Macrosystems EDDIE: Understanding Uncertainty in Ecological Forecasts

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Macrosystems EDDIE: Introduction to Ecological Forecasting.
Macrosystems EDDIE Module 6, Version 2.
http://module6.macrosystemseddie.org
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Overview of today

- Introduce the concepts of ecological forecasting and forecast uncertainty; where uncertainty comes from; how to quantify uncertainty; and steps to reduce forecast uncertainty
- **Activity A:** Students build different models to simulate water temperature for their chosen NEON site and generate forecasts without uncertainty.
- **Activity B:** Generate additional forecasts of water temperature and examine how different sources of uncertainty affect the different models.
- **Activity C:** Quantify and partition the uncertainty for forecasts made using different models and make management decisions using an ecological forecast with uncertainty.

Ecosystems are changing worldwide…

- In response to changes in climate and land use, ecological functioning in many aquatic and terrestrial systems is changing

- Lakes and reservoirs provide many ecological services; thus, understanding how these ecosystems will change in the short-term will help us better manage these vital resources

- Ecological forecasting is a potentially powerful tool to help lake and reservoir managers preemptively prevent or mitigate water quality concerns

Image: Wikimedia commons

Before we start:

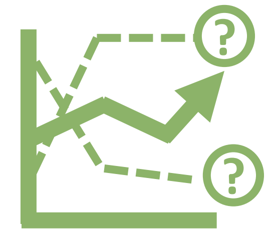
What is an Ecological Forecast?

A prediction of future environmental conditions with uncertainty

- Events have not yet occurred
- Gives a probability or a likelihood of the event to occur (uncertainty)
- Actionable

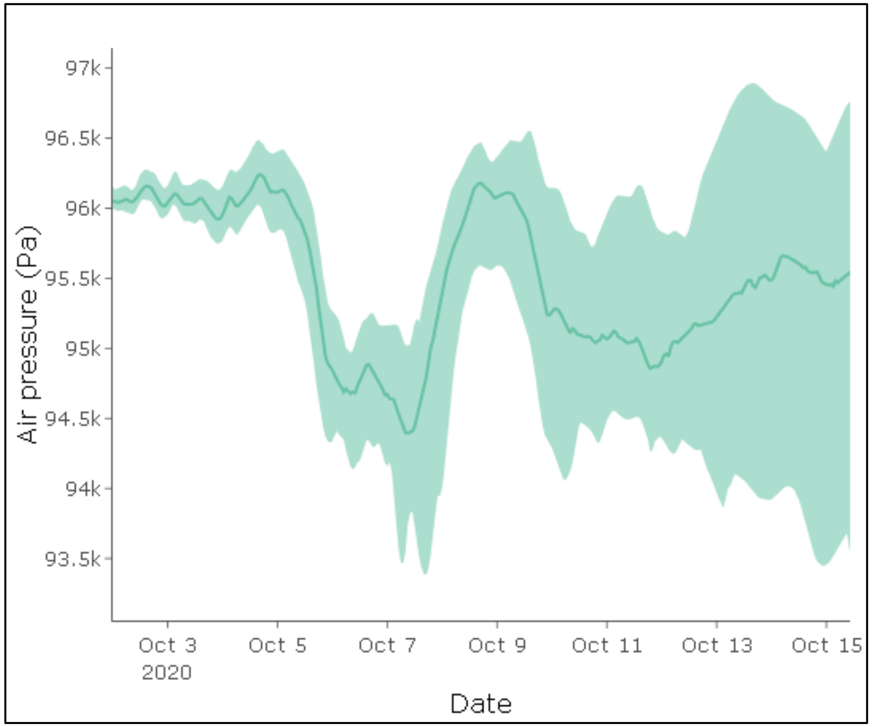
What is **uncertainty?**

- **<u>Forecast uncertainty:</u>** the range of possible alternate future conditions predicted by a model.
- We generate multiple different predictions of the future because the future is inherently unknown.
- Uncertainty generally increases as the **forecast horizon** increases.
  - **Forecast horizon:** the length of time into the future for which a forecast is generated



