AVALANCHE WARNING SWITZERLAND 2000

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ABSTRACT: Avalanche Warning has been a key task of the Swiss Federal Institute for Snow and Avalanche Research in Davos (SLF) since it was established over half a century ago. In the past, the predominant methods used for avalanche forecasting at SLF have been conventional, i.e. snow stability and avalanche hazards were predicted without analytical techniques such as formal numerical and symbolic algorithms. A paradigm shift is currently taking place: Information systems and computer programs are becoming more and more important, assisting the forecaster in collecting and analysing large amounts of field data. Furthermore, computer models are available which simulate processes in the snow cover and calculate local and regional avalanche hazards, thereby supporting forecasters and decision makers. However, the forecaster with his intuition, experience and local knowledge still plays a decisive role in the forecasting process. While the computer helps to assimilate information, to assess the hazard risks, to support the forecaster in his decision and to distribute forecasts via modern communication channels, it is still the forecasters ultimate responsibility to check and modify the computer's prediction. This new way of avalanche forecasting, which we call „computer-aided avalanche forecasting", is currently being implemented in Switzerland.

KEYWORDS: Avalanche, avalanche forecasting, snow cover

1. INTRODUCTION

About 65% (or 26'975 km^2) of Switzerland's area is alpine country with about 580 km^2 of controlled ski area and over 1'800 transportation facilities such as cable cars or ski lifts with an estimated capacity of 450 million pvm/h (person vertical meter or capacity to transport a person one vertical meter per hour). Approximately 1.7 million people (or 25% of the Swiss population) live in alpine regions and a number of important highways and railways cross the Alps. For example over 19'000 vehicles daily cross the Gotthard Pass, a very important transit route between Italy and Germany (The figures mentioned above are from the Alpenreport 1998). It is therefore no surprise that avalanche mitigation has always played an important role in the life of the people living in the Alps. Over the past 50 years about 1.7 billion Swiss francs have been invested in engineering work for avalanche protection such as snow supporting structures, deflectors or snow sheds. Together with avalanche hazard zoning this has led to a high degree of safety (compared to other hazards) in densely populated areas and on roads with high traffic volumes. Such permanent measures are not cost effective to protect recreational activities such as off-piste skiing and ski-mountaineering or less frequented roads, sparsely populated regions or ski areas. Temporary measures such as evacuation of buildings during hazardous periods, temporary closure of road or ski runs, artificial release of avalanches and careful route planning are both low cost and more flexible. However, they require an effective avalanche warning service supported by an avalanche awareness programme.

2. THE SWISS APPROACH

Since 1945 the Swiss Federal Institute for Snow and Avalanche Research in Davos (SLF) has been in charge of the national avalanche forecast which covers an area of about 27'000 km^2. Analysing daily snowpack observations and avalanche occurrences from a) a network of about 40-75 manned stations, b) information about the current weather c) the weather

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forecast and d) about 100 snow profiles recorded twice a month an avalanche bulletin was compiled two to three times a week or whenever the situation changed dramatically. Until 1997, the bulletin was issued at around 10 am. The structure as well as the information content of the bulletin has improved considerably over the years. Furthermore, with the introduction of the European Avalanche Hazard Scale in 1993 a common language to describe the snow cover stability and the probability of an avalanche release has been found which is now being used in all European countries (Meister, 1995).

Until the early 1990s avalanche forecasting at SLF was mainly based on intuition, experience and local knowledge of the forecaster. While these factors still play an important role today, progress in snow and avalanche research, especially in the development of computer models as well as rapid developments in sensor, communication and information technology during the last 5 to 10 years have opened up new ways in avalanche forecasting[*]. Mathematical analysis of measurements, numerical simulations of weather and snowpack and symbolic and statistical computations of the avalanche hazard are the key elements of modern avalanche forecasting, which can be described as „computer-aided avalanche forecasting" (CAF). A similar approach is currently being implemented and tested in France (Durand et al., 1998).

