Vancouver

This is the first of two articles outlining advances in avalanche forecasting and snow stability evaluation techniques within the British Columbia Ministry of Transportation and Highways.

Snow Avalanche Programs of the Ministry of Transportation and Highways have sponsored two initiatives in the field of computer based artificial intelligence in the past two years. These initiatives were to develop a knowledge based system to aid in snow profile interpretation and a coupled numerical avalanche prediction system. Both initiatives were undertaken as research contracts by Dr. David McClung of the departments of Geography and Civil Engineering at UBC and aim to providing objective tools to assist the Ministry of Transportation and Highways' avalanche forecasters.

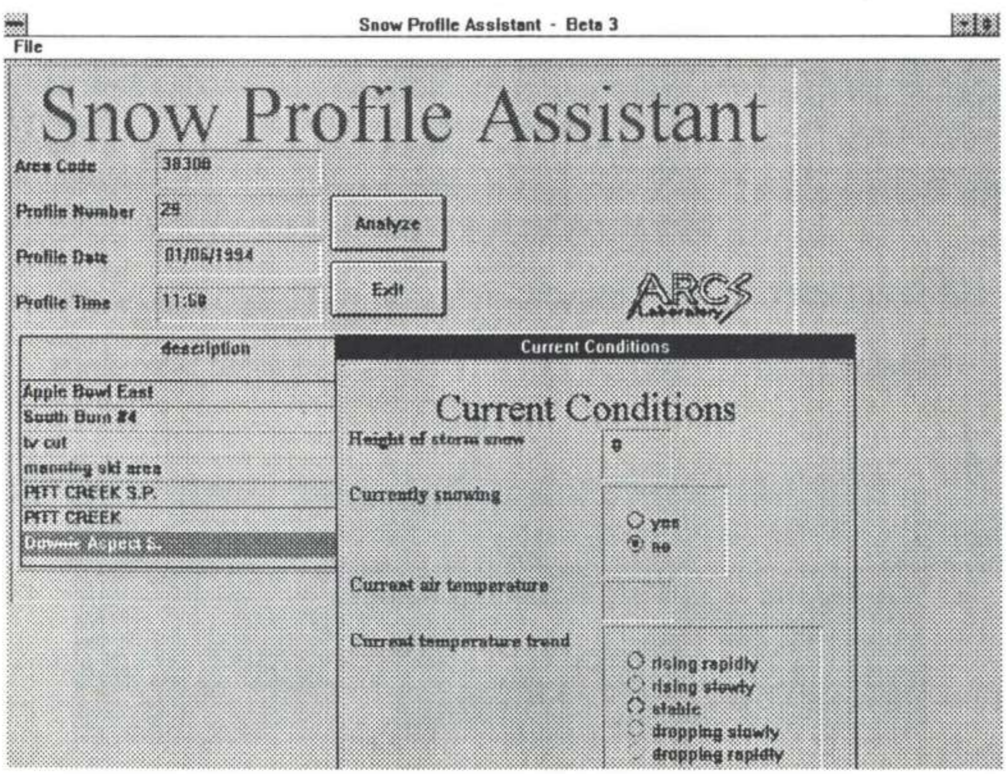
A Knowledge Based System for Snow Profile Interpretation

Snow Avalanche Programs have developed a computer based drafting tool for plotting snow profiles. Data from computer drawn profiles are stored in a relational database. New staff are hired by the Ministry with the field skills to observe the snowpack structure and document the results by plotting a snow profile but interpretation of the resultant snow stability is a highly specialized skill that must be developed through time.

The BC Science Council and the Ministry have funded the development of a knowledge (or 'rule') based system at the Applied Research in Computer Systems Laboratory (ARCS lab) of BCIT. If successful, the system will be available to all staff to assist in snow profile interpretation. Dr. Dave McClung, Professor Ed La Chapelle, renowned snow researcher from Alta, Utah, Dr. Howard Conway of the University of Washington (previously from New Zealand) and many of the Ministry's most experienced avalanche technicians, all experts in the domain of snow profile interpretation, were interviewed by knowledge engineers from the ARCS Lab (Joseph 1994).

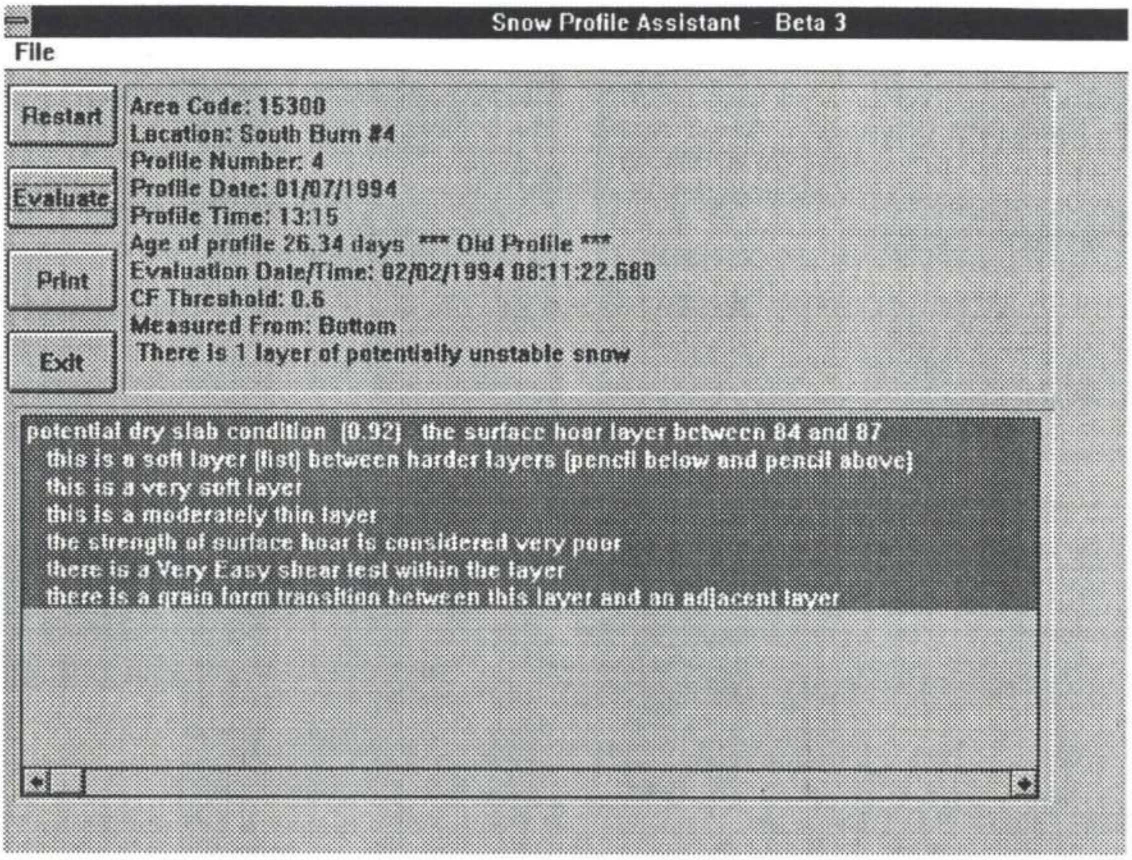
Following the interviews a set of influence diagrams were established to concisely describe the process involved in the analysis of avalanche risk assessment. These diagrams were used to code a set of rules in a computer program named "Snow Profile Assistant". Dr. McClung validated the rules which collectively represent the knowledge base of the system..

