COMPUTER APPLICATIONS FOR AVALANCHE FORECASTING

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ABSTRACT

Avalanche hazard forecasters must evaluate a number of different important parameters which often vary markedly over time and distance. A number of computer applications have been developed to help the avalanche forecaster manage the complex data. These include programs which simply graph and tabulate data into easily-ingested displays, database and statistical software, deterministic models of the snowpack evolution and stability, and finally, networks of avalanche information. This paper is an overview of computer software currently available in English and currently being used in the United States.

INTRODUCTION

Avalanche forecasters face a particularly difficult problem. First, a number of different parameters contribute towards snowpack instability; second, the effects of many of the parameters counteract each other; and third, most of the parameters vary markedly over both time and distance. With the advent of powerful, portable, personal computers many programs have been written to help take the guesswork out of avalanche forecasting.

The software ranges from relatively simple graphical displays of the important variables, to more complex database programs, to very sophisticated deterministic models which simulate snowpack structure as well as snow stability itself. This paper is a brief, non-exhaustive overview of available and commonly used computer software written for an English speaking user in the United States. It also discusses the advantages and disadvantages of each program, the sources, prices and discusses future directions of computer software for avalanche forecasting. Unless otherwise noted, all the software discussed in this paper was written in English for a DOS operating system, to run on an IBM compatible computer.

SNOWPIT PROGRAMS

The time-honored method of determining the structure of the snowpack is to dig a snowpit and examine the various layers. Because the human brain has a limited capacity to understand raw numbers, most workers like to graph the data to yield an easily-ingested visual display. For instance snow hardness, density, crystal type and temperature especially lend themselves to graphical displays. An effective graph can, at a glance, reveal the structure and composition of the snowpack, the snowpack history, and often, the present and future stability of the snowpack. Several good snowpit graphing programs are available:

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Peter Weir Snowpit Program

Perhaps the most sophisticated and powerful snowpit program was written by Peter Weir with the Ministry of Highways in Canada. It runs under the operating system Windows 3.1. The conforms completely to the standards set in the International Classification of Snow on the Ground. The program offers drop-down menus on nearly every parameter allowing the user to easily choose the appropriate value. The handles the parameters of snow type (and sub class), snow hardness, moisture, temperature, density, and crystal size, and it plots the standard international symbol for each (see figure 1).

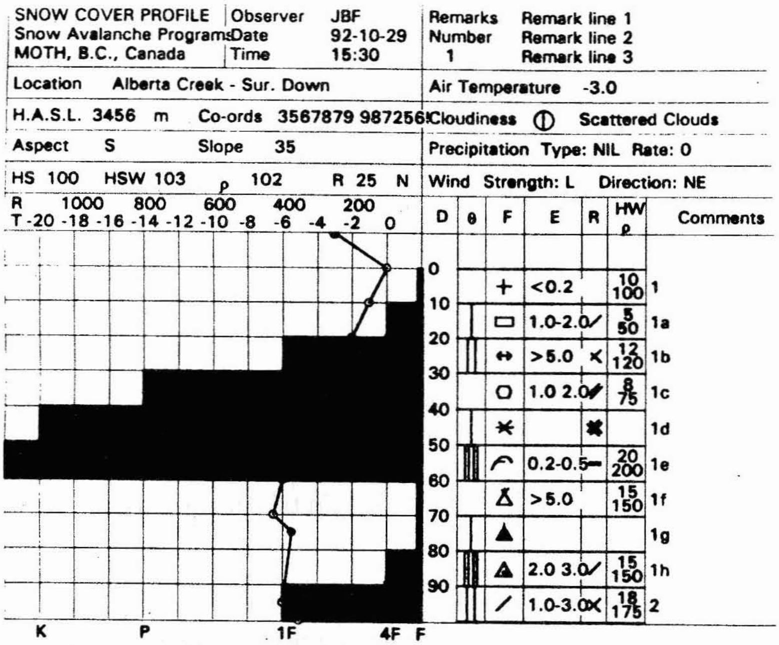


Figure 1. The plot of snowpack data from the Peter Weir program. The program runs on the operating system Windows 3.1 and conforms to the International Standard.

