Subseasonal-to-Annual Net Basin Supply and Water Level Forecasting for the Great Lakes Region

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The Laurentian Great Lakes Facts

- The Laurentian Great Lakes basin is home to 34 million people across the US and Canada

- 20% of the world's freshwater is in the Great Lakes

- Combined surface area of 244,000 km^2
  - This is larger than the combined areas of Connecticut, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont

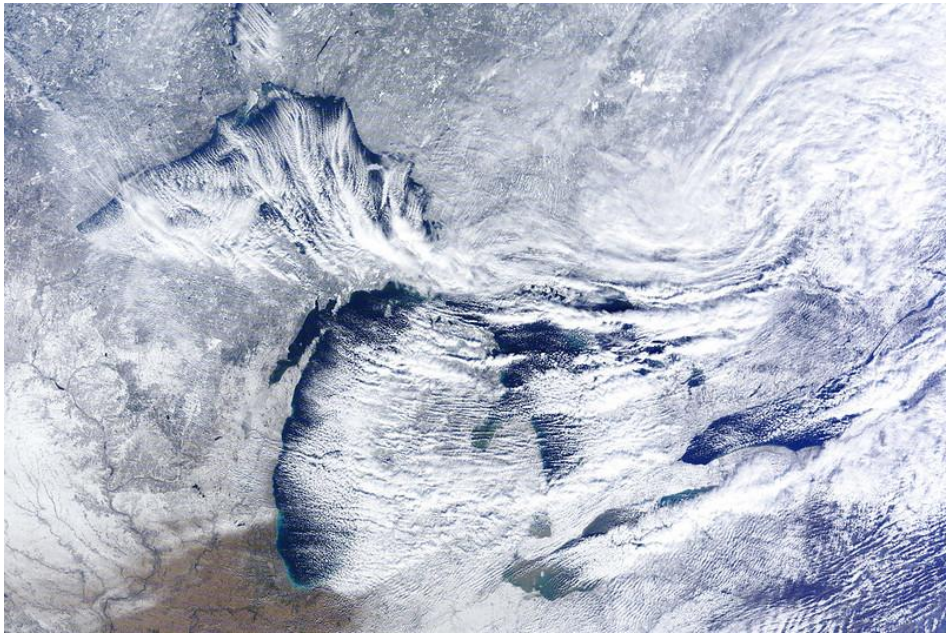
https://www.michiganseagrant.org/topics/great-lakes-fast-facts/

Great Lakes' Influence on the Atmosphere

- In the summer, cooler lake temperatures reduce the air temperature on the order of 1-3 ^{o}C downwind of the lakes and reduce precipitation amounts up to 50mm (Scott and Huff, 1996)

- In the winter, warmer lake temperatures than the air can produce significant precipitation events as well as warm maximum air temperature by 1-2 ^{o}C

- In the early winter (ice-free season), extratropical cyclones tend to accelerate entering the region and intensify (Angel and Isard 1997)



MODIS. November 20, 2014

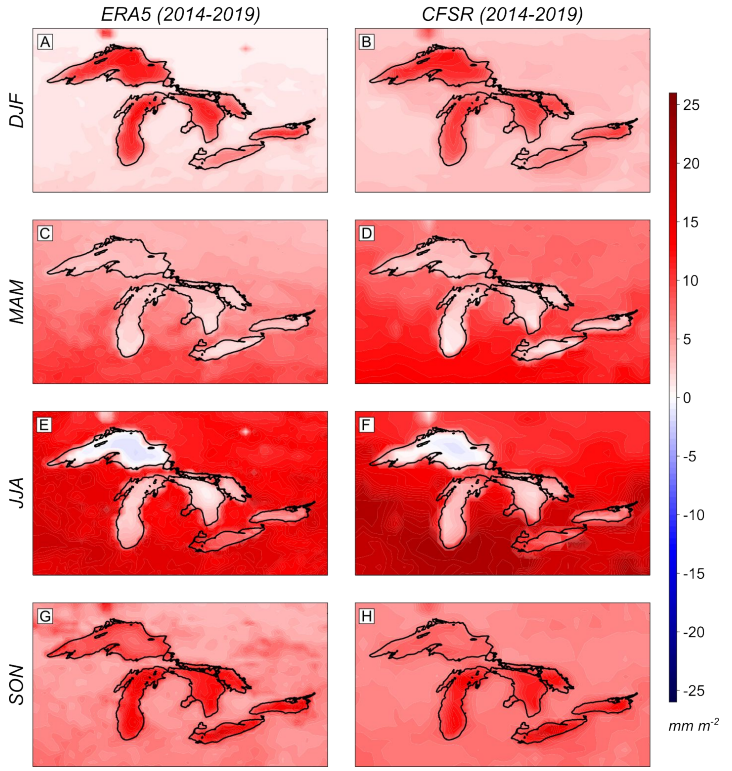
Atmosphere's Influence on the Great Lakes

