Probabilistic Modeling of Compound Flooding for Oregon Coast Estuaries Using a Reduced Complexity Flood Model

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Oregon State University

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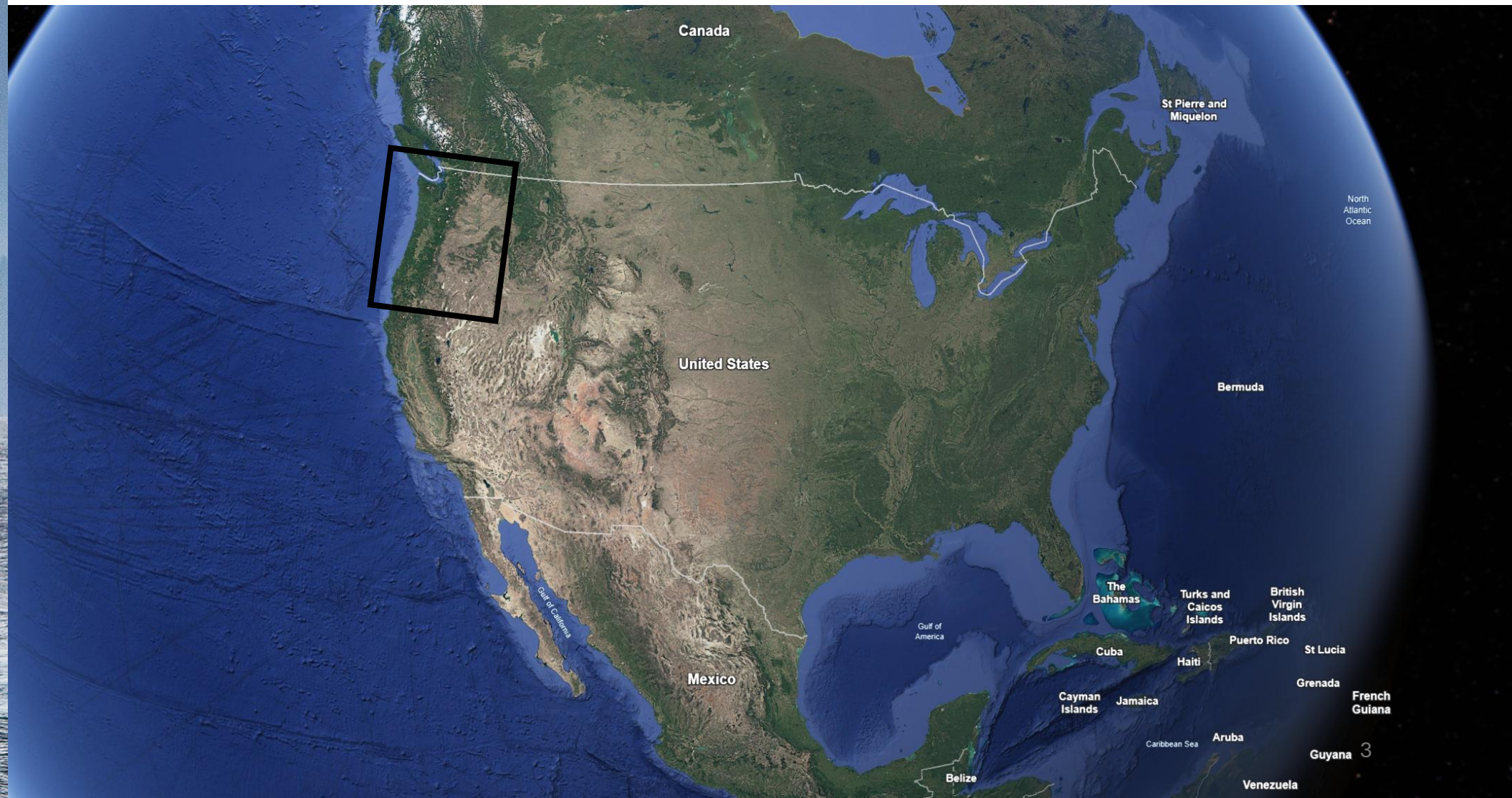
COPE COASTLINES AND PEOPLE