At the time of this writing, the program is in the final testing phase and is not ready for distribution. Upon release, however, it will likely become the standard snowpit program used by most workers because of its ease of use and its conformity to the international standard. It will be free upon request by contacting Peter Weir (see below for addresses).

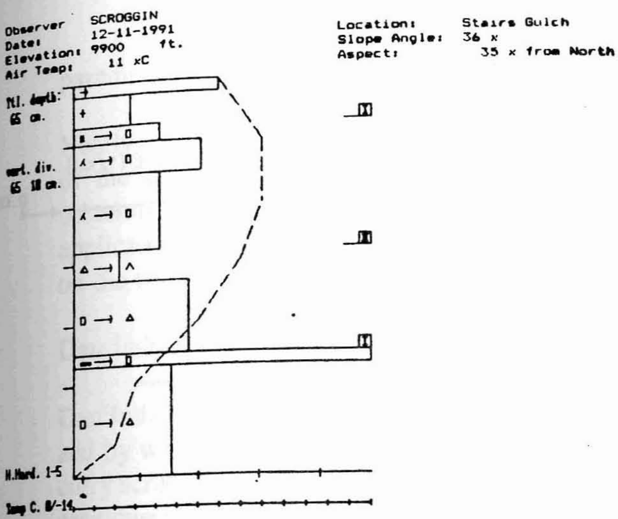
Dan Judd Snowpit Program

Other snowpit programs are older and do not conform to the International Standard. One such program was written by Dan Judd, a Utah Department of Transportation avalanche forecaster. He wrote the program in Pascal and has a menu driven user interface. Like Peter Weir's program, Judd's program stores the data for each snowpit in a separate file so it can easily be transferred over a phone modem to other avalanche workers. The program handles parameters of snow hardness or density, temperature, location of shears, and crystal type and the direction of metamorphism (for example small faceted grains turning into small rounded grains). As a unique feature, the program also calculates the cumulative shear stress on each layer based on the density of the overlying snow and the slope angle. It also gives a numerical calculation of temperature gradient between each layer (see figure 2).

Those working in maritime climates may find it lacking because it does not accept snow moisture, however it may be included under comments. It is available free of charge by writing to Dan Judd. (See below for addresses.)

Randy Trover Snowpit Program

The snowpit program written in Pascal by Randy Trover of the Snowbird Ski Patrol differs from all the above in that it is a database of snowpit information. In other words, it does not store each snowpit in a separate file, instead, it stores each pit as a record in a larger database. Consequently, it allows the user



LAYER THICK	LAYER DENSITY /H HARD	SNOW TYPE1	CHANGE DIRECT	SNOW TYPE2	CUMMUL. SHEAR STRESS	:TEMP :DEPTH	SNOW TEMP	TEMP GRAD
2	2.5	Wind blown			28	: 0	-7	-0.20
5	1	New snow			57	: 10	-9	+0.00
3	1.5	Graupel	------>	TG beginning	83	: 20	-9	+0.10
5	2.2	ET decr begn	------>	TG beginning	146	: 30	-8	+0.20
13	1.5	ET decr begn	------>	TG beginning	259	: 40	-6	+0.30
5	.8	TG partial	------>	TG advanced	282	: 50	-3	+0.10
12	2	TG beginning	------>	TG partial	420	: 60	-2	+0.40
2	5	Ice	------>	TG beginning	478	: 65	0	+0.00
18	1.7	TG beginning	------>	TG partial	654	:		

Figure 2. Graphical output from the Dan Judd snowpit program.