- We have an understanding on a process level of how the atmosphere influences the lakes
  - For example, lake ice formation or circulations within the lake

- We have less of a quantifiable understanding of how changes in lake characteristics are influenced by atmospheric conditions on more hydrologic timescales
  - Response of over water precipitation and evaporation to extratropical cyclones (ETCs) frequency
  - How are ETCs in the Great Lakes region influenced by teleconnection indices?
  - Ward et al. (*in prep)* looks to quantify these values

- Responses of the lakes to changes in atmospheric conditions leads to changes in water levels

ETC Seasonal Composites: Absolute Evaporation

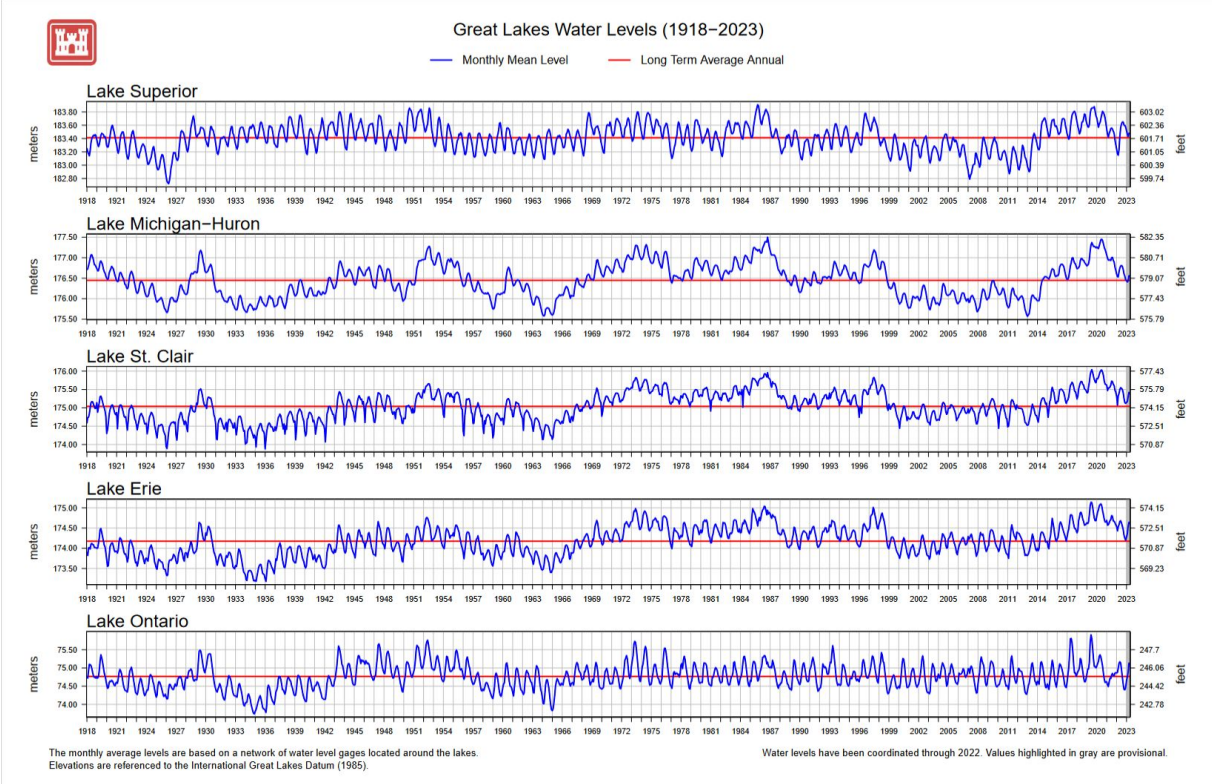


Ward et al. In Prep

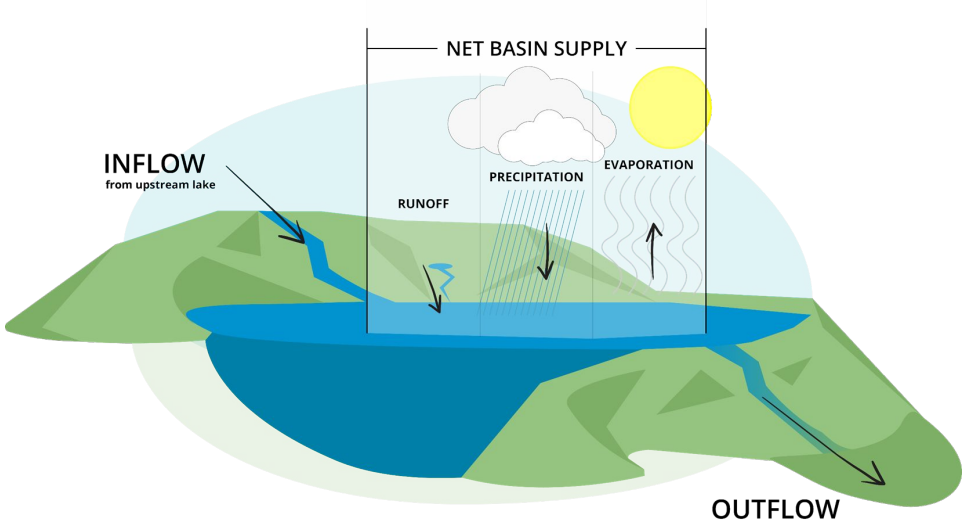
Water Levels

- Water levels on the lakes have strong seasonal changes on the order of 10's cm
