Cartographic Analysis of Avalanche Hazard Maps

A Comparison of Relevant Cartographic Factors for the Visualization of the Avalanche Bulletin

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Abstract

We cartographically analysed the avalanche hazard maps of 26 avalanche warning services. The range of the cartographic products reaches from high quality visualizations over simple bitmap-pictures to hazard charts. A survey involving 167 protagonists was conducted. Alpinists indicated that a map with detailed hazard levels for small, well-defined areas is indispensable, while a map with the hazard level dissolved over a large area is dispensable. Because of extensive data measuring, every avalanche warning service is able to differentiate the hazard level by region, height and daily temperature curve.

This paper will give a clear picture of what is needed and easily understood by an inhomogenic user group and will demand a high-quality standard for avalanche hazard maps, following common cartographical rules as well as technical constraints. The results will be addressed in a catalog of requirements.

1. Introduction

The Alps comprise 73,4% of Austria's surface (61,500 km²), with almost 50% of all Austrians (4 million people) inhabiting regions categorized as alpine. About 60 million tourists visited Austria in the last winter season, nearly 8 times more than the Austrian population counts (Statistik Austria, 2007).

In ever increasing numbers tourists, mountaineers and alpinists explore untouched nature and take more risk. Alpine touring received a real boost in the last few years and this trend goes along with a growing number of avalanche victims among these people as a result of a careless attitude towards avalanche hazard, a general neglect of investing time in tour planning and a deficit in cartographic knowledge (Mair, 1998).

Due to the fact, that in mountain regions the snow cover is persistent for more than six months of the year, it is becoming important to deal with avalanches. Some of the most well-known touring areas count nearly 500 ski mountaineers on sunny days. Statistics prove, that 22 people died in an avalanche and 52 were injured last winter season in Austria.

Fig. 1: Crown face of a dry slab avalanche at Hochtennboden, Axamer Lizum, Tyrol, 2003.

In the season 2004/2005 48 people died in an avalanche and 72 people got hurt. A total of 95% of all victims trigger the avalanche themselves. (Würtl, 2005) Consequently it is absolutely essential to be well trained, educated, prepared and equipped to minimize the risk of getting buried by an avalanche.

2. Avalanche basics

The following assumptions will give a clear picture: If you travel in avalanche terrain 100 days per year, cross 10 avalanche slopes per day and the snow is stable enough to cross on 95 percent of the slopes, for every avalanche you accidentally triggers, you get caught every third time and killed every tenth time! (Tremper, 2001) It is essential to comprehend the nature of avalanches in order to be aware of their potential danger.

For nearly most of all deadly accidents the dry slab avalanche (Fig. 1) is responsible. A "slab" is a cohesive plate of snow that slides as a unit on the weak layers underneath. Typically a slab is about 150 m long, about 50 cm deep and accelerates to around 130 km/hr after the first few seconds. Because of very sensitive weak layers, the rapid addition of the weight of a person can easily initiate the fracture on a slope. Both meteorological and topographical factors are responsible for such terrible threats. The weather deposits snow in layers, creates and changes the snowpack within its weak layers and bad surfaces. The most important meteorological factors are wind, temperature and solar radiation. But the weather has different influence on different kinds of terrain, aspect, height and slope. These topographical factors make the condition for slab avalanches and are more easy to understand because of there constancy. Weather changes every day and is a major determinant of avalanche risk, expertise is solely derived from years of monitoring it and its effects on the snowpack. (Tremper, 2001) Hence it takes a lot of experience to minimize the risk of avalanches, because avalanches are not easily predictable but often enough can produce devastating results.

3. Avalanche danger

Generally speaking, the word "danger" means the potential occurrence of a dangerous process such as an avalanche. But it does not indicate whether the process will take place. Avalanches become a "risk", until people or physical assets are situated within the reach of the "dangerous process". "Avalanche danger" describes the likelihood of occurrence of avalanches in a specific region. The exact moment of an avalanche's triggering cannot be precisely determined. (SLF, 2005)

4. Avalanche Bulletin

The avalanche bulletin combines both meteorological and topographical factors and relates them to avalanche danger. It is the main item every avalanche warning service provides. The avalanche bulletin contains information about the current avalanche danger and how it may develop within the following days with regard to the weather forecast.