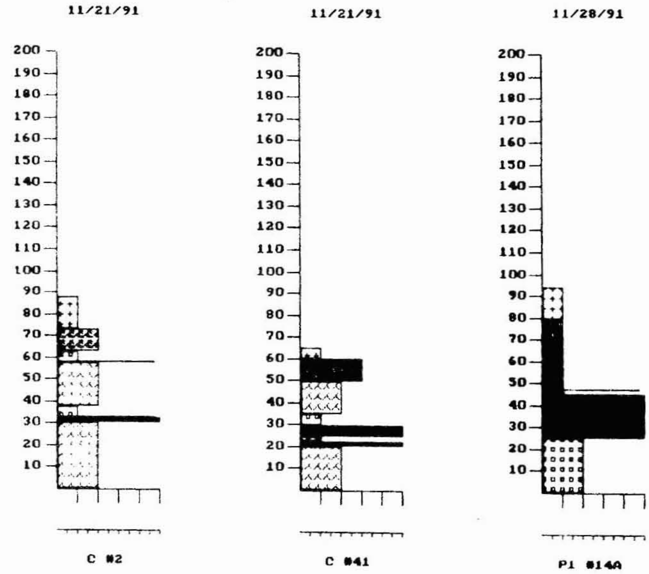


Figure 3. The Randy Trover snowpit program. It is a database of snowpit information. It allows the user to plot three different profiles on the screen at any one time.

to not only query snowpit data (for example search by date, location, depth, etc.) but it will also graph three profiles on the same page in order to compare them (see figure 3). This has obvious advantages for operational use but it's not presently possible to transmit a single profile through a modem to another computer without transferring the entire database.

The program handles the parameters of snow hardness, crystal type and temperature. At present, it does not graph snow moisture but it will be added to future versions. It is free of charge by contacting Randy Trover (see below for addresses)

Roger Atkins Snowpit Program

Roger Atkins, also a Utah computer programmer, has written a very sophisticated snowpit program which is normally linked to a larger comprehensive database (described below), however, he will sell it separately for around $150.00. Like Trover's program, it is a database of snowpit profiles, however, it can export a specific profile to a file which can be sent over a modem to another worker. It has the same query abilities as Trover's program (search by date, location, etc.) but the user can customize the program to an unlimited number of parameters that can be added or subtracted without destroying all previous data. As a unique feature it plots vapor pressure gradient as well as plotting temperature. (Figure 4, see below for list of addresses.)

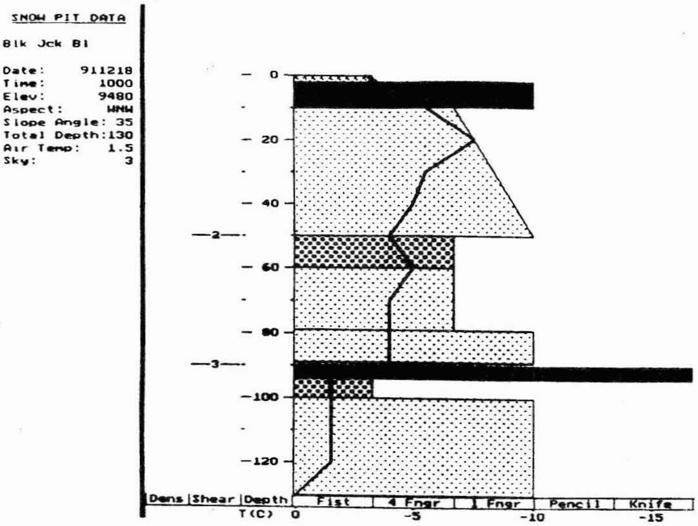


Figure 4. Graphical output from Roger Atkin's snowpit program.