The ARCS Lab's system for use in Snow Profile interpretation is now being evaluated by technicians from four of MoTH's Snow Avalanche Programs. The program uses a Graphical User interface, common to many modern PC programs.



Snow Profile Assistant's start up screen presents a list of snow profiles stored in the database. It presents a data entry window that seeks information on the current weather. Some rules in the knowledge base may "fire" if critical conditions are exceeded, adding confidence to the assertions that certain layers may potentially produce avalanches.

The program's artificial reasoning proceeds in a goal oriented fashion; A "backward chaining" process is used to test assertions like "There are conditions in the profile to support Dry Slab avalanche conditions". The program gives a textual analysis of the snow profile based on the rules that fired in the knowledge base.



For every layer of potentially unstable snow identified, the system gives a "certainty factor" in the range 0.5 to 1.0. The more evidence that exists in the snow profile to support the assertion that a layer is unstable, the higher the confidence factor

The program looks likely to become an invaluable training tool. It will be of significant benefit to individuals working alone in the snow safety arena in the province, if not world wide. The program makes the expertise of the Ministry's senior avalanche technicians available to anyone wishing to interpret a snow profile.

Depending on the outcome of the Ministry's senior avalanche technicians analysis of the program's performance in the 1994 winter the system can be fine tuned by changing the 'certainty weigh' of various rules.

The next issue will describe a Statistical Avalanche Prediction model which is has been evaluated at Kootenay Pass for the past two winters.

References

Joseph, S. (in press) " R& D at the BCIT Applied Research in Computer Systems (ARCS) Laboratory" paper submitted to "BC Professional Engineer magazine"

Snow Profile Computer Drafting Package

Peter Weir, P. Geo., Snow Avalanche Programs, Ministry of Transportation & Highways

The Canadian Avalanche Association has arranged for the commercial release of a computer based snow profile drafting program named SnowPro. The program was inspired by an earlier product developed by the New Zealand Mountain Safety Council's Snow and Avalanche Committee but uses Windows 3.1. This package has been designed by Snow Avalanche Programs of the BC Ministry of Transportation & Highways for use by its avalanche technicians and programmed by Gasman Industries of Victoria BC. SnowPro uses weather notation symbols from the NRCC & CAA guidelines, 1989 (Fig1). The interface enables data to be quickly entered and recalled at will.

The snow classification symbols and format presented in the International Snow Classification for Seasonal Snow on the Ground published by Colbeck and others in 1990 is used in the program. Observers can use the basic nine category grain shape classification or the more detailed sub classes where necessary, (for instance, Graupel is found in the Precipitation Particles sub class (Fig 2)). Provided that density information is entered, the program automatically computes each layer's equivalent water content as well as the snowpack's average density and HSW value.

A big advantage of using a PC is that snow profile data are stored in digital format and can be shared amongst other computer applications or transmitted to other users. Snow Avalanche Programs of MoTH have stored profiles in a relational database format which enables queries to be made, e.g. "show all profiles where buried surface hoar exists more than 50 cm down from the surface".