  - This is due to seasonal changes in precipitation, runoff, and evaporation

- Outflows from Lake Ontario are strongly regulated to meet needs across multiple sectors (environmental, navigation, flooding, etc.)



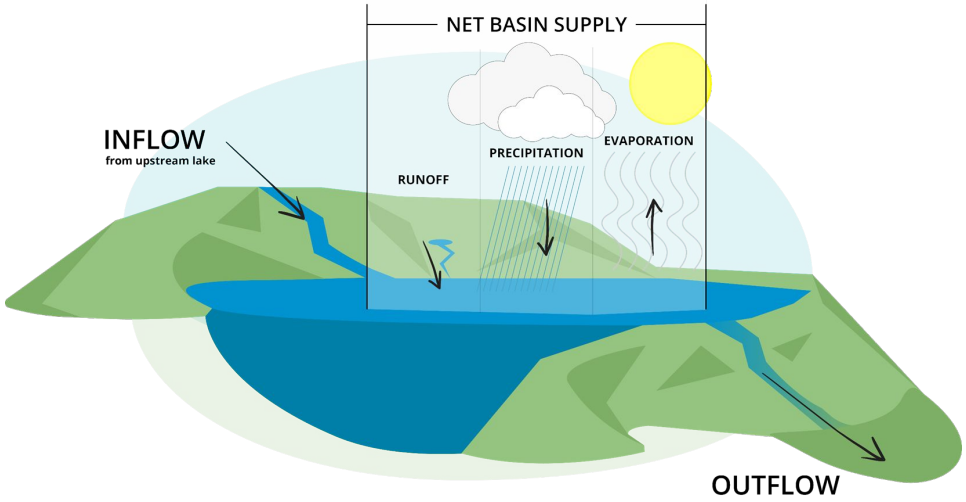
Water Levels



$$\Delta S = \underbrace{Q_{in} - Q_{out}}_{\text{Routing / Regulation}} + \underbrace{P + R - E}_{\text{Net Basin Supply}} \pm \varepsilon$$

- Changes in water levels (ΔS) for each lake are modulated by several factors:
  - Inflow/Outflow (Qin, Qout) through connecting channels
  - Precipitation (P)
  - Runoff (R)
  - Evaporation (E)
- Outflows are regulated for Lakes Ontario and Superior
  - This does add a challenge to forecasting water levels as there is a human component involved

Water Levels



$$\Delta S = \underbrace{Q_{in} - Q_{out}}_{\text{Routing / Regulation}} + \underbrace{P + R - E}_{\text{Net Basin Supply}} \pm \varepsilon$$

