USING SOUND TO REPRESENT UNCERTAINTY IN FUTURE CLIMATE PROJECTIONS FOR THE UNITED KINGDOM

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ABSTRACT

This paper compares different visual and sonic methods of representing uncertainty in spatial data. When handling large volumes of spatial data, users can be limited in the amount that can be displayed at once due to visual saturation (when no more data can be shown visually without obscuring existing data). Using sound in combination with visual methods may help to represent uncertainty in spatial data and this example uses the UK Climate Predictions 2009 (UKCP09) dataset; where uncertainty has been included for the first time. Participants took part in the evaluation via a web-based interface which used the Google Maps API to show the spatial data and capture user inputs. Using sound and vision together to show the same variable may be useful to colour blind users. Previous awareness of the data set appears to have a significant impact ($p < 0.001$) on participants ability to utilise the sonification. Using sound to reinforce data shown visually results in increased scores ($p = 0.005$) and using sound to show some data instead of vision showed a significant increase in speed without reducing effectiveness ($p = 0.033$) with repeated use of the sonification.

1. INTRODUCTION

This case study compared visual and sonic methods of representing uncertainty in spatial data, specifically UK Climate Projections 2009 (UKCP09) data [1] using an interface developed within the Google Maps API (GMAPI). Sonification is a way of representing spatial data using sound in situations where visual methods may not be possible or appropriate [2].

1.1. Use of sound

A number of studies have examined, from both theoretical and practical perspectives, how sound can be used as a supplement to visual stimuli. Krygier [3] outlines two different ways of utilizing sound – using real sounds (such as traffic noise to represent a city or bird song for the country) or abstract sounds, where the sound utilized (e.g. piano notes) represents a different variable. Kryiger highlights nine different aspects of sound that could be altered to represent spatial data, including location, loudness, pitch, register, timbre, duration, rate of change, order and attack/decay. Using one of these aspects to represent a set of spatial data is certainly possible, and there have been experiments with multiple sound variables for exploration of multivariate data [4] but these have a much higher level of complexity. Gaver [5] highlights the fact that sound is a transient phenomena, in that it is very good for representing dynamic, changing phenomena (usually, but not exclusively temporally), but can have limitations when representing a large amount of data over an extensive area, particularly if the data are highly variable.

In addition to the theoretical discussions, there have been a number of practical implementations using abstract sounds. One of the most common applications of sound with spatial data has been for maps or navigational aids for people with visual impairments; such as Zhao et al. [6] who developed iSonic which is a geographical data exploration tool for the blind. The on-screen map data were split into a 3x3 matrix, which was sonified and accessed by the user through a numeric keypad with values 1–9. When the user selected a number, the data in that quadrant were read out and each quadrant could then be zoomed in to, and the process repeated. This illustrates some of the limits on the amount of information that can be represented using sound, but the in-depth case studies with seven participants who are suggested that the interface was effective.

Fisher [7] used sound to represent uncertainty in spatial data, and it worked in a complementary manner, allowing the user to 'see' the data and 'hear' the uncertainty associate with it. His work was quite limited by the technology available at the time (1994) and did not include any user testing.

More recent examples have employed a variety of datasets and begun to report some user testing. Gluck [8] used different aspects of sound to show levels of environmental risk in the counties of New York State, by using notes with variable pitch and tempo as well as combinations of notes in the form of chords. He found that using sound and vision on a complementary basis was most successful and gave greater information and understanding than either sound or vision separately. Jeong and Gluck [9] compared haptic, sonic and combined display methods in a series of user evaluations (n=51) and found that haptic alone was most effective; however, users preferred haptic and sonic combined even though their performance was lower. The sound utilized

