TEMPORAL HYDROLOGICAL ATLASES: ADDING VALUE THROUGH INCLUSION OF THE REAL TIME

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The information and data demand to hydrological data in education, administration and research is increasing due to various emerging challenges, such as long-term spatial planning, flood protection and water resources management. Up to now, such information is primarily held in national hydrological atlas systems and obtainable in printed or partly digital form. Hydrological atlases have so far focused on the presentation of offline pre-processed data, averaged over longer time periods. Temporal or time-critical data have generally played a minor role in hydrological atlases. Yet, value to hydrological and other atlases can be added by including real time data within (or alongside) existing atlas frameworks, e.g., by offering specific temporal navigation controls, temporally aggregated data representations and interactive methods to query temporal data attributes, and to draw comparisons between visualizations generated with real time data and visualizations generated with averaged data.
In the presented paper, various aspects of a temporal data in hydrological atlas are discussed and application cases of an implemented real time system are presented.

Keywords: real time cartography, hydrological atlas, temporal navigation

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1. INTRODUCTION

Atlases can be considered a well defined and maintained collection of spatial, topic-related knowledge. They are further classifiable into the type of delivery media (print or digital) and their purpose (e.g., education, professional).
The demand of hydrological data and knowledge in education, administration and research is increasing due to various emerging challenges, such as long-term spatial planning, flood protection and water resources management. Such hydrological information is primarily held in national hydrological atlas systems and obtainable in printed or partly digital form. Hydrological atlases have so far focused on the presentation of offline pre-processed data, averaged over longer time periods. Temporal or time-critical data have generally played a minor role in hydrological atlases. Also, static cartographic visualizations are in most cases preferred to dynamic or real time cartographic visualizations.
In this paper, we aim at discussing the incorporation of the temporal dimension in hydrological and other atlases, its implications for the overall design and additional value.

2. ATLASES AND THE TEMPORAL DIMENSION

Specific temporal representation necessitates appropriate temporal data sets. Since by far not all data in atlases are suitable for visualizing temporal changes, we start with a listing of data sets that are qualified for temporal visualizations. We then move on to discuss various types of representations of temporal changes. The main classification comprises types of representation, types of data and associated tools for temporal navigation.

2.1 Suitable data

Time defines our everyday life. Our whole life is based on time. Days, months and years pass by while things are happening. In multimedia applications, time is important as well. The question 'what happened when' is inevitably coupled with a topic. In order to keep track of the various topics that change in time, temporal navigation methods and tools are required.
Temporal data may be classified into *temporal primitives* and *temporal structure* (Aigner *et al.* 2007; Frank 1998). Two main temporal primitives are identified: (1) time points, which is an instant in time; and (2) time intervals which is a time point with an extent or (two time points or a time point plus a duration). The temporal structure of data may be described by the associated time axis and the temporal primitives mentioned above. The structure is said to be *linear* when time corresponds to our natural perception of time, i.e., when temporal primitives occur sequentially, from the past to the future. The structure of time is said to be *cyclic*, when temporal primitives recur on a cyclic time axis, e.g., over the seasons of the year. The structure of time has *branching* properties, when the time axis is split into alternative scenarios, e.g., in planning and prediction.
Data meeting these prerequisites comprise road, railroad, and air traffic data; weather information on precipitation or hurricanes; hydrologic events and processes like runoff, water temperature, an others to mention just a few. But also long term temporal processes have to be considered such as date originating from the domains of climatology, geology and glaciology.
Ideally, temporal data fulfill the affordance of continuity or seamless information and every time point or time sequence is entirely available. For perceptional reasons, the data should be pre-harmonized on a specific time point or a distinct spatial domain (e.g., basins, communes). Now, not only preprocessed, averaged data are suitable for depicting the time component in atlases, but also instantaneous real time data, as it is shown in Figs. 4, 5, and 6.

2.2 Tools for temporal navigation

In temporal atlas systems and related time-critical map information systems, interactive tools to navigate in time obviously play a vital role. Different interactive methods have been proposed for navigating in temporal data. Examples are time sliders, clickable calendars, or zoomable time series graphs (e.g. Hornsby 2001; Jarke & Edward 1999; Oberholzer & Hurni 2000). In Table 1, a list of temporal navigation elements is shown, subdivided into their shapes.

Table 1: temporal navigation controls (e-Cartouche 2009).

Linear Controls	**Circular Controls**	**Other**
Interactive Time Lines / Life Lines	Knobs	Day / Night Buttons
Temporal Slider	Watches	Calendar Widgets
Smart Scrollbars	Wheels of Months or Seasons	Text Input
Small Multiples along Time Line	Cogwheel	Selection Lists (e.g. list of dates)

Interactive time lines are particularly useful as they can be linked to both visualization and navigation. Time lines can be used to show events, processes and the distribution of attribute values along time. Top left in Fig. 1, such a time line with small multiples is shown. It is taken from an interactive map application that tells the story of Pearl Harbour during the WWII. An additional clock reveals the time in a more known, human readable format. In the bottom left of Fig. 1, an airplane track application is shown which can be manipulated by a calendar tool. Flight activities are displayed, depending on the chosen date in the calendar. A similar approach is pursued in the example bottom right in Fig. 1, where selection lists are used to put together arbitrary dates, or to choose pre-defined dates of known events.

