GIS AIDED AVALANCHE WARNING IN NORWAY

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ABSTRACT: By 2008 detailed avalanche warning for the entire Norway is not available. The Norwegian Meteorological Institute only issues a general warning for large regions of the country for danger level 4 or 5, mainly based on automatic indexes integrated in the meteorological forecasting models. Regional and local avalanche warning are issued by the NGI on request of customers such as the railway or road administration and local communities. The NGI warning projects cover vast areas of several 1000 sq km with a very limited budget, approx. 2 man hours a day. Therefore the workflow has to be extremely efficient from acquiring observation data, evaluation of the situation and sending out the new forecast. It has been an aim to include the entire workflow in an all in one web application. A GIS solution was chosen to integrate all data needed by the forecaster for the avalanche danger evaluation. This interactive system of maps features background information for the entire country such as topographic maps, slope steepness, aspect and hill shade to give a 3D impression of the terrain. In each avalanche warning area, all active avalanche paths are plotted including information on the most wind exposed direction. Each avalanche path is linked to a database generated webpage, which will inform the user on more details on the path, such as fall height, release area elevation, pictures etc. In this way the forecaster easily can get an overview over large areas and can give detailed avalanche warnings to the customer. The system is under constant development and is planned to be completely available on web browser such that no special software is needed on local PCs. Future versions will include interactive access to weather data both as 2D fields as well as time series at selected stations.

KEYWORDS: Avalanche warning, GIS, internet.

1. INTRODUCTION

Avalanche warning can be practiced at different scales from large regions, down to single avalanche tracks. In Norway the national avalanche warning only covers large areas and gives general warnings for danger level 4 and 5 resulting in low resolution. These warnings are mostly based on threshold values coupled into meteorological models. In practice, these warnings are normally issued in weather situations that prohibit most kind of activity in the mountains. More detailed warnings are issued daily for NGI customers such as the road and railroad administration and local communities. All of these projects have in common that the aim of the avalanche warning service is the protection of lives and infrastructure. Currently no service is explicitly issued for recreational activities although recreationists use the warnings that exist.

Avalanche warning in Norway started already in the 1970's when the NGI research station in the Stryn Mountains was established in 1973. The station became a meteorological observation station issuing manual observations 3 times a day via long wave radio communication to the coast guard radio stations. During 30 years of research in the area, threshold values for avalanche releases were defined and a probabilistic forecasting method adopted for Norwegian conditions (Fitzharris & Bakkehøi, 1986, Bakkehøi, 1987). After the opening of the new Highway 15 to Stryn, the need for a daily avalanche warning became apparent. A warning service was established in 1980 and has since then been operated in different ways.

The probabilistic forecasting method is today applied in several road districts (Ørsta, Odda, Tromsø) by the national road administration.

During the 07/08 season five areas were included in the NGI warning services (Fig. 1, Table 1). The areas are divided into two classes. One covers the areas with a high frequency of avalanches threatening the exposed objects. The second class includes areas with low avalanche

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Figure 1: Map of Norway showing the areas covered by NGI avalanche warning services

frequency but with high consequences. The first class is covered by daily warning routine, issuing a complete bulletin each day, while for the second class avalanche warnings are only issued after a phone request from the customer. These customers are encouraged to take contact whenever wind or precipitation thresholds defined by the NGI are exceeded.

In addition to the Highway 15 project described above another important transport corridor, the Bergensbanen Railway, is covered by the NGI avalanche warning service. It runs the distance of 460 km from Oslo to Bergen crossing the mountains at a maximum elevation of 1222 m at the station Finse. The track was built in around 1900 and officially opened in 1909. Already during the first winter of operation, the traffic had to be stopped, because of the severe winter conditions. Blowing snow and avalanches covered the track and no available machinery was efficient enough to keep it open. Today, many kilometers of the railroad are covered with shelters. However, these shelters are installed to prevent drifting snow to enter the track. They are too weak to withstand avalanches and are frequently destroyed. There is only one major avalanche track threatening 400 m of the railway but numerous small tracks have enough potential to fill up the track and derail the trains.