Relative frequency of the avalanche bulletin-check	
Avalanche bulletin-Check	Percentage
Several times a week	43 %
Only while planning a tour	32 %
Every day in winter	22 %
Rare	2 %
Never	1 %

Fig. 2: Relative frequency of the avalanche bulletin-check.

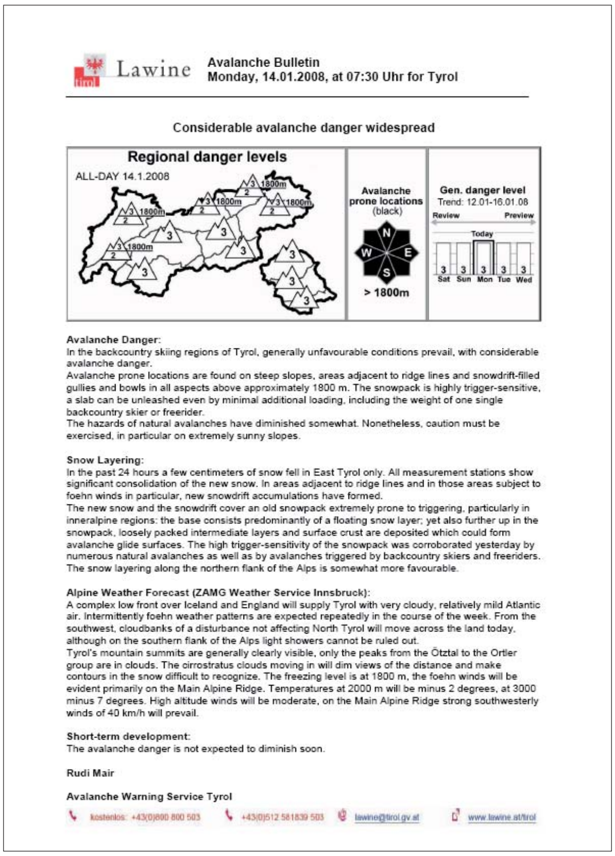
Over 40% of the alpinists check the avalanche bulletin several times a week, 32% while planning a tour, only 1% of the alpinists do not check the bulletin at all. But the avalanche bulletin as well as the weather forecast are the most popular tools for tour planning, a total of 96% o the interviewed mountaineers read the bulletin before starting a tour (Eckerstorfer, 2007).

Defined by the variables snow pack stability and avalanche probability, the avalanche hazard is rated according to the European avalanche hazard scale into a progressively rising scale of five classes ("low", "moderate", "considerable", "high", "very high") (SLF, 2005). The text of the bulletin is standardized to facilitate orientation. The avalanche bulletin contains information about (Land Tirol, 1988):

- Avalanche hazard level according to the European avlanche hazard scale
- The composition / condition of the snow blanket (setting, layering, wetting)
- The past and present weather situation and the snow blanket resulting from it
- The assumed further development of the situation (prognosis)

One main draw-back of the current avalanche warning system is that isolated slopes cannot be evaluated in the bulletin and local details are not considered. Therefore areas that are particularly dangerous are characterised in the bulletin by slope, aspect, height and type of terrain. Despite its limited scope, the bulletin must reach a variety of user groups with different alpinistic knowledge. The majority of the alpinists are hobby mountaineers and not professionals, as also depicted in the online questionnaire (only 15% were professionals) (Eckerstorfer, 2007). Therefore, it is indispensable to provide clear and comprehensible information about parameters which are relevant for avalanche formations, especially danger areas, fresh snowfalls, wind, temperature and the formation of the snow blanket.

Generally spoken, the avalanche bulletin becomes more and more important. The common security philosophy of


Lawine
Avalanche Bulletin
Monday, 14.01.2008, at 07:30 Uhr for Tyrol

Considerable avalanche danger widespread

Avalanche Danger:
In the backcountry skiing regions of Tyrol, generally unfavourable conditions prevail, with considerable avalanche danger.
Avalanche prone locations are found on steep slopes, areas adjacent to ridge lines and snowdrift-filled gullies and bowls in all aspects above approximately 1800 m. The snowpack is highly trigger-sensitive, a slab can be unleashed even by minimal additional loading, including the weight of one single backcountry skier or freerider.
The hazards of natural avalanches have diminished somewhat. Nonetheless, caution must be exercised, in particular on extremely sunny slopes.

