VISUALIZING NATURAL HAZARD DATA AND UNCERTAINTIES – CUSTOMIZATION THROUGH A WEB-BASED CARTOGRAPHIC INFORMATION SYSTEM

Melanie Kunz[a,]*, Adrienne Grêt-Regamey[b], and Lorenz Hurni[a]

[a] Institute of Cartography, ETH Zurich, Switzerland - (kunz, hurni)@karto.baug.ethz.ch
[b] Planning of Landscape and Urban Systems, Institute for Spatial and Landscape Planning, ETH Zurich, Switzerland - gret@nsl.ethz.ch

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ABSTRACT:

Communication of natural hazard assessment results is crucial to protect people and infrastructure from devastating impacts of extreme events. While hazard maps provide important information on potential impacts, their interpretation and the general knowledge exchange between stakeholders is often difficult. Web-based information systems contain the potential to support hazard management tasks by fast distribution and customization of hazard visualizations through interactive functionality. However, cartographic principles are often ignored in existing web-based visualizations which leads to poor graphical results and consequently to an impairment of the information flow. While these issues need to be solved, a new task is already waiting: the integration of uncertainty information into hazard visualizations. Since many hazard management activities rely on hazard assessment results, communication of associated uncertainties among experts is vital.
The challenge of this research is to overcome these existing shortcomings by combining high quality cartographic visualizations of natural hazard data as well as associated uncertainties with interactive functionality. The resulting web-based cartographic information system will convene the needs of natural hazard specialists by offering a high level of customization: the suggested visualizations include various cartographic techniques such as the application of textures, bars, and interpolated surfaces. The possibility to interactively select particular data sets, customize colors, choose dimensions, query attribute data, and include uncertainty information facilitates the interpretation of complex data and finally the communication among natural hazard specialists.

1. INTRODUCTION

1.1 Motivation

Natural disasters cause suffering through the harm of people and infrastructure as well as enormous economical damage. Natural hazard management aims at minimizing these impacts by the tasks of prevention, event management, and rebuilding (Bezzola and Hegg, 2008). Assessments of natural hazards form the basis for all management tasks and are therefore a crucial component of hazard management. This fact has become apparent during the last years and consequently funds for the advancement of hazard assessments as well as the enhancement of management strategies have been allocated (e.g. by the Swiss Government).

Cartographic representations have proved suitable for the communication of hazard assessment results which is reflected in the fact that the generation of hazard maps as basis for land-use-planning is standard procedure in many countries and in some places even regulated by law (e.g. Switzerland**, Colorado***, and many more). However, recent analyses of past flood events (Bezzola and Hegg, 2008) showed that the requirements towards these maps have increased over the last years: not only spatial planners for who these maps were designed work with these visual representations of natural hazard assessment results, but also many stakeholders involved in different tasks of hazard management. Bezzola and Hegg therefore suggest that hazard assessments should not be performed for a particular application anymore but as a general basis for various future uses. Once these multifaceted results exist, they can be visualized for specific users according to their requirements. These visualizations, however, have to be generated following cartographic design principles in order to produce clear and well balanced maps that are effortlessly readable.

An additional issue which is often discussed in different hazard management phases and tasks is the question of uncertainty inherent to hazard assessment results. Many important decisions that can have severe consequences for third parties (e.g. initiation of evacuation, construction bans, etc.) are based on these results. Information about the accuracy of the presented data is therefore very important. However, until now, most hazard maps pretended absolute certainty by solid borders of hazard zones even though experts agree that the definition of hazard zones is associated with uncertainty. Apart from the difficulties of quantifying existing uncertainties, this issue also poses a cartographic challenge: there are no guidelines about suitable methods for uncertainty visualization in natural hazard maps and most existing recommendations are only of theoretical nature (Pang, 2008).