Table 1: The five avalanche warning areas included in the 07/08 service (see Fig. 1 for location)

Name	**Type**	**Area** (km^2)	**No. aval. tracks**
Bergen Railway	daily	1 700	51
Highway 15	daily	140	9
Imingfjell lodges	daily	7	5
Sunnmøre road district	customer	4 500	199
North Norway	customer	22 341	130

The Northern Norway avalanche warning program is an initiative of local communities who encompass settlements that are exposed to avalanches. Usually only some selected houses are exposed in each community, such that the distances between locations that need avalanche warning are very large in some areas. Each community contributes with a local observer and sends daily messages with snow depth and new snow amount to the NGI. The regional weather service is responsible to contact NGI whenever certain threshold values for observed wind or precipitation are exceeded. After such a request an avalanche warning is issued for the area.

The Imingfjell area is a small area of 7 km^2 that covers some exposed mountain cabins, while the warning services for the Sunnmøre district focuses on exposed road sections (Kristensen et al., this issue)

In total the five areas cover 26 500 km^2 and reach 2900 km from the south to the northern most part of the country. It is obvious by these dimensions that several climatic zones as well as different weather systems must be considered during a normal day. Luckily, challenging weather conditions usually only dominate one part of the country, while the other part is rather calm. Therefore threatening avalanche conditions rarely occur in the south and in the north at the same time.

Contrary to local avalanche warnings centers within the covered area, field knowledge and first hand information is not directly available for the NGI warning group that is located in Oslo. Therefore, fast and easy access to all available information is needed to allow such a wide cover from a centralized location. This paper gives an overview over the sources for information used during every warning and an introduction to the applied technologies.