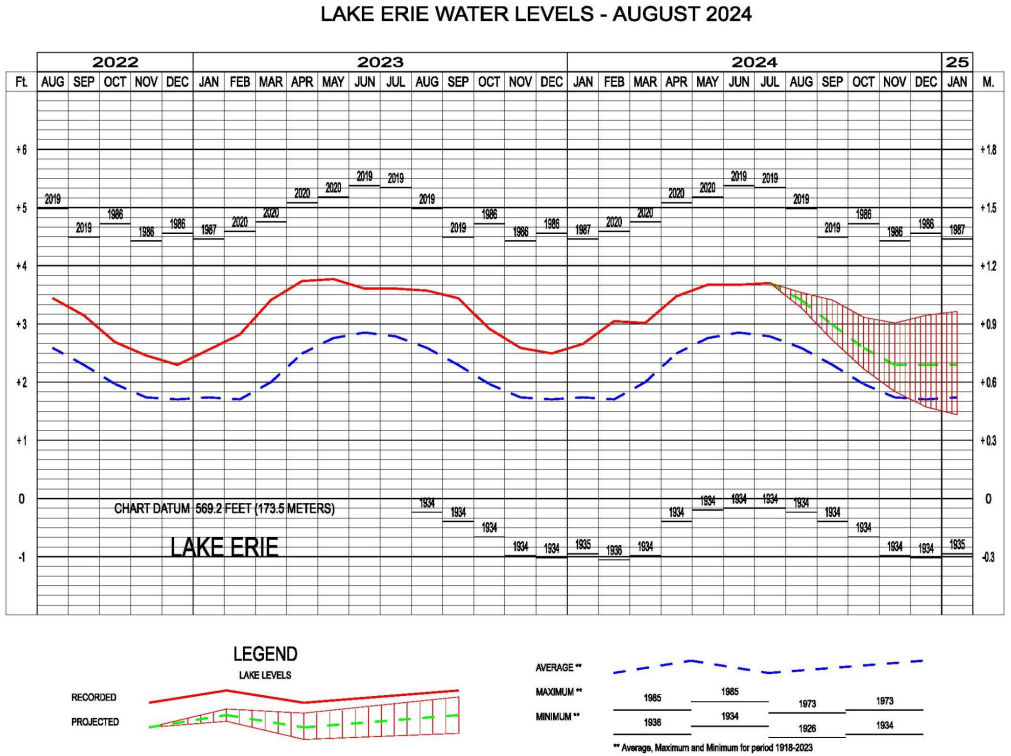
- Net Basin Supply (NBS) is the total of Precipitation (P) and Evaporation (E) over the lake surface with Runoff (R) at the edges of the lakes
- Directly observing of these variables over the water surface is challenging!
- Forecasting of the NBS can help to predict water levels as well as aid decision making

Prediction of Water Levels

- Water level forecasts for the Great Lakes are created by the United States Army Corps of Engineers (USACE) and coordinated with Environment and Climate Change Canada (ECCC) out to 6 months

- These forecasts use a suite of statistical and conceptual models along with “persistence”. These models have limited use of *forecasted* values from physics-based atmospheric models

- Great Lakes water managers, recreational boaters, shipping/navigation, and coastal communities use these forecasts for decision making



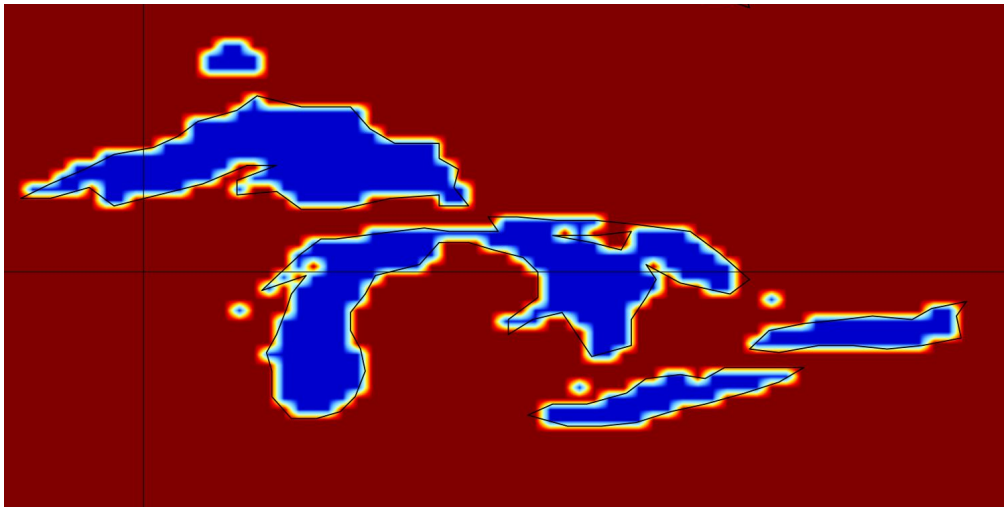
https://www.lrd.usace.army.mil/Water-Information/Water-Management/Great-Lakes-and-Harbors/Water-Level-Forecasts/#six-month-water-level-forecasts