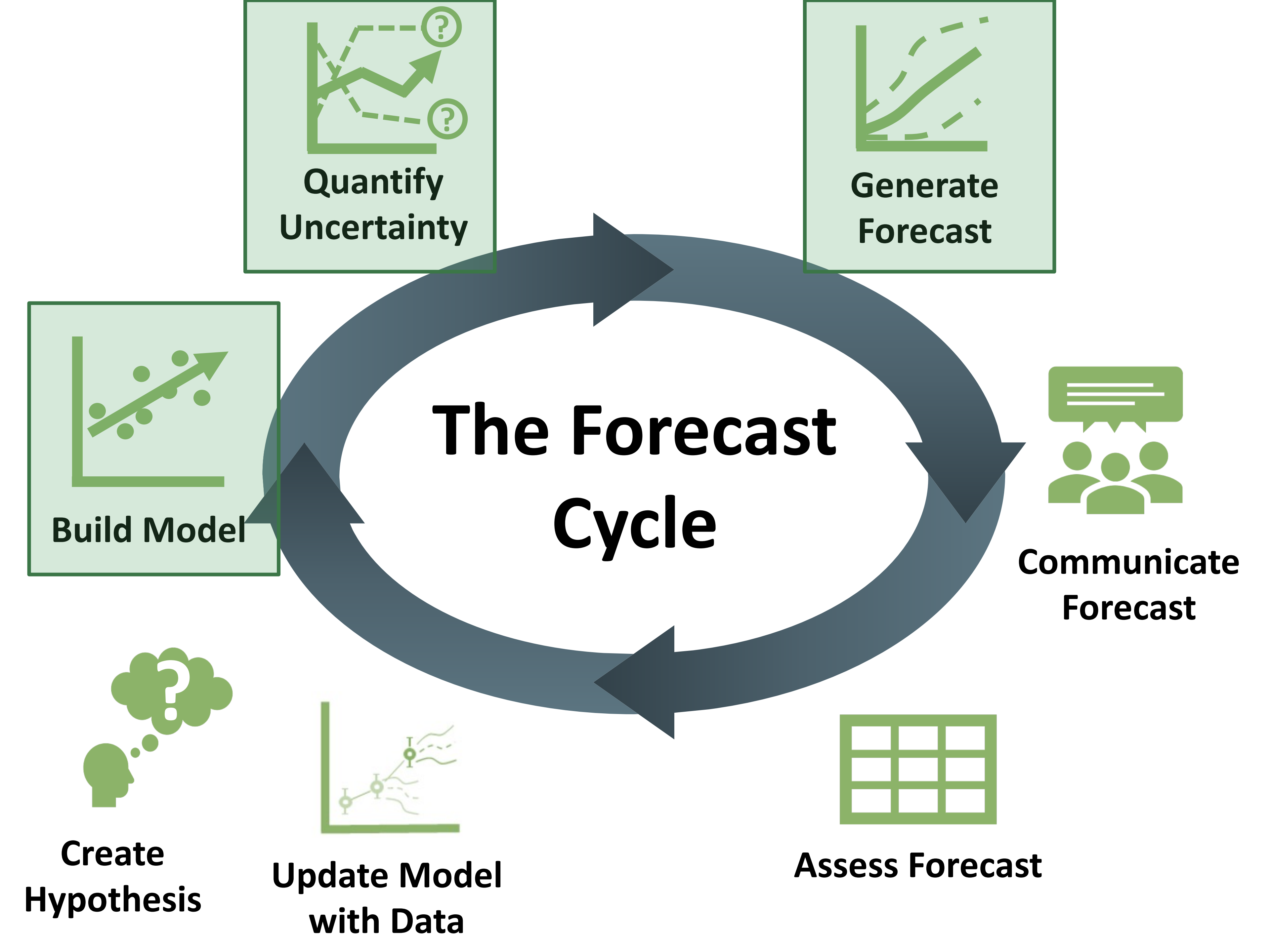
Quantify Uncertainty

Plot showing 16-day-ahead forecast of air pressure with shaded regions showing 95% confidence interval and the solid line represents the median



Our focal question for today:

Where does forecast uncertainty come from and how can it be quantified and reduced?

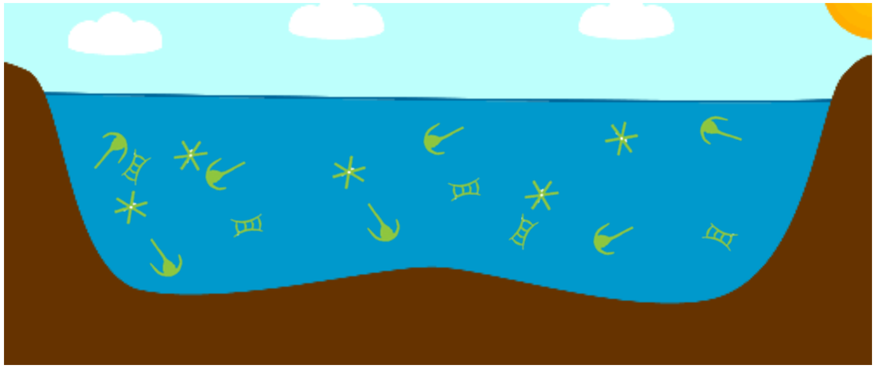


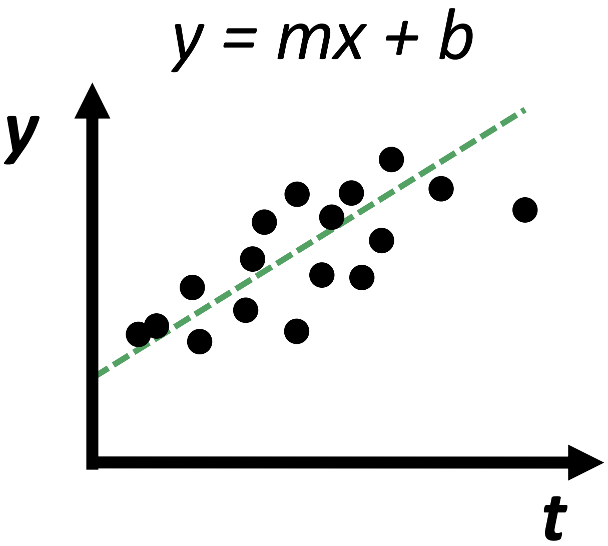
The Forecast Cycle
Quantify Uncertainty
Generate Forecast
Build Model
Communicate Forecast
Create Hypothesis
Update Model with Data
Assess Forecast

Ecological models

A model is a simplified representation of a real phenomenon, with the goal of understanding and **predicting** that phenomenon

Predicting water temperature in a lake

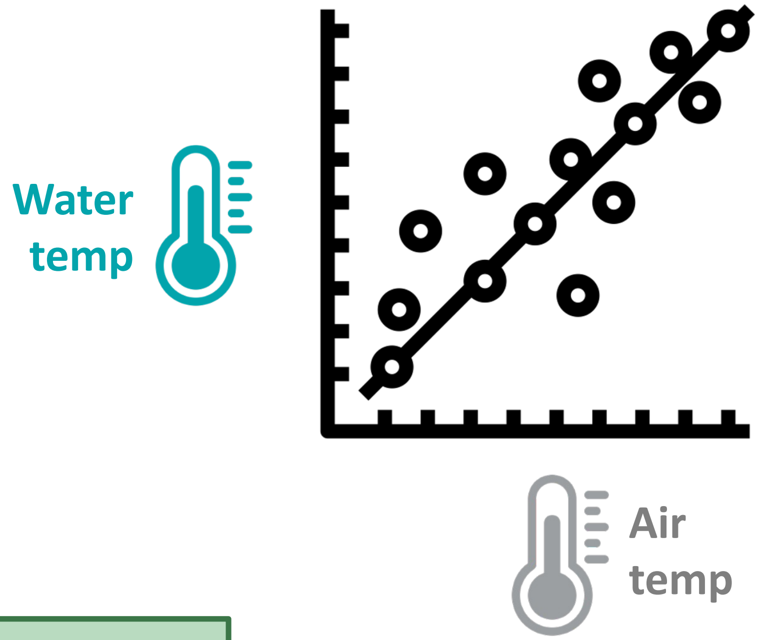




Models are inherently uncertain

<u>Sources of uncertainty:</u>

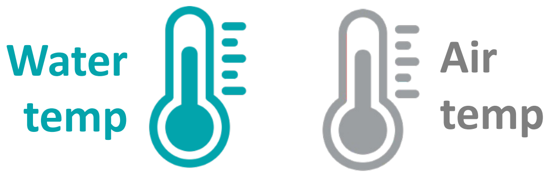
1. Process uncertainty



> **Process uncertainty** is uncertainty caused by our inability to model all processes as observed in the real world.