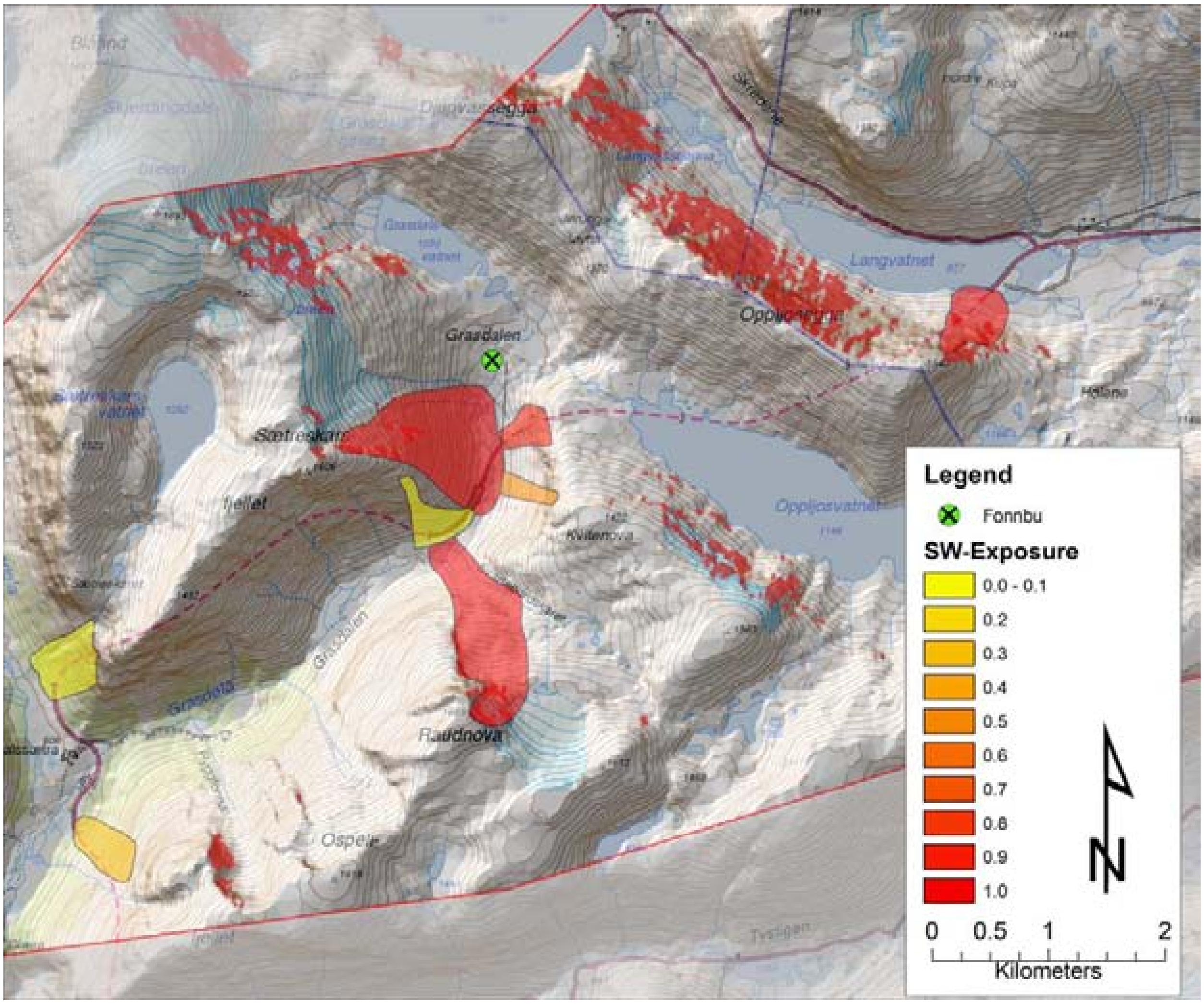

Figure 2: Detailed map of the Grasdalen area showing avalanche tracks active at winds from SW. The darker the track the more likely it is to produce avalanche at this wind direction. Each track is a hyperlink to additional information on the track (Fig. 3). The location of the NGI research station Fonnbu is shown by a cross marker which also hyperlinks to current weather information from the station.

2. MATERIAL AND METHODS

Generally three components have to be known for day to day avalanche warning: a) terrain, b) state of the present snow cover and c) the current weather conditions and forecast for the next 24 hours. In many other avalanche warning services, the knowledge of the terrain is based on personal experience of the forecasters who live and work in the area. Observations of the snow cover and avalanche activity should be covered by field work and the meteorological information is provided by local weather stations and model prognosis.

Covering as much as 26 500 km^2 from the central office in Oslo, direct observations in the field are not accessible more than once or twice a month. To address this challenge, a map information system was established that allows gathering all available information in one place.

2.1 Terrain

Topographic maps for the entire country allowed calculating maps of aspect and terrain slope for the whole of Norway. For each warning area, the most active and threatening avalanche tracks where mapped roughly and added to a database. The information collected on each track are a picture, physical characteristics such as fall height and size of release area, information on the exposed object (house, street, railway) and a