1.2 Overview and References to Related Work

The Internet has evolved to one of the most relevant media to publish cartographic information, as it facilitates greater access to spatial information, increased levels of interactivity with maps,

* Corresponding author
** Federal Law on Water Construction (WBG, SR 721.100), 1991 and Federal Law on Forestry (WaG, SR 921.0), 1991
*** Colorado State House Bill 1041, 1974

real-time locational information, and greater integration of multimedia content through pictures, sound, and video (Peterson, 2008). In recent years, web cartography shifted towards a distributed and service-oriented cartography, providing individual maps on-demand for specific purposes (Schnabel and Hurni, 2009). While early web maps were mostly raster-based and static, modern interactive applications allow for thematic as well as geographic navigation and offer visualization functionality to display available data according to the specific needs of the users. In addition, users can be guided through the map making process in order to avoid the violation of cartographic rules. Consequently, a web-based cartographic information system provides a well suited environment for the visualization and exploration of natural hazard data as well as associated uncertainties.

Chesneau (2004) analyzed over two hundred hazard visualizations which were published in geographic journals and the Internet and observed that most maps are published in printed form; interactive or multimedia environments are rare. Her analysis also showed that most web-based maps offer little interactive functionality and consequently the implementation of animations and interactivity into natural hazard visualization environments is suggested. Research by Peterson (2007) confirms that it is generally believed that multimedia and interactive techniques can convey the multifaceted and dynamic character of the spatial environment much more effectively than static paper maps.

The lack of interactive functionality in web-based applications can also be observed in tools for the presentation of spatial data in general. In Switzerland for example, such tools have become common during the past years and every canton (= state or province) maintains its own system. These so called geoportals are designed for the general public and the typical application offers little interactivity: thematic content is available in a layer structure so that users can select the topics they want to have visualized in 2D maps and sometimes the query of attribute information is possible. Further interactions are generally limited to zooming and panning.

However, the need for interactive expert tools has been indentified in recent research. Lienert *et al.* (2009) developed a web-based application for the real-time visualization of hydrological data. This application offers functionality to interactively monitor, retrace, and compare the available data. Romang *et al.* (2010) built on the experiences of snow avalanche tools and established an interactive early warning and information system for floods and debris flows. Also the issue of uncertainty visualization is topic of current research projects: Bostrom *et al.* (2008) presented a review of research about the visualization of seismic risk and uncertainty and Pang (2008) discussed the issue in detail and presented potential methods for visualizing uncertainty in natural hazards such as the application of blurriness, transparency, or fuzziness, the use of color hue, saturation, or value, the superimposition of a grid that is modified according to uncertainty values, the drawing of contour lines, the variation of the thickness, brightness, or connectedness of symbolization, the use of glyphs, histograms, or box plots, or the creation of complex 3D surfaces.

1.3 Aims

The objective of this research is to facilitate the interpretation of natural hazard assessment results by implementing natural hazard assessment data into a web-based cartographic information system. Since these systems provide collections of spatially related knowledge, they are also referred to as Multimedia Atlas Information Systems (MAIS). According to Hurni (2008), MAIS are defined as follows: they consist of a harmonized collection of maps with different topics and scales. The maps have a common legend and symbolization. MAIS dispose of interactive functions for geographic and thematic navigation, querying, analysis, and visualization in 2D and 3D mode. Unlike in many geographic information systems (GIS) applications, the data in MAIS is cartographically edited and the functionality is intentionally limited in order to provide a user-targeted set of data as well as adapted analysis and visualization functions. In multimedia atlases, additional related multimedia information, like graphics, diagrams, tables, text, images, videos, animations, and audio documents, are linked to the geographic entities.

All advantages of MAIS characteristics are integrated into our cartographic information system to ensure for a customized visualization that meets the requirements of natural hazard experts. In addition to high quality visualizations of thematic information about hazard assessment results, our system also allows for the visualization of uncertainty inherent to these results, which is needed to support users during their decision making tasks.

2. REQUIREMENTS

According to Acevedo *et al.* (2008) evaluations of visualization methods by visual design experts are faster and more productive than quantitative user studies. We therefore decided to design a first version of our cartographic information system according to the opinions of specialists in the field of web-, multimedia-, and atlas-cartography. As a first step we collected general feedback from project leaders of ongoing and completed projects of the Institute of Cartography of ETH Zurich (IKA) in order to adopt the main findings about design of graphical user interfaces (GUI), interactive functionality, and visualization methods for our cartographic information system. These projects include the Atlas of Switzerland (2004), the Swiss World Atlas interactive (2010), GEOWARN Geospatial warning system (2003), and Real-Time Cartography in Operational Hydrology (Lienert, 2009). After the development of a first version of the prototype it was presented to the above mentioned specialists who subsequently rated and prioritized specific elements and provided suggestions for improvement. The goal of these expert interviews was to determine the main priorities for the design of an optimal GUI, promising visualization methods, as well as the main functionality which should allow users to customize the visualizations in order to meet their requirements. The findings of these expert interviews were integrated in the first version of the prototype and will be explained in detail in the following sections.

