Usability of interactive and non-interactive visualisation of uncertain geospatial information

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INTRODUCTION

Geospatial data is collected and processed to represent and describe real world characteristics. This representation is naturally restricted by computational power, model approximation, and limits to measurement accuracy. Input data and each modelling step are sources of errors that are propagated through the processing chain to the end results. As we base our decisions for planning or assessment tasks on those results, it is inevitable to include also the reliability of the data to allow meaningful reasoning. Showing not only what we know, but also the degree of information we do not know, can be enhanced for instance by giving interval estimates instead of single values for the outputs. We limit ourselves to the uncertainty of attributes, and will not address positional uncertainty.

VISUALISING SPATIAL UNCERTAINTIES

For geospatial information the data reliability can be included into map representations. This yields the problem to map two dimensions, the value and its uncertainty, in one spatial representation, under avoidance of visual and cognitive overload of the user. To face this challenge, different types of presentation techniques have emerged (MacEachren 1992), such as:

- *Adjacent map pairs*, displaying results and their uncertainty (e.g. standard error) separately
- *Sequential presentation* of results and uncertainty
- *Bi-variate map*, merging results and uncertainty in a single map

Additionally, it can be distinguished between different visualisation modes, namely:

- *Static*, as one or more static maps
- *Dynamic*, *e.g.* automatic animation of realisations
- *Interactive*, the user has control over the uncertainty presentation

From the combination of these presentation techniques and modes, numerous different methods were designed for varying purposes and user groups. Metaphors, like for instance blurring the uncertain regions as if they were out of focus, are commonly applied for qualitative uncertainty information, making use of the intuitive perception for uncertainty of the user. Transparent overlays and mixing pixel methods can be used for static bi-variate maps and blinking pixels, highlighting certain regions, are an example for dynamic representations. Generally, it is assumed that static methods are easier comprehensible especially for non-experts, whereas interactive methods offer the control over the amount of information shown which can be useful for understanding the structure of the data. It is also hypothesised that bi-variate maps are less useful as adjacent maps, because bi-variate maps probably contain too much information for the user.

USABILITY TESTING

However, only few investigations have been conducted to test the performance and acceptance of different uncertainty mapping techniques for a use case (MacEachren *et al.* 2005). Furthermore, the findings of these studies vary significantly regarding which method is most useful, depending on the purpose and design of the study. Interactive methods are usually covered by toggling between the value and uncertainty map lying upon each other. Aerts *et al.* (2003) found this to be a helpful method, whereas Evans (1997) found it less helpful than other static and dynamic methods. However, most of the studies results are conform in the fact that giving uncertainty information is rather helpful than confusing for the user if it is presented in a useful way.

To verify the hypotheses mentioned above, with a special focus on the usability of interactive vs. non-interactive methods, we decided to perform a new usability study with a small set of test persons. The aim was to compare the usefulness for decision support and user acceptance of three different uncertainty representation methods. We used **Adjacent maps** of the value and the uncertainty as a simple static technique. Second, a method called **Whitening** (Hengl & Toomanian 2006), which uses the Hue-Saturation-Intensity colour model to combine value and uncertainty in one map, was applied. With Whitening, uncertain values are displayed with reduced colour saturation in the map, yielding paler regions that move out of the user's focus. As a third alternative we used **Aguila** (Pebesma *et al.*

2007), an interactive visualisation tool that stores value and uncertainty as cumulative probability functions for each pixel in space and time. In the map either the threshold values associated to a certain quantile or the cumulative probability to exceed a certain value are shown. The user can control the thresholds for probabilities or values displayed in the map through an additional control in the probability distribution function. We hypothesise that interactive uncertainty representation methods take more time to learn but are more useful for quantification and decision making tasks.

STUDY DESIGN & RESULTS

During the study we interviewed ten participants with backgrounds in geography or computer science, all non-experts in statistics for approximately 30 minutes. All three visualisation methods were presented to them in different order. The data set used for visualisation was a residual kriging analysis for annual PM10 concentration over Europe, using the kriging variance as uncertainty estimate. The study consisted of two main parts, one task performance part and one user opinion part. In the task part, two tasks had to be answered by the participants for each of the method subsequently, whereas the third task could be answered by choosing any of the visualisation methods.

The results for the first task showed the best performance for adjacent maps, the poorest for Whitening and a slightly better one for Aguila. In the second task, Aguila showed better results than the two other methods, but took the longest time to answer. For the third task all participants preferred to use adjacent maps for answering, yielding overall good results.

During the user opinion part, the adjacent maps method was clearly preferred and evaluated as the easiest comprehensible one. All participants thought they understood Whitening and adjacent maps, whereas only half of them thought they understood Aguila. Nevertheless, no one preferred Whitening or found it useful. It seems that the principle of Whitening is immediately easy to comprehend but not useful for getting more detailed information that are necessary for decisions. Several people found Aguila helpful but too complicated to understand. Some suspected it to be helpful for a more thorough analysis and for experts. Overall, all participants found uncertainty helpful for decision making, making maps more complex but not too complex. The majority also preferred interactive over static methods.

CONCLUSION

Although many different methods exist for representing uncertainty in geospatial information, not all of them seem equally helpful. We found the simplest method of showing value and uncertainty map next to each other the most effective one. Nevertheless, interactivity is suspected to support the perception of uncertainty better than static representations. For decision support it seems that different methods should be used and offered, depending on the user's background and task. A combination of simple adjacent representations for a first overview and a more complex system like Aguila for thorough and detailed analyses could possibly be a solution in future decision support systems.

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