Snow Layering:
In the past 24 hours a few centimeters of snow fell in East Tyrol only. All measurement stations show significant consolidation of the new snow. In areas adjacent to ridge lines and in those areas subject to foehn winds in particular, new snowdrift accumulations have formed.
The new snow and the snowdrift cover an old snowpack extremely prone to triggering, particularly in inneralpine regions: the base consists predominantly of a floating snow layer; yet also further up in the snowpack, loosely packed intermediate layers and surface crust are deposited which could form avalanche glide surfaces. The high trigger-sensitivity of the snowpack was corroborated yesterday by numerous natural avalanches as well as by avalanches triggered by backcountry skiers and freeriders. The snow layering along the northern flank of the Alps is somewhat more favourable.

Alpine Weather Forecast (ZAMG Weather Service Innsbruck):
A complex low front over Iceland and England will supply Tyrol with very cloudy, relatively mild Atlantic air. Intermittently foehn weather patterns are expected repeatedly in the course of the week. From the southwest, cloudbanks of a disturbance not affecting North Tyrol will move across the land today, although on the southern flank of the Alps light showers cannot be ruled out.
Tyrol's mountain summits are generally clearly visible, only the peaks from the Ötztal to the Ortler group are in clouds. The cirrostratus clouds moving in will dim views of the distance and make contours in the snow difficult to recognize. The freezing level is at 1800 m, the foehn winds will be evident primarily on the Main Alpine Ridge. Temperatures at 2000 m will be minus 2 degrees, at 3000 minus 7 degrees. High altitude winds will be moderate, on the Main Alpine Ridge strong southwesterly winds of 40 km/h will prevail.

Short-term development:
The avalanche danger is not expected to diminish soon.

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Fig. 3: Avalanche Bulletin of Tyrol, from 14.01.2008.

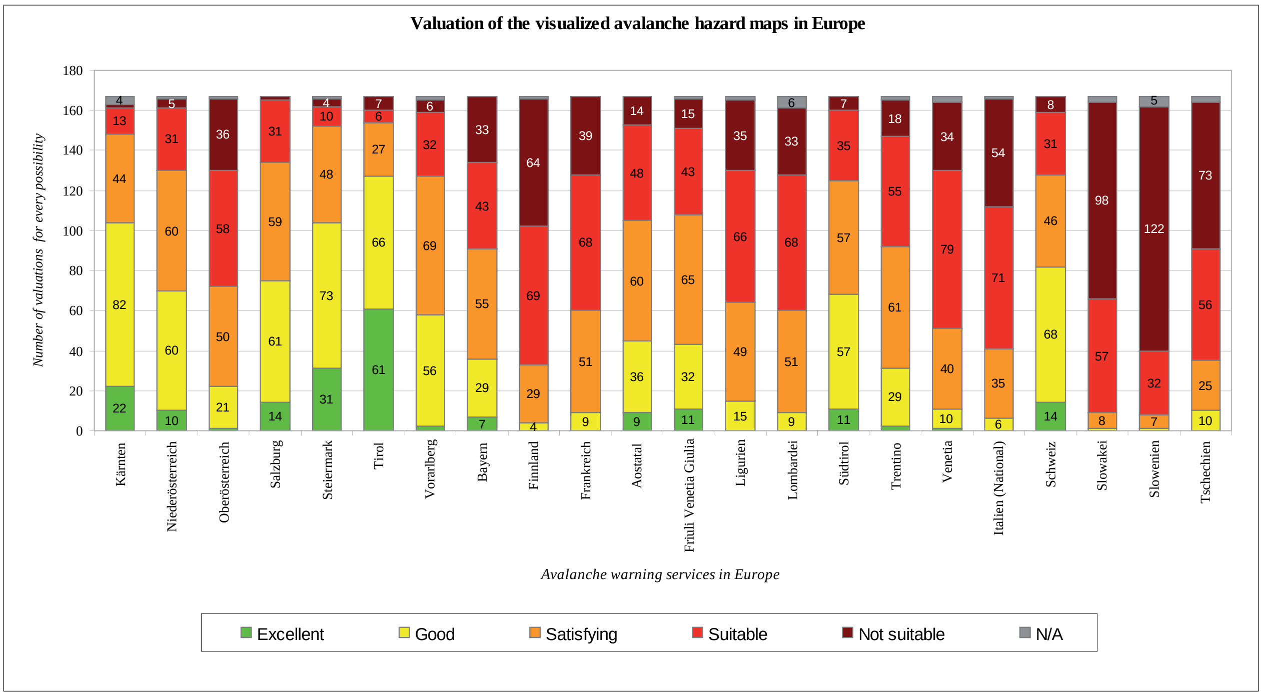

Fig. 4: Valuation of the visualized avalanche hazard maps in Europe.