2.1 User Definition and Content Requirements

Cartographic representations can only be optimized if end users and data types are known. As mentioned in the introduction of this paper, end users of our Cartographic Information System are stakeholders involved in different task of natural hazards management. These specialists encompass scientists, engineers, and spatial planners working for private companies, national or federal offices, or humanitarian organizations. Consequently, they come from different backgrounds, have different skills, and are engaged with different tasks. This very heterogeneous user group of experts will therefore exhibit different needs and requirements for hazard and uncertainty visualizations.

The goal of this research is to account for these different needs by offering interactive customization of natural hazard visualizations. Although a variety of visualization methods have to be provided to meet the different visual preferences, the underlying data set will remain the same as all users are interested in the answer to the following questions: (1) Is a specific area endangered by natural hazards? (2) What processes can occur? (3) How frequent and how intense will the hazardous events be? The level of detail the answers to these questions have to offer varies from user to user and from task to task. We therefore provide the option to interactively choose the data layers of interest as well as scale and dimension of presentation. Apart from thematic data map backgrounds for orientation in form of aerial images, topographic maps, and survey plans are available. This background data is provided in form of raster images.

Thematic data includes assessment results of the processes snow avalanche, debris flow and flooding. Available data comprise snow heights, velocities, and pressure for snow avalanches, flow height and velocities for debris flows, as well as water depths and velocities for flooding. Raster-based input data (ascii-files) are loaded into the cartographic information system and converted into interactively queryable 2D and 2.5D symbolization (areal symbolization, bars and interpolated surfaces).

As mentioned in the introduction, uncertainty inherent to natural hazards assessment results presents an issue for many stakeholders. The question of how to visualize this information forms a major part of this research and will be discussed in detail in section 3. Uncertainty information is also imported in form of raster files and converted into 2D and 2.5D symbolization that can be interactively queried.

2.2 Visualization Requirements

2.2.1 General Requirements: Chesneau's research (2004) showed that most web-based hazard maps are raster based and lack cartographic quality. Cartographic principles are often ignored because the mapmakers are domain specialists and not cartographers. In order to generate visually appealing and effortlessly readable maps, cartographic principles such as an appropriate choice of color, balance between thematic layers and base map, or maximum numbers of classes have to be followed.

Additionally, screen maps have to be designed coarser and simpler than paper maps in order to convey the desired information under less than ideal conditions of low screen resolution, increased viewing distance, and shorter reading time (Jenny *et al*., 2008). All these guidelines and suggestions are implemented in our cartographic information system: the offered colors, base maps, and layer combinations are in accordance with these rules and ensure cartographically high quality maps.

2.2.2 Symbolization Requirements: The Swiss standard coloring for hazard maps (yellow for low hazard, blue for moderate hazard, and red for high hazard, as explained in Loat and Petrascheck, 1997) are not always considered to be sensible or logical (Zimmermann *et al*., 2005).

We therefore offer different color schemes for the depiction of thematic data from which the user can choose the most appealing. Snow avalanche parameters for example can be visualized in grey, blue, or purple (see Figure 1), the cold colors reflecting the characteristics of snow. For all color schemes at least one of the options convenes the needs of color vision impaired users.

Further shortcomings of hazard maps include illegibility due to the included wealth of information and unsuitable symbolization (Zimmermann, 2005). The issue of information overflow can be solved by interactive navigation functions, such as a layer structure of the data or adaptive zooming. If the overlaying of several layers is of interest nonetheless, suitable area symbolization such as gridded patterns can avoid the overlapping of thematic information.