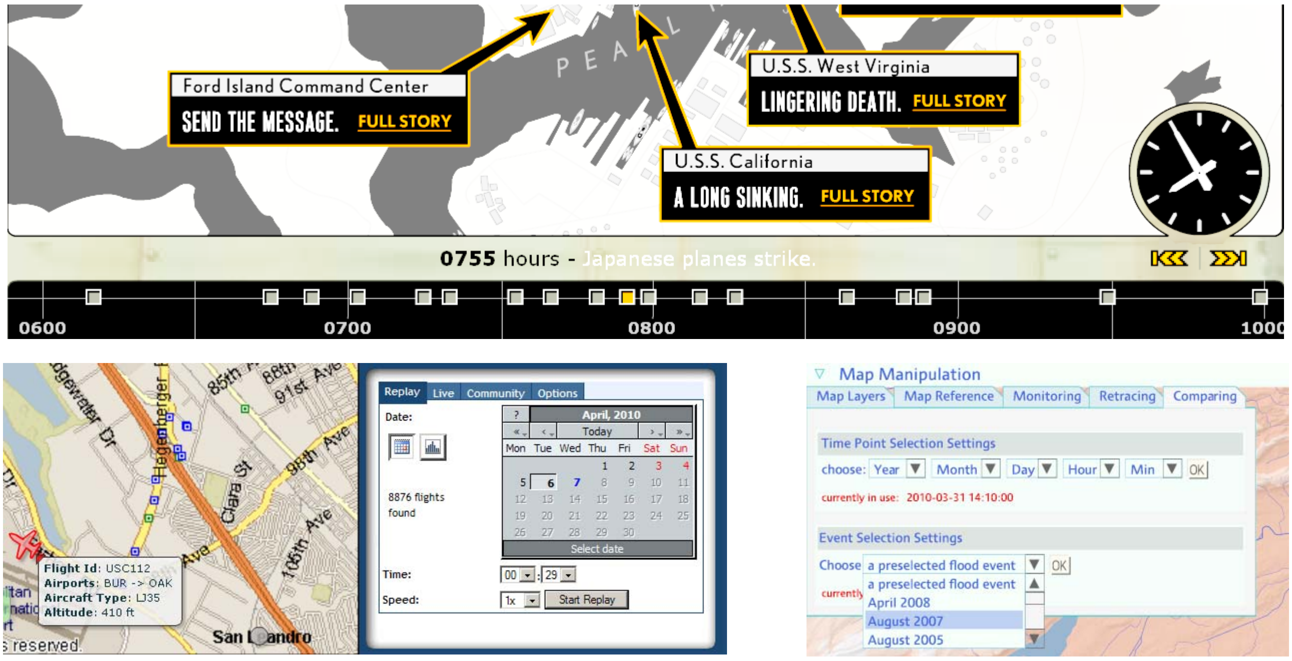

Figure 1. Temporal navigation controls: time line with multiples (top), calendar (btm. left), and selection list (btm right) Map sources: www.nationalgeographic.com, http://oak.webtrak-lochard.com, and Lienert et al. (2010).

There are numerous other examples of temporal navigation tools. Particularly in the field of scientific visualization (see Dykes *et al.* 2005 for a definition), advanced multimodal tools are introduced to facilitate multi-dimensional data analysis through visual analysis. The tools allow for temporal navigation as well as simultaneous temporal and spatial navigation. More specifically, methods are suggested for temporal aggregation, finding spatial patterns of similar temporal changes and direct-manipulation metaphors on 3D objects for temporal navigation (Andrienko & Andrienko 2007; Wolter *et al.* 2009).

2.3 Representation of temporal changes

Temporal visualization can be achieved by means of static or dynamic graphical representations. In this chapter, we will mainly focus on visualization techniques rather than on animation techniques (see Buziek *et al.* 2008). For grasping and understanding temporal processes in depth, graphical representations are more important than animations.

