Analyzing the Environmental Effects on the Danger of Avalanches using Geoinformation Technology

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ABSTRACT: Actual and high quality spatial data and information are the foundation in the daily workflow in a common avalanche warning center. One essential activity is the analysis of spatial data every day. Geoinformation (GI) Technologies offer great capabilities to improve workflows of acquiring, storing, analyzing and visualizing this spatial data. This paper will outline the potentials of GIS Technologies in detail using the example of the Carinthian Avalanche Warning Center (Austria). The focus of the presentation will detail how a GIS based raster model is used for evaluating spatial information of automated generated weather station data. Based on reclassifying the meteorological factors precipitation, temperature and wind regarding their influence on avalanche formation we propose a weighted overlay analysis. Furthermore this basic evaluation of weather data is correlated to the terrain parameters slope, aspect, curvature and altitude. The terrain data is derived from a Digital Elevation Model (DEM) in a resolution of 10m. Finally we visualize the results and provide a basic assessment of potential hazard zones. The model was tested for the regions Hohe Tauern, Carnic Alps and Karawanken in Carinthia using weather station data of February 2006 and our results were compared to the evaluation of the danger zones reported by an avalanche expert in those days. Future developments are partitioning the observation area in disjoint regions and calibrating the GIS model for each region based on its specific weather and terrain characteristics. Using standard Web-GIS techniques we will provide optimized maps as well as more sophisticated analysis possibilities.

KEYWORDS: GIS, meteorological analysis, weather stations, raster model, avalanche bulletins

1 INTRODUCTION

The preparation of avalanche bulletins involves daily analysis of meteorological data. In the case of the Carinthian Avalanche Center no GI capabilities were used to support avalanche experts in their daily workflow. For this reason the manual analysis was time consuming and prone to errors that arise through manual data processing and interpretation. In this paper we present approaches to improve this workflow in its time consuming aspect as well as in the analysis capabilities aspect.

We discuss a raster model that evaluates the actual influences on avalanche potentials given through the actual weather situation. The model processes raw data collected by automatic weather stations and pre-processed, interpolated raster data. In a second step the first result of a regional evaluation is related to morphologic data given through a DEM with cell size of 10x10 meters, and evaluated based on criteria defined by an avalanche expert. Finally this result is visualized as spatial representation of a common textual avalanche bulletin.

Furthermore we discuss problems that arose during implementation phase and describe weaknesses and possible improvements of the models applied. In the end, an outlook for the next steps, induced by this project, is given.

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2 METHODS

2.1 Raster Model Generation

Raster models were used in earlier approaches to evaluate actual avalanche danger.

Cookler and Orton (2004) developed a model that analyzes the parameters wind speed, snowfall, aspect and slope. The 4 parameters are classified by their importance for the actual avalanche danger and afterwards incorporated in a formula that generates a daily forecast value for each raster cell.

Maestro (2004) identifies regions that are exposed to avalanche danger based on their morphologic features. He observes the parameters altitude, slope, aspect, curvature and green cover and classifies them based on their influence on avalanche formation. He then simply multiplies the 5 parameters and reclassifies the result. The output is a raster map that represents the calculated risk level for each cell.

Kriz et al. (2004) present techniques for a cartographically optimized visualization of avalanche relevant data, like snow height difference, temperature and current avalanche danger for the Tyrolean Avalanche Warning Center (Austria). Furthermore they offer their services regarding actual avalanche danger on various platforms like the Internet and mobile devices to the public.

Our approach combines different aspects and general intentions of these approaches. We differentiate between regional danger potentials that are primary induced through actual weather phenomena, including precipitation fallen as snow, wind and temperature, and local danger potentials that relate the regional potentials to the underlying terrain features altitude, slope, aspect, curvature and wood. In general these factors are discussed in literature by Hopf (1996), Schweizer et al. (2005) and McClung & Shaerer (2006) and generally seen as relevant for avalanche formation.

The regional danger potentials are classified after the European Avalanche Danger Scale and can be seen as avalanche danger map as used in common avalanche bulletins. The main difference lies in the dynamic regionalization according to the influence of regional weather, instead of regions with fixed boundaries that are assigned one or two danger levels.

The local danger potentials represent information given in avalanche bulletins generally in textual form. This includes an evaluation for each observed cell on basis of the regional danger level at this position in combination with slope, aspect, altitude and curvature, based on principles discussed in Hoffmann (2001). If this evaluation of one cell fulfills criteria that the location should better not be entered, it is marked as local danger potential. A simple example for a positive evaluation of a local danger potential is a cell that has been assigned a regional danger potential of considerable and the slope for this cell is beyond 35°. Through the visualization of these results in maps also less experienced people can apply the complex information presented in an avalanche bulletin in situ.