It is obvious that this largely office-based forecasting must rely heavily on a mesoscale weather forecasting model which accurately predicts parameters such as precipitation (amount and intensity), temperature and wind. Furthermore, online field data from a dense network of remote snow and weather stations are needed to drive the computer models as well as avalanche observation reports to provide feedback for the verification process. While a fully computer-based forecasting system has difficulty processing incomplete or contradictory data, a computer-aided approach combines the objectivity of a formal procedure with the advantage of combining computed information with the forecaster's intuition, experience, knowledge and personal observation. This is the basic philosophy behind the programme *Avalanche Warning CH-2000* which was launched in 1995. The overall aim of this programme is to modernise avalanche warning in Switzerland and to improve the temporal and spatial resolution of avalanche forecasting on a national, regional and local level, thereby helping to prevent avalanche accidents. In order to achieve this goal the following tasks must be accomplished:

- Building a network of remote snow and weather stations to measure parameters such as precipitation, wind, radiation and temperature near avalanche starting zones.
- Establishing an information system to link local, regional and national centres and to distribute warning information to the general public. This information system should make use of electronic communication channels such as the Internet, telephone, fax as well as radio and TV stations.
- Developing computer programs to model snowpack factors such as density, settlement, temperature distribution, metamorphism and stability as well as the redistribution of blowing and drifting snow by wind.
- Implementing computer programs to calculate the avalanche hazard on a local and regional level.
- Providing avalanche forecasts tailored to the needs of the different user groups (e.g. recreational skiers and mountaineers, mountain guides and ski patrollers, safety services). Together with an avalanche awareness programme this should help to ensure that everybody who travels through avalanche prone terrain has the necessary information and knows how to use it.

3. ARCHITECTURE

Figure 1 shows the general architecture containing all major modules and information paths. Shaded boxes denote input sources and white boxes indicate computer models.

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[*] Weather forecasting, which is similar to avalanche forecasting (e.g. physical models, simulation tools or analysis procedures) has gone through a similar transition about 10 years ago.

3.1 Input data

Three types of information sources are used as input:

- meteorological forecasts
- field measurements
- avalanche observations and field assessments of the avalanche hazard.

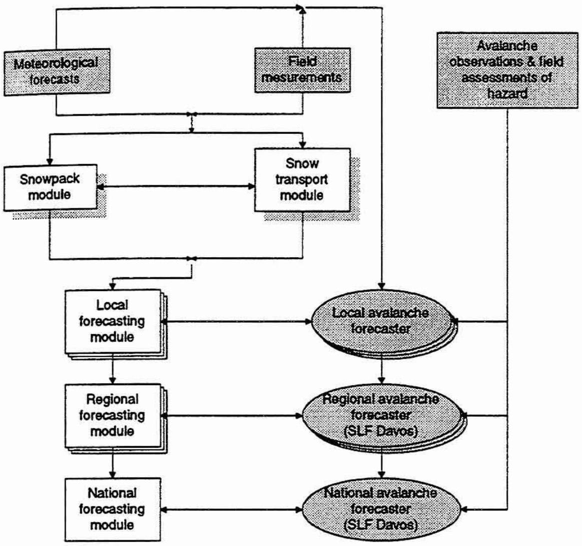

Figure 1. General architecture

For the meteorological forecast (e.g. precipitation, temperature, cloudiness and wind) the weather prediction model of the Swiss Meteorological Institute (SMI) is used with a grid spacing of 14 km (Majewski, 1991).

For field measurements data from about 65 automatic weather stations of the SMI can be accessed. Furthermore, about 60 automatic snow and weather stations of the SLF, which are located near avalanche starting zones at altitudes between 1600 m and 3200 m a.s.l. and 75 manned observation stations of the SLF are available. Figure 2 shows the location of the automatic snow and weather stations together with the manned observation stations. While the automatic stations measure snow and wind parameters every 30 minutes the observers transmit their measurements once or twice a day. The continuous stream of data from the automatic weather stations is used to drive the various computer models such as the snowpack model. Furthermore about 100 snow profiles are available at fortnightly intervals.