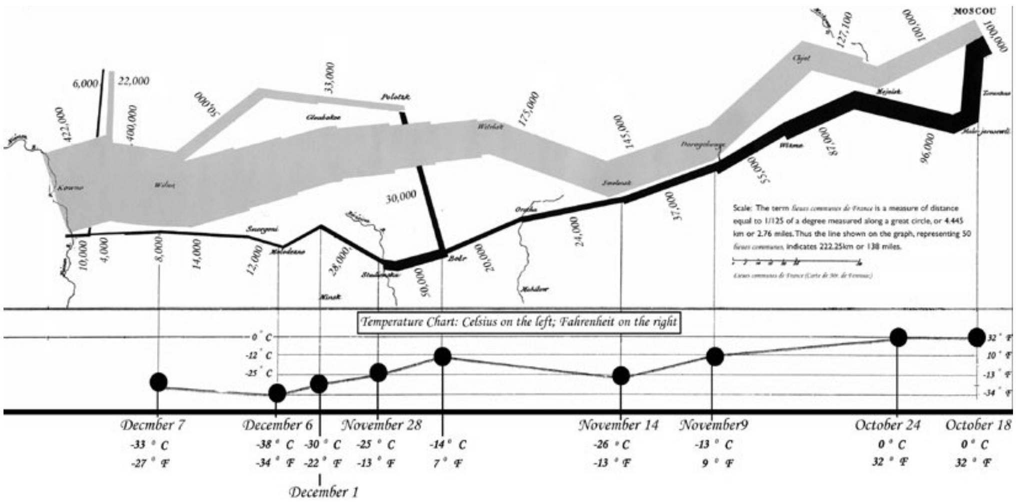

Figure 2. Static temporal map illustrating the crusade of Napoleon 1st against Russia (Minard 1862).

A striking example of temporal change by means of a static graphic is shown in Fig. 2. The change is illustrated by a flow diagram of the crusade of Napoleon 1st against Russia between 1812 and 1813 (Minard 1862). Using the thickness of the grey line, the dramatic loss of soldiers on their march to Moscow is noticeable at a glance. On their retreat, low temperature claimed even more victims, which can be easily observed by connecting the black line and the temperature curve below.

Static representations like Minard's map in Fig. 2 offer synoptic views. They allow for analytical comparison and because of its static nature they may have a more complex composition, adding the temperature component for instance. Graphical means for depicting time change are multivariate symbols like bar charts, pie charts (Huber *et al.* 2007), flow diagrams and, generally speaking, graphical variables (color, size, form, orientation).

Dynamic representations have a more volatile character and therefore work best with either slightly changing variations, or distinct steps. In both cases, the user should be able to follow the variation and perceive a direction or a quantity of change. Graphical means for dynamic temporal data could be flow maps and arrows, color and intensity transitions, fading and dissolving. Nice examples incorporating real time data on traffic jam and on airplane routes are shown in Fig. 3.

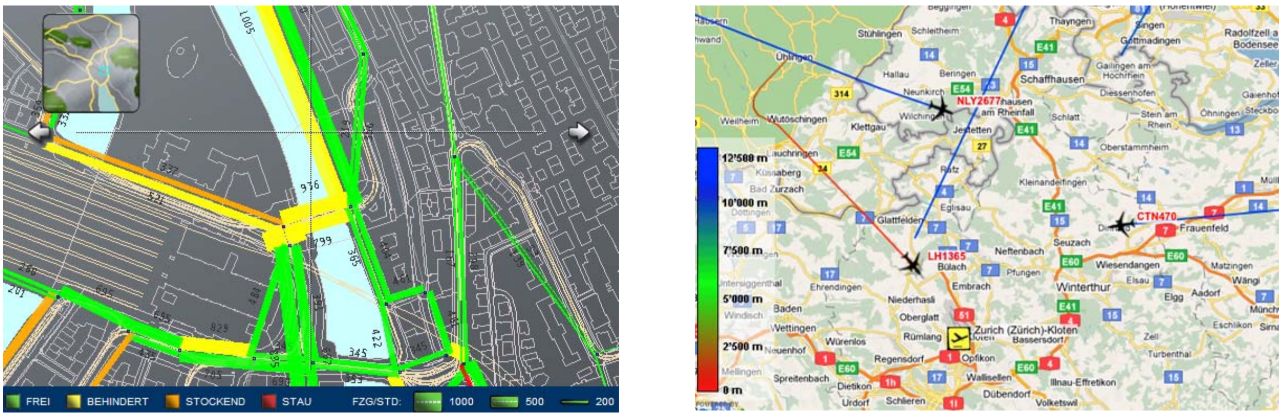

Figure 3. Dynamic representation of temporal changes: real time traffic jam map (left) and flight traffic map (right). Map sources: www.zueritraffic.ch and http://radar.zhwin.ch.

3. REALIZATIONS IN HYDROLOGICAL ATLASES

Hydrological atlases can be looked at as platform to the topic water. Many countries administer such hydrological atlases (e.g., www.hades.unibe.ch in Switzerland, http://had.bafg.de in Germany, or www.boku.ac.at/iwhw/hao/ in Austria) and their content is primarily distributed in analogous form. On the websites, entire data sets can be downloaded for further analysis, queries and incorporation in individual applications. However, as yet, no fully digital, web-based atlas version with interactive tools is available in the three mentioned countries, although the need for action has been identified (e.g. Fuhrmann 2000). Real time data are not incorporated at all in these three works.

In this chapter, we discuss how temporal data and temporal changes have been visualized in hydrological atlases, particularly in the printed version of the Hydrological Atlas of Switzerland HADES (see more details on this atlas in the next chapter). The methods involve specific cartographic symbolization, temporal aggregation and, in some cases, the inclusion of real time data.

