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

Background

Visualizations are critical tools for efficiently enhancing human understanding of complex ideas (Larkin and Simon 1987). Visualizations are often used to communicate scientific concepts and data to a broad audience (Kelleher and Wagener 2011, Ware 2000). Given the nascence of ecological forecasting, however, there remains a large gap as to how best to develop forecast visualizations, both for forecasters and targeted stakeholder users.

In comparison to other forms of scientific visualizations, producing appropriate forecast visualizations presents a unique challenge given that forecasts are inherently uncertain, yet their output is used as guidance for making crucial management decisions. Uncertainty is a notoriously difficult concept for most individuals to grasp, as well as to represent graphically (Bonneau et al. 2014, Potter et al 2012). There are numerous studies looking at different ways to visualize uncertainty in data (Olston and Mackinlay 2002, Potter et al. 2012, Smith Mason et al. 2017, Wiggins et al. 2018), but little consensus has emerged as to the best approach for visualizing forecast uncertainty for both comprehension and decision support. 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 efficacy of different visualizations for representing 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 ensemble forecasts of algal concentrations (ug/L) influence **comprehension of forecast uncertainty** in water quality managers?
2. How do different visual representations of uncertainty of ensemble forecasts of algal concentrations (ug/L) **influence decision making** of water quality managers?

Proposed Methods

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) alternate visualizations of ensemble forecasts of algal concentration, derived from my Ch. 1 research and FLARE collaborators. The visualizations will vary by type of figure plot, number of figures, and the medium by which the forecasts are delivered to the user (see below, under *Forecast Visualizations*). Managers at the Western Virginia Water Authority in Roanoke, VA will be surveyed following an IRB protocol 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 on a figure plot, 2) a figure plot with 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) an animation of forecasts showing the history of forecast skill up to the present, and 5) interactive visualizations of the figures described above 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 choose one of multiple management actions provided with the intention to manage their water resource by maximizing water quality and minimizing financial burden. (e.g., through choosing to perform management actions such as dosing the water 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 managers to assess 1) comprehension of uncertainty and 2) trust in the forecast output as a function of the provided forecast visualization (i.e., does a better understanding of uncertainty influence a respondent’s level of trust in the forecast output as a tool?). The survey will be designed to measure the amount of prior knowledge/experience with probability concepts and algal blooms to assess individual differences in responses to the given scenario. Comprehension will be assessed in this survey by the respondent’s ability to interpret and explain the scientific information presented (following Hegarty 2011, McMahon et al. 2015). For example, the managers will be asked direct questions about the scientific content, such as “What is the expected algal concentration on X day into the future?”. Respondents will be asked - as managers of the waterbody where the forecast visualization is based - to make a **management decision** based on the visualization they received.

Chapter 4: Many potential avenues

The focus of this chapter is dependent on the findings of the preceding three chapters. While this is broad, I envision three potential avenues forward grounded in my research on water quality, ecological forecasting, and visualizations:

1. Further explorations of forecast visualizations – *building off of Chapter 3*
   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 – *building off of Chapter 1*
   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 the work that was originally included as part of Chapter 1, which has now split into two distinct projects.
   2. Motivation: There is a lot of momentum for this work already and it provides a logical next step for the Chapter 1 research
3. Developing forecasts for Lake Sunapee, an oligotrophic drinking water source lake in New Hampshire – *building off of Chapter 1*
   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. This work would extend my research from Chapter 1 by applying similar concepts but different methods to another drinking water lake. It is likely that other questions regarding the application of FLARE in other systems will emerge as this work develops.