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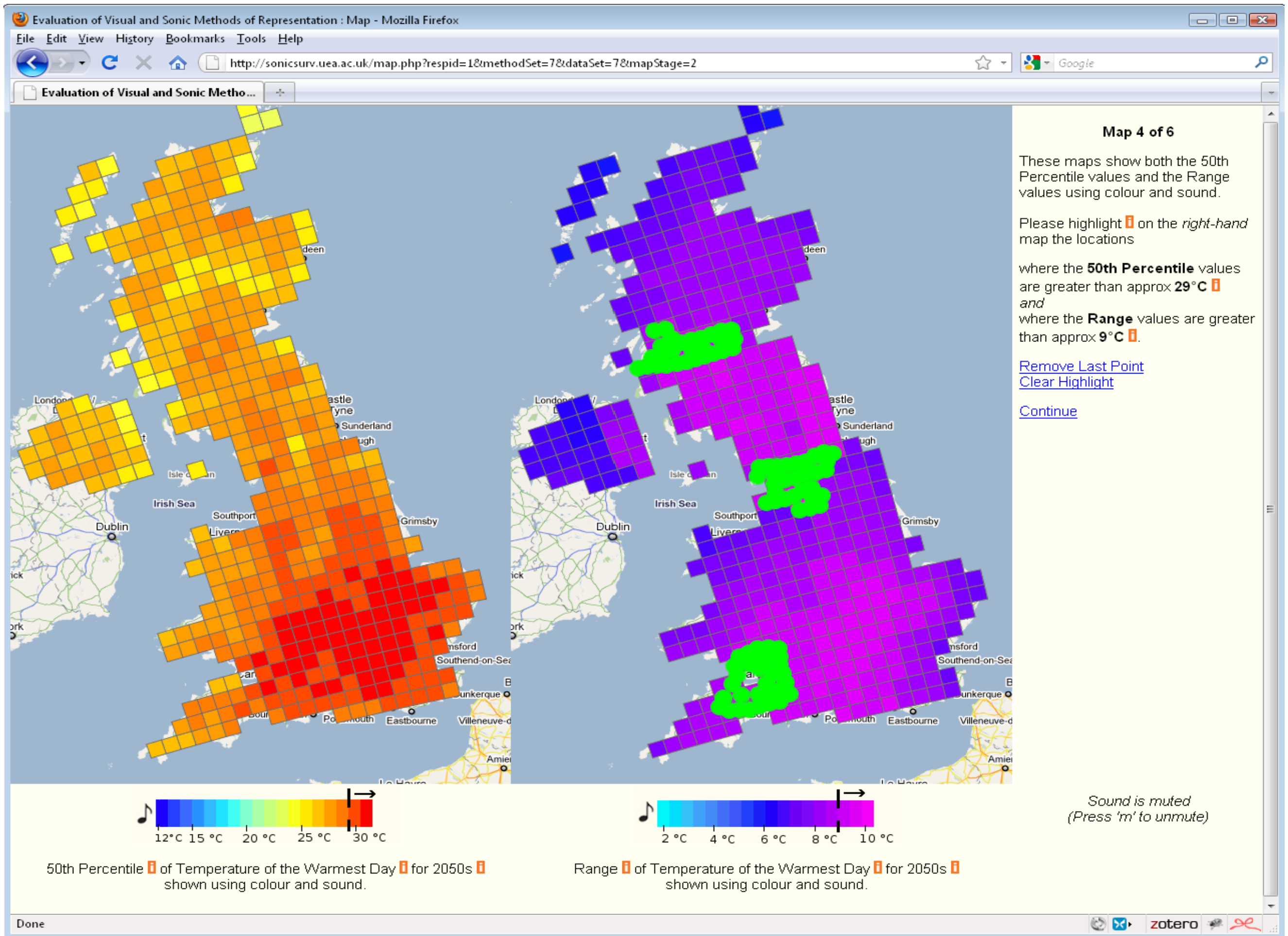

Figure 1: Screenshot of Google Maps interface with UKCP09 overlay and an area highlighted. The respondents were not allowed to pan or zoom the map.

involved variations in volume of a clip of music, and this abstract nature could mean that these results have a limited wider applicability. MacVeigh and Jacobson [10] used real sounds to represent three different land uses (sea, land and harbour), which participants in their experiment found very easy to understand. This type of research has been rare to date and comparison of studies is complicated by a lack of consistent terminologies and different research frameworks [11].