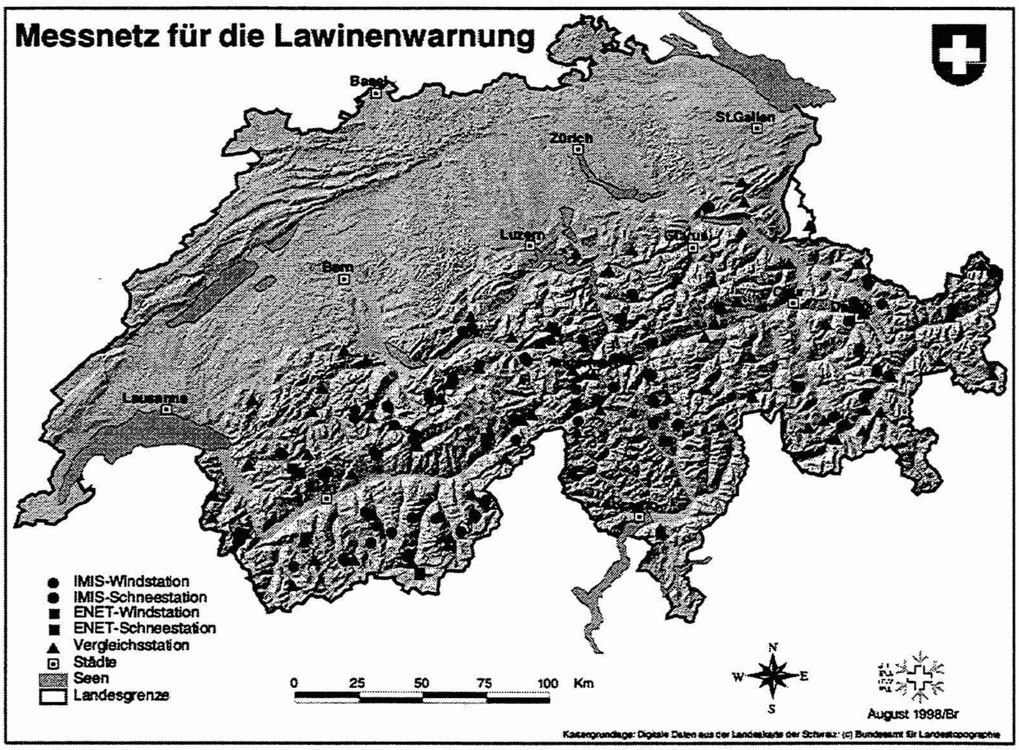

Figure 2. Locations of the remote snow and weather stations and manned observation stations.

Avalanche observations and subjective judgements about the local avalanche hazard are the third information source available. We receive them from our observation stations and from guides and ski mountaineers using standardised questionnaires (between 500 to 1000 per winter) (Brabec et al., 1998).

3.2 The Snowpack Module

The formation of avalanches is determined by the mechanical properties of the snowpack and its failure as a result of applied stress. A slab avalanche or a loose snow avalanche formation requires that the shear stress equals or exceeds the shear strength. In order to assess the mechanical stability of a snowpack the shear strength of the snowpack must be known. However the calculation of the shear strength is difficult and requires a thorough understanding of the physical processes in the snowpack. A one-dimensional snowpack model (see Figure 3) has been developed at SLF (Lehning et al., 1998a and Lehning et al., 1998b). It calculates parameters such as snow height and settling rate, amount of new snow, temperature and density distribution in the snow pack, an index on the formation of surface hoar as well as melting, sublimation and water transport. A metamorphism scheme is under development. Microstructural parameters such as grain size and co-ordination number are used to establish a link to the mechanical properties such as viscosity. The final aim is to describe weak layers and their mechanical stability.