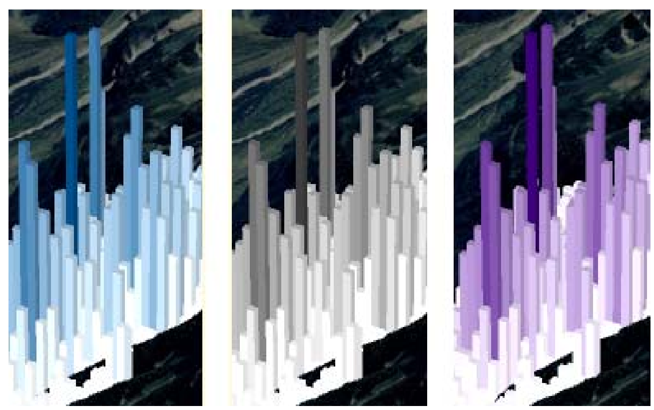

Figure 1. Different color schemes for the depiction of snow avalanche assessment results

In order to convene the needs of the heterogeneous user group, different visualization methods are offered: apart from traditional 2D maps also a block diagram (3D view of a rectangular extract of the surface as shown in Figure 2) can be chosen as background for the thematic data. Hazard assessment results as well as uncertainty information can then be added in form of texture, bars, or interpolated surfaces. This 2.5D symbolization complements the standard 2D maps and gives an overview on the terrain and the dynamics of hazardous processes. According to the cartography experts real 3D symbolization such as little abstracted, photorealistic representations of hazardous processes does not bring any advantages for the analysis of natural hazards data and was therefore not implemented in our system.

2.3 Functionality Requirements

A very significant element of the usability of MAIS is the degree of interactivity which is based on the richness of interactive

functionality (Hurni, 2008). Cron (2006) analyzed these functions and provides suggestions for structured GUIs. Her classification of functionality is based on Ormeling's (1997) outline and encompasses general functions, functions for navigation, didactic functions, cartographic and visualization functions, and GIS-functions. General functions are permanently available for the users, irrespective of the displayed data. Navigation functions comprise functions for spatial, thematic, and temporal navigation. Didactic functions offer explanations about maps, predefined tours, movies, or images as well as self control functions to test the acquired knowledge. Cartographic and visualization functionality allows for the graphic modification of visualizations and are used for the enhancement of the map message. They encompass map manipulation, redlining (addition of drawings, labeling, and comments), and exploratory data analysis. GIS-functionality serves for the handling of space and object oriented as well as thematic information. They include spatial and thematic information retrieval functions as well as analysis functionality.
To determine the importance of single interactive functions, we presented a list of potential functions (see Table 1) to the IKA cartography experts. The experts were asked to prioritize the functions from 1 (must be implemented) to 4 (very low priority). The prioritization was evaluated and the findings served as guideline for the first prototype of our cartographic information system for the visualization of natural hazard results and inherent uncertainties. A summary of the findings concerning the prioritization of interactive functionality is provided in the following sections.

2.3.1 General Functions: The cartography experts considered a graphical scale bar, buttons to switch between 2D and block diagram mode, as well as highlighting the according legend entry when the mouse is moved over symbolization as the most important general functions for a cartographic information system.
Functions that are rated useful but not first priority will be implemented in a later phase of the project and include a help menu with explanation about the proper use of the functions, the option to go back to the last viewed map, and a print option.

2.3.2 Navigation Functions: Concerning the spatial navigation experts suggested prioritizing the functions of zooming, panning, tilting and rotation (for block diagram mode only), and the display of an overview map.
However, zooming is only judged as useful if adaptive zooming is implemented. Adaptive zooming means that each zoom level is generalized according to its scale so that the map is not only magnified, but also more information is displayed when zooming in (Brühlmeier, 2000).
Top priority for thematic navigation was given to the implementation of a layer structure so that data may be individually chosen for display by the users. The need for a search engine for names and places was assigned second priority.
Temporal navigation of natural hazard assessment data is not part of this research and according functionality will therefore not be implemented.

General Functions
Information about zoom factor (figure, e.g. 1 : 10 000)
Graphic scale bar
Switching between 2D and 3D mode
Highlighting of legend
Help menu
Print option
Jump to previous map display
Navigation Functions
Zooming
Panning
3D navigation (rotation and tilting)
Overview map
Layer structure
Search function for place names
Explanatory Functions
Integration of additional information about data and uncertainty
Photo archive
Cartographic and Visualization Functions
Free addition and removal of layers to the display
Layer transparency
Free classification of thematic data
Choice of colors
GIS Functions
Display of coordinates (x, y, z)
Measurement tool
Display of statistical data
Generation of cross sections
Display of tooltips for attribute query
Real GIS functions such as spatial intersection, creation of buffers, etc.