1.2. UKCP09 dataset

The following section introduces the data and techniques used, before describing the nature of the experimental design. The UKCP09 dataset is the latest in the series of future climate projections for the UK [1]. In all of the previous versions of this dataset, users were given a single number for the prediction of a particular climate variable, under a specific emissions scenario for a particular location and time. This dataset now provides users with a range of values and probabilities which they need to be able to integrate into their existing work flow and decision making processes.

Uncertainty is a variable that is often ignored in cartography for a number of reasons, including the fact that the map is visually saturated, and so this variable is used as an example for this sonification study. Sound is already used regularly to create maps for users who are blind, with sound replacing the visual medium. However, very limited work has considered using sound in combination with visual representation methods with the aim of incorporating more data or communicating more effectively. Using sound may provide a way to include this additional data whilst avoiding visual saturation.

2. METHODOLOGY

One of the main premises of the evaluation was to compare different visual and sonic methods to see which was most effective at representing the uncertainty within the data. The participants were shown four different maps, utilising a combination of the different UKCP09 data sets (Summer Mean and Warmest Day) for different time periods (Baseline, 2020

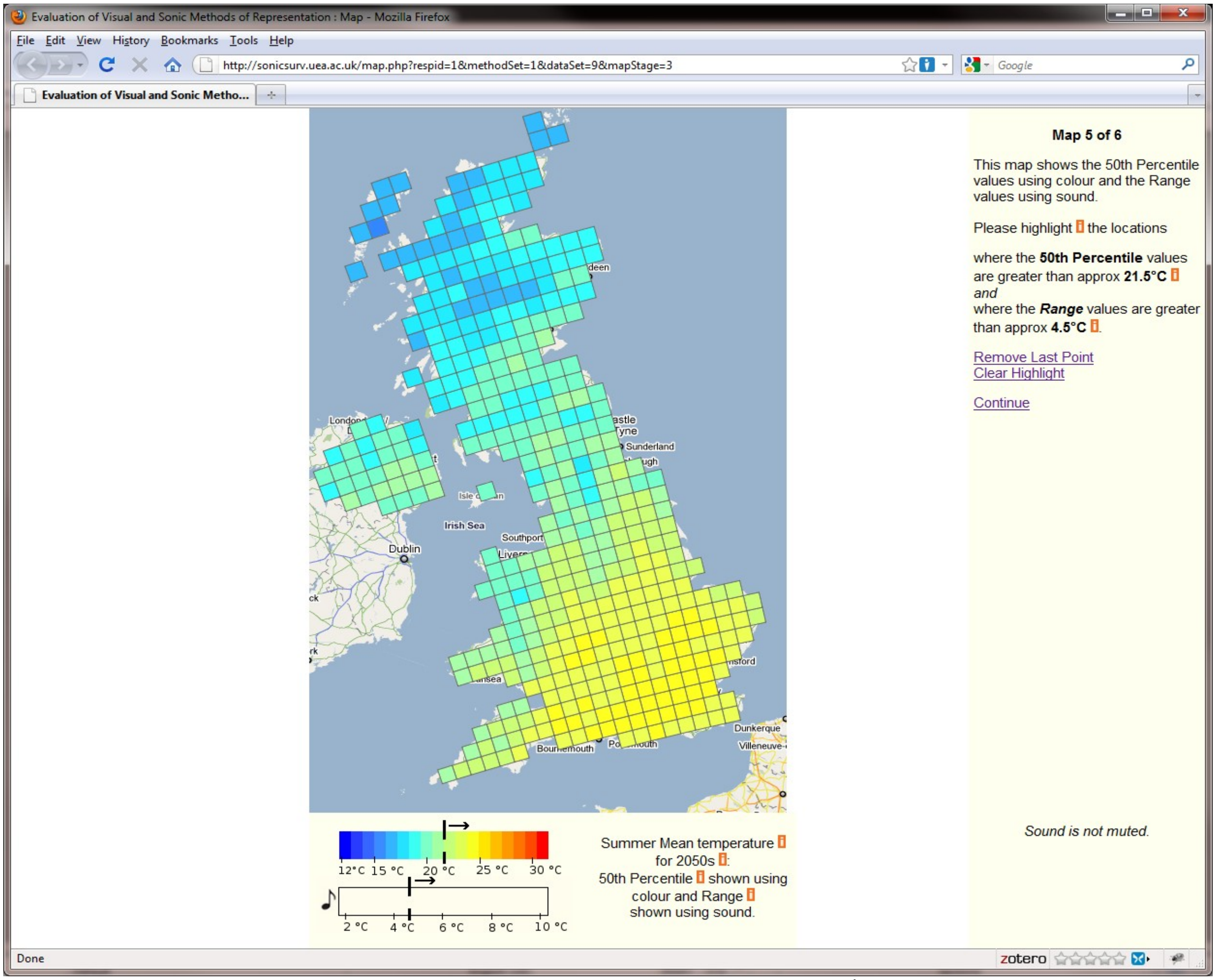

Figure 2: Screenshot of the evaluation map with the VS representation method, where the 50th percentile data is represented visually and the range data is represented sonically. See http://vimeo.com/17029358 for a demonstration.

and 2050). The interface showed combinations of the 50th percentile and range of the data, on either one or two maps (see Figure 1 for an example). Users were asked to highlight areas on the map that exceeded specific values.

Three main methods were used to evaluate the benefit sound might bring to this traditionally visual interface. All methods showed two different, but related, data sets (the 50th percentile and the range of the projected temperature increase) and asked participants to highlight areas on the map where both the 50th percentile and the range exceeded specified values. The first method (VV) just showed the data visually, using blue-red and light blue-purple colour scales, as shown in Figure 1. This was the baseline method, where sound was not used at all. The second method (VSVS) showed both data sets using vision and sound, with 50th percentile on the left and range on the right maps (see Figure 1). As the participant moved the mouse over the map, the relevant sound was played for that value (see video at http://vimeo.com/17029341). They were asked