3.1 Temporal changes in hydrological atlases

Temporal changes in the Hydrological Atlas of Switzerland are in many cases represented by cartographic and graphic symbols. In Fig. 4, a clipping of map and the associated symbol legend are shown which represent the temperature changes of streams between 1976 and 2005. The 30-years time period is split into six 5-years intervals. For each interval, a bar chart was created that represents the number of hours during which temperatures above 15 °C were measured. The chart is further divided into temperature classes. This symbolization lets users easily see the changes of the hydrological parameter.
Further methods to visualize temporal change include the placing of additional time series graphs on the plate (not on the map), or to arrange various small maps in succession. Latter method is applied in the atlas plate containing seasonal precipitation data (Plate 2.7). Here, four maps representing the four seasons are arranged prominently on one page. On another page, maps representing all 12 month are arranged in succession – similar to a film strip – to better draw inter-annual comparisons.

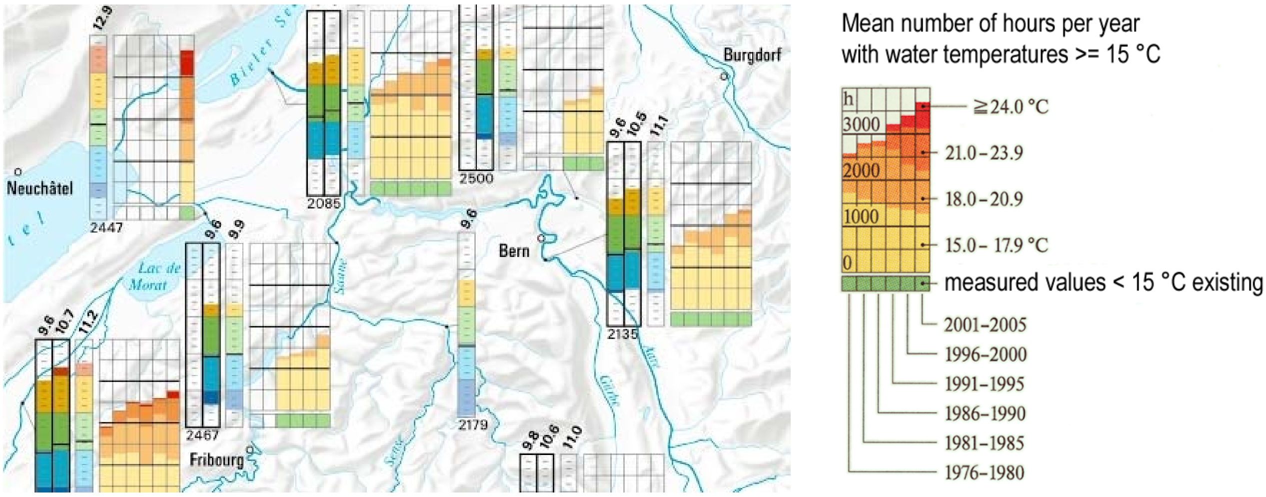

Figure 4. Temperature changes of streams 1976-2005 and associated legend (HADES 1992-2010, modified).

3.2 Temporal aggregation and departures from reference periods

Atlas plates typically aggregate the temporal information of the presented topics and show one averaged state. The temporal scales considered in the Hydrological Atlas of Switzerland include the following temporal aggregation levels:

- multi-annual trends (e.g. postglacial glacier variations, Plate 3.8)
- multi-annual means (e.g. components of the hydrological cycle, Plate 6.3)
- seasonal and monthly means (e.g. precipitation, Plate 2.7)
- daily means during selected years (e.g. low flows, Plate 5.11)
- daily extremes (e.g. snow depths, Plate 3.2)

Using the example of precipitation or temperature data, long reference periods are drawn on to calculate the mean value of long-term annual or seasonal or monthly values. These averaged values of such reference periods are used to compare with subsequent years or periods in order to detect trends and anomalies (e.g. Founda & Giannakopoulos 2009). The departures from reference periods constitute the basis for additional maps, as planned in the newest delivery of the Hydrological Atlas of Switzerland, to be released in the middle of 2010.

3.3 Inclusion of real time data

A prominent example of an online atlas that includes real time hydrological data is the Atlas of Canada (http://atlas.nrcan.gc.ca/) and the National Atlas of the US (www.nationatlas.gov). These atlases, however, are not exclusively hydrological atlases, as they incorporate various topics other than hydrology. Apart from gauge locations and hydrographs in separate browser windows, no further real time information is included and visualized.