model process

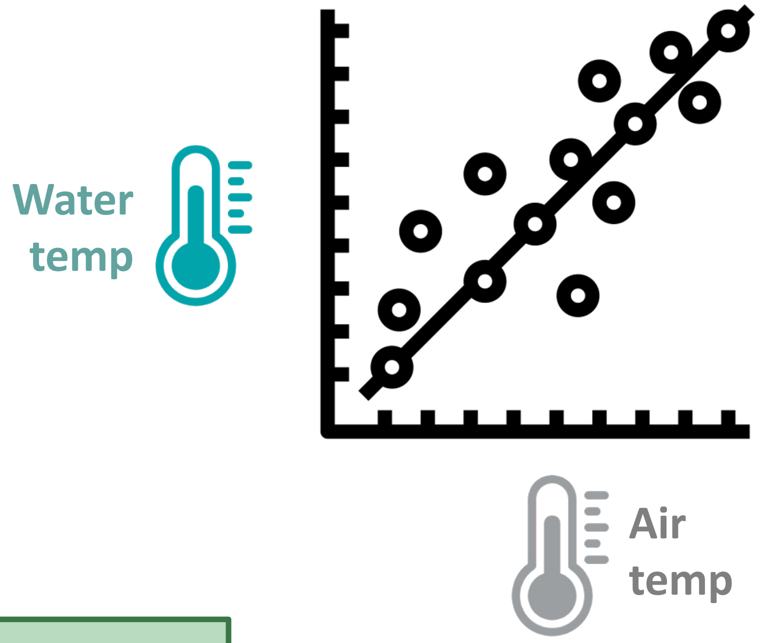
$$y = mx + b$$



Models are inherently uncertain

<u>Sources of uncertainty:</u>

1. Process uncertainty
2. Parameter uncertainty



Parameter uncertainty refers to the uncertainty in the model parameter values, which can be due to having a limited set of data used to calibrate a model.

parameters

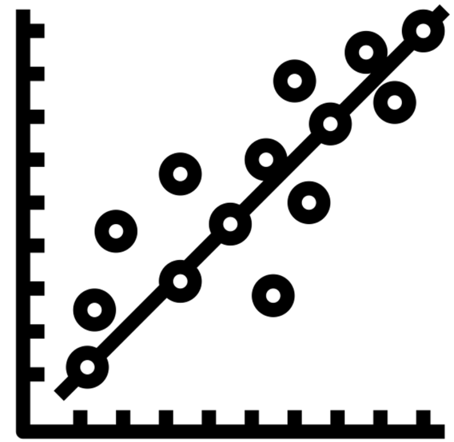
$$y = mx + b$$

Models are inherently uncertain

<u>Sources of uncertainty:</u>

1. Process uncertainty
2. Parameter uncertainty
3. Initial conditions uncertainty

Water temp tmrw



Water temp today

Initial conditions uncertainty refers to uncertainty arising because the current conditions in an ecosystem are not precisely known.

initial condition

$$y_{t+1} = m y_t + b$$

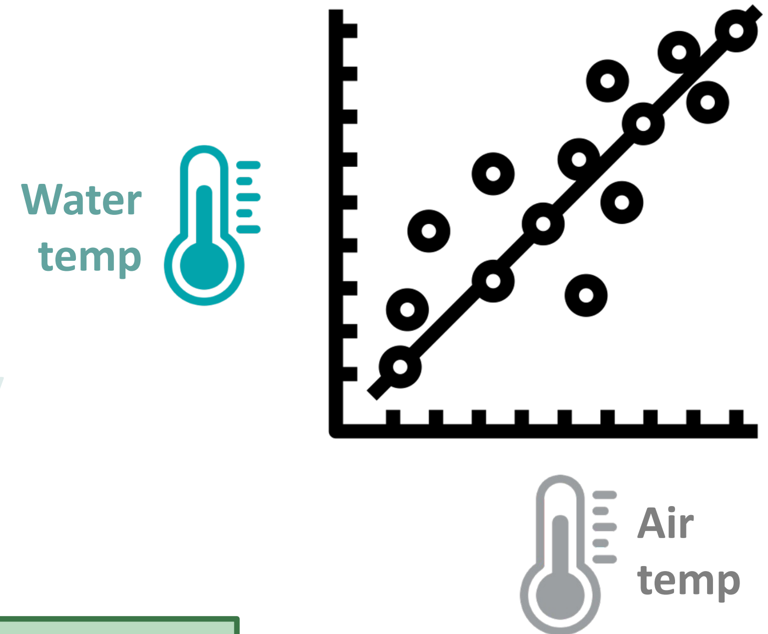
Water temp tmrw

Water temp today

Models are inherently uncertain

<u>Sources of uncertainty:</u>

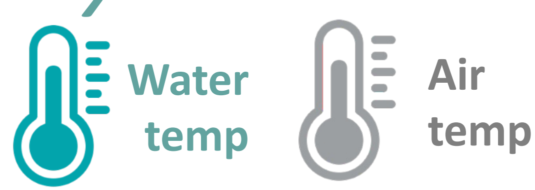
1. Process uncertainty
2. Parameter uncertainty
3. Initial conditions uncertainty
4. Driver data uncertainty



Driver uncertainty comes from inaccuracies in the forecasted variables used to drive the model.

driver data

$$y = mx + b$$



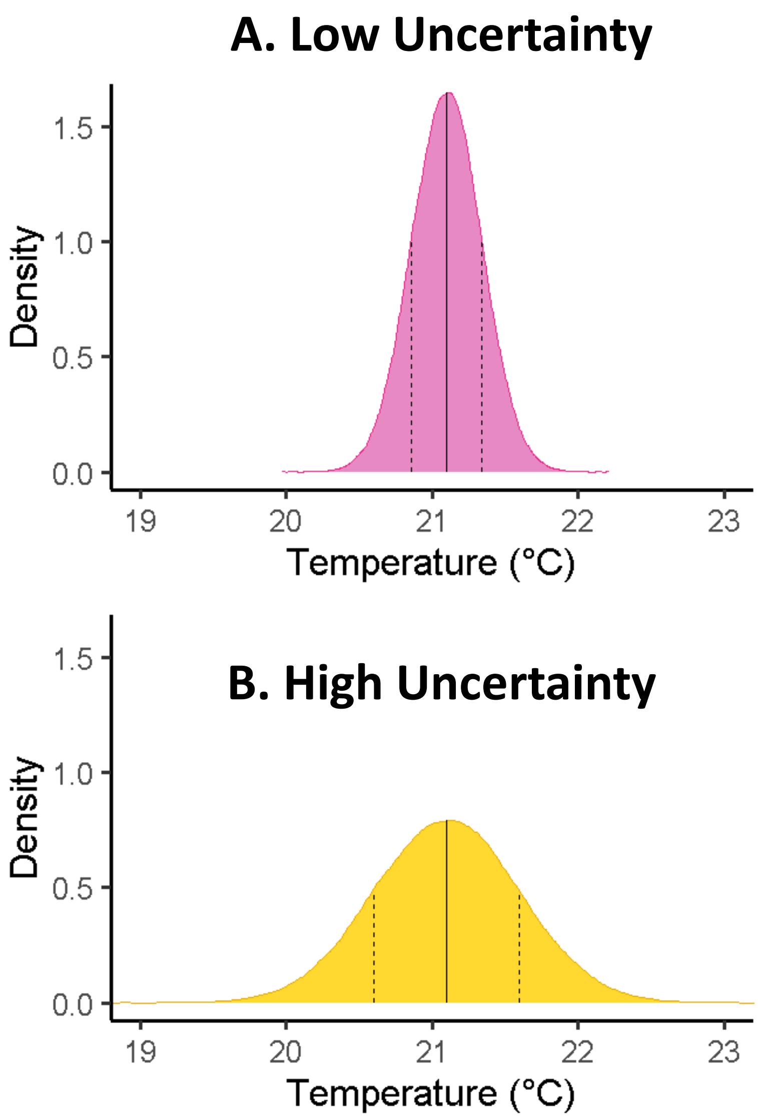
Using Distributions to Represent Uncertainty