USCRP US COASTAL RESEARCH PROGRAM

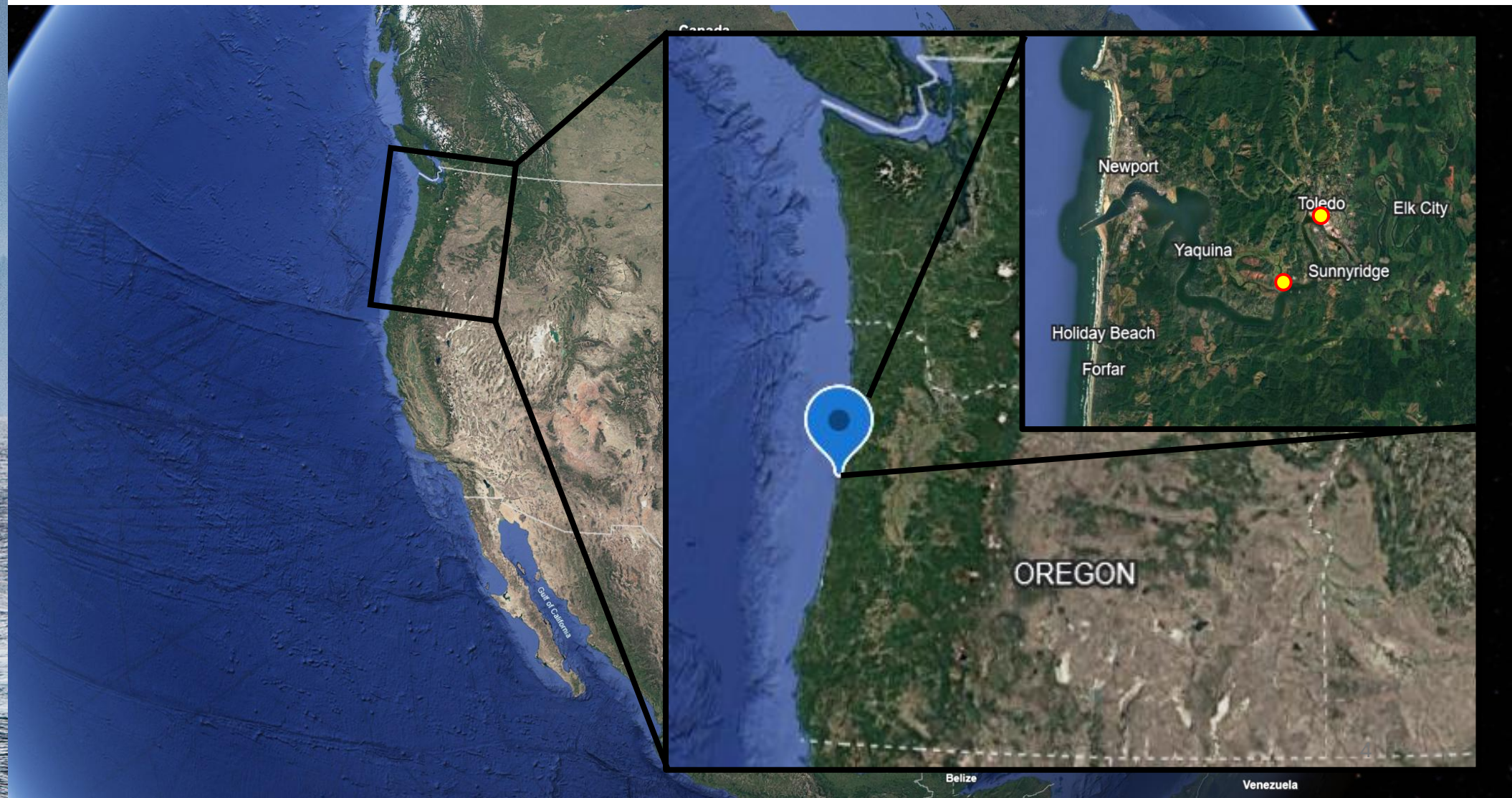
Motivation

- **Coastal communities are increasingly vulnerable to flooding**, but extreme events don’t always come from a single driver
- **Compound flooding occurs when multiple drivers** such as storm surge, river discharge, and extreme precipitation interact to amplify the impact of flooding
- **Flood assessments typically rely on short observational records**, which may not capture the full range of possible extreme event combinations