4. APPLICATION CASES

Different existing research projects deal with hydrological data visualizations. The three main projects are shortly discussed hereafter: firstly, the Atlas of Switzerland (AoS) at the Institute of Cartography, ETH Zurich; secondly, the mentioned Hydrological Atlas of Switzerland (HADES) at the Geographical Institute of the University of Berne; and thirdly, the project "Real-Time Cartography in Operational Hydrology" (RETICAH), which is a joint research projects between the two institutes.
At the Institute of Cartography, ETH Zurich, the renowned project Atlas of Switzerland is carried out and the release of the third version is expected by the end of 2010. It is a highly interactive DVD-based National atlas and contains more than 1650 map themes, from the field of Nature and Environment, Society, Economics, State and Politics, Traffic, Energy, and Communication. Thematic data are represented in both 2D maps and 3D visualizations, like panoramas, block diagrams, and statistical surfaces (AoS3 2010).
The group for hydrology at the Geographical Institute of Berne is responsible for the whole scientific and cartographic editing of the Hydrological Atlas of Switzerland (HADES 1992-2010). HADES is an atlas collection of hydrological knowledge researched and gathered by experts from national research institutes. It covers the topics precipitation, snow and ice, evaporation, rivers and lakes, water balance, balance of matter as well as soil water and groundwater.
Another research project deals with the methodology and scientific question involved in real time cartography in the domain of early warning and operational hydrology (RETICAH). This joint project investigates automated cartographic workflows applied to raw real time measurement data from sensors. Various relevant aspects that need to be automated – such as data acquisition, harmonization, storage, cartographic modeling, cartographic visualization, and archiving – are investigated. In order to serve as a proof-of-concept and for demonstration purposes, a hydrological real time map information system was set up. It consists of a real time spatial database and a web-based cartographic user interface (Lienert *et al.* submitted).

4.1 Static, interactive cases

Temporal changes might be visualized by map symbolizations that show the difference between the starting and the end states of a phenomenon. Thus, the changes themselves are visualized by cartographic symbols on static maps. Symbols might represent a variety of changes:

- the absolute or relative quantities of change of the map item in question
- the rates of changes over time
- the duration of change
- the location displacement

An example of a static map representing temporal changes is shown in Fig. 5. The bar chart symbols represent the mean monthly runoff per decade. Any of the decades between 1901 and 1999 can be selected interactively.

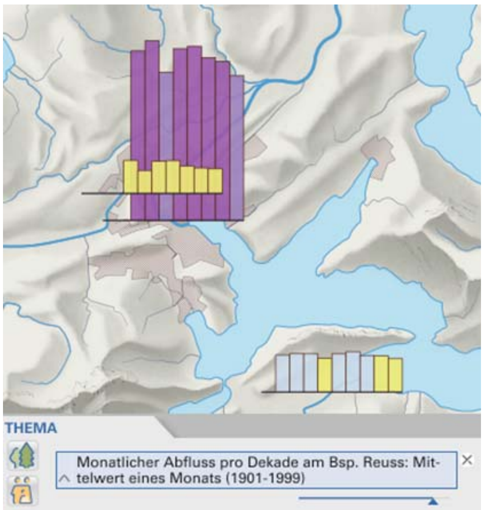

Figure 5. Static map of temporal change of runoff (AoS3 2010).

4.2 Dynamic, interactive real time cases

Including real time data in atlas information systems allows users to easily compare instantaneous data at different locations with those data that have been statistically inferred and processed. Real time, or even forecast data, can be

contextualized and related to long-term time series. The temporal navigation between the different temporal aggregation levels needs to be adapted to each application. Some methods have been proposed above.
In order to demonstrate the direct comparison between real time maps and atlas maps compiled by averaged data, three selected examples are discussed in the following using the hydrological parameters (1) snow depths, (2) precipitation, and (3) specific discharge.
The map shown left in Fig. 6 represents the averaged, long-term snow depths in central Switzerland. The data have been gathered and modeled by a third-party research institute, i.e., the WSL Institute for Snow and Avalanche Research SLF which is specialized in snow research. Afterwards, the data have been edited cartographically, visualized and integrated into an existing atlas framework by cartographic professionals (AoS2 2004).
In contrast, the map right in Fig. 6 shows the snow depths distribution in real time within the cartographic framework RETICAH. The identical spatial extent is shown, but somewhat different symbol colorization and legend classifications are used. The snow data are delivered over the internet by the third-party research institute in real time, already provided in form of a web-enabled raster image format. In the RETICAH framework, raster images are integrated through separate mapserver software in order to clip and tile data. Further automatic processing on the raster data is applied so that the edges of image pixels are smoothed for a more genuine appearance. Also, dynamic legend functions are applied in order that the map can be explored interactively using the computer mouse. The values of the map are returned when the map is being moved over with the mouse, and piped to functions that automatically create legends in which the specific value is highlighted (see also Lienert *et al.* 2009a).