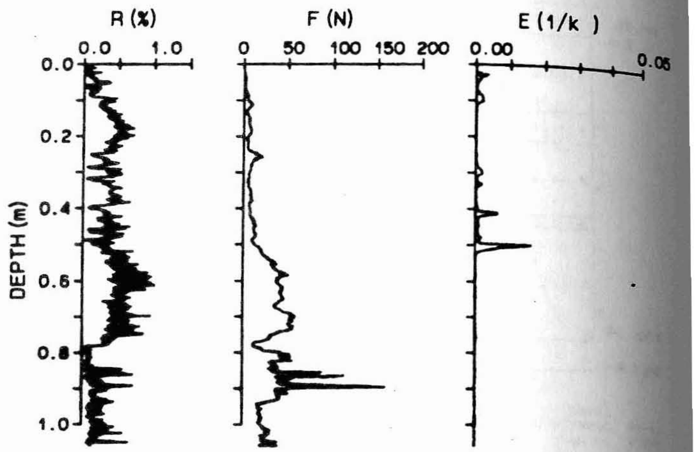


Figure 5. Graphic output from the automated snowpack probe by Abe et. al. R= reflectivity of laser light. F=resistance to penetration. E=electrical resistance.

AUTOMATED SNOWPACK PROBES

Avalanche workers have always wished for a probe which they could simply insert into the snowpack, thereby bypassing the more time-consuming conventional snowpit. Japanese researchers (Abe, et. al., 1992) have come one step closer. They have designed a probe which simultaneously measures snow hardness (using a load cell), temperature, snow moisture (using a dielectric measurement) and reflectivity of laser light (see figure 5). A number of different profiles are stored on a portable micrologger and then uploaded onto a conventional computer back in the office.

Because snowpack properties vary, sometimes drastically, across an avalanche starting zone, a probe such as this would allow avalanche workers to map an avalanche starting zone to determine the aerial pattern of buried weak-layers. This could not only help determine if a slope is unstable, but determine the optimum explosive placement for avalanche control.

I hope that this type of research continues and that one day automated snowpack probes will be lightweight, portable and inexpensive. Ideally, they would accurately measure snow strength in various layers with a high resolution, snow temperature, crystal type and water content. An instrument like this would be a revolutionary innovation for avalanche forecasters.

DATABASE PROGRAMS

One of the earliest computer applications for avalanche forecasting was to utilize standard database programs for avalanche and weather information. For instance, database programs have been used in Europe for some time (Buser, 1983) and especially in France, for instance, Model La Plagne (1986), AIPRA (1984), and ADIPRA (1991). These programs store data on weather, avalanches, snowpack or any other pertinent information. They have two uses, first to graph the data for easier visualization of the critical parameters, and second, to search previous data for critical precursor patters to avalanche activity.

Nearly any modern database or spreadsheet software can handle this type of problem. However, because of the complex inter-relationships between the parameters, and the large numbers of parameters, customization of the database using its programming language is often required to create a useful application. This task is quite daunting for a casual user, but several American programmers have taken on the task.

Dan Judd Program

Dan Judd of Utah has adapted the Paradox database program both by customizing the standard application and by writing specific code in the Paradox programming language. The program uses customized user entry screens specifically adapted to data most often used by American avalanche workers. It is set up for easy queries of past data and is pre-configured for graphical display of both weather and avalanche data. One can display weather and avalanche data on any time scale from a seasonal history chart to graphing weather parameters within a specific storm (see figure 6). The storm report ingeniously calculates and graphs a number of useful parameters including settlement rates within both the new and old snow, and the cumulative snow and precipitation amounts.

Since this program runs within a standard database program (Paradox) the user can modify and customize much of the program to serve their individual needs. If the user wants to make changes in the layout, the menu structure or the analysis of the data he must modify the source code of the Paradox programming language which Judd will perform upon request.