Table 1. List of potential interactive functionality that was rated by the cartography experts (Grouping according to Cron, 2006).

2.3.3 Didactic Functions: Didactic functions are not needed for an expert system. However, the integration of explanatory functions, such as detailed information about the assessment results (methodology, date of assessment, etc.) as well as details about the uncertainty information (method of quantification, etc.) was rated to be of second priority. The implementation of a photo archive was listed as an interesting but not necessary feature.

2.3.4 Cartographic and Visualization Functions: First priority for map manipulation functionality was assigned to the free addition and removal of layers to the map display as well as the control over layer transparency to avoid concealment of important information. The altering of colors was rated second priority.
Redlining was only mentioned as innovative idea that could be considered as comments or drawings of experienced specialists might be of interest to other users.
Functions for exploratory data analysis should primarily include the free modification of data classification (choosing number of classes, thresholds, as well as coloring). The option of a split display for the comparison of different thematic layers is an idea that will be considered in a later stage.

2.3.5 GIS Functions: None of the proposed spatial navigation functions was prioritized by our experts. The display of current cursor position coordinates and measurement tools were only assigned second priority.

Thematic and object related information (attribute information) can be retrieved and displayed in form of tooltip windows. Tooltip windows appear next to the cursor when moved over thematic symbolization (e.g. bars). This functionality was considered to be important. However, apart from the display of tooltip information also the option to remove this additional window from the display was given high priority. Further development could foresee to offer different levels of tooltip information. The display of statistical data (such as mean values, etc.) has second priority.

Analysis functions are used to generate new information and connections between spatial phenomena (Bollmann and Koch, 2001). None of these functions were assigned first priority. Analysis functionalities to be implemented in a later phase include merging, intersection, and aggregation of thematic layers. The generation of cross sections was rated to be of very low importance.

3. VISUALIZATION OF UNCERTAINTIES

The dilemma of needing accurate assessment data for the planning of mitigation tasks to minimize the impacts of natural hazard events and the inability to provide assessment results without uncertainties has been a well discussed issue in the natural hazard management community for the last years. Some experts advocate the inclusion of uncertainty information in hazard visualizations while others argue that additional information only confuses the map reader. Evans (1997) investigated this issue and found that the graphic depiction of reliability information was accessible and comprehensible by all participants of her study.

Presently only a few hazard representations include information about uncertainty and existing visualization tools and techniques are quite rudimentary (Pang, 2008). In order to remedy this obvious shortcoming, we integrated information about uncertainty in our cartographic information system and offer different methods for its visualization.

Uncertainty encompasses different concepts such as imprecision, imperfect knowledge, inaccuracy, inconsistency, missing information, noise, ambiguity, lack of reliability, etc. (Pang, 2008). These aspects can be expressed in different ways, e.g. as statistical variations or spread, min-max range values, data quality or reliability, likelihood and probabilistic estimates, etc.

In our system the exploration of uncertainty inherent to the available thematic data is also provided by interactive functions: on the one hand uncertainty can be displayed in a tooltip window when the cursor is moved over symbolization of a thematic layer, expressed as single scalar value. On the other hand we provide the option to visualize uncertainty either as additional layer or combined with the visualization of the thematic data. If uncertainty is visualized in an additional layer, isolated from the data in a separate layer, color is used for its representation in both, 2D and the block diagram mode. In the block diagram mode also the variable size (height of bars and interpolated surfaces) is used for the depiction of uncertainty values. In the combined visualizations uncertainty is mapped to saturation, transparency, or density of speckles (after Djurcilov *et al*., 2002) of texture overlay.

4. PROTOTYPE

The implementation of the experts' opinions concerning design and useful functionality resulted in a first version of the cartographic information system for the visualization of natural hazards assessment results and inherent uncertainties. It was designed as a Java Web Start application, which allows for the implementation of the needed interactivity and the 3D block diagram mode. The GUI of the system makes use of existing modules of the interactive version of the Swiss World Atlas (Swiss World Atlas interactive, 2010) which will be published this fall. This elaborate user interface has been designed for high school geography students and is characterized by its intelligible layout. Time-consuming training should therefore be prevented. Until now, our Cartographic Information System provides standard assessment results of gravitational natural hazards for the study area of the "Stampbach" area in the community of Blatten, Switzerland. Figure 2 shows the GUI of our cartographic information system; the map window is set to block diagram mode and the display shows the thematic layer "maximum snow height" symbolized by colored bars. The height of the bars represents the snow height in meters (superelevation of 50). Active bars are highlighted in red and supplemented with a tooltip window.