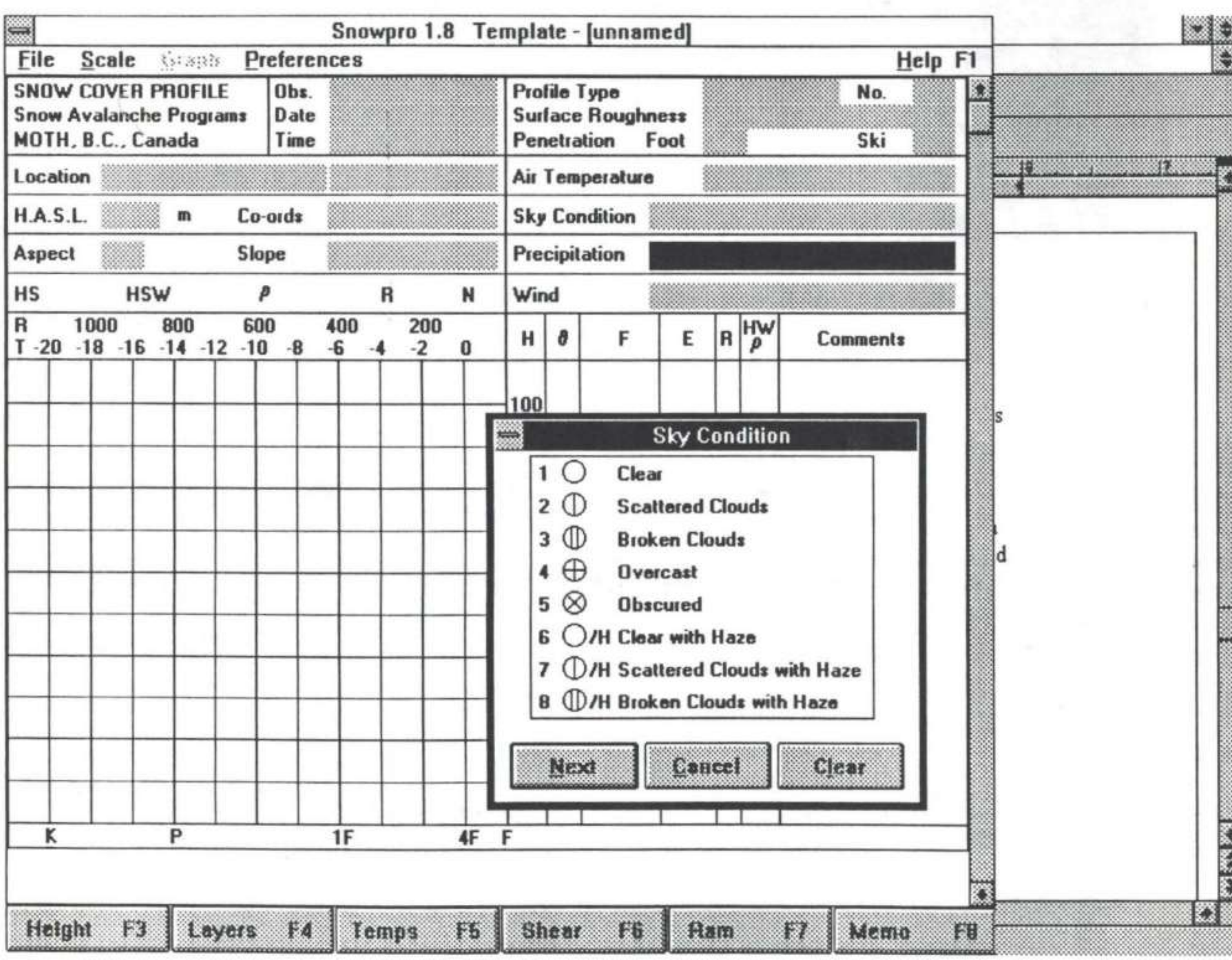


Figure 1: Main data entry screen with sky condition window pop up.

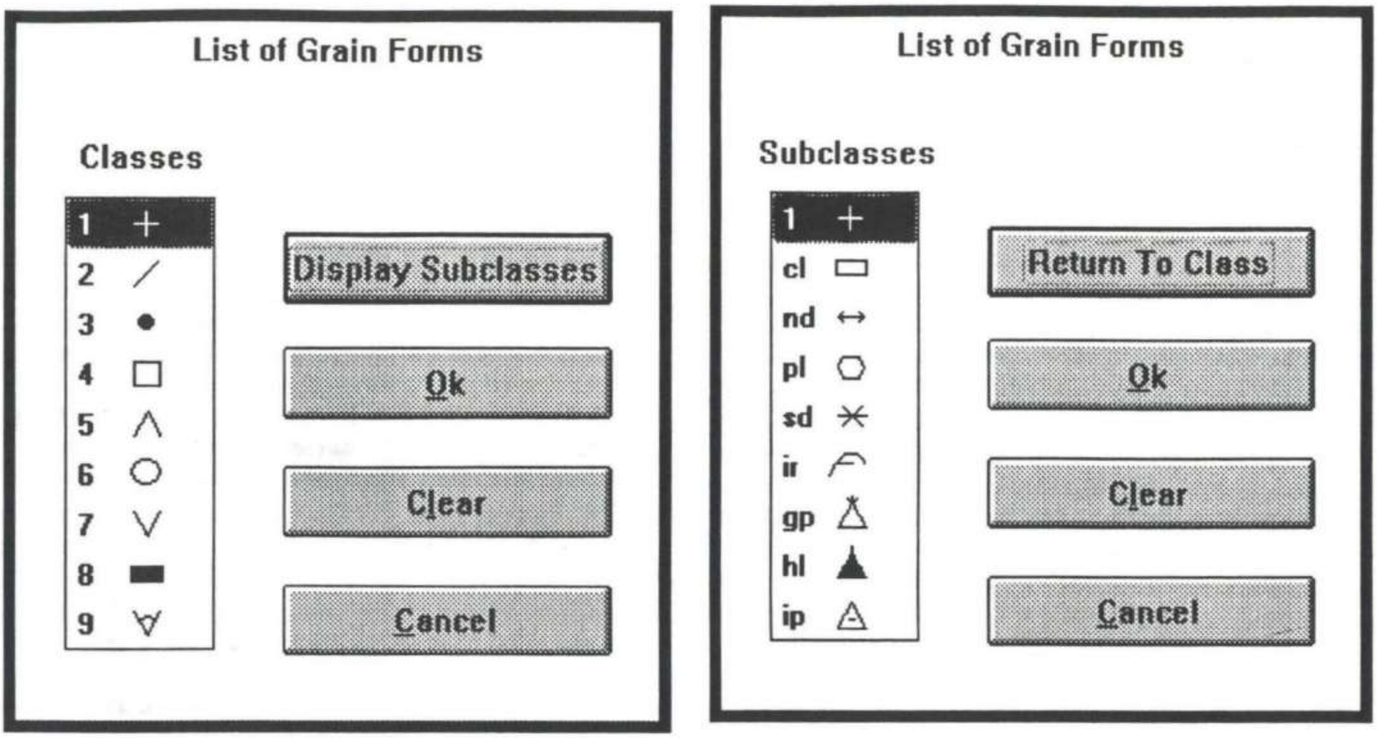


Figure 2: Grain form basic and sub class data entry windows

SnowPro runs in the MicroSoft Windows 3.1 operating environment on 386 or 486 PCs with VGA or better screen displays. This environment supports a wide range of printers with laser printers giving exceptionally clear print outs.

Gasman Industries Ltd will market the product and continue to upgrade the program as well as providing user support. As an introductory offer, Gasman Industries, phone (604) 383-8376, Fax (604) 383-8692, will offer CAA members a 50% discount for purchases made within the first 3 months of the projected March 1994 release date.

Avalanche Safety Workshop '93

An avalanche safety workshop in Calgary raised $8,500 for the Canadian Avalanche Centre's Public Avalanche Bulletin! In support of toll free avalanche information, 220 backcountry skiers, climbers, snowmobilers and snowshoers paid $60-70 to hear 12 speakers on November 13 and 14.