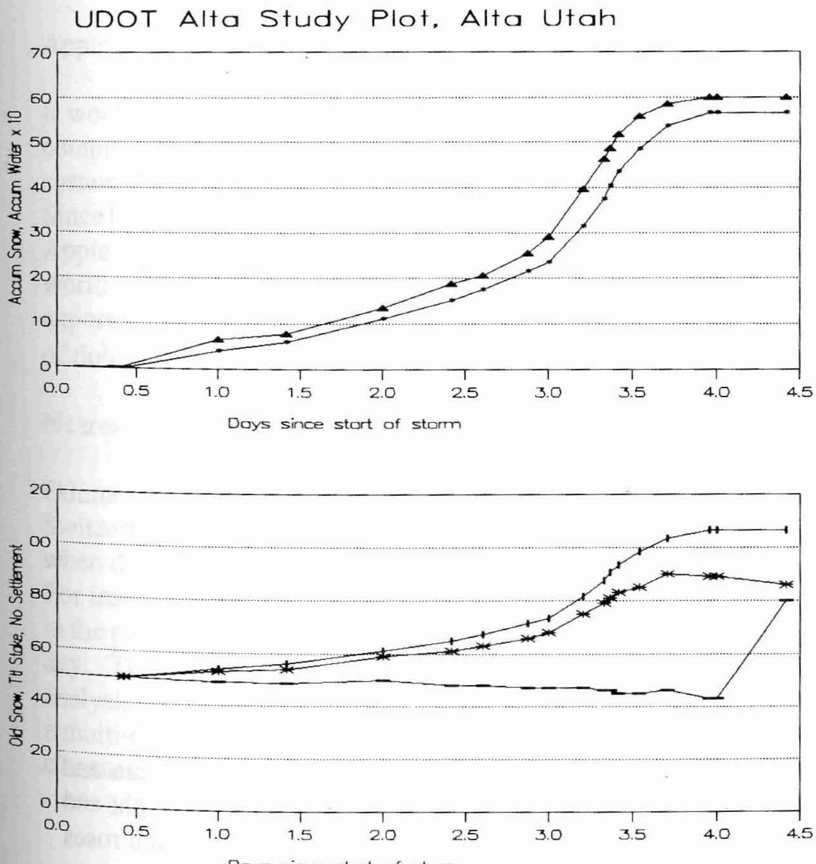


Figure 6.
Graphical output from the Dan Judd program. The upper graph is accumulated snow and accumulated water X 10. On the lower graph, the upper line is a no-settlement line (total stake at storm start plus new snow). The middle line is the total stake. The lower line is the Old snow surface which is calculated by subtracting the storm stake from the total stake. In this way one can see settlement within the old snow without measuring the old snow surface dirctly.

Perhaps most useful, the program directly accepts data from automated weather stations. This, for instance, allows users to store, query, or graph hourly data from any micrologger output. One of the disadvantages of the program is that it is not presently set up to graph wind data, however Judd plans on remedying this in future revisions. The program (with a run-time version of Paradox) sells for $150.00. See below for the address of Dan Judd.

Roger Atkins Program

The disadvantage of using standardized database programs is that they must operate within the limitations of the software. For this reason, many programmers have chosen to write their own software. One of the most sophisticated of these customized database programs was written and tested over the past several years by Roger Atkins, a computer programmer and helicopter ski guide in Utah. The program, written in Pascal, is a complete database of weather, avalanche, snowpack and even operational data. It is a very powerful and flexible program offering a well-thought-out design. It was originally created for a large Canadian helicopter skiing concession to keep track of several different mountain ranges and several sub-areas within each range. Therefore the program will handle several different geographical areas at once, each with several different study plots, automated weather stations, hasty snowpit profiles, and operational data such as closures or avalanche control measures. It also directly accepts hourly data from automated weather stations, but only through a standardized input format; the user must reconfigure their data into the standardized format (see figure 7).

