Using GIS and 3D Modeling for Avalanche Hazard Mapping

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Introduction

Avalanches represent a very short, local, dynamic event in snow covered mountainous regions. They are not easily predictable and often enough can produce devastating results. Avalanche cartography deals with the causes and consequences of such incidents and tries to depict them in a variety of ways. The most common cartographic representation within this field is the avalanche hazard map. It incorporates mainly large-scale topographic elements with thematic features. In such maps, both direct and indirect aspects of avalanches are considered.

Using Geographic Information Systems (GIS) to capture data, to utilize the capability of analyzing topographic terrain information and to evaluate thematic scenarios is becoming essential within avalanche research and for the production of avalanche hazard maps. Besides just visualizing what has happened and depicting locations of potential risk, it is now possible to experiment with different approaches and to visualize complex results in a cartographic demanding way. Taking advantage of high quality digital terrain models within GIS and combining the results with perspective three-dimensional spatial presentation, it is now feasible to enhance hazard mapping with dynamic components.

The main objectives of avalanche hazard mapping today are therefore to be seen in the following fields:

- Digital Terrain Model (DTM) assessment for high quality feature derivation using GIS functionality
- Incorporation of dynamics using animation and simulation techniques
- Perspective three dimensional terrain modeling for advanced topographic comprehension
- Cartographic design, layout and presentation using multimedia technology

Avalanche Hazard Mapping

The mapping of avalanches and their consequences has a long tradition not only in the alpine areas of the Austrian Alps, though it has seldom really been in the center of public interest. The primary consumers till now were mainly official municipalities and planers. However, due to recent casualties, hazard mapping is now becoming en vogue and more conscious to the public. Mountainous regions are becoming the center of interest. The combination of high snow cover and highly sophisticated infrastructure with human interaction is playing a major role. The protection of transport routes, settlements, tourism areas and ultimately human lives is essential.

Due to the fact that in high altitude regions in Austria (above 1500m) snow cover is persistent for more than six months of the year, it is becoming important to deal with causes and effects of avalanches. The focal point is mainly in populated and touristic regions. Monitoring the weather and analyzing the resulting conditions is one important aspect of dealing with potential crucial avalanche situations. On the other side it is decisive to understand and capture the topographic situation. According to avalanche experts around the world terrain slope is an important factor in understanding and predicting potential avalanches.

Slope	*Avalanche Probability*
below 10°	practically no avalanches are triggered
10° - 28°	avalanches are scarce
28° - 45°	major danger zone for avalanche triggering
above 45°	high avalanche frequency, however low snow accumulation due to steepness

Tab. 1: Slope and Avalanche Probability (DAV, 1994)

Furthermore it is essential to comprehend the nature of avalanches in order to be aware of their potential danger. Statistics of fatal avalanche accidents within the Alps of the past decades show a tendency towards individual triggering of avalanches caused by winter tourists and mountaineers. Nether the less, exceptional events such as the avalanche disaster in Galtuer in February 1999 in the Austrian Alps, that resulted in the loss of over 35 lives, still do occur and produce, beside the human grief, extensive economical damage.

There are various numbers of areas in which avalanche hazard mapping is momentarily focusing on:

- Large-scale municipality and regional planning
- Leisure hazard mapping
- Event chronology
- Potential probability of avalanche hazards
- Animation of occurrences
- Simulation modeling
- Hazard and risk management
- Small-scale regional overview

DTM Enhancement and GIS Analysis

In order to evaluate and use slope for avalanche classification, it is important to have a high quality base digital elevation model (DEM). DEMs can be derived from digital terrain models (DTM) in numerous ways. Using isolines from existing topographic maps with breaklines and height points to produce DTMs is very common. It is however important to be aware of the quality restrictions that arise when using such methods. Resolutions of 5-10m are ideal for avalanche mapping. Larger DEM resolutions such as 25-50m are widespread, though can not represent critical features of terrain that are important for avalanche modeling and mapping. A common factor for deriving DEMs from isolines is [resolution of DEM = isoline interval / 1.5]. This is of course depends on the

quality of the primary topographic registration. A good compromise for avalanche mapping is the scale 1:25.000 with a DEM of 10-15m.

The major reason of using GIS within avalanche hazard management is to analyze and model scenarios that can help understand or even predict possible occurrences. In order to do this, it is important to have large-scale terrain and thematic information. Topographic maps (isolines, hydrology, infrastructure, etc.) and DTMs represent large-scale terrain information in an effective way. Available in digital form, they act as base for modeling and GIS analyzing.

