Chapter 3: Optimizing forecast visualizations with incorporated uncertainty as decision support tools for water resource managers

Background

Visualizations are critical tools which efficiently enhance human understanding of complex ideas (Larkin and Simon 1987). Producing appropriate visualizations of forecasts presents a unique challenge given that forecasts are inherently uncertain and yet their output is often used to make crucial management decisions with human health implications. Additionally, uncertainty is a notoriously difficult concept for most individuals to grasp, as well as to represent graphically (Bonneau et al, in *Scientific Visualization* 2014, Potter et al 2012). There are numerous studies looking at different ways to visualize uncertainty in data (Potter et al 2012, Smith Mason et al 2017, among many others) but little consensus as to the best approach for visualization uncertainty of forecasts for both comprehension and decision support. Additionally, it has been well documented that different approaches to visualizing uncertainty result in differential comprehension by users (Kinkeldy et al 2017, Mckenzie et al 2016) indicating that representation of uncertainty has important implications for influencing decision-making. In this chapter, I propose to determine the best approach to visually represent uncertainty in ensemble forecasts of algal concentrations at a single location to optimize application for decision support.

Research Questions

1. How do different visual representations of uncertainty of vector forecasts (ensemble forecasts of algal concentrations (ug/L)) influence **comprehension of uncertainty** in water quality managers?
2. How do different visual representations of uncertainty of vector forecasts (ensemble forecasts of algal concentrations (ug/L)) **influence decision making** of water quality managers?

Proposed Methods, Q1

To assess the effect of different visual representations of uncertainty on comprehension and decision support, we will produce n = 5 (as a starting point, this number may need to change) visualizations of ensemble forecasts of algal concentration. Managers at the Western Virginia Water Authority in Roanoke, VA will be surveyed as to their comprehension and preferences of the visualizations as a baseline study. Results from this study will be used to further improve visualizations for a broader survey of managers across geographic regions, in order to better generalize our results. The larger manager pool will be accessed through collaborations within the North American Lake Management Society (NALMS). A preliminary analysis to determine the number of respondents necessary in order to make a representative sample size will be conducted.

*Forecast Visualizations*  
There are many ways to visualize uncertainty, each of which have been shown to have differential responses in comprehension and decision support (Smith Mason et al 2017, Wiggins et al 2018, Olston and Mackinlay 2002). Visualizations produced for this study will include 1) all possible ensembles as individual lines, 2) a data summary showing the ensemble mean and a 95% confidence interval (i.e., an extrinsic representation, sensu Smith Mason et al 2017), 3) an intrinsic representation of uncertainty that will present the entire range of forecast ensembles as a single polygon (Olston and Mackinlay 2002), 4) and animation of forecasts showing the history of forecast skill up to the present, and 5) an interactive visualization developed using R Shiny apps that will allow the user to explore multiple data visualizations.

*Assessing the effect of visualizations on comprehension and decision making*To assess the effect of uncertainty on comprehension and decision making in water managers, a forecast scenario indicating a severe algal bloom (which should elicit some management decision) will be developed into the visualizations mentioned above. Managers will receive one of the visualizations and be asked to make a decision about how best to manage their water resource to maximize water quality and minimize financial burden (i.e., through management actions such as dosing the water resource with chemicals). The scenario may or may not include a background primer on probability and uncertainty.

After viewing the visualizations, a **qualitative survey** will be given to manager to assess 1) comprehension of uncertainty and 2) trust in the forecast output (i.e., does a better understanding of uncertainty influence a respondent’s level of trust in the forecast output as a tool) as a function of the provided forecast visualization. The survey should also include questions to measure the amount of prior knowledge/experience with probability concepts and algal blooms to assess individual differences in responses to the given scenario. Respondents will be asked as a manager of the water body the forecast visualization is based at to make a **management decision** (e.g. a given decision is predicted (‘modeled’), the realized decision of the subject is observed).

Chapter 4: Many potential avenues

1. Further explorations of forecast visualizations
   1. Potential questions
      1. Do managers and scientists differentially perceive visual representations of uncertainty within forecasts of algal bloom densities (ug/L)?
      2. Does the comprehension of uncertainty by managers vary between forecast variables? (e.g., binary (presence/absence of bloom) or continuous (concentration of algal biomass) variables)
   2. Contingent upon further development of Chapter 3
   3. Motivation: learning a new body of literature for Chapter 3 that could be further applied to a fourth chapter
2. Process-based vs. empirical forecasts
   1. Potential question
      1. How well can an empirical model and a process-based model forecast near-term phytoplankton dynamics over a 16-day period (assessed by comparing quantified uncertainties of a probabilistic forecast with observed dynamics)?
         1. This stems from Chapter 1, which has now split into two distinct projects
   2. Motivation: There is a lot of momentum for this work already
3. Developing forecasts for Lake Sunapee
   1. Potential questions
      1. How well can we forecast near-term phytoplankton dynamics in a large, oligotrophic lake?
      2. What are the major drivers of uncertainty in our forecasts?
   2. Motivation: Applying similar approach to what we have used in FCR to expand the forecasting network to a north temperate lake with different geology, weather patterns, land use, infrastructure, etc. to test the ‘robustness’ of FLARE