- Uncertainty can be represented as a distribution of all possible values

Here, uncertainty is represented as a normal distribution around the mean of 21.1°C with:

A. Low uncertainty

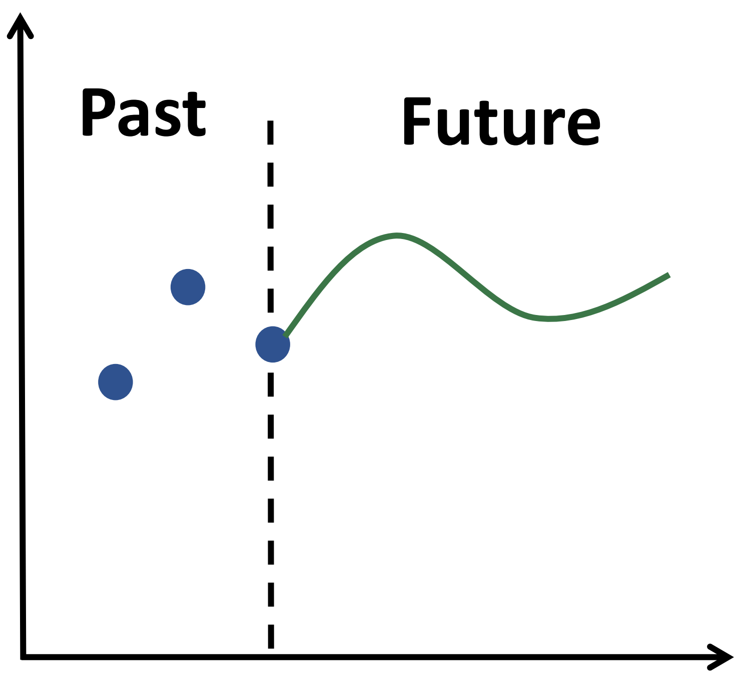
B. High uncertainty



Deterministic vs. Probabilistic Forecasts

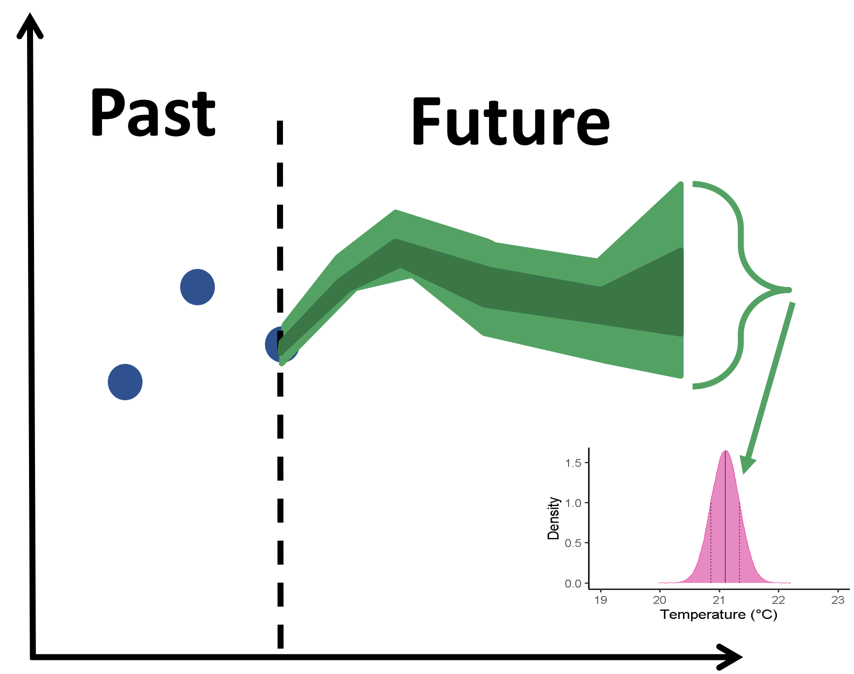
Deterministic forecast

- A single line represents the future
- Uncertainty is not accounted for



Probabilistic forecast

- The range of future outcomes are represented with a likelihood of each occurring
- Uncertainty is accounted for



Ensemble forecasts

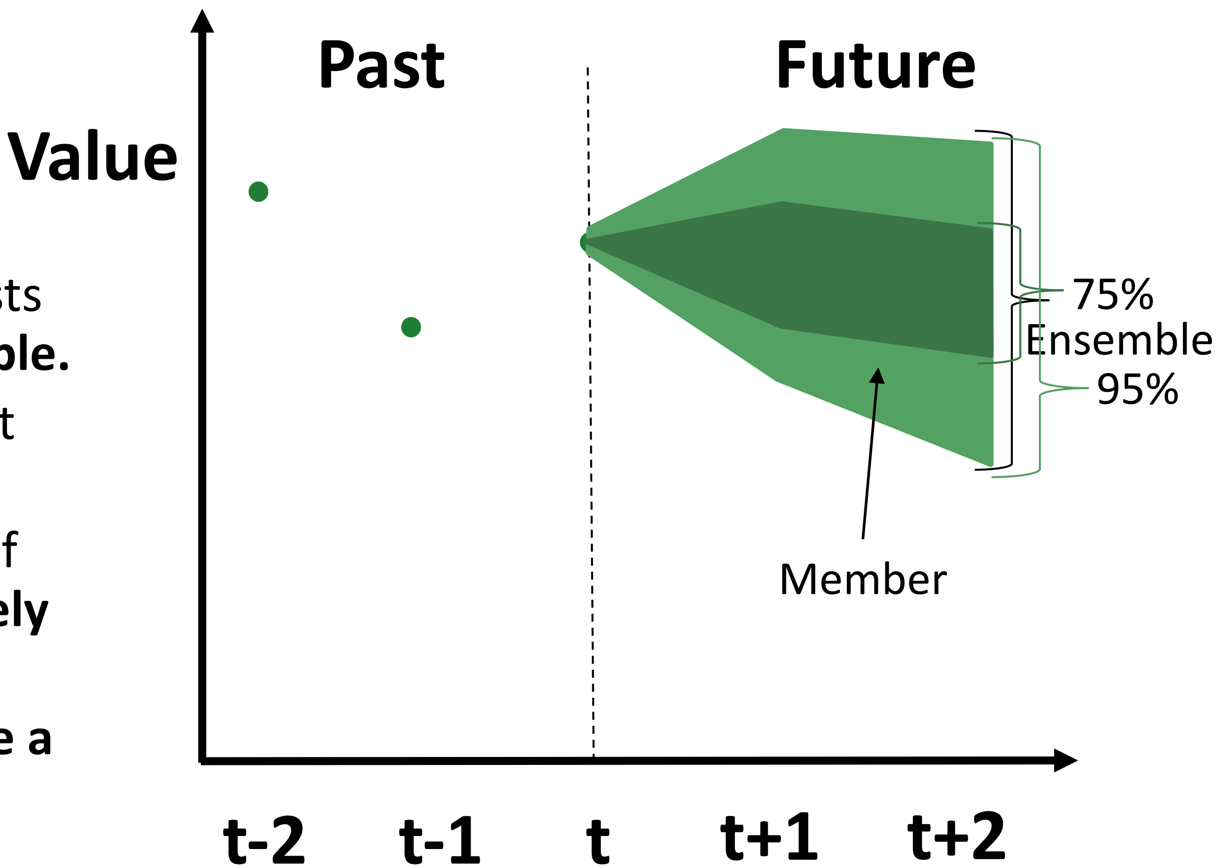
Instead of running just a single forecast, a model is run multiple times with slightly different conditions, often based on a distribution of possible values