Project Overview

- This project looks to better utilize physically derived forecasts of atmospheric variables to predict NBS and by extension lake level changes through the use of data driven models (AI/ML)

- This approach will partially utilize output from the CFSv2 and CFSR to train a data driven model to predict NBS out at least 9 months
  - Ultimate goal is to have predictions of NBS out to 12 months

- This project is part of the Bipartisan Infrastructure Law to improve Subseasonal to Annual predictions (BIL-SA)

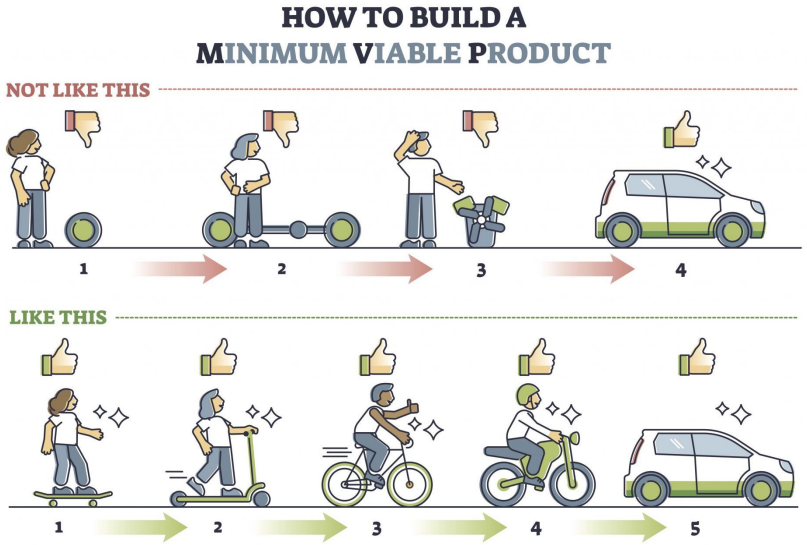


Land-Sea Mask in .25˚ resolution CFSR

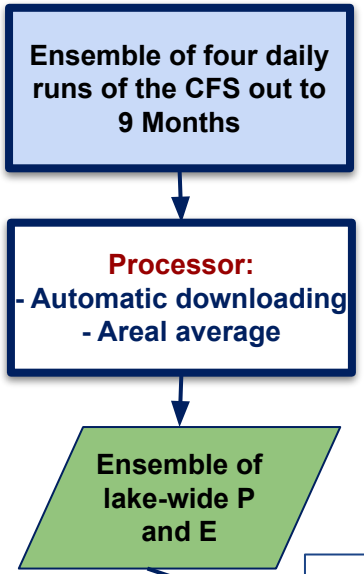
Minimum Viable Product (MVP)

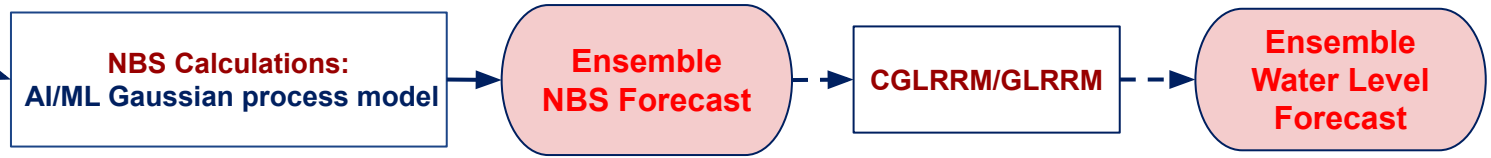
- The “Minimum Viable Product (MVP)” is a development philosophy being used in our group to go from concept to operational model
  - The thought is to get key pieces working well at first (“skateboard”) before adding more advanced features (“car”)