The implementation of the models is done in ArcGIS 9.2 ModelBuilder and includes additional Python and Visual Basic for Applications (VBA) scripts.

2.2 Weather Data

Weather data that is analyzed on behalf of our models is provided by 2 departments of Amt der Kärntner Landesregierung. The Carinthian Avalanche Warning Center collects raw data of about 20 weather stations in high alpine regions. These weather stations are equipped inhomogeneous, not all of them offer sensors for each parameter, mainly depending on their age. This leads to an amount of 9 weather stations that are equipped with sensors for wind speed and wind direction.

The department for hydrography runs 55 stations that collect temperature and precipitation data. This data is manually checked for errors and serves as basis for an interpolation for whole Carinthia. This data is available as ASCII Files that can be processed in ArcGIS 9.3.

2.3 Regional Danger Potentials

The model for evaluation of regional danger potentials analyzes the three factors precipitation, wind and temperature in a raster analysis operation for the whole area of Carinthia. In a first step, precipitation fallen as snow is estimated. A script checks for each cell of the input raster files if temperature is below 0°C and if precipitation has occurred. In this case the precipitation amount is added to the actual observation period sum. Another step is averaging the wind observation and interpolating the result for the whole area based on the raw data provided by the Avalanche Warning Center. For this calculation we apply a Kriging function that uses a spherical semivariogramm model and takes the 6 nearest neighbor stations in account.

After this pre-processing step the 3 factors are classified after table 1 that represents ideas presented in Hopf (1996), Hoffmann (2001) and McClung & Shaerer (2006). This step is necessary to conduct standardized values that can be compared and combined with each other afterwards.

Table 1: Classification of the observed values precipitation, wind and temperature

Class	Precipitation	Wind	Temperature
1	0 mm – 4 mm	0 m/s – 4 m/s	0 °C – 1 °C
2	4 mm – 10 mm	4 m/s – 7 m/s	-3 °C – 0 °C
3	10 mm – 20 mm	7 m/s – 9,5 m/s	-6 °C – -3 °C
4	20 mm – 40 mm	9,5 m/s – 12,5 m/s	-12 °C – -6 °C
5	40 mm – 90 mm	12,5 m/s – 15,5 m/s	-24 °C – -12 °C
6	> 90 mm	> 15,5 m/s	< -24 °C

In the following step, the three independent factors are combined in a weighted overlay operation, where the influence of precipitation is weighted with the factor 3, wind with 2 and temperature with 1. These weights were discussed with an expert of the Carinthian Avalanche Warning Center and were seen to be appropriate for a mid-winter scenario involving relevant precipitation periods.

The result of this operation is a danger index for each raster cell. Finally this index is classified into 5 classes regarding the levels of the European Avalanche Danger Scale.

2.4 Visualization of Danger Potentials specified in Avalanche Bulletins

The visualization of local danger potentials is a combination of information gained in the regional danger potentials evaluation and textual information about altitude, exposition and curvature at risk in a corresponding avalanche bulletin. A cell-by-cell query checks the values regional danger potential, altitude, slope, exposition, curvature for each cell with the assumption that under specific conditions concerning regional avalanche danger and morphology, slopes steeper than a specific angle should be omitted. A cell that is assigned regional avalanche danger “considerable”, in disadvantageous exposition that is steeper than 30° should be omitted and gets visualized as local danger potential. A cell that is assigned regional avalanche danger “moderate”, in advantageous exposition that is not steeper than 40° will not be visualized as local danger potential. Detailed information about the decision matrix can be found in Hoffmann (2001).

The visualization for its own can be done in several ways. Figure 3 presents a simple raster map where local danger potentials are symbolized as additional class. Figure 4 presents a large scale 3D visualization for the area of Heiligenblut (Austria) that offers full 3D observation capabilities. The advantage of this approach is the fact that such visualizations are easier to interpret, so even a non-expert is able to distinguish between slopes that should not be entered and slopes that are relatively harmless.

3 RESULTS

The models were tested for the region Carinthia and weather data from winter 2005/06. The following figures provide a comparison of an evaluation done by an avalanche expert of the Carinthian Avalanche Warning Center and the output of the discussed models. If you are reading the hard copy version of ISSW proceedings the figures will not look appropriately due to the missing color. Please refer to the digital version or visit www.umweltmonitoring.at for a colored version Figure 1 presents the avalanche danger evaluation by an expert for February, 20th 2006.