the 1970s and 80s, which claimed that the snow blanket as the main scientific object is a homogeneous structure and has therefore no danger zones in it, has become obsolete. Furthermore, experts like Werner Munter, a pioneer in the field of practical avalanche research, introduced a conscious risk management. He suggests guidelines to facilitate the decision-making and planning process and invited the mountaineers to "deal with probabilities in a playful way" (Munter, 2003). Risk management deals with the avoidance of steep slopes depending on the hazard level. Risk management methods (StoporGo, SnowCard, Method of reduction) aim to provide a maximum risk reduction.

Therefore the Consortium of the European Avalanche warning services (ARGE EAWS) introduced a new design for the avalanche bulletin (Fig. 3). The most important information should be on top, less important information at the bottom of the text. As a result, the actual regional hazard level is explained on top, followed by avalanche prone locations and information about the general avalanche hazard, snow pack, weather and avalanche hazard trend. (Eckerstorfer and Nairz, 2007)

5. Avalanche hazard map

The cartographic visualization of the current avalanche hazard level can be seen in a close relation to the written avalanche bulletin. *"The so called avalanche hazard map incorporates mainly a topographic map with thematic avalanche features"* (Kriz, 2001). A concise, easy-to-understand representation is able to communicate the information quickly. The avalanche bulletin is often too complicated to understand for lay people, the avalanche hazard map is able to show the current hazard level, divided by height, region, daily temperature curve and aspect. Unfortunately, this ideal case is not always given and the information is not always processed satisfyingly.

In a questionnaire I asked if the visualization of the avalanche bulletin is dispensable. 64% protagonists use the avalanche hazard map to gain all the information needed, people with poor alpine education rely on the cartographic visualization to a higher degree (50%) than people with alpine experience (80%). Mountaineers and alpinists also trust the written bulletin much more (nearly 95%) than winter tourists and hobby-mountaineers (60%). (Eckerstorfer, 2007)

And therein lies the challenge. From the cartographer's point of view, meteorological and topographical factors have to be portrayed in their context on a map. It is a tricky task, to simplify real world three-dimensional phenomena into a spatial model, so to consider a map as a model of reality. To show the terrain-specific parameters that influence the avalanche paths a large-scale topographic map is well suitable. (Kriz, 2001). Slope and aspect, the most important topographic features can be derived easily from topographic maps. The various meteorological factors are much more difficult to visualize for cartographers and defy an easy visualization with conventional (static) cartographic tools. The main objectives of avalanche hazard mapping are therefore (Kriz, 2001):

- Cartographic design, layout and presentation using multimedia technology
- Digital Terrain Model (DTM) assessment for high quality feature derivation
- Combination of various fields of study (avalanchescience, risk research, web design, psychology of perception)

As a result, a consistent high-quality standard for avalanche hazard maps, following common cartographic rules should be achieved, so that the avalanche hazard map will fulfil