The workshop was conceived by Mike Mortimer and Tony Daffern, organized by Tony, Mike, Alf Skrastins, Steve Chambers and Bruce Jamieson, and sponsored by Abbot Pass Trading Company (The Hostel Shop), Campus Recreation at the University of Calgary, Explore Magazine, Ortovox, and Rocky Mountain Books. Staff from the University of Calgary's Outdoor Program Centre hosted the workshop by registering the attendees, running the audio visual equipment, and organizing the poster display and beverages. Judy Breeze worked with Mike and Tony to advertise the workshop.

Speakers included: Clair Israelson, Marc Ledwidge, and Brad White from the Canadian Park Service, James Blench and Dwayne Congdon from Canadian Mountain Holidays, Alan Dennis from the Canadian Avalanche Centre, Gerald Edwards from the Canadian Institute of Safety Search and Rescue, George Field from Kananaskis Country, Bruce Jamieson from the University of Calgary, Chris Stethem from Chris Stethem and Associates, and Bruce Tremper from the Utah Avalanche Forecast Center. Barry Blanchard spoke about snow and international mountaineering at the reception on Saturday night.

Our thanks to the organizers, sponsors, speakers and Outdoor Program Centre staff, all of whom volunteered their time to support avalanche awareness and the Public Avalanche Bulletin.

Security and Survival:

The Avalanche Balloon System for Back Country Operations

Walter Bruns

The avalanche balloon system (ABS) is an innovation in the field of avalanche safety and survival. You will likely hear and read more about it in the future. This article examines the issues underlying operational use of the ABS in commercial back-country situations.

Inventor Peter Aschauer has been developing the ABS since 1980. There are now 2,500 units in use, mostly in Europe. They are gaining acceptance among guides, ski patrols, and off-piste ski-tourers. One heli-ski operator in the Caucasus is using them with clients.

Actual avalanche involvements where skiers have deployed the ABS are few. The number of tests and simulations conducted to date does not yet allow for statistically significant analysis. However, testimonials to its effectiveness are numerous. Client demand for its use is likely to grow. Operators can seize a marketing advantage by using the ABS, building on the perception of its advantages in facilitating rescue and ensuring survival.

The registered name of "Avalanche Balloon Secutem," or the title on the manufacturer's brochure of "Avalanche Balloon Survivalsystem," implies a link between the device, security, and survival. At the same time, the manufacturer's literature contains disclaimers referring to many other factors that influence one's chances of becoming caught in or surviving an avalanche. There is potential for the perception that the ABS system adds a greater degree of safety than can be scientifically proven. Newspaper headlines read "This rescue balloon has saved my life!" Well, maybe.

Overall safety for back-country skiers in a mountain environment is a product of security precautions and chances for survival in the event that a mishap occurs. This can be expressed as a formula:

[margins of security] x [chances of survival] = net safety margin.

The margins of security we consciously decide upon (as probabilities) multiply with the chances of surviving an avalanche, also probabilities, to yield a net safety margin.

There are many factors that contribute to the term [margins of security]. Some of the more important categories are snow stability evaluation, hazard assessment, and risk management. Each of these in turn are a product of many factors. Similarly, the size of the slide, the kind of terrain it covers, the forces on the skier's body, the nature of the snow and the deposit, and the method and speed of recovery of a buried victim are some of the factors contributing to the term [chances for survival].

Some factors are quantitative, some qualitative, and some are intuitive or just plain guessed at. In addition, each factor is given a weighting as to confidence level, relative importance in the term, or its general relevance to the specific situation. Guides have to constantly calculate this string of hundreds of multiplicands, each suitably weighted or filtered, to determine a net safety margin. And all the while circumstances are changing!

Tools such as the probe, shovel, and avalanche rescue transceiver only enter the equation under method and speed of recovery. They are not security precautions - they are devices that **may** improve chances for survival once an incident has occurred. In fact, there is no link whatsoever between these devices and a skier's margin of security, **except insofar as having them may instill a level of confidence that affects the judgment of hazard or acceptance of risk**.

The avalanche balloon system is analogous to the avalanche rescue transceiver in many respects. Both represent technological advances over previous practice. But again, there is no **unique** cause and effect relationship between **having** the ABS and one's margin of security, nor between **using** the ABS and one's chances for survival if caught. Any intimation thereof in promotional material would be unjustified.

Avalanche transceivers are a significant improvement over earlier means to find buried skiers, such as trained dogs, avalanche cords, and probe lines. Transceivers do not necessarily invalidate or supplant other, older means of recovery which remain as fall-back options in the event that transceivers fail (or are not used). Transceivers are passive in the sense that all skiers transmit continuously while in avalanche terrain. They become active when searchers switch to receive and conduct a systematic search for the buried skiers. Recent models allow for induction line searches which further reduce search times. There is no doubt that this technology has been a major contributor to improved survival margins in avalanche burials. Use of transceivers has become common practice and is the accepted standard of care in commercial (guiding) situations.

The ABS now offers a step in the same direction. It differs from the transceiver in two ways: the skier must activate it immediately upon becoming involved in an avalanche, and it has an active, mechanical influence on the extent of burial. **If** a skier caught in an avalanche has both the presence of mind and physical ability to trigger the balloon by pulling the rip cord, and **if** ambient conditions and other factors affecting survival chances in the avalanche do not impair the effective inflation and function of the balloon, and **if** one accepts that the device improves flotation of a skier caught in moving snow, **then** it is reasonable to expect that, in general, a lesser depth of burial would result for the person to whom it is attached. Thus, the ABS would facilitate a faster recovery of the buried skier, or permit visual location and even faster recovery, or allow for self-rescue, or it might keep the skier completely on the surface. So, if the net effect of the ABS is to improve margins for survival, then every argument that supports the use of transceivers applies equally to the balloon system.

Does this mean that use of the ABS will become common practice for back-country skiing? And if so, will this set a new standard for commercial operations? An analytical answer involves weighing all factors contributing to **both** the margins of security and the margins of survival, which together yield a net margin of safety.