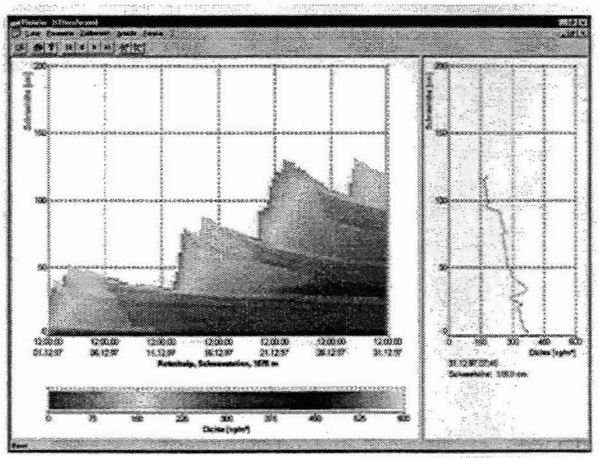

Figure 3. Example of a density evolution profile at the location of a remote snow station.

3.3 The Snow Transport Module

Blowing and drifting snow is a major feature of mountain snowpacks and essential for avalanche forecasting. The task of the snow transport module is to quantify and forecast snow transport by wind. In a first step, a local snow drift index will be developed using wind speed measurements of the remote snow and weather stations together with the snowpack model which provides information on snow erodability. This nowcast index will be extended to a short term forecast index using the output of the SMI's weather forecast model. In a second step a more regional approach will be pursued to calculate a high resolution assessment and forecast of snow transport by wind (Gauer, 1997). In this step, a mesoscale atmospheric flow model with an interface to SMI's forecasting model will be applied.

3.4 Local Forecasting Module

In order to assist local avalanche forecasters an avalanche prediction system based on the nearest neighbour method (Buser, 1983) has been developed a number of years ago. Using non-parametric statistics the program searches the database for „similar cases". For each day, the system stores a set of snow and weather parameters (numerical values) together with the avalanche events. Using a suitable distance measure, the nearest neighbours can be calculated. This approach has been widely used in Switzerland and abroad (Buser, 1989, Kristensen et al., 1994) for local avalanche forecasting[*]. An improved version of the program called NXD2000 (see Figure 4) is available and will be developed further in three respects. Firstly, the system is being connected to the network of automatic stations.

This allows to automatically collect the input parameters such as wind, temperature, new snow, density or radiation from locations near avalanche starting zones, rather than taking measurements manually. Since the parameters

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[*] The term local (or microscale) avalanche forecasting is used to describe avalanche prediction on a small scale, i.e. for an area of up to 100 km^2.

are measured every 30 minutes not only single data points but trends such as a temperature rise or fall can be taken into account. Secondly, by coupling the system to the snowpack module and the snow transport module, parameters such as density, temperature distribution, surface hoar index as well as stability and drift index can be included. Thirdly, by connecting the local avalanche forecasting systems to the snow and avalanche information network the local forecast as well as the local avalanche observations are available at the national centre in Davos.

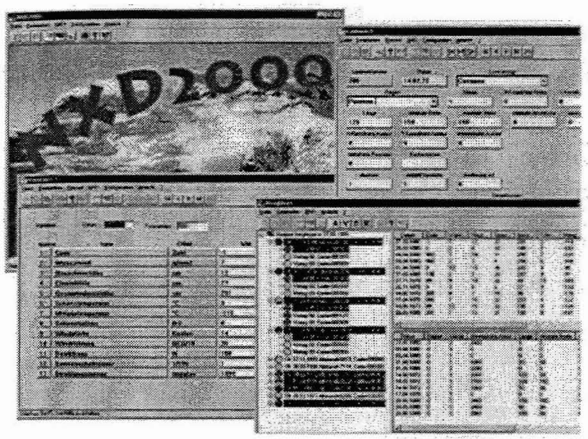

Figure 4. Input and output window of NXD2000, the Swiss local avalanche forecasting system.