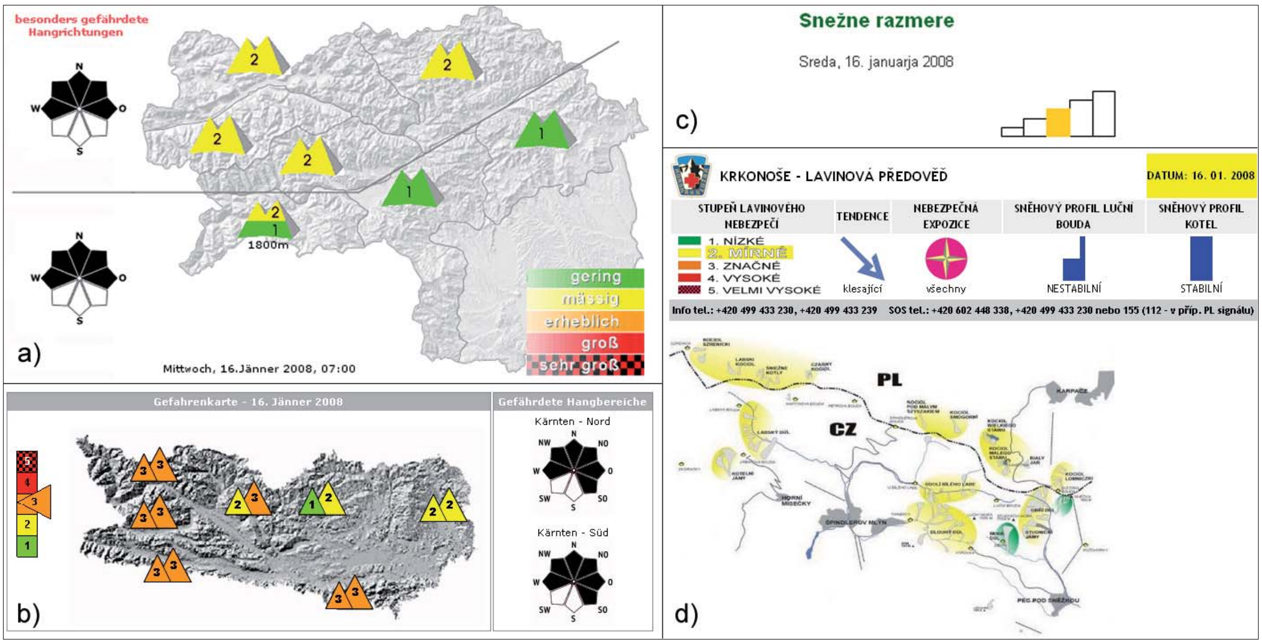

Fig. 5: Sample of 4 different avalanche hazard maps in Europe.

its role as a carrier of communication and information in the sense of the cartographic communication process. The principles of cartographic communication enable efficient methods to disseminate up-to-date information and offer a direct connection between the cartographic product and the user as well as the possibility to respond immediately.

6. Questionnaire

I cartographically analysed the avalanche hazard maps of 26 avalanche warning services (Eckerstorfer, 2007). The range of the cartographic products reaches from high quality visualizations over simple bitmap-pictures to hazard charts. A survey carried out on 167 protagonists was made. Alpinists indicated that a map with detailed hazard levels for small, well-defined areas is indispensable and a map with the hazard level dissolved over a large area is dispensable.

Fig. 4 shows the number of valuations given by the protagonists for every avalanche warning service in Europe. The avalanche hazard map of Tyrol (cf. Fig. 6a) is the best rated as “excellent” by 67 individuals, followed by the maps of Steiermark / Styria with 31 (Fig. 5a), Kärnten / Carinthia with 22 (Fig. 5b), Salzburg and Switzerland with 14. The hazard map of Slovenia with 162 “not suitable”-mentions received the lowest rating of the tested maps (Fig. 5c). Also the Czech Republic with 73 and Finland with 64 (Fig. 5d) did not achieve a good result, because either they do not provide a hazard map or the cartographic visualization is incomprehensible.

To receive a ranking, I calculated the overall average grade for every avalanche warning service (1 = “excellent”, 2 = “good”, 3 = “satisfying, 4 = “suitable”, 5 = “not suitable”). Outstanding winner was Tyrol with an average grade of 1,99, because the protagonists valued the clear topographic representation and the classification of the various mountain regions. Both ensure a good and fast overview and orientation. Other criteria for a good ranking were the differentiation of the avalanche hazard level by height, daily temperature curve and aspect, which are offered for example in Sytria with 2,30 (Fig. 5a), Carinthia with 2,33 (Fig. 5b) and Switzerland with 2,71 (Fig. 6a). Slovenia (Fig. 5c) was ranked last with an average grade of 4,70 due to the insufficient information of the stacked bar graph without key.