The implemented functionality allows users to choose among the layers they want to explore and navigate spatially with the help of a navigation tool or by mouse actions. The position of the cursor is displayed in form geographic coordinates (including altitude) in the bottom left corner of the map window, together with a scale bar. Two dominant buttons are placed in the top left corner of the map window and serve for switching between 2D maps and the block diagram mode. Map symbolization includes 2D texture, bar symbols, and interpolated surfaces. This symbolization can additionally be altered by choosing from different color schemes. Whenever the mouse is moved over symbolization elements, the active element is highlighted and information about its values (including uncertainty) is displayed in a tooltip window.

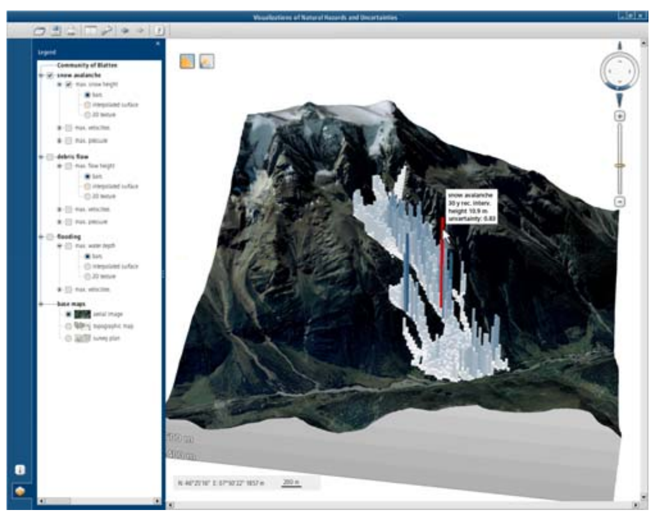

Figure 2. Graphical user interface of the cartographic information system for the visualization of hazard assessment results and associated uncertainties.

In addition to the choice of the thematic layers and symbolization, also the base map can be selected; an aerial image, a topographic map, and a survey plan are available.

5. CONCLUSIONS

The existing need for customized hazard visualization is suggested to be satisfied by the help of interactive cartographic information systems. Our prototype of such a system offers different visualization methods and interactive functionality to customize them accordingly. The addition of a block diagram mode as supplement to the standard 2D map mode opens new options for the visual analysis of natural hazard assessment results. With the integration of uncertainty visualizations into our system we aim at supporting the tasks of natural hazards management, including decision making processes.

The applied Java Web Start technology allows for immediate repose to the interactive functionality. In addition, it makes use of rendering algorithms that result in high quality visualizations in 2D and 3D.

With the resulting interactive cartographic information system we provide an innovative tool for the user specific visualization of natural hazard assessment results and associated uncertainties.

6. OUTLOOK

The first version of our cartographic information system for the visualization of natural hazards assessment results and inherent uncertainties has been designed according to feedback from cartography experts. Since user-centered approaches are suggested for the development of cartographic systems (Schobesberger, 2009), and Acevedo *et al.* (2008) emphasize that expert critiques cannot replace quantitative studies, the prototype will be further enhanced by user-tests and additional interviews with natural hazards specialists in order to optimize the usability of the system. Special attention will be paid to the issue of uncertainty visualization. Such visualizations are expected to be of value to natural hazards experts, however, their effectiveness will have to be confirmed by user-tests.

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8. REFERENCES

Acevedo, D., Jackson, C.D., Drury, F., Laidlaw, D.H., 2008. Using visual design experts in critique-based evaluation of 2D vector visualization methods. *IEEE Transactions on Visualization and Computer Graphics* 14(4), pp. 877-884.

Atlas of Switzerland, 2004. http://www.atlasofswitzerland.ch (accessed August 19, 2010)

Bezzola, G.R., Hegg, C., 2008. Ereignisanalyse Hochwasser 2005, Teil 2 - Analyse von Prozessen, Massnahmen und Gefahrengrundlagen. Umwelt-Wissen.