3.5 Regional Forecasting Module

The national avalanche bulletin issued by SLF covers all parts of the Swiss Alps. Since winter 97/98 it is being issued daily at 5pm as a forecast for the following day with an outlook on the following two days. Its structure and content is synoptic, describing the general snow and weather situation and listing the avalanche hazard levels for every region using the European Avalanche Hazard Scale (see Figure 7). With the tremendous growth of winter sports, the demand for a more regional forecast* i.e. more detailed forecast has increased. This forecast must be easy to understand by people with little avalanche education. As part of the programme *Avalanche Warning Switzerland 2000,* regional avalanche forecasts were introduced in 1997. Figure 5 shows an example of a regional forecast of the Grison region, an area of about 5'000 km². For each sub-area the hazard level with corresponding slope aspect and altitude range is given.

In order to support the forecaster a computer program is under development to calculate the regional avalanche risk. This model employs data from remote snow and weather stations, measurements from manned observation stations, as well as information from snow profiles to generate the hazard level with the corresponding slope aspects and altitude range. The computer model generates a data structure which contains for each area the predicted hazard level with the corresponding slope aspect and altitude range. At this stage, the forecaster can manually check and alter the model's prediction. When the editing process is finished the bulletin is generated automatically (for an example, see Figure 5).

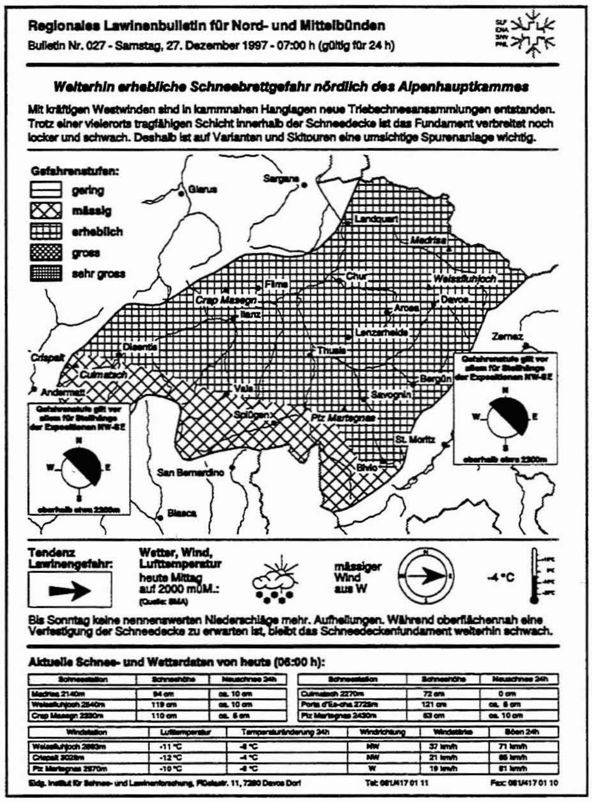

Figure 5. Example of a regional forecast for the Grison region in Switzerland.

3.6 Role of the forecaster

With the implementation of the programme *Avalanche Warning Switzerland 2000*, the role of

* In our terminology, regional forecasts cover an area between 1000km² and 5000 km².

the forecaster is changing. In the past, experience, intuition and local knowledge were the most important skills. In the future, the forecaster additionally needs analytical skills as well as the knowledge on how to interpret the output of the models. Having all the information at the tip of his fingers, the difficult task of the forecaster is to quickly survey the information, to judge the different factors and to take decisions based on various pieces of sometimes contradictory information. In particular, his task is to analyse the field data and the various predictions of the weather forecasting model. Furthermore, the output of the snowpack model has to be studied and compared to the snow profiles from our field observers. The output of the hazard prediction model has to be checked and compared with the avalanche reports. The forecasters findings and decisions are discussed at the daily briefing. Furthermore, a supervisor has to check the quality of each forecast issued. At the moment, we are in the process of establishing a formal procedure and a set of rules which should guarantee the quality and objectivity of each forecast.