7. Catalog of requirements

Because of extensive measuring data every avalanche warning service is able to differentiate the hazard level by region, height and daily temperature curve. Therefore a clear cartographic visualization should be aspired. This could be achieved with a catalogue of requirements for a high quality avalanche hazard map:

7.1. Differentiation and cartographic visualization of the avalanche hazard level

The analysis of all 26 avalanche hazard maps in Europe showed that different regions require a varying cartographic visualization and differentiation of the avalanche hazard level (Eckerstorfer, 2007). A differentiation of the hazard level by region, height and daily temperature curve depends on the topographic and climate conditions in the region:

- Differentiation by region
  - For widespread areas with different meteorological influences.

- Differentiation by height
  - For mountain areas with great heights and big altitude difference.

- Differentiation by daily temperature curve
  - Especially for spring time with distinctive daily temperature curve as well as strong cooling in the night and strong warming the next day.

- Differentiation by aspect
  - Because of meteorological factors wind and solar radiation. Always in connection with the altitude at which avalanche prone locations take place.

The four possibilities of differentiation of the avalanche hazard level need several, complex cartographic solutions. The avalanche hazard level can be visualized by colorizing the area or by using multilayer, coloured symbols. The colour correlates the colour of each hazard level according to the European avalanche danger scale. It is absolutely necessary to picture both, colour and the hazard level by number. By using symbols (mountain symbols are common and clearly understood) it is important to pay attention to its size. Small symbols are hard to distinguish/read but oversized symbols can hide important topographic information underneath and make the map look overloaded and unclear. Color codes pose a problem to achromates, who cannot distinguish the hazard level, therefore additional black & white avalanche hazard maps are required.

- Differentiation by region
  - By using a multilayer, coloured symbol with the hazard level as a number for every region.
  - By colorizing the different regions, separated by the region borders. (Fig. 6a)

- Differentiation by height
  - By using a multilayer, coloured symbol (the hazard levels for lower and higher altitudes are indicated on the bottom and top, respectively, as well as the height, at which the hazard level changes. (Fig. 6b)
  - By colouring the different altitudes using a DTM. (Fig. 7a)

- Differentiation by daily temperature curve
  - By using a multilayer, coloured symbol (on the left side the hazard level for the morning situation is indicated, on the right side for the afternoon situation). (Fig. 5b & 6c)
  - By colorizing the different regions and using two maps, one for the morning situation and one for the afternoon situation. To avoid any confusion it is absolutely necessary to label each map.

- Differentiation by aspect
  - By using a wind rose displaying avalanche prone locations for the indicated altitudes. Usually endangered aspects are shaded in black and explained in a text above the wind rose. (Fig. 6d)

