Helping Users Make Decisions by Visualizing Weather Uncertainty

Imogen Cleaver-Stigum, Andrew Nolan, Matthew St Louis, Jyalu Wu, Professor Lane T Harrison

1 Introduction

Our group has spent a lot of time looking into uncertainty visualizations, and we feel the final project may be one place we can apply them in an interesting way. Specifically, we are inspired by quantile dot plots, hypothetical outcome plots, and value-suppressing uncertainty pallets.

We see precipitation uncertainty as a concise metric for binary decision-making. We might present participants with several visualizations that display the uncertainty around precipitation and ask them how they would handle certain situations (e.g. moving a wedding inside a cathedral rather than on its lawn, walking instead of driving for a short-distance errand, cancelling a hike with friends). Our goal would be to find out how the visualization type affects the participant's answers, what visualization types make the user feel most confident in their decisions, and what visualization types are most accurately readable to participants.

2 One-Sentence Description

Can we empirically determine what visualization type best helps users understand weather uncertainty to make decisions?

3 Project Type

Empirical Experimentation

4 Audience

We target users who are making precipitation-sensitive plans or who are otherwise interested in better understanding precipitation uncertainty to make decisions.

Beyond the visualization's use for people checking the weather. Our experiment may be useful for researchers interested in uncertainty tools, as we will provide a comparison between different tools.

5 Approach

We will present users with a series of visualizations similar to our survey in A3. Each would encode uncertainty in precipitation. These visualizations for comparison might include a quantile dot plot, a map with precipitation uncertainty encoded as a series of areas, a hypothetical outcome plot, a hypothetical outcome map, and a map with a value-suppressing uncertainty pallet. We may add or substitute other visualizations as we find them. We would compare these to more conventional visualizations, such as error bars, traditional precipitation maps, and hourly point estimates with weather icons.

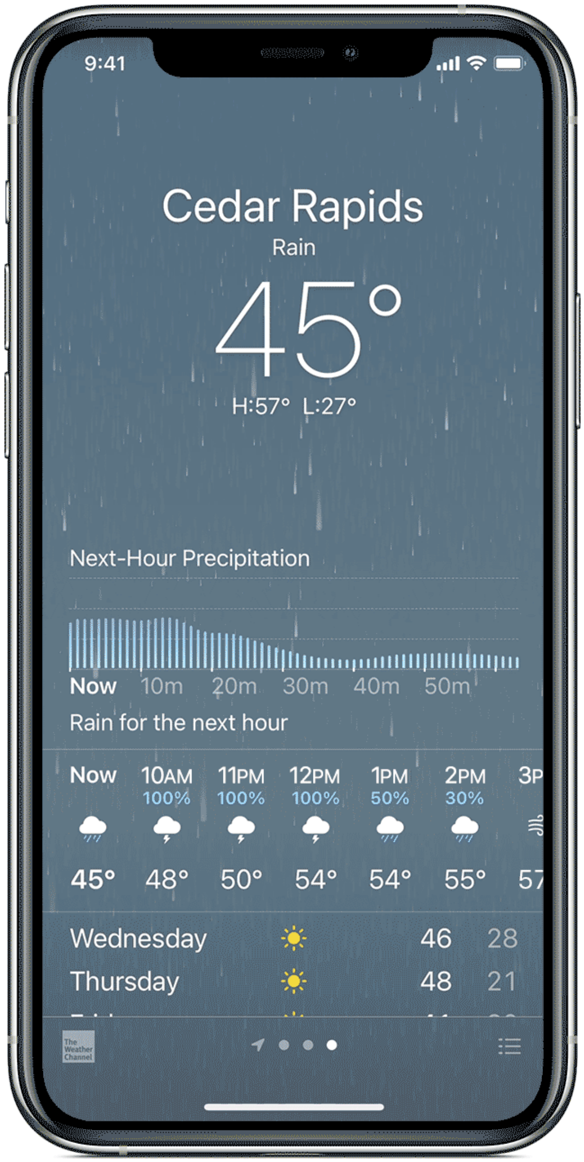

Figure 1: Standard weather prediction visualizations including icons, percentages, and a barchart of rainfall over time. We intend to compare our original visualization types to standard visualizations like this.