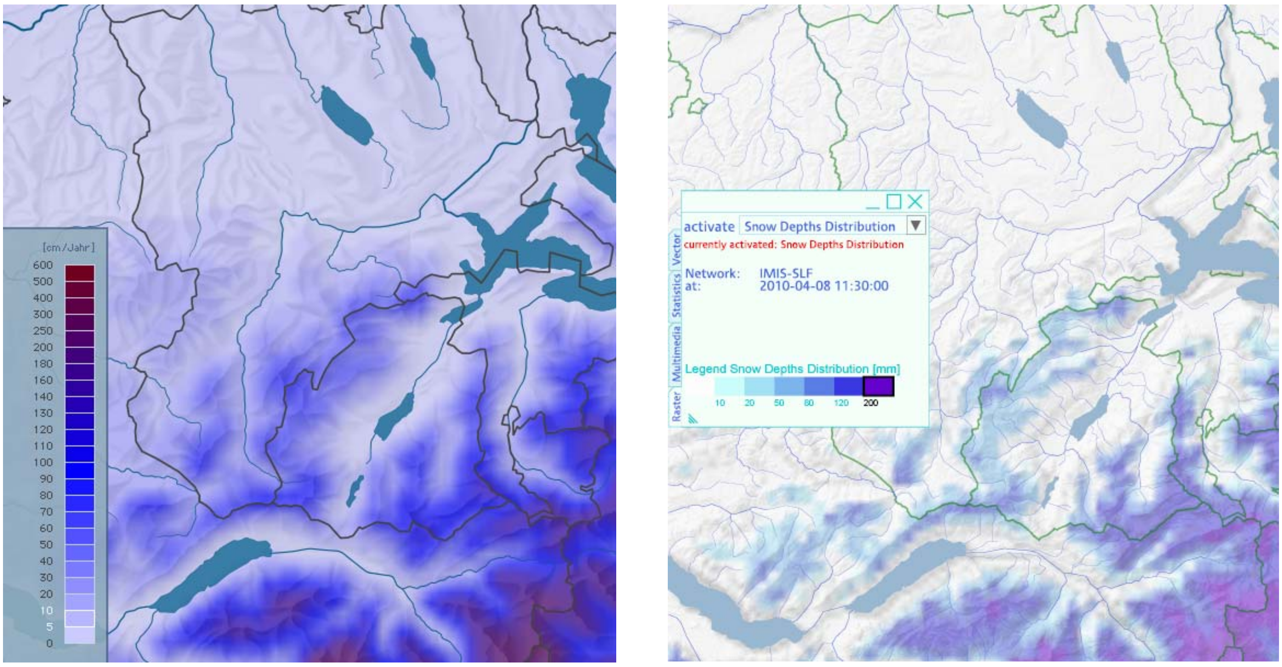

Figure 6. Mean annual snow depths between 1982 and 2001(left) and real time snow depths (right).
Sources: AoS2 (2004), Lienert et. al (submitted), with data from WSL Institute for Snow and Avalanche Research SLF.

A more complex example in terms of data format and processing workflow is provided in the two maps in Fig. 7. Both maps represent precipitation that has been interpolated from point gauges, which are also depicted on the maps. The map left is taken from the Atlas of Switzerland 2. Again, the data of the period 1971-90 has been modeled by a third-party research institute using state-of-the-art interpolation methods, suited for long-term averaged precipitation data. Additionally, precipitation gauges are indicated by bar charts of varying height. The lighter the bar's color, and the higher the bar itself, the higher are the annual means.
The map right in Fig. 7 has been extracted from the RETICAH framework. It also shows precipitation interpolated to the area, along with real time 10 minutes precipitation sums at ground gauging locations depicted by framed rectangles.