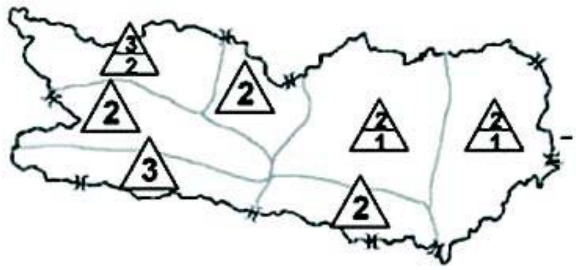

Figure 1. Evaluation of avalanche danger through an avalanche expert of the Carinthian Avalanche Warning Center for February, 20th 2006

Figure 2 serves for better understanding of the prevailing situation on that day. It represents precipitation fallen during temperatures below 0°C. Beneath regions in the East where temperatures were too high for snow there are also regions in the far north, where temperature would have been low enough, but no precipitation occurred.

Figure 3 presents the output for the regional danger potential evaluation. The classification is made regarding the European Avalanche Danger Scale. The regions in the West of Carinthia show a tendency for danger level “considerable as it is assigned by the expert too. The danger level decreases towards east primarily induced to the small amount of new snow.

Additionally to the regional danger potential evaluation, this figure presents the query of local danger potentials. Due to the fact that the DEM data was only available for the regions *Upper Tauern*, *Carnic Alps* and *Karawanken,* the evaluation of local danger potentials is limited to these regions.

Figure 4 gives a closer look to the ski area of Heiligenblut (Austria) and describes a possible improvement to Figure 4 for the visualization on large scale. The 3D visualization is conducted in ArcScene 9.2 and offers a simple approach to complex textual information in an avalanche bulletin.

The comparison shows that in situations where the actual avalanche danger situation is mainly affected by weather phenomena, the model’s outputs and the expert’s evaluation correlate to a high degree. Negative effects on outputs calculated by the model are discussed in chapter 4.

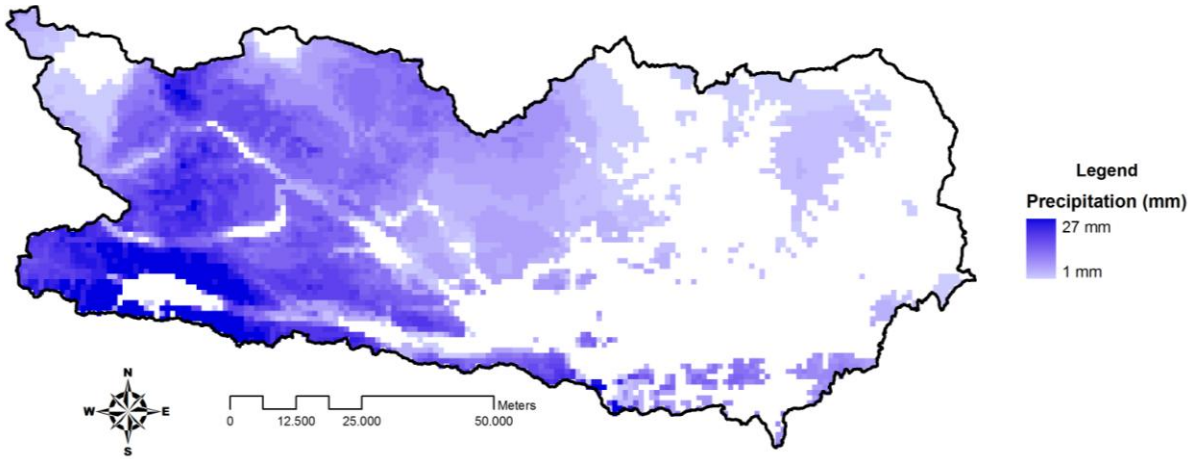

Figure 2. Precipitation that was falling during temperatures below 0°C, darker colors representing higher amounts