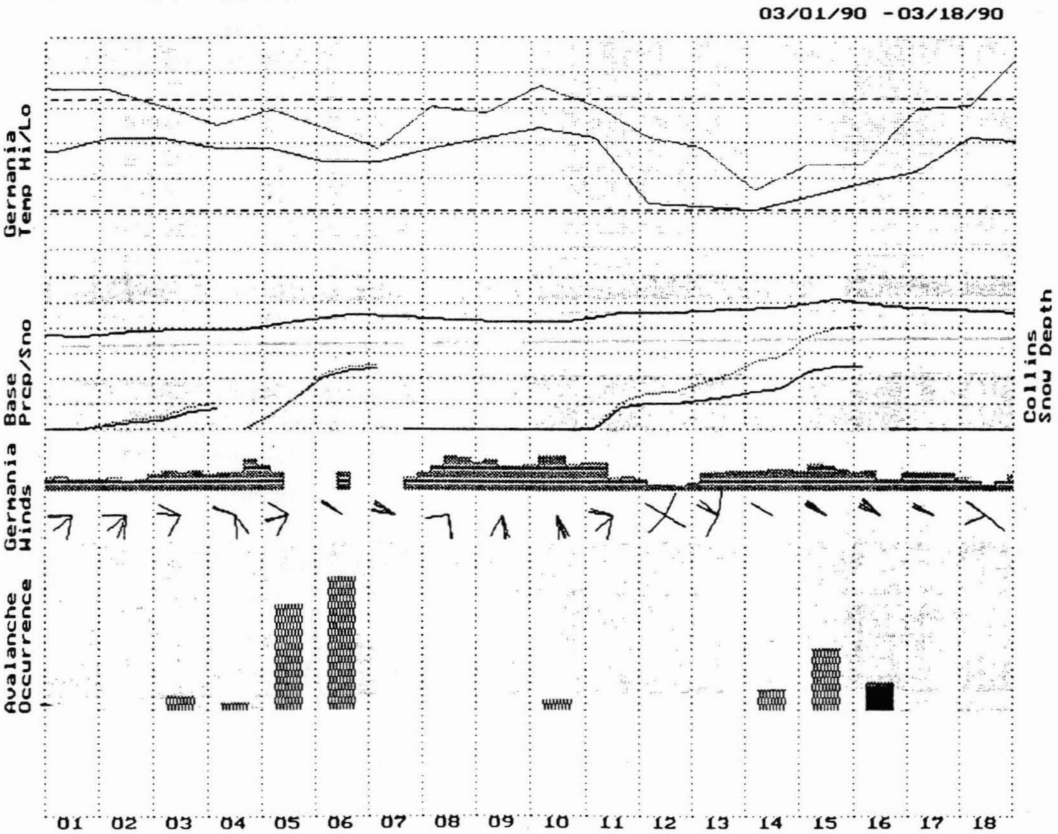


Figure 7.
A seasonal history chart from the Roger Atkins program. The top pair of lines are the minimun and maximum temperature. The next lower set of lines marked Base Prcp/Sno are the total snow height and the cumulative storm interval snow and water X 10. The blocked graph is the wind speed with wind roses of wind direction plotted below it. Finally on the bottom is the number of avalanche occurrences.

As a unique feature, it plots snow surface data or snowpack data on a two-dimensional ''cone'', similar to looking at a map view of a single mountain where the center of the cone is the highest elevation. Atkin's program also plots wind data as wind roses where the user can graphically see from which wind direction the strongest or most persistent winds have been blowing. The program sells, complete with the snowpit section, for around $500.00.

Randy Trover Program

Randy Trover, the assistant snow safety director at Snowbird in Utah, has developed yet another powerful program which combines a database program (dBase) with powerful graphical routines written in Pascal. The program is a complete database of both weather and snowpack information. It is one of the few programs which uses the standard Forest Service green and blue sheets as a basic template. Yet there are a number of additional features, for instance, the user can number each storm in the entire history of record-keeping and thereby search all past data storm-by-storm instead of day-by-day as many of the other database programs do. The disadvantage of day-by-day queries is that critical patterns of weather, snowpack and avalanche activity seldom confines itself to discrete 24-hour periods. Consequently, finding these patterns within individual storms instead of 24-hour periods is bound to be more successful.

The graphical section of Trover's program uses a windows-like interface and allows the user to open up several windows of storm plots at the same time. In this way the user can not only visually compare the patterns of several past storms on the screen, but they can zoom in on any section of the plot simply by outlining the area of interest by pointing and clicking with a mouse.

Unfortunately, Trover's program is still in the development stage and is not yet for sale.