Weighing factors can be taken literally. From the manufacturer's specifications, each armed ABS device weighs 2 kg; built into a small day pack it weighs 3.6 kg. A full helicopter load of skiers would weigh an additional 41.6 kg, plus whatever extra gear each guest might carry in the pack. That extra weight marginally reduces safety for helicopter operations on every flight, all other factors remaining constant.

Continuing this line of thinking, safety for individuals in the back-country would improve if each guest carried a small radio, and survival margins would improve if each guest had a probe and shovel in the ABS pack. Including these extras, additional loads in a helicopter group reach 80 kg or so. In addition, each skier could carry a radio device with reflecting decals in their ski suits, and the helicopter could have a remote sensing antenna for the transceivers on board as well, should an aerial search be more practical. Finally, we could re-attach the avalanche cords and bring the dog along too, for good measure!

In ski-touring situations, one can load up the members of the party with safety and survival gear until the added exertion of carrying it impairs judgment or slows travel or reaction capabilities to the point where net safety is actually compromised. Commercial operators could compensate for the extra weight by taking less fuel, or one less passenger. The operator could even adjust the guide/client ratio as an alternative to or in addition to other measures. Doing so maintains or improves net safety but at the expense of operating margins.

Finally, how the ABS (and other safety measures) interact with seemingly unrelated components of a trip or operation must be considered. Imagine the consequences of ABS balloons accidentally inflating during helicopter flight or in an accident such as a helicopter rollover.

Balancing the triangle of safety, service, and resources is a subject in itself; it is also the essence of viable commercial operations.

So, how do we find a balance? Where do we draw the line in terms of how many and what resources are employed, and by whom - guide, guest, operator, or pilot?

Every client, as a willing participant in a hazardous sport, must accept some degree of risk and acknowledge a shared responsibility. The levels of risk and responsibility will be **outlined** by the nature of the activity and the specifications of the enterprise. Waivers, extensive safety orientations, transceiver exercises, and the ski partner system are some examples in helicopter skiing. The actual levels of risk and responsibility will be **determined** by the guide (or guiding team, operator, and pilot in combination). The extent to which the client influences levels of risk is slight. In other words, the client's control over margins of security is minimal - it is entrusted to us.

Newspaper headlines read "This rescue balloon has saved my life!" Well, maybe.

Clients have much more control over margins of survival in terms of their actions and reactions in the event of a mishap. Margin of survival is also much closer to each individual's own interest. Different people accept different levels of risk and responsibility. That's why some clients bring their own radios, and why we might expect growing demand for the ABS from some of our clientele, while others do not want to carry a guest pack or choose to ski without their partner.

I doubt that there is a satisfactory analytical answer. It's tough to draw a line. If anything, the solution lies in a rational allocation of resources to the various sectors commensurate with the degree of influence each enjoys over the final outcome. Given the choice between investing a lot of money in radios and balloons, or applying those funds to snow research, guides' training, and industry information systems, what makes more sense? Efforts in terms of avoidance can maximize the margins for security and overshadow the need for additional margins of survival. Better that guides understand the multitude of variables than loading themselves and their people with more equipment.

To the question of whether the ABS will set a new standard, consider the following analogy. Seat belts have been statistically proven to improve survival chances for people in motor vehicle accidents. They are a standard generally enforced by law. Airbags represent a significant technological improvement over seat belts. They are now becoming the standard for passenger vehicles. Bus companies are in the business of moving people. Their operators are trained professionals that manage risk for their clients by how they drive the bus. There are no requirements (as yet) for passengers to wear seat belts, let alone provisions for airbags in front of every seat.

Security margins are the responsibility of the guide/operator. Where a guide evaluates the stability of the snow, a bus operator evaluates the road conditions. Hazard assessment is terrain analysis under the given conditions, be it for loaded snow slopes or a winding road. Risk management is the decision-making process by which guides/operators act, subject to their evaluations and assessments.

Friends that are ski mountaineering, ski patrollers that are on a control route, or guides doing investigative work are like people driving fast cars. The levels of risk they accept often far exceed norms. They should certainly wear transceivers (seat belts), and it may be a good idea to have the ABS (airbags in the vehicle) if they push the envelope.

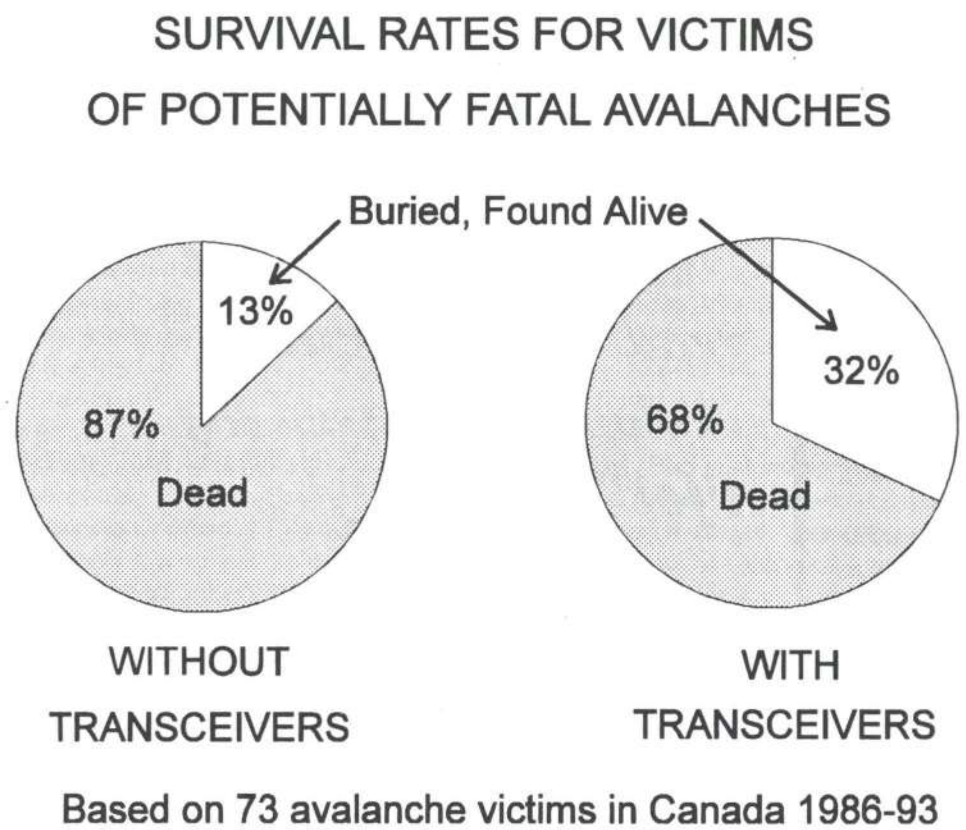
Bus drivers should not be pushing the envelope. Nor should guides with their clients. You can have some fun with the analogy: is a former race car driver a better bus driver?! Does a superb technical alpinist make a better guide?! Try guiding your group through hazardous terrain pretending that no-one is wearing a transceiver! But then, some bus companies already have seat belts...