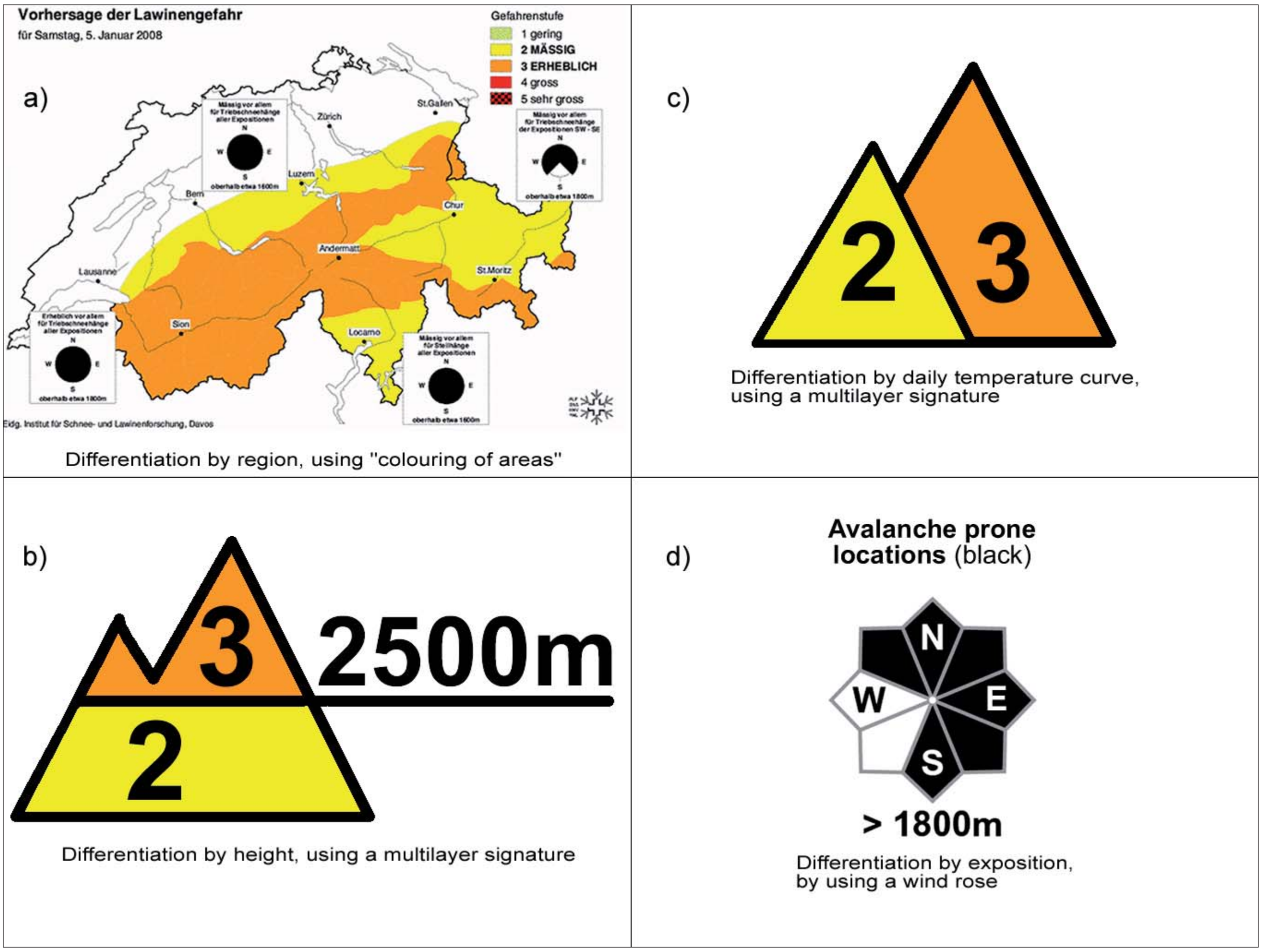

Fig. 6: Four possibilities of differentiation between the avalanche hazard level

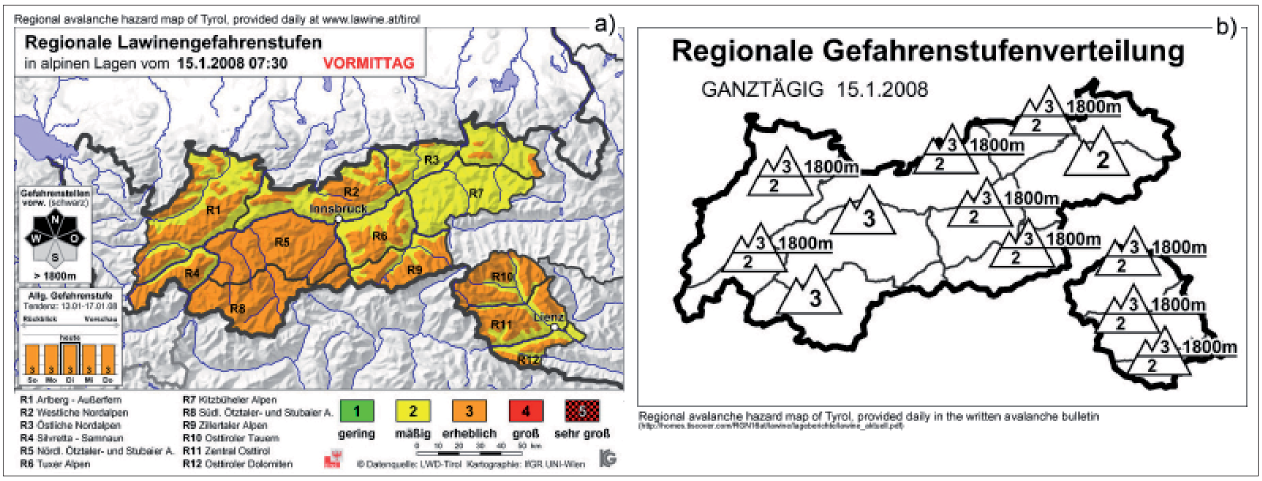

Fig. 7: Comparison of the regional avalanche danger maps provided as different products in Tyrol.