Apple MacIntosh Systems

It would seem that computer applications for avalanche forecasting is limited strictly to IBM compatible computers but this isn't so. Jackson Hole ski area is unique in that they use an Apple MacIntosh computer system, and use standardized database programs written for MacIntosh. They find the program quite useful. Since both the present and future generations of Apple hardware are capable of running any DOS programs, Apple computer users are no longer locked out of the numerous software choices for the IBM compatible world. In the final analysis it doesn't matter which system or software is used as long as the data can be exported in a standardized form to be shared with other users, which nearly any database program is capable of doing.

Nearest Neighbors Program

Othmar Buser et. al. (1986), from the Swiss Institute of Snow and Avalanche Research in Davos Switzerland, wrote a program in the mid 80's which is similar to the other database programs except that when doing a query, it calculates the closeness of fit between the present day and any past similar days. For instance, after entering the weather and snowpack data for the present day, it will not only find all days in the past with similar conditions, but it will rank them on how closely the conditions resemble the present day. The initial important variables were chosen statistically by doing a stepwise linear discrimination analysis on all the available parameters. Using this subset of parameters, each past day can be plotted on a multi-dimensional vectorspace. Then the Euclidian distance to each of the various points represents the closeness of fit.

Although the original program was written in German, it has been recently translated into English, and avalanche forecasters from Scotland have been using the program successfully. Contact Othmar Buser for more information or for a copy of the program (see addresses below).

DETERMINISTIC MODELING OF THE SNOWPACK

Crocus

Perhaps the most powerful computer tool in forecasting avalanches is also one of the most difficult to create: modeling of the snowpack as a function of weather conditions. A team of French researchers at the Centre d'Etudes de la Neige has created a very powerful computer program, called Crocus, which simulates the evolution of temperature, density and liquid water profiles of a snowpack as a function of weather conditions (Brun, et.al., 1992). Using previous studies on metamorphism and heat flow through a snowpack as well as their own research, they have created a computer model which simulates various aspects of snow evolution throughout the season, including settlement, crystal types, temperature profile and liquid water content. In tests of the model, even without recalibration during the season, it very accurately simulated the evolution of the snowpack throughout the season.

The input parameters are measured each hour and include air temperature, humidity, wind velocity, incoming short wave and long wave radiation, liquid and solid precipitation. Output parameters include total snow depth, snowpack temperature profile, crystal types and sizes, and free water content. The French would like to eventually use this model to simulate snowpack evolution on a regional scale--to simulate all aspects and locations in the French Alps. To do so, they must monitor a number of automated weather stations and add some meteorological variables.

Sue Ferguson and Mark Moore from the Northwest Avalanche Center in Seattle are working with an English language version of the model and attempting to add meteorological parameters to it. This type of modeling has obvious advantages in not only forecasting avalanche hazards for large areas, but for simulating the melting of the snowpack each spring. Contact Eric Brun for conditions of availability (see addresses below).

The Swiss Model

Gubler and Bader (1989) developed a computer model using air temperature and precipitation to simulate the snowpack settling strain rate, density, temperature profile, snow surface temperature and finally stability. It was designed to model initial failure of slab avalanches within new snow. It does not take into account metamorphism of the snow. This model, although a preliminary one, is an important step in developing an accurate, regional-scale model of snow stability based on weather conditions. We hope that in the future, the best aspects of both the French and Swiss computer models can be combined into a useful computer tool for the practicing avalanche hazard forecaster.

COMPUTER BULLETIN BOARDS OF AVALANCHE INFORMATION

Despite our best efforts at avalanche hazard forecasting, the best indicator of avalanche activity is other avalanche activity. Therefore, sharing of avalanche occurrence information with other avalanche workers can often keep surprises to a minimum. Computer bulletin boards of current avalanche and weather information exist in three locations in North America, in the Washington-Oregon area, in the Utah-Wyoming-Montana area, and finally in western Canada.