to highlight the area where both data exceeded the specified criteria on the right hand map. The third method (VS) used only one map (see Figure 2) and showed the 50th percentile data visually (using a blue-red colour scale) and the range data sonically. Again, as the user moved their mouse over the map, the sound changed to represent the range data, and they were asked to highlight the locations that exceeded both thresholds for the relevant data (see video http://vimeo.com/17029358 for example). This method was shown to the user twice.

The sounds used in previous similar examples have been quite varied, with Fisher [7] using pitch and volume and MacVeigh and Jacobson using more 'natural' sounds – birds, waves and machinery. For this study, it was decided to vary pitch of musical notes, as this provides a very clear and easy to understand scale to map the data values on to, and it is reasonably easy for participants to hear the 'high' and 'low' ends of the scale, and link these to the 'high' and 'low' data values. Previous work [2] altered the pitch of piano notes. It was said that these notes could have benefited from being sustained, as this would make it easier to get an overall picture of the data and provide a smoother transition between different notes for different data values. Trumpet notes were used for this exercise to create the sustain element, and to act as a comparison to see whether the type of instrument made a difference. Unfortunately when implemented, the trumpet notes suffered from the conversion and compression required to play them in the web interface and so sounded very electronic.

The computer based questionnaire was developed over 6 months, using the Google Maps API. This allowed anyone with just a web browser to take part in the evaluation, whereas previous work [2] had utilised the ArcGIS framework to develop a sonification tool, which required the users to have ArcGIS installed on their computers.

Google Maps and Google Earth are well-used for presenting spatial information to varied audiences, both in an official capacity [12] and via more informal "mashups" [13], [14]. GMAPI was chosen for these case studies largely due to the dominance of Google Maps in online mapping [15], with the conclusion that this would give the greatest chance of existing user familiarity with the interface and base mapping style. The cartography of the base maps is clearer in many ways than alternatives Bing Maps and Yahoo! Maps [16], both of which also offer an API [17], [18]. The existence of resources to assist with development was the other main motivation for choosing GMAPI; online documentation, tutorials and user forums are more developed than for the alternatives, and experience within the department was also a consideration. The GMAPI interface was utilised for spatial data collection of the survey, and was embedded within a questionnaire that the participants completed.