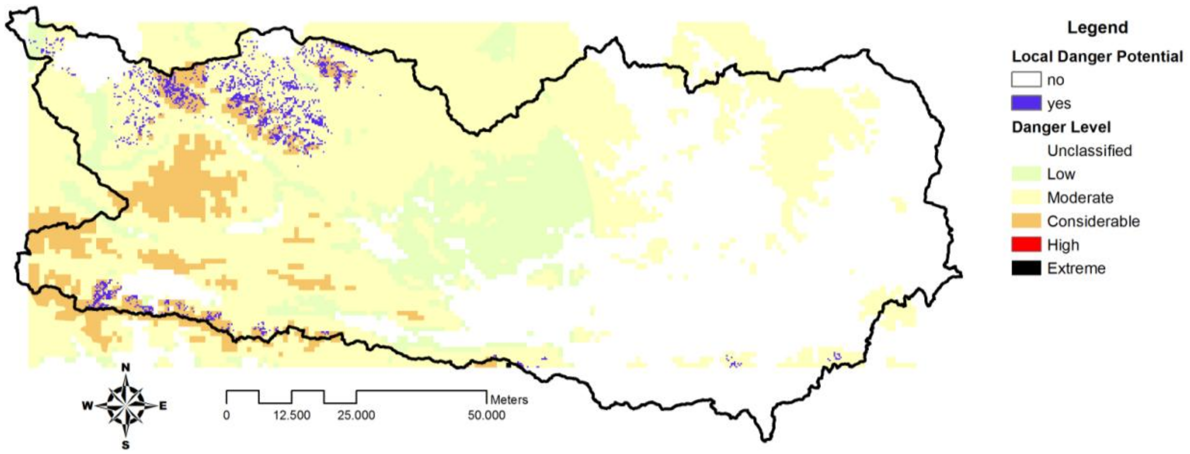

Figure 3. Additional information on local danger potentials for February, 20th 2006

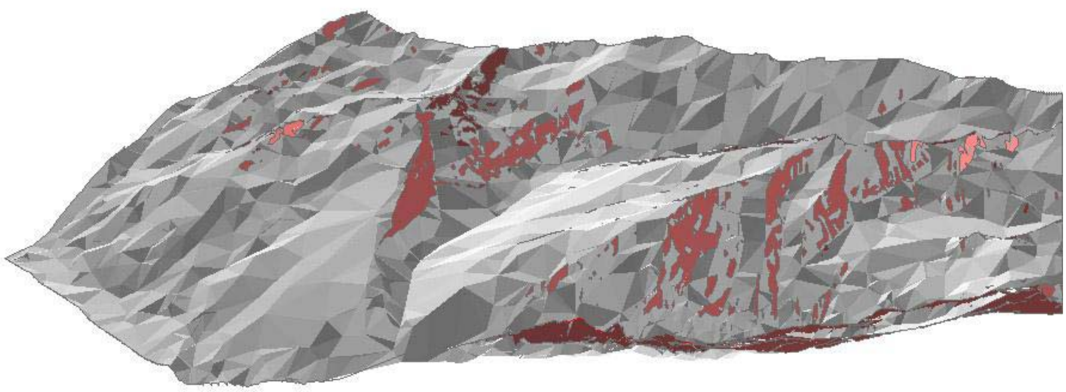

Figure 4. 3D visualization of local danger zones for Heiligenblut (Austria) done with ArcScene 9.2

4 CONCLUSION

The results show quite a good accordance to the evaluation of the avalanche expert. Nevertheless this model is optimized for a specific scenario that involves cold temperatures and precipitation. Different scenarios like typical spring situations with strong warming during the day would lead to an adaption of the model parameters. An important factor in the process of avalanche formation is actually the snow pack itself and the presence of weak layers. In this model the influence of snow pack was not included due to the fact, that an interpolation over some distinct measurements would hardly make sense. The snow pack differs too much also in relatively small areas, so this factor was excluded from analysis. To conclude snow pack properties in an interpolation process is also a topic for further research.

The analysis of wind speed also bears potential for improvement. As described there are about 10 weather stations that are equipped with wind sensors over whole Carinthia. This might be not sufficient particularly for the fact that these stations are exposed to extreme weather conditions and malfunctions happen especially under harsh conditions. Possible solutions for this problem are on the one hand an improved sensor network with optimized station locations or on the other hand a combination of the different sensor networks operated by various organizations.

Another fact that should always be on mind is the use of DEMs in analysis. In our approach we used a DEM in a resolution of 10 m to conclude local danger zones. The calculation of slope is not unique and the result of this operation can have different meanings. Additionally the representation of the actual terrain is limited to the resolution of the raster. Terrain features that are smaller than the resolution cannot be modeled appropriately and so features that support triggering of an avalanche might be overlooked.

5 OUTLOOK

The Carinthian University of Applied Sciences, Department of Geoinformation focuses on the topic environmental monitoring and possible applications of this topic, like avalanche research in this case. In this focus topic we work on the evaluation of different standards that deal with sensor networks, summarized under Sensor Web Enablement (SWE). This new initiative of the Open Geospatial Consortium (OGC) presents techniques for a standardized manipulation of sensor data via various services for data transfer, alerting and sensor planning.

Another major project for future is error detection and correction of sensor data. In this first project the input data is either raw data or manually corrected data. This process of data validation is time consuming and the next goal is to define criteria and algorithms that can be implemented for an automated error detection and correction.

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