Will the ABS become a standard? Not right away. Not even if one operator begins to employ them as a matter of practice when others do not. The ABS may evolve into an industry standard if it is refined and improved and by way of market forces, e.g. if clients vote with their feet and point their skis towards the operator that uses them.

Walter Bruns is an ACMG Mountain Guide, former manager of Bugaboo Lodge, and presently responsible for all field operations at Canadian Mountain Holidays. Opinions expressed are those of the author.

Transceivers and Avalanche Survival

Bruce Jamieson



Between 1986 and 1993, 73 people were either killed or completely buried by avalanches in Canada. 13% of the 32 victims without transceivers survived, and 32% of the 41 victims with transceivers survived. (Avalanche News 21, 24, 25, 27, 30, 33, 35, 38, 40).

The reason why only 32% of those with transceivers survived probably involves avalanche size. Since the pie charts only show survival rates for class 2 *and larger* avalanches, many victims were probably fatally injured by avalanche motion.

Clearly, we should minimize our exposure to avalanches--especially large avalanches--by careful evaluation of terrain and snow stability. Although transceivers do improve survival rates, they are only a last resort.

Publications

VIDEO PRODUCTIONS

A VHS video *Winning the Avalanche Game* is distributed by the Wasatch Interpretive Association in Salt Lake City, Utah. The cost is US $19.95 plus $10.00 shipping to Canada. To order, send Cheque or Money Order to the Wasatch Interpretive Association, P.O. Box 526246, Salt Lake, Utah, 84152-6246.

Snow and Weather Record Keeping for Independent Guides

Jim Bay

When I was first asked to present this topic I was not at all sure how to approach it. The A.C.M.G. membership has a vast amount of experience in guiding and making observations of the mountain environment. Both the A.C.M.G. and the Canadian Avalanche Association Level 1 or 2 (or equivalent) avalanche courses stress the value of good observations and record keeping.

Because there are some distinctly different segments of winter guiding activities, it might be useful to compare and discuss the different approaches used in gathering and recording weather and snow stability information.

Over the past few years there has been a significant increase in the level of avalanche safety work done by various government and private agencies. There has also been a large increase in the general avalanche knowledge of the backcountry skier population.

What this means to us as guides is that there is more quality snow and weather information available, and it is for the most part, easy to access.

But we still have to take the time to get it!

A large percentage of the A.C.M.G. membership has at some time worked in the heliski industry. While working as part of a heliski operation the guide becomes involved in an organization with a very formal system of information gathering which usually includes:

•detailed weather forecast information

•operator Information Exchange

•field observations (avalanches, snow profiles, stability tests, mountain weather)

All of this information is recorded and kept on file for future use. The field observations are generally recorded, if not in the field book, on the end of day summary, which includes a consensus opinion on local snow stability.

This quest for information and the need to record it is part of an industry (heliski) wide desire to make the skiing experience as safe as possible and to reduce the level of liability in the event of legal actions.

I think that most guides working in this industry feel the amount of information gathering is reasonable, considering the scope of operations and the present legal climate surrounding accidents.

The aim of this presentation is to generate some discussion from the membership and to come up with an opinion on how to best approach the issue of information gathering and record keeping.

When we work as modern independent guides we still must consider seriously the issues of risk management, liability, and negligence.

Some questions we should now ask ourselves:

• What are we presently doing?

• How much information is enough?

• How much should we write down?

Some points to consider:

• "If it hasn't been recorded: it hasn't been done"

• If we do not take advantage of reasonably accessible resources, can we be considered negligent?

• Can professional organizations like the ACMG and CAA back us up if we have an accident and have not used these resources.

• When we are near a telephone we can access nearly all available resources.

• Are radios becoming more of a standard part of a guides equipment? Is telephone communication in the backcountry a reasonable expectation?

Examples of currently available sources of weather and snow stability information.

• Canadian Avalanche Centre - Public Avalanche Bulletin & Industry Information Exchange

• Parks Canada - backcountry forecasts

• Commercial backcountry operators - heliski, lodges,etc.

• Ski Area operators

• Individuals - guides, avalanche professionals, Park Wardens/Rangers, experienced amateurs

• A.E.S. offices

It is important that professional guides take advantage of these resources and consistently make reasonable efforts to gather and record information pertaining to the safety of our activities.

New Public Information Numbers in Calgary and Vancouver

Local numbers for public avalanche information bulletins are now available in Calgary and Vancouver. The Calgary number is courtesy of the Calgary Herald Talkies.

For avalanche information in Calgary, please call 243-7253. When prompted, dial SNOW (7669). Once in the avalanche information section of the Talkies, it is possible to obtain specific summaries for Banff, Kananaskis, Yoho, the Rockies, and the North Columbia Mountains.

For avalanche information in Vancouver, please call 290-9333. Summaries for the South Coast and Vancouver Island, North Columbia Mountains, South Columbia Mountains, and the Rockies are available on this number.

All users are encouraged to use these local numbers. By doing so, reductions in 1-800 use will save the CAA substantial amounts of money. As a money saving measure, it is expected that the 1-800 number will not be available in Calgary or Vancouver next year and the local numbers alone will be available.

CAA members are asked to pass this information on to any users they are aware of. The 1-800 service will continue for areas outside the major centres.