The UKCP09 data set was used as an example, with the Summer Mean Daily Temperature 50th percentile (central estimate) used directly, and the range was calculated (90th percentile - 10th percentile). For visual representation, the data was added to the Google Maps interface via a KML (Keyhole Markup Language [19]) file. The KML was created by including the data in ArcGIS and adding the colour scheme before using the KML export option. A number of ways of including the data for the sound with Google Maps were explored, but in the end the values were stored in an array (written in the coding) with their location (latitude and longitude). For the sonification, the nearest value was retrieved in real time and the relevant sound was played, using a Flash add on [20]. When the participant moved the mouse to a different grid square, the sound continued playing if the same sound was required, but if a different sound was required, the original one was stopped and the new one started. (see Figure 1 and http://vimeo.com/17029341 and http://vimeo.com/17029358).

2.1. Implementation

Participants were recruited through informal networks at UEA (n = 62) and through gatekeepers who provided access to UKCIP staff (n = 8) and Ordnance Survey staff (n = 8). Policy makers were also approached, but they were geographically dispersed, so they were asked to complete an online version of the survey (n = 3). In total, 81 respondents completed the evaluation.

The evaluations were held in small groups, usually between 3 and 6. The participants were asked to read and sign a information sheet and consent form before starting the evaluation. Participants completed the computer based questionnaire independently, which usually took 30-40 minutes. For the maps in the computer based questionnaire participants were asked to highlight specific areas which exceeded a stated threshold value. The threshold varied depending on the data set being shown, but usually required about 1/3 of the area to be highlighted. The area the participant highlighted was saved as a series of points, which were subsequently processed before the main section of the analysis. The computer based questionnaire also included various questions covering a number of different areas, which may have an impact on users ability to understand the sonification.

Discussion sessions were held at the end of each evaluation session for a duration of around 20 minutes. A semi-structured method was followed, with a list of points to cover but the discussion was allowed to take its own course if the participants were suitably enthused. The discussions were recorded (with the participants consent) and subsequently summarised.

3. RESULTS

A number of outliers were removed from the data, as well as results from the non supervised version of the survey (n = 3) giving a final n = 71.

The results consisted of the data from the questionnaire and maps, as well as the qualitative information from the short discussion sessions. For each map and method combination, the selected area for each user was compared with the 'correct' answer (the area that exceed the specified values) and given a comparative score (the phi value) between 1 and -1, where 1 would mean the user had selected the correct area, and -1 would mean the user has selected the inverse of the correct area. Scores varied from 0.2 to 1.0, and were grouped for the different methods, data and users. A cluster analysis was performed based on the phi scores, producing six distinct clusters (see Figure 3).

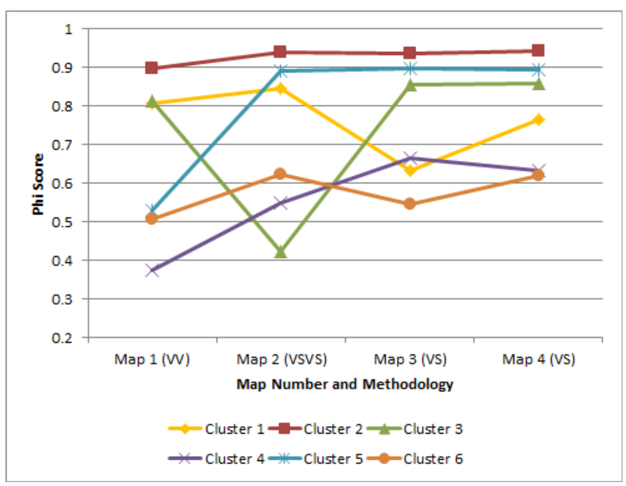

Figure 3: Results clustered into six clusters, shown for each map and methodology by phi score.