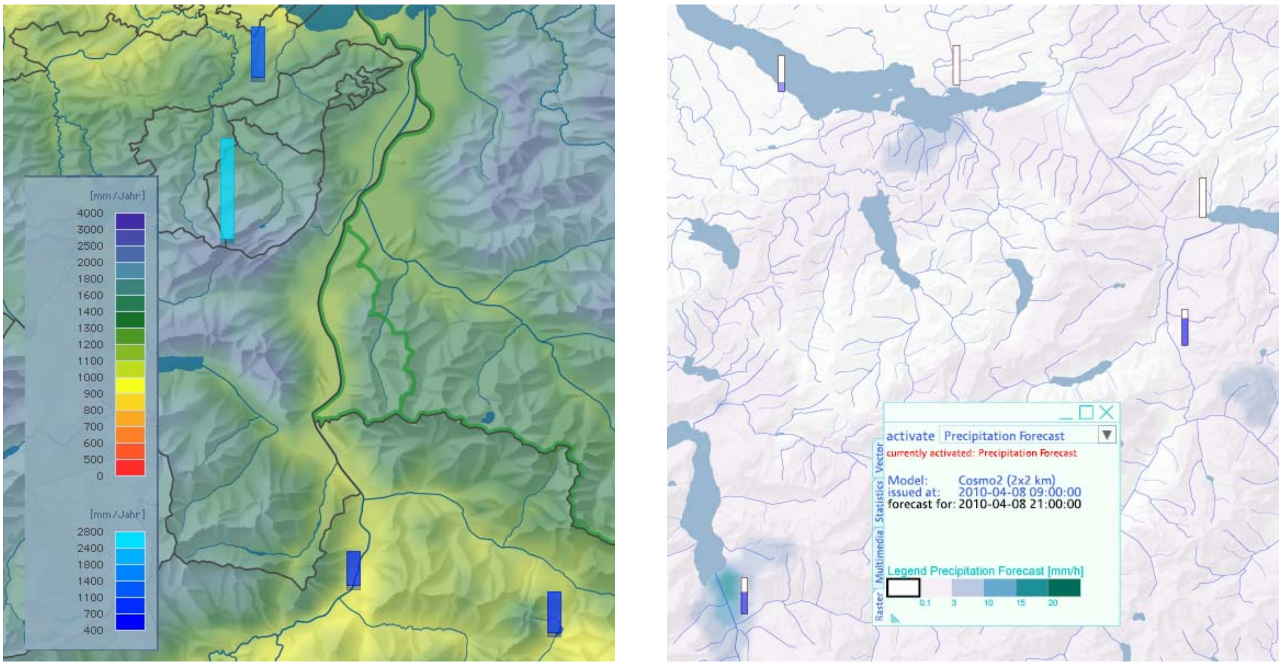

Figure 7. Mean annual precipitation between 1971 and 1990 (left) and real time precipitation forecast (right). Sources: AoS2 (2004), Lienert et. al (submitted), with data from Federal Office for Meteorology and Climatology MeteoSwiss.

Both the forecast precipitation data and the real time data are part of a data set delivered in real time by the Federal Office for Meteorology and Climatology. The forecast is delivered every three hours as an interpolated grid. Upon its arrival at our project server, it must additionally be geo-referenced and provided in a coordinate system. Furthermore, the grid data have to be automatically classified, colored and converted to a web-enabled image file.
Unlike the map left in Fig 7, a color scheme has been chosen which uses darker colors for higher precipitation amounts. The classification is, of course, adjusted to instantaneous real time values, thus has a smaller overall range. As mentioned, the symbols for precipitation gauges are represented by framed rectangles. Unlike the map from the atlas, left in Fig. 7, the bars are confined to a fixed height. Such a symbolization approach was chosen, in order to consistently manage unexpectedly high, outlier, or erroneous real time values.

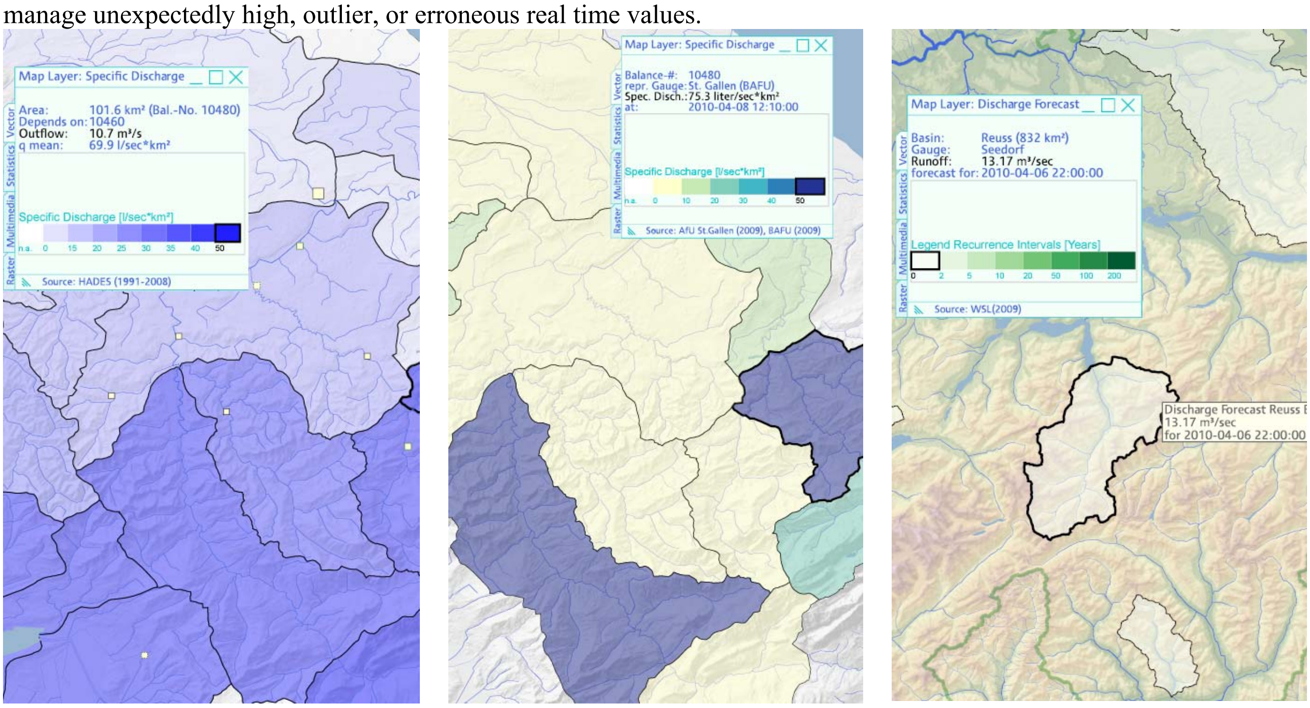

Figure 8. Specific discharge 1961-1980 means (left), in real time (middle,) and forecast runoff of entire basins. Sources: Lienert et al. (2009b), HADES (1992-2010), with data from Canton of St.Gallen, the Swiss Federal Institute for the Environment, and the Swiss Federal Institute for Forest, Snow and Landscape Research.