4. AVALANCHE INFORMATION SYSTEM

Figure 6 shows the information system which links together the various input sources, the different computer systems, the data base and the distribution channels. A data collection server downloads data from remote snow and weather stations at hourly intervals and collects the data from manned observation stations once or twice per day. This information is fed into the national data base, a relational database system, which acts as central data store. Various applications (e.g. snowpack module, regional forecasting module, database browser or GIS-applications) which run on the application server, access this database. A WEB/MAIL/FAX server is used to allow the general public to fetch the forecasts via WWW (World Wide Web) or to receive them by mail or fax. An InfoBOX server is used to communicate with local forecasters, ski patrollers and safety experts in the different parts of the country.

4.1 Internet

Over the last few years the Internet has become a very popular way to distribute information. More and more people have access to the Web. During winter 96/97 about 65'000 requests for information (see Figure 7 and 8 for an example) over the web were processed. During winter 97/98 this number increased to about 350'000 requests.

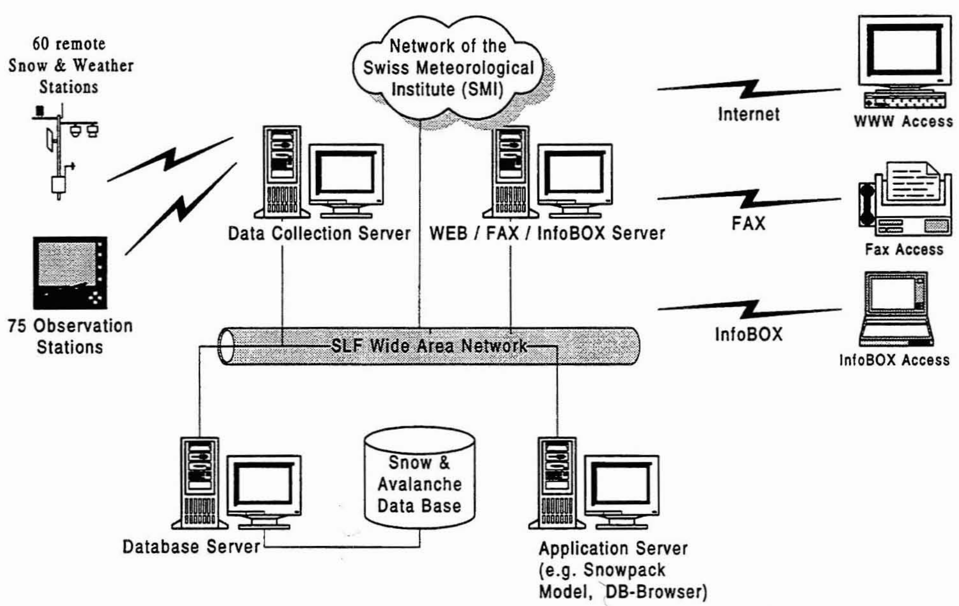

Figure 6. Snow and avalanche information network.

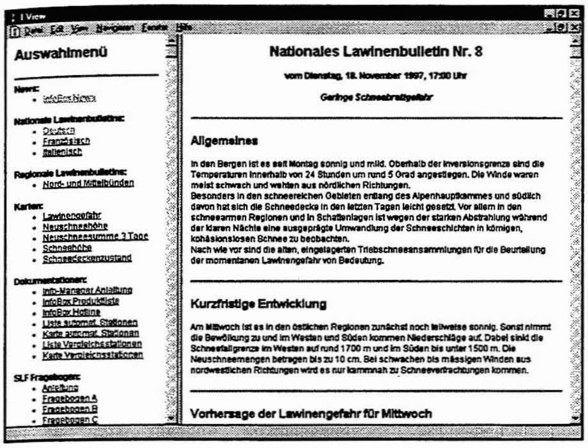

Figure 7. Browser with selection panel (left) and selected document, i.e. national forecast (right).