On the one side GIS can offer classical functionality such as depicting singularities (slope, aspect, event chronology, etc). On the other side GIS can be used to combine multifaceted attributes using various complex features to produce highly sophisticated results. One of the major input variables for most analysis and models is terrain slope information derived from a DEM.

Cartographic Essentials

In order to depict the GIS results correctly and in a sound fashion it is essential to understand the various visualization methods and base information cartography has to offer. A common form of presenting avalanche relevant information is in using a printed map with large-scale topographic terrain information as a base combined with specific thematic information – such as avalanche paths, potential hazard areas, event chronology etc. Terrain information in maps consists mainly of isolines, hydrography, land cover -- in some cases rock depiction and hillshading -- and infrastructure. The detail as well as accuracy within these cartographic products is primarily dependent on the scale. Widespread map scales that are being used for such base maps range from 1:1.000-1:5.000 (land register maps) over 1:25.000-1:50.000 (classical topographic maps) all the way to 1:100.000 or smaller (regional overviews). Other common base maps in large scales are orthophotos or satellite images that show a high amount of detail however lack a generalized depiction.

Using so-called map related representations allows the depiction of avalanche information in a new dimension. Map related representations can be either static, view-only illustrations (photo panoramas, 3D perspective views, photographic documentations etc.) or dynamic, interactive multimedia presentations (animation, simulations, 3D GIS applications, virtual reality etc.). In all cases the third dimension as well as in some cases the temporal factor time is present and can be utilized. High quality DTMs are required for these applications.

Multidimensional Cartographic presentation

Till now avalanche hazard mapping has been mainly using large-scale printed maps to represent static as well as dynamic features. The major focus of interest was to depict potential areas of risk or to show areas that have been subject to past hazard occurrences. Using the broad spectrum of cartographic symbolization it is possible to visualize the dynamic characteristics of avalanches and their causes. Qualitative and quantitative line symbols as well as arrow symbolization are the most common forms of representation. However, in order to depict temporal dynamic events static mapping very quickly reaches its limits. Map related representations, such as animation or virtual reality can be used, provided that the topographic and thematic base information is of high quality.

Animations can show the temporal dynamic aspects of avalanches from a given optimized viewpoint. This can be either a map-like orthogonal standpoint all the way to a perspective three-dimensional point of view. Adding interaction to animation allows the user to work individually with the cartographic presentation. The fully optimized interactive solution is the incorporation in a virtual reality surrounding. The user is no more the viewer but instead becomes a part of the representation and can interact from within.

Examples

The following exemplary list of avalanche mapping illustrations show a small cross-section of the diversity of possibilities cartography can offer:

- European Avalanche Services http://www.slf.ch/welcome-en.html
- North American Avalanche Centers http://www.avalanche.org/
- Visualization of the Austrian Avalanche Bulletin (Master Thesis at the University of Vienna, Department of Geography and Regional Research) http://www.gis.univie.ac.at/karto/karto-aktiv/dipl_app.html
- Photographic Panorama and Potential Avalanche Risk Map Silvretta (KRIZ, GALANDA 1998)
- Map of Avalanche Risk Levels http://www.lawine.at
- Avalanche Risk Forecast, Switzerland http://www.wsl.ch/slf/avalanche/avalanche-de.html
- Avalanche Atlas Uri 1:25.000, Schweiz (FRUTIGER 1980)
- Animation of Flowheight, Avalanche Disaster in Valzur, Austria (VOLK, KLEEMAYR 2000)
- Animation of Flowdepth and Flowpressure of the Avalanche Disaster in Galtür, Austria http://www.bmlf.gv.at/ge/forst/wlv.html
- Scenario of the Avalanche Disaster in Galtuer, Austria (VOLK, KLEEMAYR 2000)
- Simulation of the Lechleiten Avalanche, Austria http://www.bmlf.gv.at/ge/forst/wlv.html
- Avalanche Disaster Galtuer, Aerophoto Map, Austria http://tiris.tirol.gv.at/kat/galtuer/bericht.html
- Torrent and Avalanches, Tirol Atlas, Austria http://geowww.uibk.ac.at/land/atlas/e-lawine.html
- Example from the Sign Construction Set for Natural Hazards, Switzerland http://www.tydac.ch/kt98/thumb_spans.htm
- Touristic Winter Map, Nizke Tatry – zimne strediska, Slowakei, Slowenska kartografia, Bratislava 1990

These and more examples on avalanche mapping can be viewed at http://www.gis.univie.ac.at/karto/avalanche

GIS analysis and modeling in combination with cartographic presentation is essential for interpretation of avalanches and their outcome.

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