In order to demonstrate another typical hydrological visualization example, plate 5.4 of HADES has been digitized and incorporated in the RETICAH framework. The plate contains the specific discharge of hydrological balance basins. Specific discharge is discharge per unit area of an upstream basin, and thus, it is “normalized” discharge for better comparison. Choropleth maps are the most suitable method to cartographically visualize these data. They offer a comprehensive and spatially differentiating view of the long term discharge situation. The darker the colors of the basins, the higher are the discharges. Mountainous or alpine basins generally tend to have higher specific discharges due to their higher precipitation, fewer vegetation and soil cover for water storage, as well as higher slopes.
In the map left in Fig. 8, the averaged atlas version is shown, with data classification according to HADES. In the middle, the real time map of specific discharge is shown, with a slightly different classification and a different color scheme. In the map right in Fig. 8, entire selected basins have experimentally been attributed the hydrological forecast data provided by the Swiss Federal Institute for Forest, Snow and Landscape Research. The map goes one step further as it classifies the forecast runoff automatically into long-term extreme runoff statistics (in terms of recurrence intervals). The darker the coloring of the basin, the rarer are the forecast runoff values. This map also acts as an example how to advance even further with temporal atlases. It does not only include real time data, but forecast data delivered in real time which are automatically classified into long-term historical values.

5. DISCUSSION AND OUTLOOK

5.1 Outlook on RETICAH and general benefit for other applications

Nearly all of the required features, data sets and temporal aggregation levels for improved flood monitoring are implemented in the RETICAH system. A continuous dialogue with potential users (hydrologists in crisis management groups) has to be kept up, and further improvements – particularly on the cartographic user interface of RETICAH – must be made. First tests with hydrologists showed the usefulness of data visualization not primarily based on tables and graphics, but also represented on interactive maps. The main development activities in the RETICAH framework include improving (or complementing) temporal navigation and to translate other time-critical themes (such as natural hazards, traffic information, flight data, etc.) into the RETICAH framework.
In cartography, there is a strong tendency to combine spatiotemporal issues. Tools for easy navigation, information retrieval and data analysis in 2D and 3D geographic space are still scarce. Scientific experiments have been carried out to translate the 2D graphics of Joseph Minard, shown above in Fig. 2, into 3D visualization. Fig. 9 shows one of the results of these attempts. Applications like RETICAH could further contribute to this space-time-theme problem by continuously developing new data handling and visualization methods.

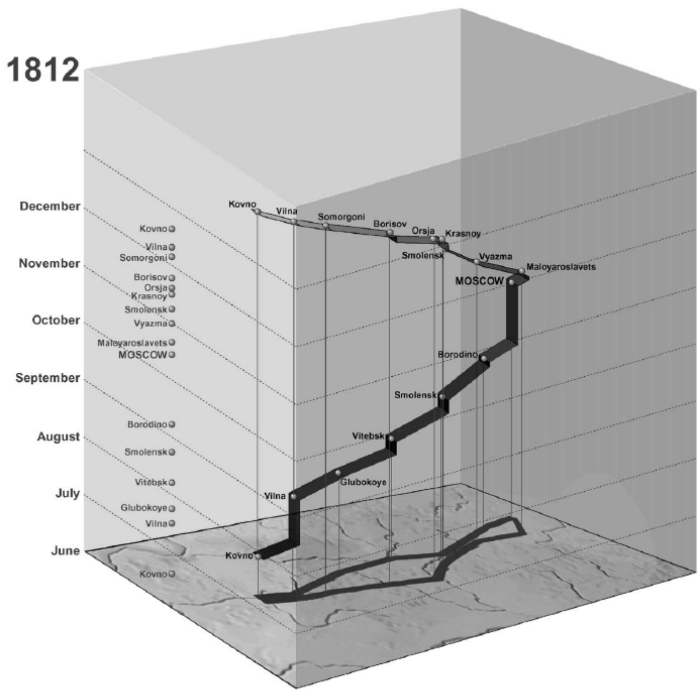

Figure 9. Alternative 3D-visualization of Minard’s map using the space-time cube (Kraak 2003).

5.2 Outlook on atlases

As interactive atlas systems are moving from off-line to modular on-line applications, both pre-processed and real-time data are increasingly visualized and handled in form of interactive maps. In the near future, atlas systems will be conceptually designed and implemented within atlas platforms. In other words, internal and even external program extensions from third-parties will be interfaced and be allowed. By then, specific tools or system components handling real time data may then be attached or even incorporated by just sticking them together (piping). The concept of Atlas platforms will be of collaborative nature where everyone contributes contents. Consequently, hydrological data could be gathered and integrated not only be experts, but also by laymen and school classes. However, open access to such a powerful visualization system requires strict quality control mechanisms, for example in terms of a cartographic editor team. Only high-quality data and visualizations should be permanently retained in such atlas platforms.

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