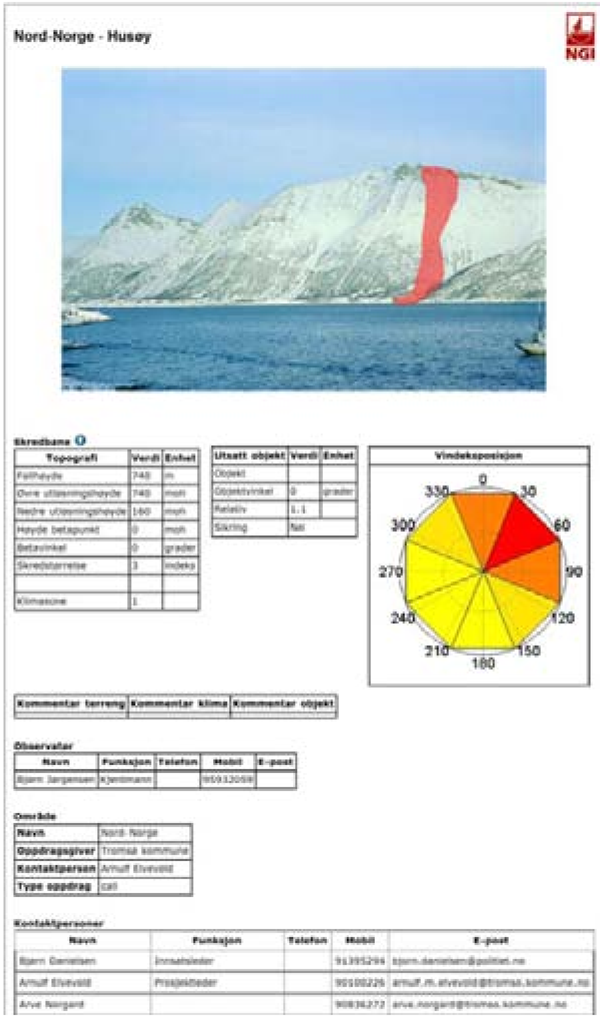

Figure 3: Example for an automatically generated webpage for an avalanche path in Northern Norway.

classification to which wind directions this track is most exposed. This information is used in the GIS to create interactive maps. For example at wind direction SW all areas steeper > 30^o in the lee of SW are highlighted in the map together with a graded color scheme showing those tracks in shades of red that are most prone to avalanche with this wind direction (Fig 2). A click on the track itself opens a web page displaying the photo and the additional information on the track (Fig 3).

In this way the forecaster can keep an overview over large areas and fast pick out the most exposed tracks. Each forecaster is entitled to contribute with improved information on the tracks to help to transfer experience and knowledge to other colleagues.

2.2 State of the snow cover

Information on the present state of the snow cover is difficult to access from the office. Local observers can provide some information, but no regular observation program is included in the NGI warning services. Only the communities in Northern Norway provide daily observation of new snow depth. However, each warning areas has their local representatives of the customers that can be contacted to discuss the present situation at hand. This is done regularly and phone numbers are just a click away on the interactive maps. Field work is done in the areas when the weather or observations by other people indicate that there might be instabilities in the snow cover that need a closer investigation

2.3 Meteorological information

Due to the lack of regular field observations, the nowcasting is heavily dependent on automatic weather observations. Each area is equipped with one or several stations. The stations are operated by different agencies such as the road or railroad administration, the Norwegian Meteorological Institute, NGI and hydro power plants. Each station has therefore its own logging interval, data format and transmission system. In daily operation, this is by far the weakest spot of the entire warning system. Introduction of national standards on data transmission are under development and will be implemented within 2009 to improve the accessibility to meteorological observation data. Data from the stations is visualized and published on the net using Matlab code.

Prognosis and observation data is freely available from the Norwegian Meteorological Institute since 2007. Prognosis data is delivered both as point prognosis for up to ten days as well as meteorological fields. Satellite and radar observations are also included. The interactive avalanche warning map gives access to weather charts for 200 stations throughout the country. Meteorological fields are currently only displayed with custom designed software by the Norwegian Meteorological institute, called DIANA (Bergholt, 2007). The software allows, just as in traditional GIS, to stack all information such as wind and pressure fields, satellite images and precipitation prognosis in one map. This map is then easily looping the prognosis for several days (Fig. 4). It is the ambition to include these features into the avalanche warning map, such that all information is available in one map.