Project Area

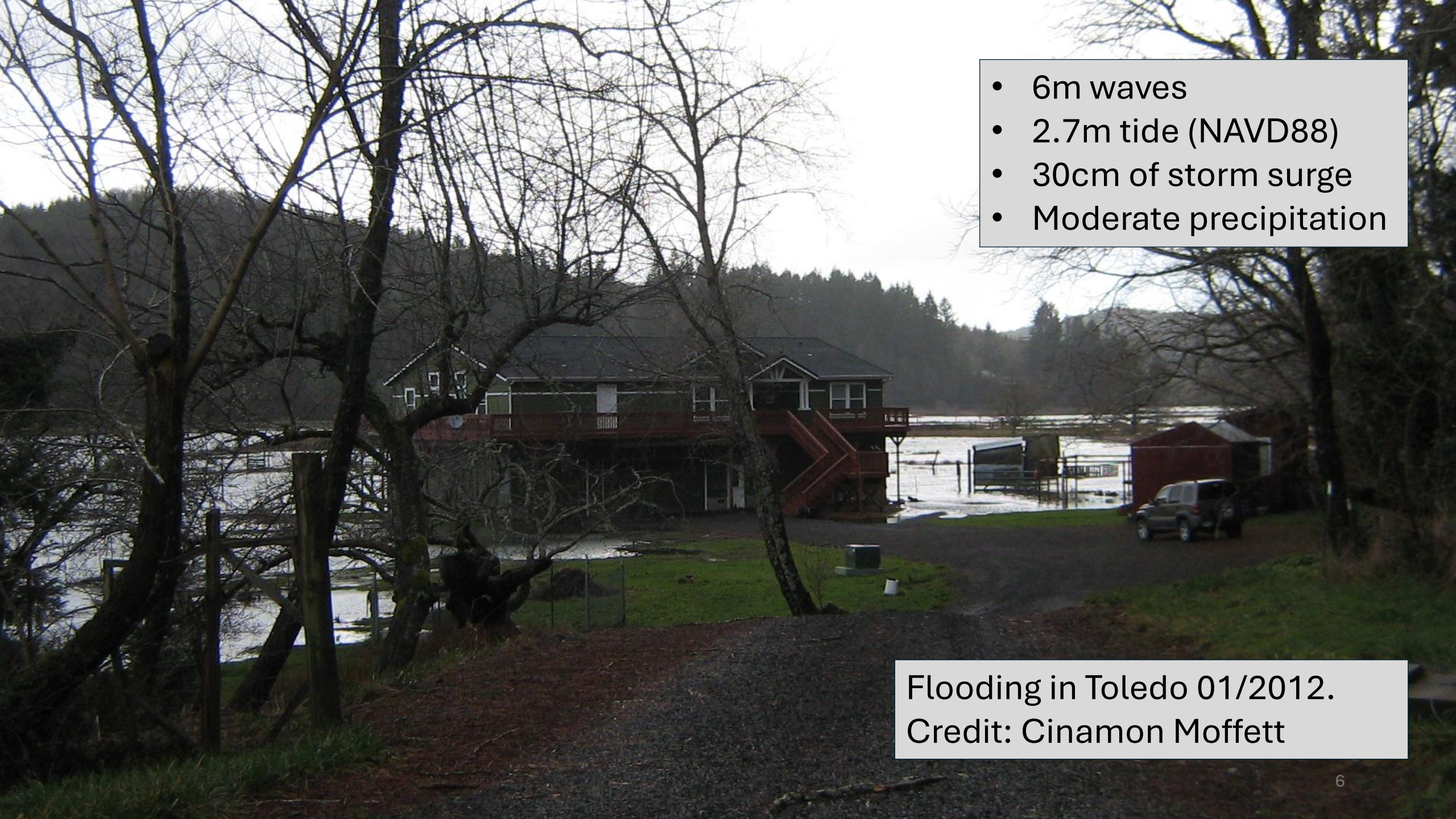


Project Area



- 6m waves
- 2.7m tide (NAVD88)
- 30cm of storm surge
- Moderate precipitation

Flooding in Toledo 01/2012.
Credit: Cinamon Moffett



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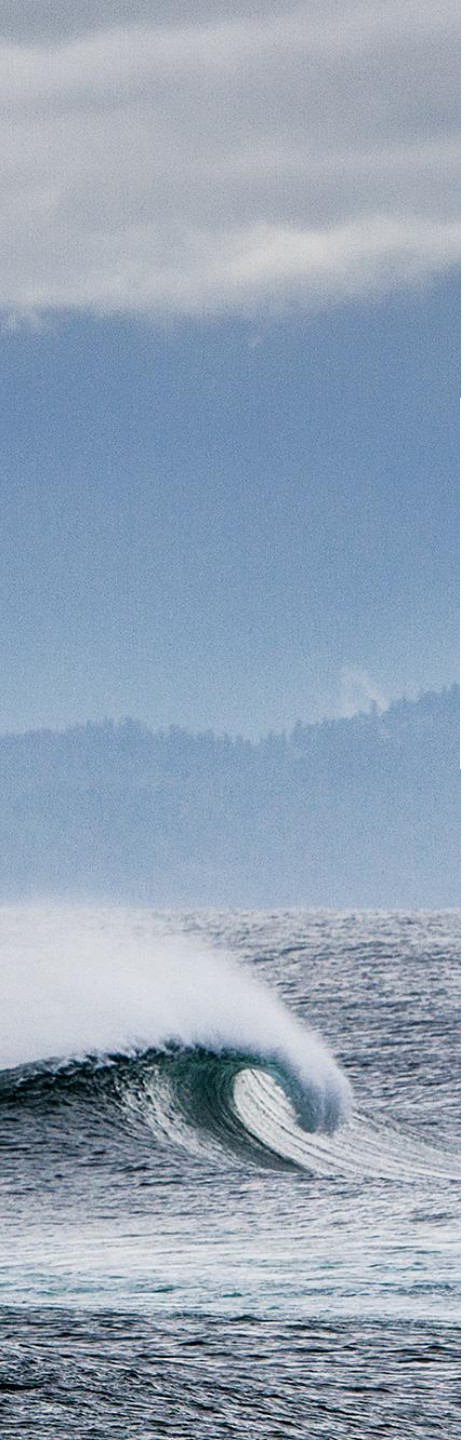
Research Goals

Our overarching goal is to use a probabilistic approach to assess compound coastal flooding and explore different community adaptation pathways

- We want to answer some key questions:
  - What are the comparative advantages and limitations of probabilistic approaches for evaluating compound coastal flooding in PNW estuaries?
  - How can probabilistic compound flood modeling inform long-term adaptation pathways?