In the Utah system, for instance, users can call into a central Novell network, log on, exchange electronic mail, exchange snowpit profiles, receive a detailed mountain weather forecast and download weather maps and satellite images to be displayed on the users' remote computers. The Utah Avalanche Forecast Center keeps track of avalanche activity and will attach a special avalanche occurrence section to the weather forecast whenever unusual avalanche activity is occurring. Avalanche forecasts, warnings and any unusual avalanche activity is also broadcast over the Forest Service Data General computer network.

One of the largest problems in the United States is the standardization of data--what data to collect, how to collect it and in what computer format to exchange with other computers. Formally, the Forest Service had standardized data format, but since the Forest Service has given up much its leadership position in avalanche forecasting and control, each ski area and each highway control team has slowly evolved their own unique systems. The Canadian Avalanche Association plans on meeting to resolve this problem with standardized data formats. We hope that the U.S. will adopt their lead and thereby open the door for a real-time national or international computer network of avalanche and mountain weather data.

LIMITATIONS OF COMPUTERS

Perhaps the most interesting aspect of computer application for avalanche forecasting is what computers can <u>not</u> do. Despite years of research and development, computers still have a difficult time with two important parts of avalanche hazard forecasting: pattern recognition, and knowing which information is pertinent to a particular problem.

On the other hand, computers are very good at data collection, archival and presentation in graphical forms. Computers have taken much of the tedium out of avalanche work. Now with automated stations, computers can automatically call the microloggers at various stations, archive the hourly data, calculate a number of different parameters based from the data, and plot the data in a number of useful ways. Then this data is available at the touch of a button when the forecaster needs it.

But the analysis of the data is a different matter. Even with the inevitable arrival of sophisticated modeling programs and expert systems, the avalanche phenomenon is so complex that I believe the only computer capable of consistently solving the puzzle will be the most powerful computer of all--the human brain. Despite years of intense research, scientists have not been able to teach computers how to do many of the simple things humans take for granted, such as seeing, walking, and picking out which information is pertinent to a particular problem.

Unless major advances are made (and this is unlikely with the present lack of funding for avalanche-related research) computers should be used as <u>tools</u> for the decision maker--the human being--and not as a decision making machine. I do not believe that a computer will ever out-perform an experienced, hard working, mountain-wise forecaster. There is absolutely no substitute for time spent in the mountains, digging snowpits, examining the layers, looking, feeling, asking questions, and seeking answers to those questions. In this way a forecaster discovers the pattern of instability, both spatially and temporally, and no computer can duplicate this.

Because of this, I believe that it is a mistake to take an experienced, skilled avalanche forecaster and make a computer programmer out of them. It's a rare person indeed who can be good at both avalanche forecasting and computer programming. Because of the computer's well-known tendency to take a tremendous amount of time and their equally well-known tendency to be completely addictive, avalanche forecasting and computer programming tend to be mutually exclusive.

I believe that in an operational setting, it is best advised to give the job of managing the computer system to a lower ranking avalanche forecaster and keep the most experienced and skilled avalanche forecaster doing what is most important--looking at the snowpack and analyzing the data.

CONCLUSIONS

Computers can be an important tool for avalanche hazard forecasting. First, they can remove much of the tedium by automatically collecting, tabulating, calculating, and graphing the important data in a variety of easily-ingested ways. Second, database programs and nearest neighbor programs can search through past data to find similar snowpack and weather patterns to the present pattern and display the resulting avalanche activity which occurred on those past, similar days. Third, a new generation of computer models can automatically predict the effect of ongoing weather on the evolution of the snowpack. Finally, computer networks allow avalanche workers to share weather, avalanche and snowpack data, and also receive weather maps and satellite imagery.

Although computers can be a valuable tool for an avalanche forecaster, they can never replace a human avalanche forecaster. Computers have a very difficult time with both pattern recognition and knowing which information is critical to a particular problem. Computers should be used only as tools and should not be used as decision making machines which overrule the judgement of experienced human forecasters.

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