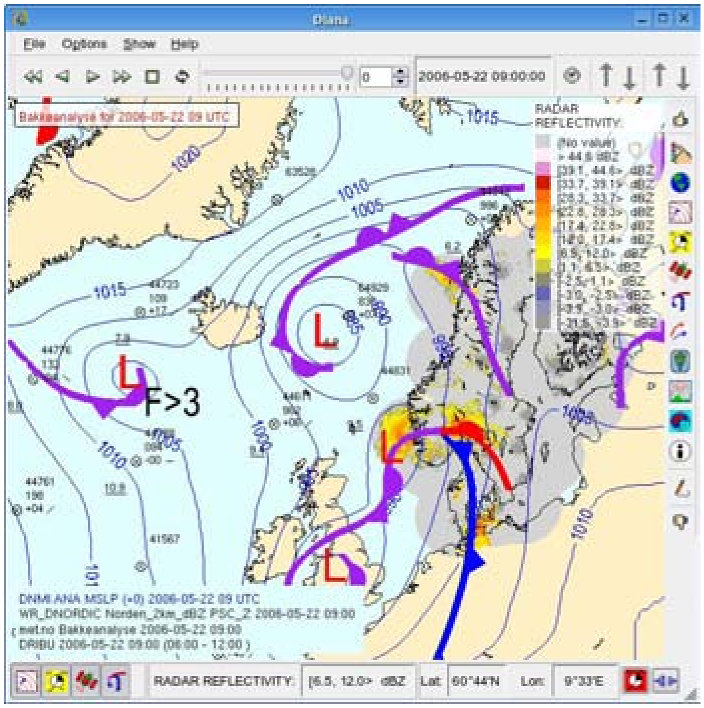

Figure 4: Screenshot from the meteorological visualization tool DIANA

2.4 Web cam

A visual impression of the weather conditions is always a valuable addition to the observations from weather stations. Therefore a number of open web cams from Norway are also linked to the map, such that the forecaster easily can access the picture from several areas around the country. An example from the same evening in April is shown in Figure 4. The two pictures are just 3 hours apart. Mountain areas are usually only covered by cameras in ski areas, but the number of cameras is increasing also in interesting mountain locations.

2.5 Technical platform

Three technologies are used to produce the avalanche warning map. The map itself is set up in ArcGis and is published on ArcIMS (internet map server). The meteorological data is collected from various sources and stored in central databases (ORACLE). From here, the data is imported into Matlab routines to analyze and visualize the data and publish the figures on the net. The entire system is automatically updating every 10 minutes.

3. RESULTS

Today the avalanche warning map includes detailed information on five warning areas. In total 394 avalanche tracks are documented in the database, most of them with picture and detailed description of the track. While the forecaster earlier had to open a large number of different web sites to gather information for the warning process, now a single map based gateway enables direct access to all information. Experience has shown that forecasters prefer certain meteorological stations for their work in a given area just because they did not remember the names of other stations close by. The use of maps, where all stations are displayed with their position solves such problems easily. Also the question of how representative the station is for the area is much easier to evaluate when its location is displayed in relation to the warning area and wind direction.

The warning areas that receive their evaluation after a customer request cover large areas. Therefore, avalanche warnings are usually only issued for selected locations where the weather conditions are severe. Here the maps let the forecaster easily use the basic information such as “strong wind from NW with heavy precipitation in the Northern Lofoten Islands”, to zoom in on the single tracks that actually endanger dwellers and their houses in this area.

The results obtained from the meteorological and terrain information enables the forecaster to fill in the web based registration of the avalanche bulletin for each area. Finally the bulletin is sent out by e-mail and SMS to the customers to predefined lists for each area. Additionally, the danger level is posted on a webpage that informs recreationists about avalanche and snow conditions.

The map has been applied successfully in the season 2007 / 2008 and will be further developed this autumn to include meteorological fields and the possibility to display loops of several days.

Figure 5: Web cam pictures from the Bergensbanen railway. The images are from the 04 April 2008 at 17:45 and 21:00 respectively illustrating the direct feedback on the weather conditions by pictures.

4. DISCUSSION

The limited resources of the centralized NGI avalanche warning service reduces the physical presence of the forecasters in the warning area. The two persons on duty have to cover vast areas with their evaluation every day. The establishment of a map based information platform for the whole process from studying the current weather condition, the terrain and weather development to issuing the bulletin, reduces the workload of the forecaster significantly. All information is ready available from the map, such that no other tools for the forecasters work are needed. In every day work, the system has to be user friendly and adjusted to the workflow of the forecasters. Otherwise such a new system is not accepted.

In practice there are several challenges due to that fact that the presented system is dynamical. Every ten minutes a check for new data is performed to update the weather figures. Since there is a large variety of data sources for these figures, missing links or updates easily bring the system into trouble. It will be the focus of the ongoing development to increase the reliability of the system for the oncoming winter.

5. CONCLUSION

Avalanche warning is a process that operated both in time and space. Therefore, dynamical maps are an obvious approach to gather all information needed for the forecasters work. Today's GIS tools allow easily linking together information from different sources into one map. The challenge is to prepare the data from all these sources such that the system can be updated automatically with new data at least once every hour. The acceptance of the system by the forecaster depends on reliability and user friendliness. Both are under constant improvement in close communication with the users to deliver the product they need for the daily work.

6. REFERENCES

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