Measurements During Rain-on-Snow

Dr. Howard Conway, Dept. of Geophysics, University of Washington, Seattle

During the past several years we have made measurements of avalanche activity, snow properties, and weather in the Cascade mountains near Snoqualmie Pass, Washington. The terrain lies between 900 metres and 1700 metres above sea level. It is common for mid-winter rain-on-snow events to occur at these elevations. A typical snowpack contains a relatively homogeneous base of 2 to 3 metres which has settled and grain-coarsened during one or more episodes of rain. Storms deposit up to one metre of new snow and subsequent rain often caused some or all of the storm snow to avalanche. Measurements have been made with the help of the local highway avalanche crew (Craig Wilbour, Steve Breyfogle, Lee Reddon, and Joe Wilson) and the NW Avalanche Center. Support for the research has been provided by Washington State Department of Transportation and the U.S. Army Research Office. Here we report and discuss some results from the research.

I. Timing of avalanche release during rain

The potential for avalanche release increases significantly immediately following the onset of rain. This is an important realization that has consequences for planning avalanche control. The timing is surprising because it had previously been thought that the avalanches release only after liquid water penetrates and weakens a sub-surface layer which implies a delay between the onset of rain and the time of avalanching. Our observations and measurements indicate that the avalanches often released several hours before water had penetrated to the sliding layer.

Immediate avalanche activity is particularly high when the snow stability prior to rain is already close to critical. The climate of the Western States is favourable for producing this condition. The east side of the mountains is influenced mainly by cool Arctic air, while the west side is dominated by relatively wet, warm marine air from the Pacific Ocean. Snow that has accumulated under Arctic type conditions is relatively unstable and therefore particularly prone to avalanching when a strong westerly system moves into the region and causes rapid warming and rain. This means that it is possible to predict the timing of immediate avalanche activity with reasonable accuracy (within an hour) by forecasting the meteorological conditions in the avalanche starting zones. This can be done by continually monitoring weather from a network of stations surrounding the starting zones and located in the tracks of approaching storms.

Avalanches do not always release immediately after the rain starts but they can be delayed several hours. It is thought that the release of these avalanches is related to liquid water penetrating and weakening the snow and also to the increased stress from the weight of the rain. Accurate prediction of the timing is more problematical because it is difficult to define precisely the penetration of water into layered snowpacks. In our experience the delay varied up to thirteen hours, but longer delays have been observed in situations when the snowpack was deep and had not been previously wetted.

II. A return to stability

Even if rain continues, avalanche activity is usually rare after a drainage system has developed. Once drainage is established, water is less likely to weaken the snowpack or cause the stress to increase. In fact, the stress may decrease as water drains from the snowpack. In some cases it is possible that water at the ground/snow interface could cause large, full-depth avalanches but we did not observe this phenomenon during the study. At Snoqualmie Pass, it usually took 15 to 20 hours of rain to establish a drainage system but we expect this time would vary depending on snow depth and stratigraphy as well as the rate of rainfall. This is discussed in the next section. The surface becomes dimpled during water infiltration. This occurs because moisture increases the rate of densification and so snow within a channel settles faster than the dry snow outside a channel. The wavelength of the dimples corresponds to the spacing between the sub-surface drainage channels.

III. Infiltration of water and the timing of the return to stability

A 2-dimensional array of thermistors buried in the snow was used to monitor changes of temperature (figure 1). We assume that zones

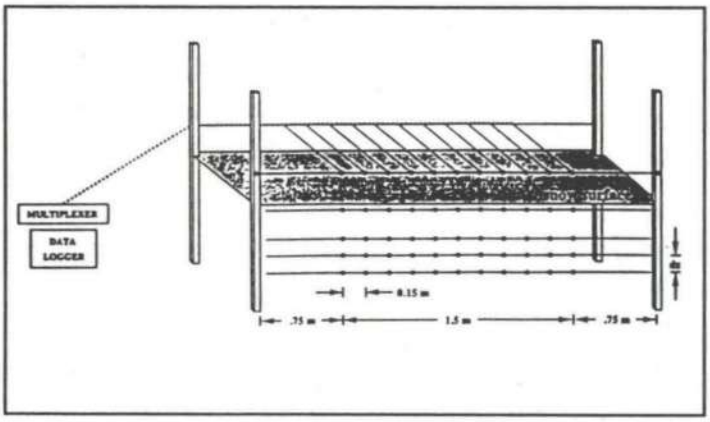


Figure 1: Experimental setup for measuring temperature. Each point marks the position of a thermistor.

at 0°C contain liquid water and in this way we track the progress of liquid water into the snow. Snow stratigraphy has a strong effect on the pattern of wetting. Vertical flow tends to be diverted laterally above ice layers and also within layers of low density snow which have a low permeability. Characterizing infiltration is difficult because the hydraulic properties often change significantly as a result of grain-coarsening that occurs when snow is wetted. Other things being equal, water penetrates homogeneous, coarse-grained snowpacks faster than those that contain multiple stratigraphic horizons.

The timing of outflow is determined by the rate of precipitation as well as the hydrological properties of the snowpack. The time of runoff (t, the time in hours since the onset of rain) can be written:

$$t = V_w * \grave{E}_w * h_s / PI$$

where V_w is the fractional volume of wetted snow at the time of runoff, $\dot{E}_w$ is the average moisture content of the wetted snow, h_s is the snow depth (m), and PI is the average rate of rainfall usually ranges from 2 to 5 x 10^{-3} m/hr. Measurements indicate that water usually penetrates the snow through channels that occupy less than 50% of the total volume of the snowpack (ie. $V_w = 50\%$). Values for $\dot{E}_w$ range from 8 to 10%. Under these conditions we expect the return to stability could range from 12 to 72 hours after rain has started.

IV. Deformation and properties of snow

It is of interest to measure the rate of deformation in snow because laboratory tests by others have shown that shear failure occurs only if the strain rate exceeds 10^{-4} s^{-1}. The lab tests were made using samples that were 20 mm thick and may not be directly applicable to tests over thicker layers because it has been shown that strain is usually concentrated in a shear band that is just 1-2 mm thick. However, although the value for the critical strain rate may vary with sample thickness, we expect the same principles would apply and we wanted to investigate the feasibility of using measurements of strain rate to determine slope stability.