- Our definition of the first MVP phase (“skateboard”) needs to:
  - Download and preprocess CFS data
  - Carry out an AI/ML predictive model
  - Postprocess the predictions for end users



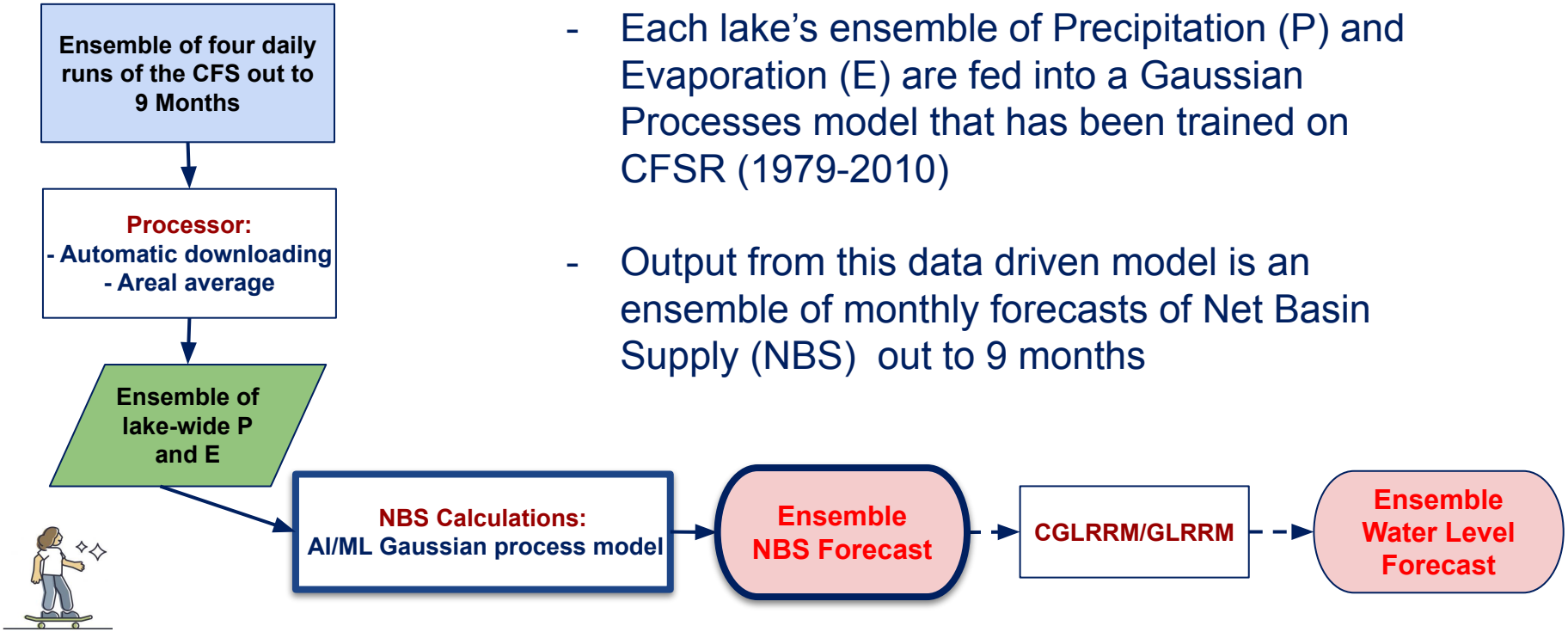
Current MVP Workflow





- Preprocessing steps download the four daily model runs of CFS out to 9 months
- Currently only over water precipitation, air temperature, and latent heat flux are used for each lake surface
  - Air temperature and latent heat flux are used to calculate evaporation