We primarily plan to get weather data from NOAA or one of several free weather API's (https://www.tomorrow.io/blog/top-8-weather-apis-for-2020/). For our experiment/survey, we plan to use historical data so we can curate it ourselves. For our stretch goal of developing a usable visualization, we would be using real-time data. We expect moderate cleanup and transformation to aggregate entries across days. In addition, we may randomly generate hypothetical weather data given the experimental nature of this idea.

We also plan to send the survey to friends, family, classmates, and additional WPI students.

5.1 Details

Our aim in this assignment is to present weather data to users in a way that helps them understand the uncertainty so that they can make decisions. We are not sure exactly how this will look because we see a few separate axes of uncertainty. We are not sure which will prove most helpful to users, but we hope to learn more through experimentation, surveying, or research. The axes of uncertainty we have identified are as follow:

- Given that it will rain, when will the storm hit?
- Given a storm, what is the probability that it will hit your geographic location?
- Some combination of these two

To display this uncertainty, we propose a list of candidate visualizations. Some are existing weather displays, some are baselines we are hoping to beat, and some are visualizations that may be novel to weather data. Our current list of candidate visualizations is as follows:

- Baseline text
    - Potentially turn the point estimates into text
    - Transcribed NOAA weather conditions
- Point estimates (icon, temperature, chance of rain)
- Barchart with error bars - percent precipitation in the next hour, day, week, etc
- Compare to the weather channel app or something similar

- Hypothetical Outcome Plots
- Quantile dot plot
- Map that displays expected rainfall with a value-suppressing uncertainty pallet
- Map that shows expected storm path as uncertainty

We plan to set up some kind of experimentation application, similar to A3. This would present users with different visualizations and collect data to compare the visualizations. We might ask users to interpret different representations of weather data in different ways, including reading the uncertainty, choosing which statement best characterizes a given uncertainty representation, and making a decision on whether or not to move plans to accommodate the weather. We plan to use curated data or data that we can carefully procedurally generate if we can find appropriate guidelines on realistic weather data.

5.2 Evidence for success

We collect enough data to make statistically valid claims about which weather uncertainty visualization is most effective.

6 Best-case Impact Statement

If there is a common consensus on which viz is most easily understood/captures weather uncertainty the best, that indicates that we have a winning viz and the experiment was successful.

7 Major Milestones

1. Finish reading academic papers on uncertainty visualization to understand some of the best practices on this topic
2. Decide which visualizations to build and include in the survey
3. Send out the survey to a diverse sample population
4. Analyze feedback from the survey

8 Obstacles

8.1 Major obstacles

- If the participants in our study are not a diverse group that is representative of the larger population we are targeting with this project, we will not know if the winning visualization(s) are readable for everyone and not only the population we sent the survey out to. Two biases that might come up in our project are:
    - Response bias - The people who respond to the survey may be people who already know a lot about weather uncertainty.
    - Selection bias - We most likely will only send to people we know so this wouldn't represent the whole population.
- If we choose to try to survey the public in order to obtain a more diverse set of participants, we might run into some difficulties in spreading the word.
- In order to make the best weather uncertainty visualization, we'll have to understand a little about how the human brain works.

8.2 Minor obstacles

- Creating a nice looking uncertainty visualization in D3.
- Since we won't have much time for this project and would like to release the survey to the public masses as soon as possible, we will have difficulty finding the time to optimize the survey for mobile devices and might have to give up on that.

- Deciding which map projection to use if we're using maps as one of our vizzes.

9 Resources Needed

- A literature review of uncertainty visualizations
- Knowledge about weather patterns and uncertainty in weather
- Weather datasets that include the uncertainty of the weather at a given moment
- Code to create visualizations of the weather data
- A server or database to host or store results of the survey (e.g. Firebase)
- Lots of study participants

10 Related Publications

There are many publications we can draw from and build upon for our project, such as:

