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Case study

# Evaluating the use of uncertainty visualization for exploratory analysis of land cover change: A qualitative expert user study

Christoph Kinkeldey [a,*], Jochen Schiewe [a], Henning Gerstmann [b], Christian Götze [b], Oleksandr Kit [c], Matthias Lüdeke [d], Hannes Taubenböck [e], Michael Wurm [e]

[a] HafenCity University Hamburg, Lab for Geoinformatics and Geovisualization (g²lab), Hamburg, Germany
[b] Martin Luther University of Halle-Wittenberg, Department of Remote Sensing and Cartography, Halle, Germany
[c] GeoData Institute, University of Southampton, Southampton, United Kingdom
[d] Potsdam Institute for Climate Impact Research, Potsdam, Germany
[e] German Aerospace Center (DLR), German Remote Sensing Data Center (DFD), Oberpfaffenhofen, Germany

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ABSTRACT

Extensive research on geodata uncertainty has been conducted in the past decades, mostly related to modeling, quantifying, and communicating uncertainty. But findings on if and how users can incorporate this information into spatial analyses are still rare. In this paper we address these questions with a focus on land cover change analysis. We conducted semi-structured interviews with three expert groups dealing with change analysis in the fields of climate research, urban development, and vegetation monitoring. During the interviews we used a software prototype to show change scenarios that the experts had analyzed before, extended by visual depiction of uncertainty related to land cover change.

This paper describes the study, summarizes results, and discusses findings as well as the study method. Participants came up with several ideas for applications that could be supported by uncertainty, for example, identification of erroneous change, description of change detection algorithm characteristics, or optimization of change detection parameters. Regarding the aspect of reasoning with uncertainty in land cover change data the interviewees saw potential in better-informed hypotheses and insights about change. Communication of uncertainty information to users was seen as critical, depending on the users' role and expertize. We judge semi-structured interviews to be suitable for the purpose of this study and emphasize the potential of qualitative methods (workshops, focus groups etc.) for future uncertainty visualization studies.



## 1. Introduction and background

Uncertainty is an inherent characteristic of geodata and can play an important role during their analysis (Zhang and Goodchild, 2002). Thus, a research effort in GIScience is to develop methods to incorporate uncertainty into geodata analysis. In the last decades, a wide number of user studies have been conducted to assess potential benefits of uncertainty visualization for this purpose (MacEachren et al., 2005). While the vast majority of studies focus on the impact of uncertainty visualization on decision making (Griethe and Schumann, 2005) only very few deal with potential effects on reasoning with geodata.

This research contributes to filling this gap with a user study about if and how geodata uncertainty can be utilized in land cover change analysis. The study is based on a concept to utilize uncertainty in change analyses that includes a measure for uncertainty in change (Kinkeldey, 2014b), a technique to visualize uncertainty (*noise annotation lines*, Kinkeldey et al., 2014), and a software prototype for change analysis (*ICchange*, Kinkeldey, 2014b). We report upon interviews with three expert user groups utilizing the software prototype to analyze land cover change data and discuss the concept. Topics include the use of uncertainty in change analysis, as well as potential and benefits of the software prototype and the uncertainty visualization technique.

This article is based on a workshop paper that summarized preliminary results of this study (Kinkeldey and Schiewe, 2014). It extends the paper by detailed descriptions of the study method and the change scenarios used in the interviews, and by presenting an in-depth discussion of the method and findings, as well as

* Corresponding author.
*E-mail address:* christoph@kinkeldey.de (C. Kinkeldey).

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recommendations for future work.

## 2. Method

The goal of this research was to assess the concept for uncertainty-aware land cover change analysis described in Kinkeldey (2014a). The main questions being if expert users would find it useful for their work and where they see benefits and limitations. In past uncertainty evaluation research, the majority of user studies applied quantitative methods, i.e., mainly experiments in laboratory settings or over the Internet (Kinkeldey et al., 2014). Exceptions include a number of qualitative studies, for instance, a focus group study by Roth (2009a) to investigate the impacts of uncertainty visualization on decision making in the context of floodplain mapping. Other authors conducted interviews to evaluate the usability of a tool utilizing uncertainty visualization (Slocum et al., 2003) and the usefulness of different visualization techniques to depict uncertainty (Gerharz and Pebesma, 2009). Apart from this, mixed methods (combining quantitative and qualitative methods) have been applied, but remain very rare (e.g., Štěrba et al., 2014). For our study we needed to make sure that several topics were covered. At the same time, we wanted to leave room for a discussion of new aspects and ideas. We identified the method of semi-structured interviews as suitable for our purposes because it connects these requirements.