7.2. Topography

In order to use slope and aspect for avalanche classification and to give the user a good overview and orientation over the region, it is important ho have a high quality base digital elevation model (DEM). DEMs can be derived from digital terrain models (DTM) in different ways. Using isolines from topographic maps with breaklines and high points is very common. (Kriz, 2001) It is essential to be aware of the quality and the resolution of the produced DEM to achieve the best results, standards and guide-lines for the implementation of DTMs and DEMs should be determined.

7.3. Map elements and cartographic visualization

Cartographic design issues as well as the visualization of the thematic elements play an important role, especially in the fields of understanding the given topic. They are essential for spatial communication and effective perception of information. An avalanche hazard map always consists of a title, a frame, a key, furthermore a wind rose to display avalanche prone locations, a catchline with the most important information, date and time to make sure, that the map is up-to-date and a hazard level trend, symbolised by arrows or a t. Therefore, high quality cartographic visualization is fundamental to ensure an optimum usability.

Because of technical constraints it is sometimes necessary to provide a less high quality cartographic product without all its technical possibilities in compiling and visualizing. As a result, the avalanche cartographer has to adapt the map or several map elements to ensure, that its target group is able to gain the information provided. For example a hazard map with a shaded relief and a hazard differentiation visualized by colouring the particular areas is impossible to read after it was sent per fax. So the cartographic visualization has to be smart, simple (KISS) and hit the nail on the head (Fig. 7a & 7b).

7.4. Technical implementation and web design

Nowadays technical implementation (Kinberger, 2003, Pichlbauer, 2007) and web design is becoming more and more important. This "trend in cartography" demands new rules and basic conditions. Kraak and Brown (2001) supported this view and commented that technical constraints hamper the visualization of data. There are some adjustments necessary in the sense of visualizing data and utilising interactivity and dynamic. The advantages of cartographic representations on the Internet can be seen in up-to-dateness, interactivity, spatial communication as well as efficient and cost-effective dissemination. Four premises are important for a web based avalanche prediction tool (Kinberger et al., 2003):

- An Internet interface as a portal for visualization

- Cartographic expertise for geospatial representation

- Automatic weather data retrieval from external locations

- The use of automatic cartographic procedures

For example at the avalanche warning service of Tyrol, the map compilation is totally automatic. Tyrol has a very complex and powerful database driven online decision support system for cartographic visualization and analysis of current avalanche relevant factors in the Tyrolean Alps. All information, reaching from meteorological and spatial data to the avalanche danger situation can be interactively made accessible to the user (Kriz et al., 2004).

7.5. Colour and Cartography / psychology of perception

The representation of the five levels of the European avalanche danger scale must communicate critical consequence and support understanding. Visualization can be successfully accomplished by applying a set of cartographic guidelines according to the desired understanding of the avalanche danger scale (Low – green, moderate – yellow, considerable – orange, high – red, extreme – red w/black). Colour perception is not easily analysable but indispensable to create an initial feeling of alertness with the first view of the avalanche hazard map. Dealing with colours to show the hazard level is quite complicated and leads to accurate analysis about colour and cartography as well as the psychology of perception.

The use of green correlates with the widely used decision support description of "green light terrain" (Fredston, Fesler, 1994). Neither the colour yellow nor orange are emotionally assigned to levels of risk and thus do not provoke alert behaviour (CAA, 2002). In contrast, red is the widely accepted colour of danger and risk. Additional research to validate the actual colour code and the understanding of the effect of different colours to different map users need to be conducted.

8. Outlook

An important task of my work is to analyse the gateway between map and user. As mentioned above, an inhomogeneous user group makes demands on the information the avalanche warning services offer. More and more people explore the mountainous regions but only a few of them know about the risks and dangers of a beautiful snow covered landscape. When investigating avalanche accidents the most consequential question is not one of slope angles, aspect and weather conditions, but one about the victim's cognitive skills. "What interfered with the person's judgement at the crucial moment?"

The avalanche hazard map has to be easy to understand for people with less alpinistic knowledge and experience and should as well offer enough specific information for mountain guides and professionals.

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