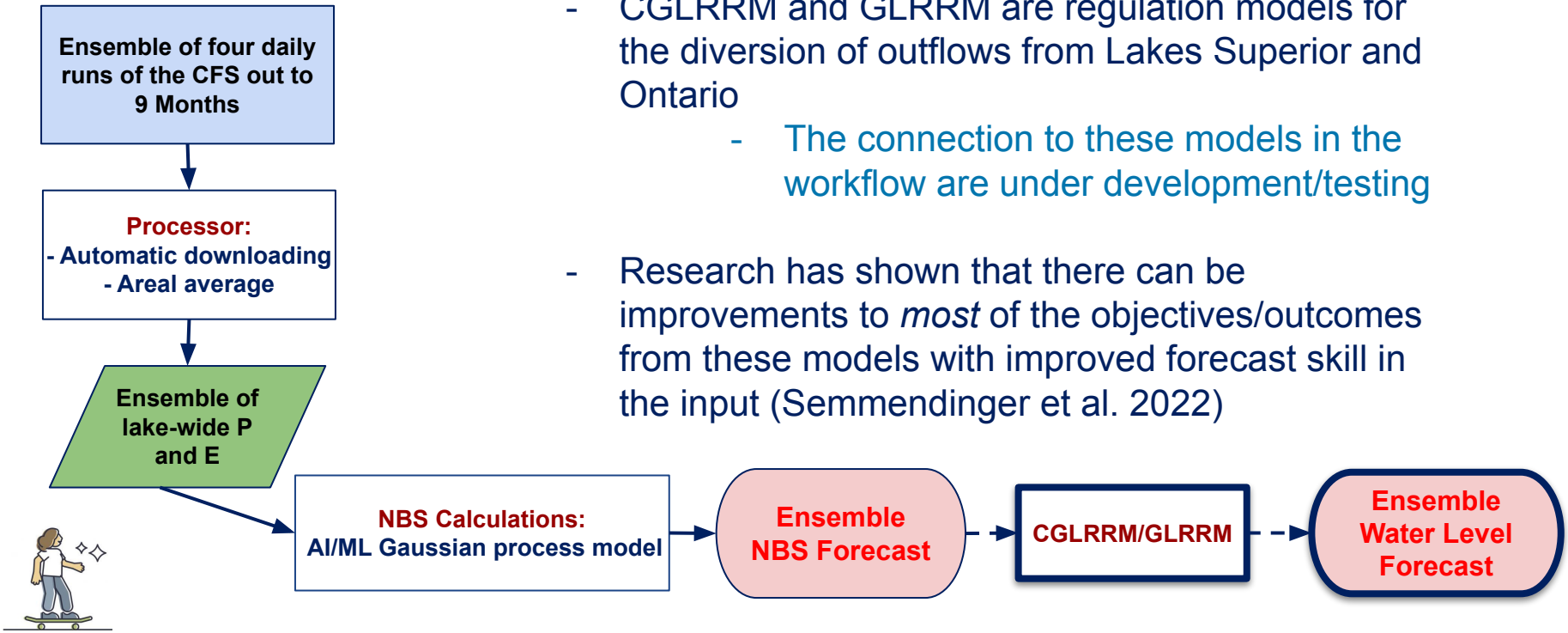
Current MVP Workflow



- Each lake's ensemble of Precipitation (P) and Evaporation (E) are fed into a Gaussian Processes model that has been trained on CFSR (1979-2010)

- Output from this data driven model is an ensemble of monthly forecasts of Net Basin Supply (NBS) out to 9 months