We measured the components of deformation separately. Vertical motion was measured by constraining a velocity shoe so that it could only slide vertically down a fixed pole. Its position was measured using a sliding contact on a resistance wire which created a voltage divider circuit which could be monitored with a data logger. Slope parallel motion was measured by attaching a rotary potentiometer to the vertical shoe and running a cord downslope to a second shoe (see figure 2). Pairs of shoes were set sequentially at the surface as snow accumulated.

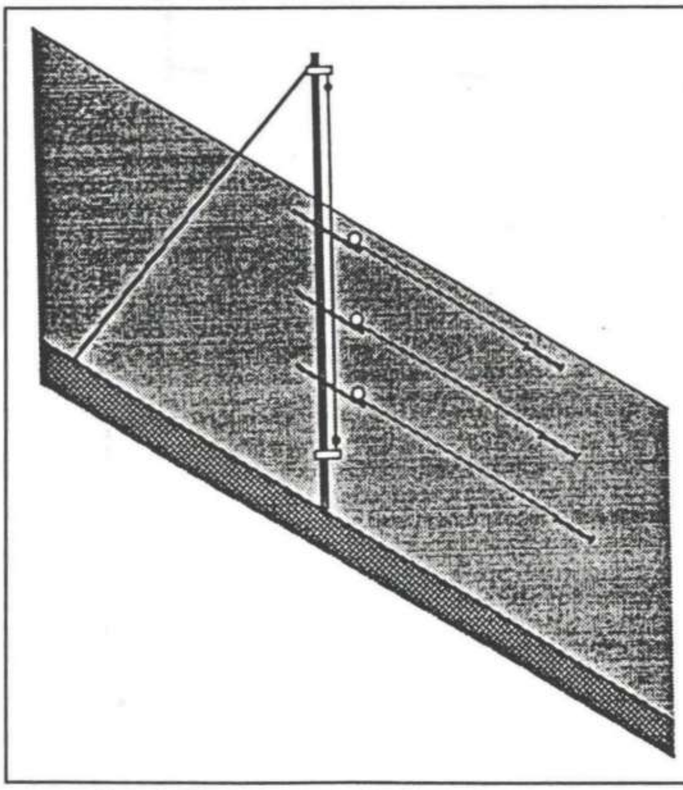


Figure 2: Experimental setup for deformation on slopes

Figure 3 shows two deformation profiles measured in the middle of a 36° slope. The material lines are spaced at hourly intervals. Measurements on the 20th shows the creep velocity at the surface (2 to 3 x 10^{-6} m/s) was more than 15 times faster than the older snow below. Calculations show the shear strain rate within the upper 400 mm of new snow was about 5 x 10^{-6} s^{-1} during the first hour and then it decreased. Although the slope that we monitored did not avalanche, nearby slopes did avalanche at times when the strain rate on the test slope approached 10^{-5} s^{-1} (measured over 200 - 400 mm). Following the discussion above, this could easily be equivalent to a strain rate of 10^{-4} s^{-1} measured over a 20 mm sample, or 10^{-3} s^{-1} measured over a 2 mm shear band. It would be useful to make more measurements with increased spatial resolution to determine whether this rate is critical.

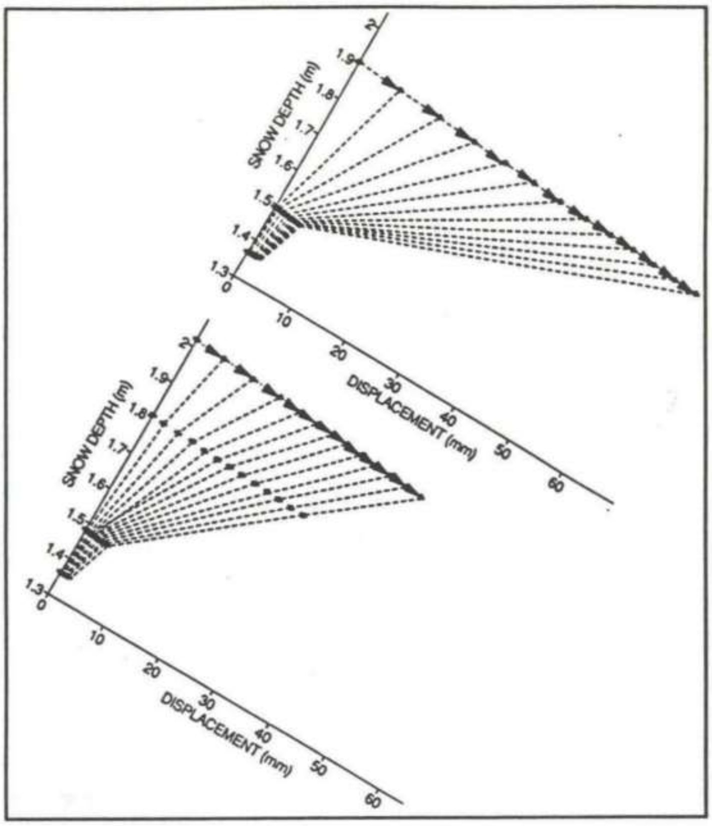


Figure 3: Deformation profiles on a 36° slope. The material lines are spaced at hourly intervals. The first profile starts at 1300 on January 20th and the second profile starts at midday on the 21st. About 40 cm of snow had accumulated between January 19th and 20th and an additional 21 cm fell between the 20th and the 21st.

Analysis of the measurements indicates that metamorphic processes can have a major influence on the rate and pattern of deformation within new snow. New snow often contains complex grain structures and thermodynamic processes act to cause grains to shrink and round and these changes cause the bulk volume of the snowpack to decrease independently of gravity. The process accelerates with increasing temperature and in the presence of small amounts of liquid water which not only increase the rate of metamorphism but also form liquid bridges resulting in *capillary strain*.

We think that a better understanding of the deformation of snow is crucial for understanding snow slope stability. We would like to determine the benefits and feasibility of using measurements of deformation as an operational tool for avalanche forecasting. More experiments are planned for the future.

EDITORIAL NOTE

The intention of *AVALANCHE NEWS* is to assist communication among persons and organizations engaged in snow avalanche work in Canada. Short articles cover accidents, upcoming and past events, new techniques and equipment, publications, personal news, activities of organizations concerned with avalanche safety, education and research.

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