The complete set of forecasts is referred to as the **ensemble.**

Individual forecasts within it are **ensemble members.**

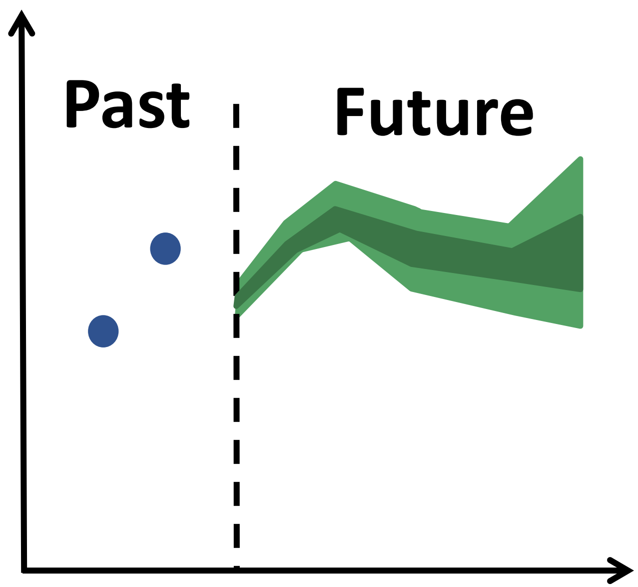
Commonly, each member of the ensemble is **equally likely** to occur.

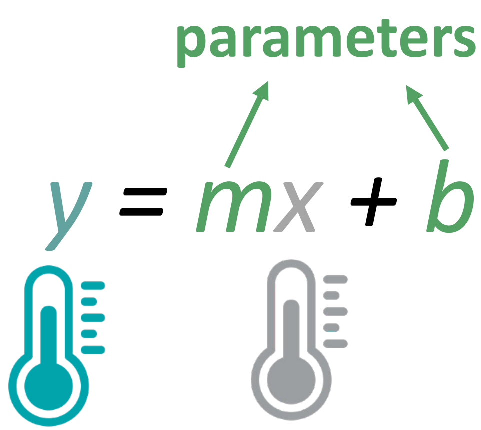
- **This allows us to generate a probabilistic forecast!**



Managing Forecast Uncertainty

- **Step 1:** *Quantify* uncertainty
  - What is the magnitude of uncertainty?
  - From what source(s) does uncertainty arise?





- **Step 2:** *Reduce* uncertainty

Managing Forecast Uncertainty

- **Step 1:** *Quantify* uncertainty
- **Step 2:** *Reduce* uncertainty
  - Methods for reducing forecast uncertainty depend on which source of uncertainty you are trying to reduce

Type of uncertainty	Approach	How it works
Process	Improve the forecast model	Changing the model structure to better reflect the real world can reduce process uncertainty

Managing Forecast Uncertainty

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Parameter	Collect more data	Collecting data on key parameters, such as growth rates, can reduce parameter uncertainty

Managing Forecast Uncertainty

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Initial conditions	Collect more data	Collecting more frequent data can give a more accurate picture of current ecological conditions, reducing initial conditions uncertainty

Managing Forecast Uncertainty

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Parameter	Collect more data	Collecting data on key parameters, such as growth rates, can reduce parameter uncertainty
Initial conditions	Collect more data	Collecting more frequent data can give a more accurate picture of current ecological conditions, reducing initial conditions uncertainty
Driver	Improve driver forecast	A more accurate driver forecast with lower uncertainty will lead to lower driver uncertainty

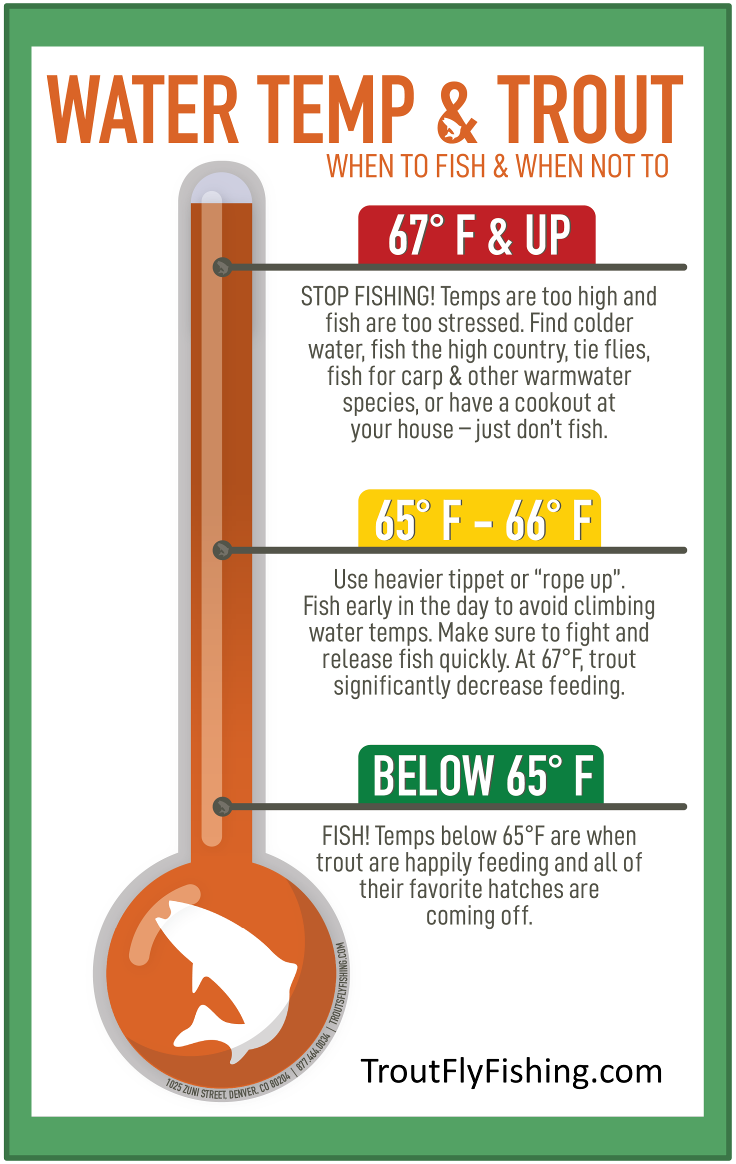
Today…

We are going to generate forecasts of **water temperature in lakes** using **ecological models** calibrated to real data from the **National Ecological Observatory Network (NEON)**.