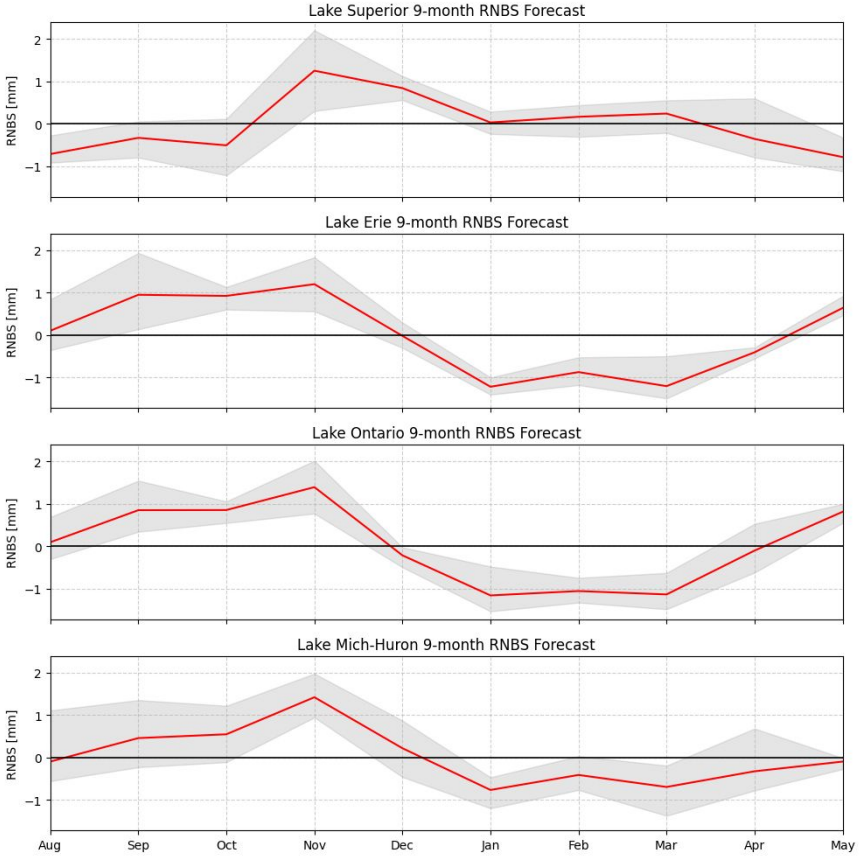
Current MVP Workflow



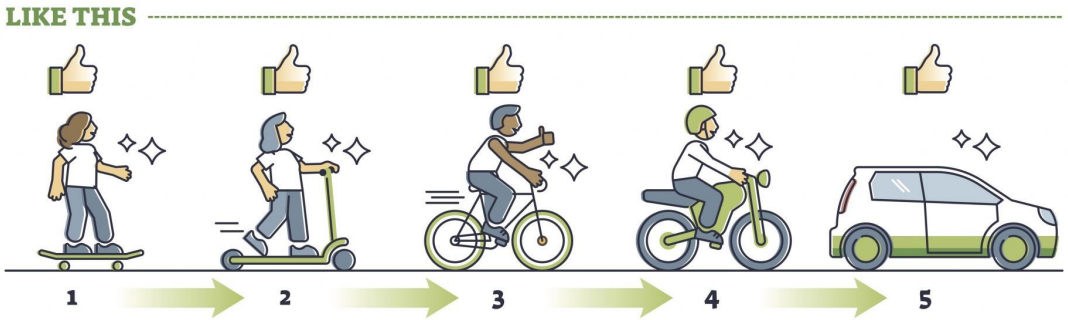
- CGLRRM and GLRRM are regulation models for the diversion of outflows from Lakes Superior and Ontario
  - The connection to these models in the workflow are under development/testing
- Research has shown that there can be improvements to *most* of the objectives/outcomes from these models with improved forecast skill in the input (Semmendinger et al. 2022)

Early Results from the MVP

- These are *very* early results from the current workflow
- The Gaussian Process model is able to predict a signal that shows an increase in NBS during the late fall with a decrease in winter to early spring for most of the lakes
- Just starting the verification process on this workflow…



How do we get to a car?



Several additional features that are to be added/evaluated (but not limited to):

1. Extend the forecast to 12 months
2. Bring in additional initial conditions of the system like snow cover, soil moisture, etc.
3. Add additional modeling approaches for NBS to diversify the ensemble
4. Explore the application of large-scale atmospheric state/evolution
5. Further engage with operational partners and stakeholders

How do Great Lakes Scientists Evaluate Models?

- First and foremost, we are very limited in overwater observations
  - Specifically in terms of Precipitation and Evaporation

- Observations we do have are sometimes inconsistent between the US and Canada

- Preferred output from models:
  - Skin temperature
  - Ice cover over time
  - Surface heat fluxes
  - Standard near-surface variables (2m Temp, 10m Winds, MSLP, etc.)

MODIS. March 4, 2009

Conclusions

- Representation of the Great Lakes is key to accurately representing both lake AND atmospheric processes

- Very early results are promising that AI/ML can provide forecasted NBS quantities

- This project has further highlighted the need for multidisciplinary approaches to solve some of these problems
  - Atmospheric scientists, hydrologists, data scientists, stakeholder engagement specialists

Questions?

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