### 2.1. Interviews

To evaluate the usability of the concept we conducted three semi-structured interviews with expert groups that are concerned with land cover change analysis. The core idea was to utilize the software prototype for the interviews to present change scenarios the interviewees had already worked on. We found three groups of two to four experts dealing with change analysis who were interested in taking part in the interview. The groups covered the areas of climate research, urban remote sensing, and vegetation monitoring. The interviews had four parts:

1. **Introduction**: In the first part we explained the concept and the software prototype showing an exemplary change dataset, not yet the data for the discussion, to keep the focus on the prototype and the visualization technique. The participants were free to ask questions.
2. **Uncertainty**: The main part of the interview started with questions about the role of uncertainty in the specific dataset. First, we showed the experts their change scenario without uncertainty and asked them about insights they had gained from it so far. We then added the uncertainty display to let them explore uncertainty related to the changes. Instead of operating the software prototype themselves, participants were asked to give instructions to us. This idea is adapted from pair analytics that involves a visual analytics expert operating the tool and a subject matter expert posing the questions (Arias-Hernandez et al., 2011). This was done to ensure that the discussion stays focused on the data and to avoid discussions about the usability of the prototype, an aspect that had already been assessed during its development (Kinkeldey, 2014b). The questions were about, if and how the uncertainty display helps to confirm, reject, or modify the insights they had reported on before the uncertainty display was added. In addition, we were interested in their opinion about the significance of uncertainty in change analysis from a general view, i.e., not related to the presented dataset.
3. **Tool and visualization**: Subsequently, we asked the participants about their opinion on the *ICchange* software prototype and on *noise annotation lines*, the technique we used to display uncertainty in the map (Kinkeldey et al., 2014). We talked about the potential of the prototype to support them in their work compared to the software they currently use. Regarding noise annotation lines, we asked them whether they find this technique usable for their tasks.
4. **Open questions**: In the last part the interviewees had the opportunity to make comments about the topics covered in the interview, and to express ideas and criticism.

The introduction took 10–20 min depending on the number of questions from each group. With all three groups the interviews took about one hour (excluding the introduction). The division of the discussion into the four parts was not strict but served as a rough guideline. We recorded the discussion with two separate voice recorders (notebook and smartphone). After transcribing the recordings in writing we categorized the findings related to ‘change detection and analysis’, ‘reasoning with uncertainty’, ‘communication of uncertainty’, and ‘tool and visualization’.

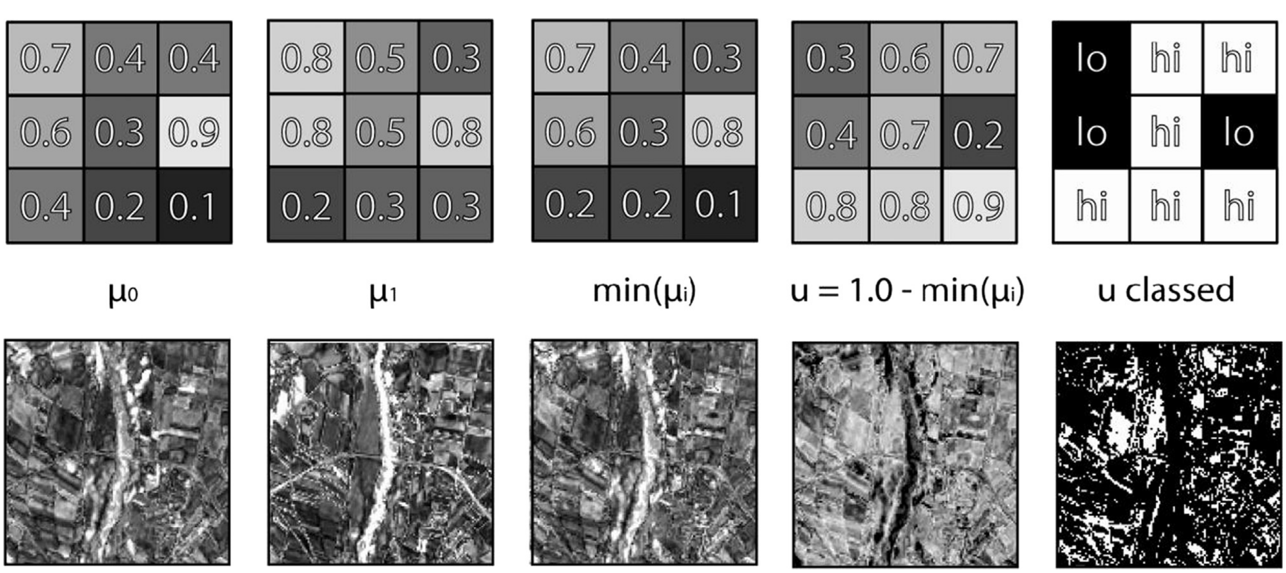


**Fig. 1.** Change uncertainty measure derived from class membership values $\mu_i$ [reprinted from Kinkeldey (2014a)].