We will **explore** the sources of your forecast's uncertainty, **quantify** its uncertainty, and learn how to **manage** the **uncertainty** of your **forecast**.

Water temperature

- **Water temperature** influences
  - Biological activity and growth
  - Water chemistry
  - Biodiversity
  - Water quality
- Land use change and climate change can affect water temperature
- Predicting future water temperatures can help resource managers prevent water quality degradation



Forecast models

We will be forecasting future water temperature using four simple models:

$$\text{Water temp}_{t+1} = \text{Water temp}_{t}$$

Persistence model

Forecast models

We will be forecasting future water temperature using four simple models:

$$\text{Water temp}_{t+1} = \text{Water temp}_{t}$$

$$\text{Water temp}_{t+1} = m \times \text{Water temp}_{t} + b$$

$$\text{Water temp}_{t+1} = m \times \text{Air temp}_{t+1} + b$$

Linear regression models

Forecast models

We will be forecasting future water temperature using four simple models:

$$\text{Water temp}_{t+1} = \text{Water temp}_{t}$$

$$\text{Water temp}_{t+1} = m \times \text{Water temp}_{t} + b$$

$$\text{Water temp}_{t+1} = m \times \text{Air temp}_{t+1} + b$$

$$\text{Water temp}_{t+1} = \beta_0 + \beta_1 \times \text{Water temp}_{t} + \beta_2 \times \text{Air temp}_{t+1}$$

Multiple linear regression model

National Ecological Observatory Network (NEON)

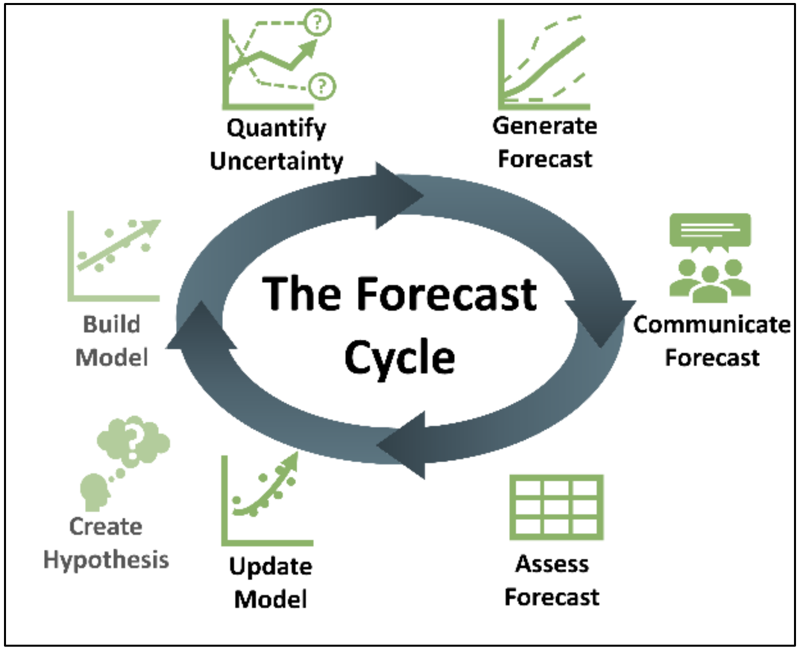
- We will be forecasting water temperature at NEON sites
- NEON is a continental-scale observatory designed to collect long-term open-access ecological data to better understand how U.S. terrestrial and aquatic ecosystems are changing

Operated by Battelle

Image: Phenocam

Learning objectives of today's module:

- Define ecological forecast uncertainty
- Explore the contributions of different sources of uncertainty to total forecast uncertainty
- Understand how multiple sources of uncertainty are quantified
- Identify ways in which uncertainty can be reduced within an ecological forecast
- Describe how forecast horizon affects forecast uncertainty
- Explain the importance of specifying uncertainty in ecological forecasts for forecast users and decision support



Activity A

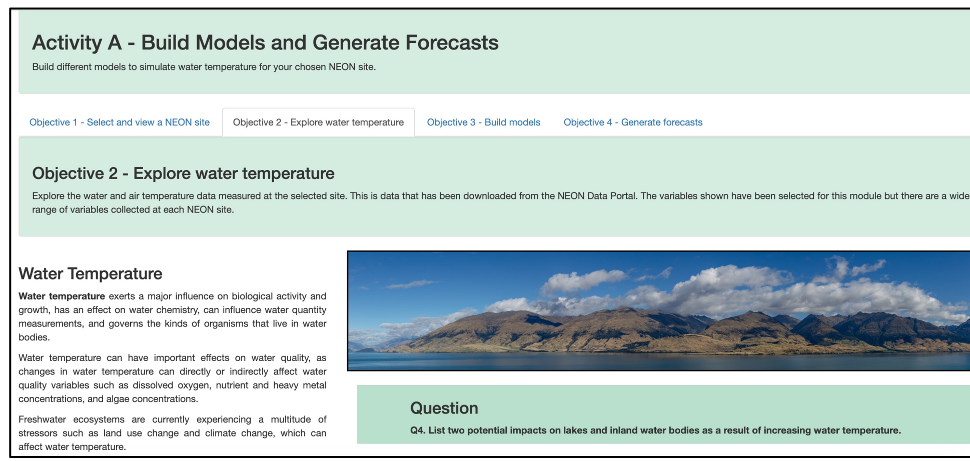
With a partner (work in pairs):