The vast majority of participants said that the VSVS method (where vision and sound showed the same information) was the easiest to use and best represented the data. This agrees with the results, as VSVS increased in the vast majority of participants scores (significant mean phi increase from 0.680 for VV to 0.768 for VSVS, $p = 0.005$). Cluster 3 was the only group to perform worse, in contradiction to the rest of the participants. There were no obvious differences for cluster 3 in areas such as learning style, which might have explained the differences. Their knowledge of probabilistic data was significantly lower than the rest ($p = 0.027$) so this might indicate that knowledge of the data set is required to best use the sonification.

Additionally, awareness of the UKCP09 data set seemed to have an impact on the ability to use the sonification for both the clusters and individual results, with those with awareness of the UKCP09 data scoring higher than those without ($p < 0.001$). It was thought participants with a strong sonic learning style would have performed more effectively than those with a strong visual learning style but this was not the case, with a very small difference between them. This could be because the visual learning style is comparable to spatial literacy (ability to use spatial data / maps) which is required for this evaluation. Those with lower spatial / GIS knowledge performed less well than those with higher spatial / GIS knowledge, but this difference was not significant.

The VS stage (where the 50^{th} percentile data was shown visually and the range data sonically on the same map) also performed reasonably well (mean phi = 0.783 and 0.821) but took the participants longer to complete (but not significantly) and was said to be harder in the discussion sessions (see Figure 4).

There appeared to be a learning effect (particularly between the last two maps, both using VS method) but this was quite difficult to separate from the other variables, given the design of the study. A future experiment would ideally randomise the order of maps in an effective way to negate this issue. Randomisation was considered for this experiment, but the way it was implemented was considered too confusing in the pilot stage of the developments. There was a significant increase in speed ($p = 0.033$) between map 3 and map 4 which may show experience of the sonification can help speed up analysis without compromising the phi score. However, more testing is required to confirm this conclusion.

4. CONCLUSION

Overall the results showed that sound can be used to display spatial data. Uncertainty is the example used in this evaluation, but these results could be applied to other datasets as well.

Feedback on the success of using sound varied significantly between different people, and may be impacted by some of the measures in the questionnaire. The results show that awareness of the data influenced the ability to use the sonification. There may be some impact as a result of the learning style and/or musical knowledge of the participant, but the questionnaire in its current form did not detect this very effectively. A future improvement would be to attempt to refine the questionnaire to capture this data.

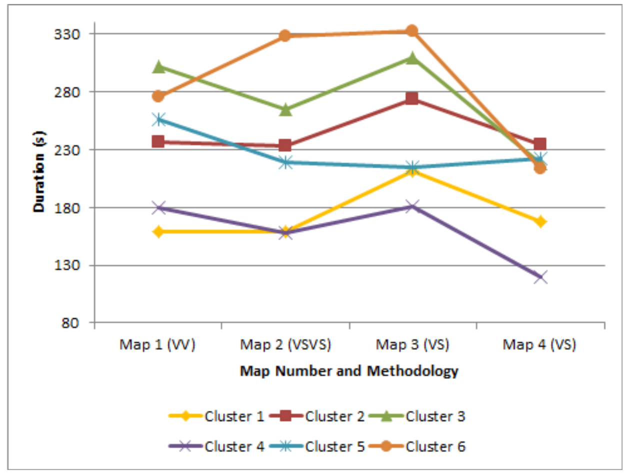

Figure 4: Results clustered into six clusters, shown for each map and methodology by duration.

Other improvements to this evaluation include refining the code to enhance performance and remove minor bugs, and consider using a more varied data set to prevent users from assuming the area they needed to highlight was in the south-east of the country, which was the case in 5 out of the 6 datasets used in this evaluation.

Overall sound can be used effectively to show uncertainty in the UKCP09 data set, but some people found it much easier to utilise than others. Future research should explore what factors influence this, and see whether using both different sounds and/or different sonification methods can address this issue.

5. ACKNOWLEDGMENT

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