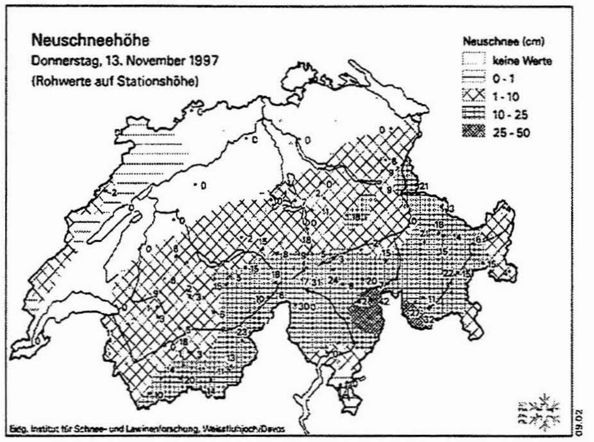

Figure 8. Map of Switzerland with the amount of fresh snow.

4.2 InfoBOX

While the web is the main information channel for the general public, a service called InfoBOX was set up three years ago. This service links together national, regional and local avalanche specialists in Switzerland. So far, about 140 specialists, i.e. people who are in charge of avalanche safety in villages or towns, in ski areas or on highways, are using the InfoBOX service. Via this service, snow and weather data from automatic stations (see Figure 9) or weather forecasts can be accessed 24h a day.

Furthermore the output of the different computer simulations e.g. snowpack data can be downloaded and displayed (see Figure 3). The local forecasting program NXD2000 is also part of the InfoBOX (see Figure 4). The experience gained over the last three winters have shown that the InfoBOX software package is an extremely useful tool for local forecasters. In order to train the InfoBOX users and to facilitate the exchange of ideas, a workshop is organised annually at the beginning of the winter by SLF.

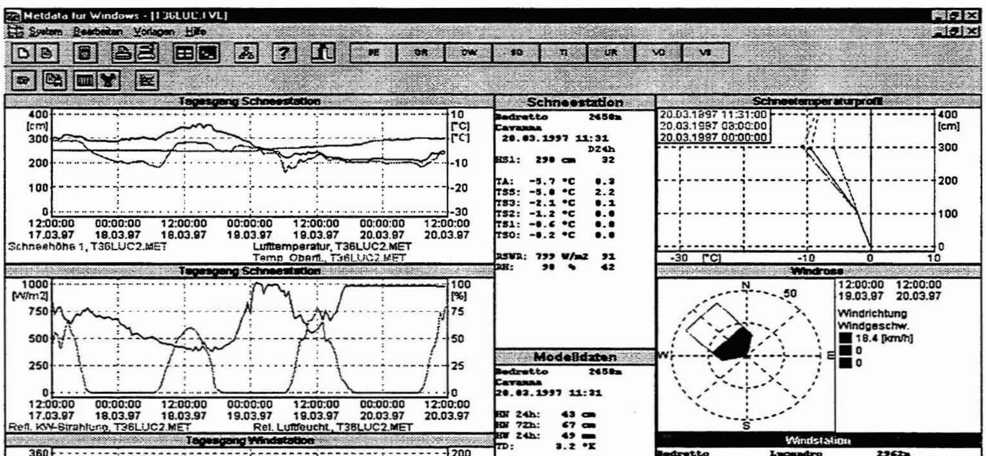

Figure 9. InfoBOX window showing a 3-day plot from an automatic station

5. CONCLUSIONS AND OUTLOOK

In this paper the programme *Avalanche Warning Switzerland 2000* has been described. While the overall aim is fairly ambitious the implementation is pragmatic. Each module of the system is implemented, tested and evaluated independently. Each winter, new components are added and already existing components are improved. Because the system is used operationally by local, regional and national forecasters our research team gets valuable feedback. Over the next two years the main effort will be spent on developing the snow transport module, improving the snowpack module as well as the local and regional forecasting module.

While a scientific evaluation of the different modules will be very important, we will also pay close attention to the needs of our forecasters as well as the needs of snow boarders, off-piste skiers or ski mountaineers. From a scientific point of view, our aim is to improve our knowledge about avalanche forecasting. But the most important task of the whole programme „Avalanche Warning Switzerland 2000" is to help to prevent avalanche accidents.

6. ACKNOWLEDGEMENTS

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