Bollmann, J., Koch, W.G., (Eds.) 2002. *Lexikon der Kartographie und Geomatik in zwei Bänden.* Band 2 Karto bis Z. Spektrum Akademischer Verlag, Heidelberg/Berlin.

Bostrom, A., Anselin, L., Farris, J., 2008. Visualizing Seismic Risk and Uncertainty. *Annals of the New York Academy of Sciences* 1128, pp. 29-40.

Brühlmeier, T., 2000. *Interaktive Karten – adaptives Zoomen mit Scalable Vector Graphics*. MSc Thesis ETH Zurich. http://www.ika.ethz.ch/teaching/Diplomarbeit-Bruehlmeier.pdf (accessed September 8, 2010)

Chesneau, E., 2004. Proposition pour une cartographie du risque. *Le Monde des Cartes*, no. 181(2004), pp. 55-70.

Cron, J., 2006. *Graphische Benutzeroberfläche interaktiver Atlanten*. BSc Thesis Hochschule für Technik und Wirtschaft Dresden. http://www.ika.ethz.ch/teaching/Diplomarbeit-Cron.pdf (accessed September 2, 2010)

Djurcilov, S., Kim, K., Lermusiaux, P., Pang, A., 2002. Visualizing scalar volumetric data with uncertainty. *Computers & Graphics* 26 (2002), pp. 239-248.

Evans, B.J., 1997. Dynamic display of spatial data-reliability: Does it benefit the map user? *Computers and Geosciences* 23(4), pp. 409-422

GEOWARN, 2003. http://geowarn.org (accessed August 19, 2010)

Hurni, L., 2008. Multimedia Atlas Information Systems. In: *Encyclopedia of GIS*. Springer, Berlin/Heidelberg.

Jenny, B., Jenny, H., Räber, S., 2008. Map design for the Internet. In: Peterson MP (Ed.) *International perspectives on maps on the Internet.* Springer, Berlin Heidelberg New York, pp. 31-48.

Lienert, C., Weingartner, R., Hurni, L., 2009. Real-Time Visualization in Operational Hydrology through Web-based Cartography. *Cartography and Geographic Information Science* 36(1), pp. 45-58.

Loat, R., Petrascheck, A., 1997. *Berücksichtigung der Hochwassergefahren bei raumwirksamen Tätigkeiten*. BWW, BRP, BUWAL, Biel, Switzerland.

Ormeling, F., 1997. Atlas information systems. Proceedings of the 17th International Cartographic Conference ICC, Barcelona, Spain, Vol. 2, pp. 2127-2133.

Pang, A., 2008. Visualizing uncertainty in natural hazards. In: Bostrom, A., French, S.P., Gottlieb, S.J. (Eds) *Risk assessment, modeling and decision support*. Springer, Berlin Heidelberg.

Peterson, M., 2008. Trends in Internet and Ubiquitous Cartography. *Cartographic Perspectives* 61, Fall 2008, pp. 36-49.

Peterson, M.P., 2007. Elements of multimedia cartography. In: Cartwright, W., Peterson, M.P., Gartner, G. (Eds) *Multimedia cartography*. Springer, Berlin, pp. 63-73.

Romang, H., Zappa, M., Hilker, N., Gerber, M., Dufour, F., Frede, V., Bérod, D., Oplatka, M., Hegg, C., Rhyner, J., 2010. IFKIS-Hydro: an early warning and information system for floods and debris flows. *Natural Hazards*, Online First™, March 10, 2010.

Schnabel, O., Hurni, L., 2009. Cartographic web applications – developments and trends. Proceedings of the 24th International Cartographic Conference ICC, Santiago, Chile.

Schobesberger, D., 2009. Toward principles for usability evaluation in web mapping - usability research for cartographic information systems. *Proceedings of the 24th International Cartographic Conference ICC*, Santiago, Chile.

Swiss World Atlas interactive, 2010. http://www.swissworldatlas.ch (accessed August 19, 2010)

Zimmermann, M., Pozzi, A., Stoessel, F., 2005. Hazard maps and related instruments – The Swiss system and its application abroad. Vademecum of the Swiss Agency for Development and Cooperation SDC.