- **When (ish) is my bus**: attempts to visualize uncertainty in bus arrival times for decision-making. The authors of this study sought out to improve the existing OneBusAway app by visualizing uncertainty. They surveyed users on what aspects of bus arrival times were useful and how they used the app in their everyday lives. From this, they designed a few different uncertainty visualizations, including the novel quantile dot plot. This is very similar to the research we plan to conduct. We would likely also start by assessing what weather data people need to see and ideating potential representations of it. We would then ideate on what visualizations might best meet the needs that users express or that we find in our research. In addition to mimicking this process, quantile dot plots may be an interesting visualization to examine.
- **Hypothetical Outcome Plots**: This research proposed a novel uncertainty visualization that represents an uncertain distribution dynamically rather than statically. The idea is to have a chart that periodically updates to show a new hypothetical draw from an uncertainty distribution, and the user can mentally aggregate these draws to get a sense of the overall distribution. We might borrow from this technique to visualize uncertainty in weather data dynamically.
- **Value-Suppressing Uncertainty Pallets**: This research focuses on examining color pallets that can communicate uncertainty efficiently and effectively. These color pallets allocate more colors to more certain data and fewer colors to less certain data, which can help clear visual noise from a map. We are interested in attempting to apply this technique to a map showing expected precipitation or some other metric.
- **Sanyal et al.** created **Noodles**: a tool for visualization of numerical weather model ensemble uncertainty. This tool visualizes ensemble uncertainty for water-vapor mixing ratio, perturbation potential temperature, and perturbation pressure. They quantified uncertainty using individual ensemble member standard deviation, interquartile range, and the width of the 95% confidence intervals after performing bootstrap aggregation to ensure the data followed a normal distribution. Using *uncertainty glyphs*, *uncertainty ribbons*, and *Spaghetti plots* they designed a user interface for exploring weather uncertainty. This research was evaluated by two meteorologists. The tool

appeared to be effective for seeing areas of uncertainty in the weather. However, the features used and the target audience of this tool are for expert meteorologists. Our team can build upon the visualizations used in this research but with specifically precipitation data that can be easily interpreted and used by casual users interested in the weather.

- **The Effect of Uncertainty Visualizations on Decision Making in Weather Forecasting**: This paper examines a few different ways of visualizing weather uncertainty in wind speeds. The technique it proposes (using a combination of maps for the worst case, average case, and variability, each with its own hue-based color scale) does not seem particularly useful. This paper's main use for us lies in understanding what to avoid when designing our own visualizations.
- **Visual Reasoning Strategies and Satisficing: How Uncertainty Visualization Design Impacts Effect Size Judgments and Decisions**: This paper looks at how people perceive uncertainty based on how far apart visually two plots are. It also looks at whether this changes when the mean is superimposed over the uncertainty plot (for example, a normal distribution bell curve with the mean highlighted) and finds that including/emphasizing the mean makes people less likely to accurately perceive the uncertainty. However, the paper also finds that accuracy of the uncertainty perceptions does not necessarily benefit the viewers' decision making. This is relevant to us because we want to understand which types of plots are best for visualizing uncertainty, as well as how people are going to use this uncertainty in their everyday decision making about precipitation.
- **In pursuit of error: A survey of uncertainty visualization evaluation**: In this paper, **Jessica Hullman et. al.** designed a *taxonomy* to help improve the process of evaluating the effectiveness of an uncertainty visualization. This taxonomy has six levels of decisions that are used to evaluate vizzes, and depending on which decision you decide on for each level, your *evaluation path* will differ. They also give recommendations for evaluators of uncertainty vizzes. We will try to follow both the taxonomy and the recommendations when self-evaluating our vizzes throughout the project, from building them to analyzing survey responses.
- **Why Authors Don't Visualize Uncertainty**: This paper outlines the reasons why visualization authors choose not to visualize uncertainty after surveying 90 of them. The paper also references the contradiction that many authors state that uncertainty visualization is extremely important but choose not to delve into that field. This paper will allow us to understand the misconceptions and general attitudes towards uncertainty visualizations, as well as understanding some problems we might run into while building them.

11 Define Success

There are several ways we will measure our success in this project:

1. *Experimental results.*

We want to learn more about what helps people understand and visualize uncertainty to make decisions. We will learn this by analyzing the results of our experiment.

2. *An experiment site.*

We will develop a site to host the experiment so we can send the link to our participants. This will probably include frontend (react) and backend (firebase), a database where we store our results as the users complete the survey/experiment, and the visualizations themselves, similar to A3.

3. *Graduate.*

All of us need this class to graduate so we will consider that another success.

4. *Publish.*

Any results comparing visualizations, even if our hypotheses fail, may be possibly publishable.

Stretch Goals

In addition to our success measures, we have come up with some extra goals that we would like to complete if we have time after the survey. We would like to make an app that shows live weather using the visualization our survey determines is the best.

12 References

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