Objective 1: Select a lake site

Objective 2: Explore water and air temperature data

Objective 3: Build water temperature forecast models

Objective 4: Generate deterministic forecasts

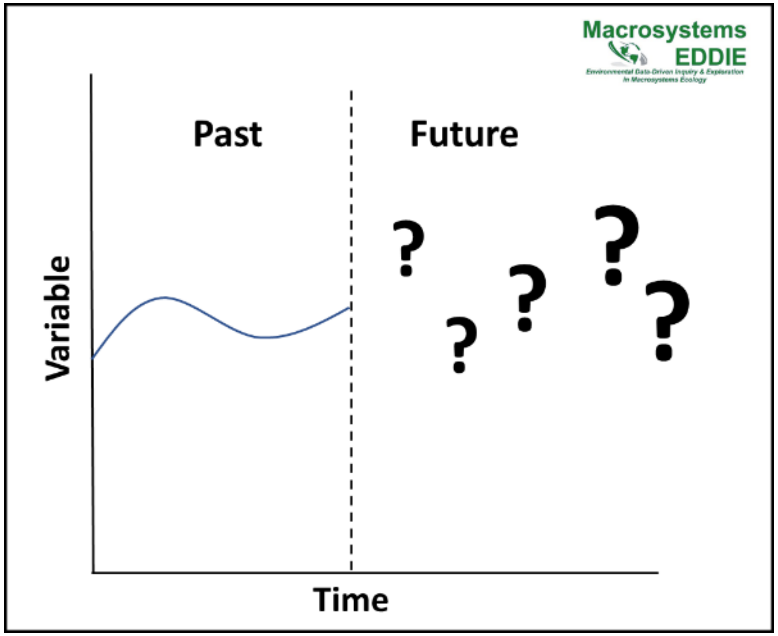


Activity B

With a partner (work in pairs):

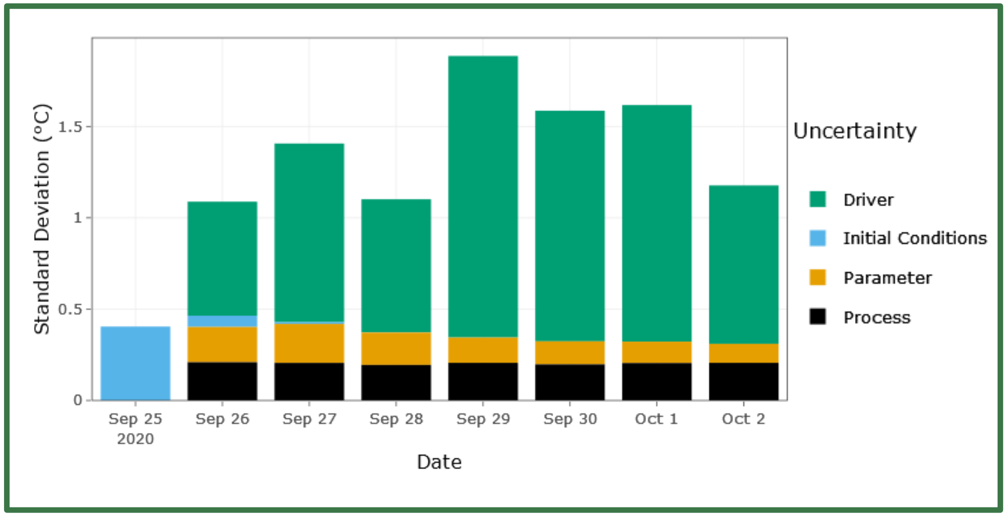
Explore forecast uncertainty and compare how different sources of uncertainty affect the different models.

- **Objective 5:** Process uncertainty
- **Objective 6:** Parameter uncertainty
- **Objective 7:** Initial conditions uncertainty
- **Objective 8:** Driver uncertainty



Activity C

With a partner (work in pairs):



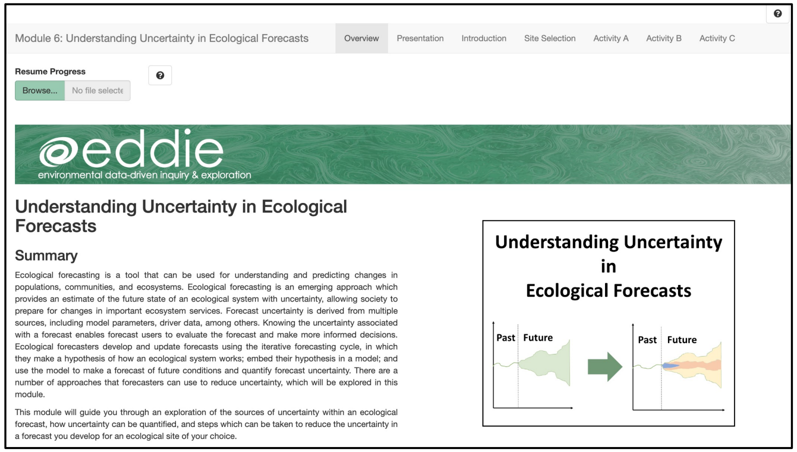
Objective 9: Generate forecasts with total forecast uncertainty and quantify the different contributions of each source of uncertainty to forecasts

Objective 10: Decide from which depth to release water from a reservoir using forecasts which include uncertainty

Source

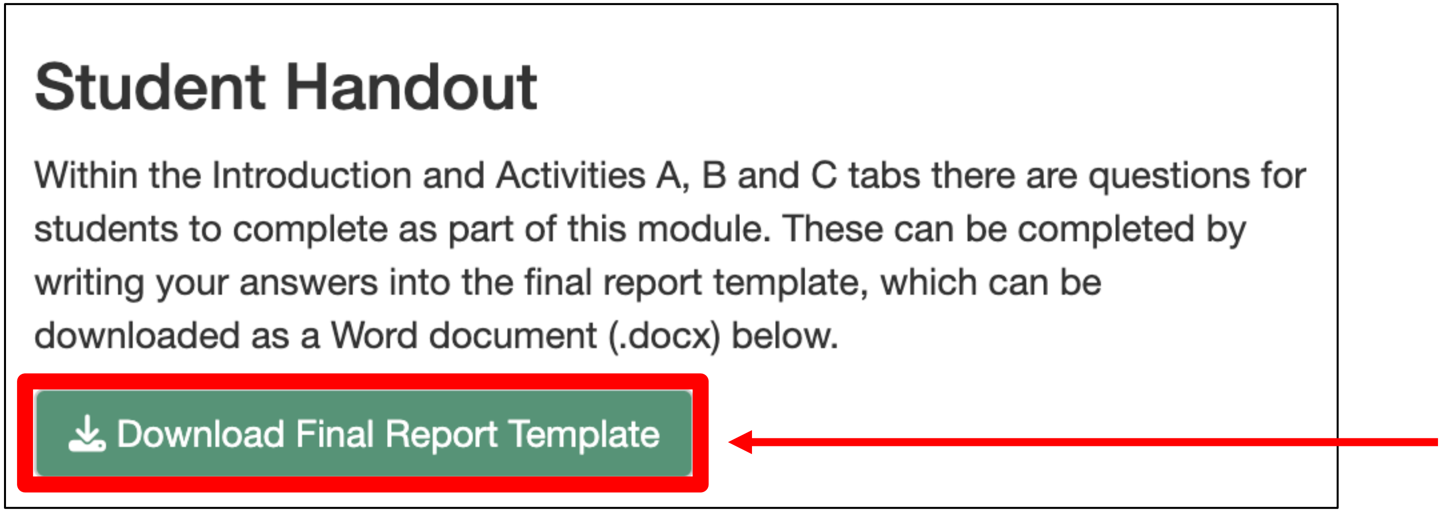
Shiny App

- The module can be accessed at: https://macrosystemseddie.shinyapps.io/module6/
- This is an interactive webpage built using R
- It has interactive plots and options embedded which allow you to build your own personal model, visualize and explore the data, and answer questions



Downloading the Report

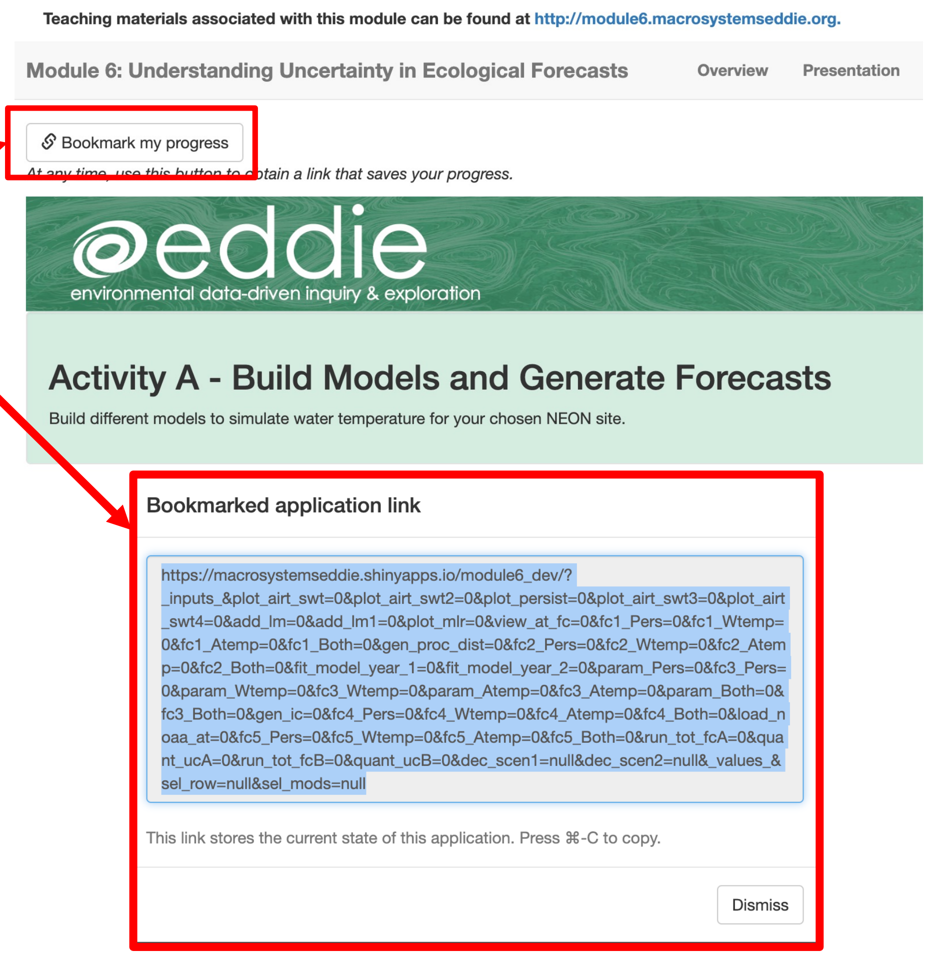
1. Navigate to the “Introduction” tab
2. Click on the “Download Final Report Template” button to download a Word document into which you can type your answers.



Saving & Resuming Progress

Saving Progress

1. Scroll to top of the page.
2. Click on the "Bookmark my progress" button. A pop-up window with a *very long link* will appear.
3. Copy-paste the link and store it at the top of your final report.



Resuming progress

1. Open your browser.
2. Copy-paste the link into your browser.
3. As you navigate through the tabs in the module, your progress will reappear.

We recommend that you save your progress often!

- Because the Shiny app can time out after inactivity (15 minutes) or disconnect if an internet connection is interrupted, we don’t want you to lose your work.

- Save your progress as you go, as well as every time you close your computer or close the Shiny app in your internet browser.

- After you save the link somewhere safe, you should be able to resume your progress where you left off!

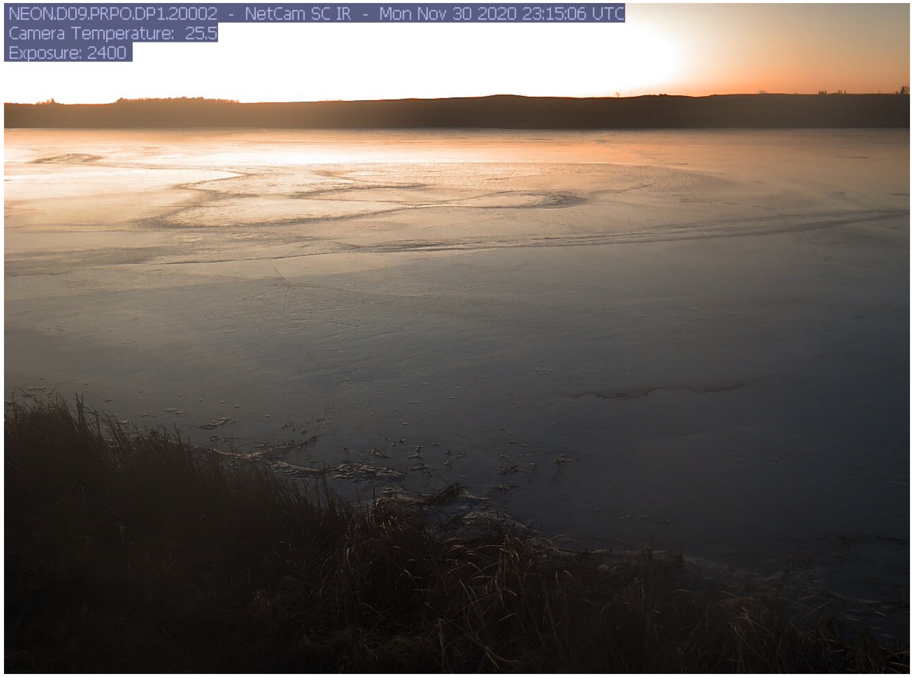
Let’s Go!

- For the activity we will work in pairs.
- Each pair selects the same NEON site and works through Activities A, B, and C.
- It is possible that more than one pair will be assigned to the same lake.

Lake name	Students
Barco Lake	
Prairie Pothole	
Little Rock Lake	

https://macrosystemseddie.shinyapps.io/module6/

Thank you for participating!



Check out other ecological forecasting modules:

- **Module 5:** Introduction to Ecological Forecasting
- **Module 7:** Using Data to Improve Ecological Forecasts
- **Module 8:** Using Ecological Forecasts to Guide Decision-Making

Find out more at: macrosystemsEDDIE.org

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