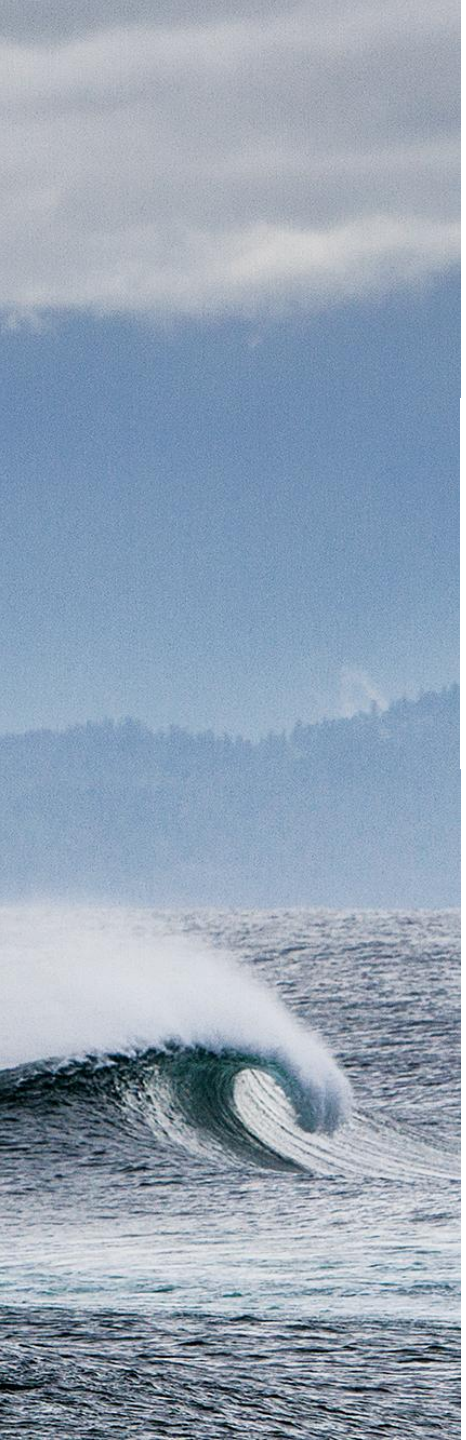


Model Coupling

Reduced Physics
Flood Model

SFINCS

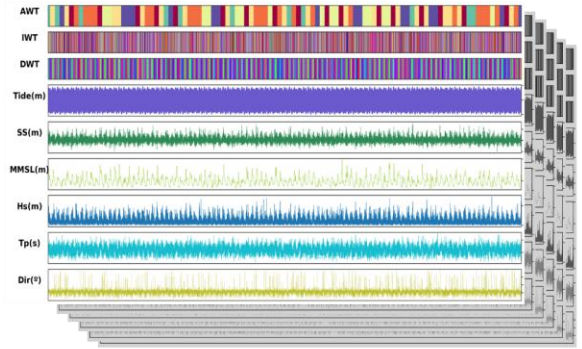
Leijnse et al. (2021)



Model Coupling

Stochastic
Climate Emulator

Reduced Physics
Flood Model



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MUSCLE

Anderson et al. (2019)

SFINCS

Leijnse et al. (2021)

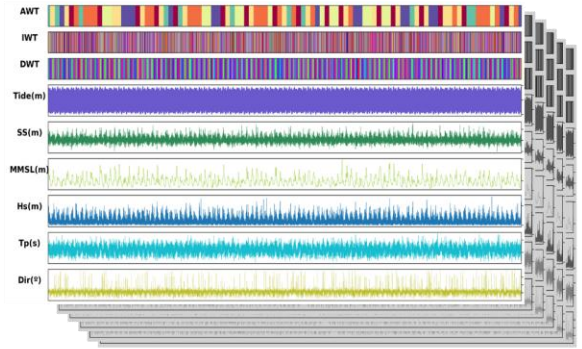
Model Coupling

Produces realistic future combinations of flood drivers (storm surge, waves, tides, NTR's…)

Simulates flooding quickly and accurately!

Stochastic Climate Emulator

Reduced Physics Flood Model



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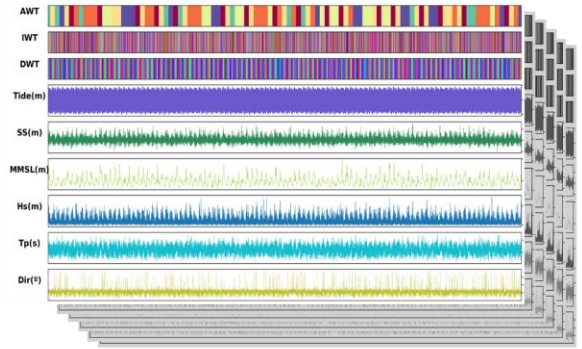

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Probabilistic (Response-Based) Compound Flooding Analysis

MUSCLE

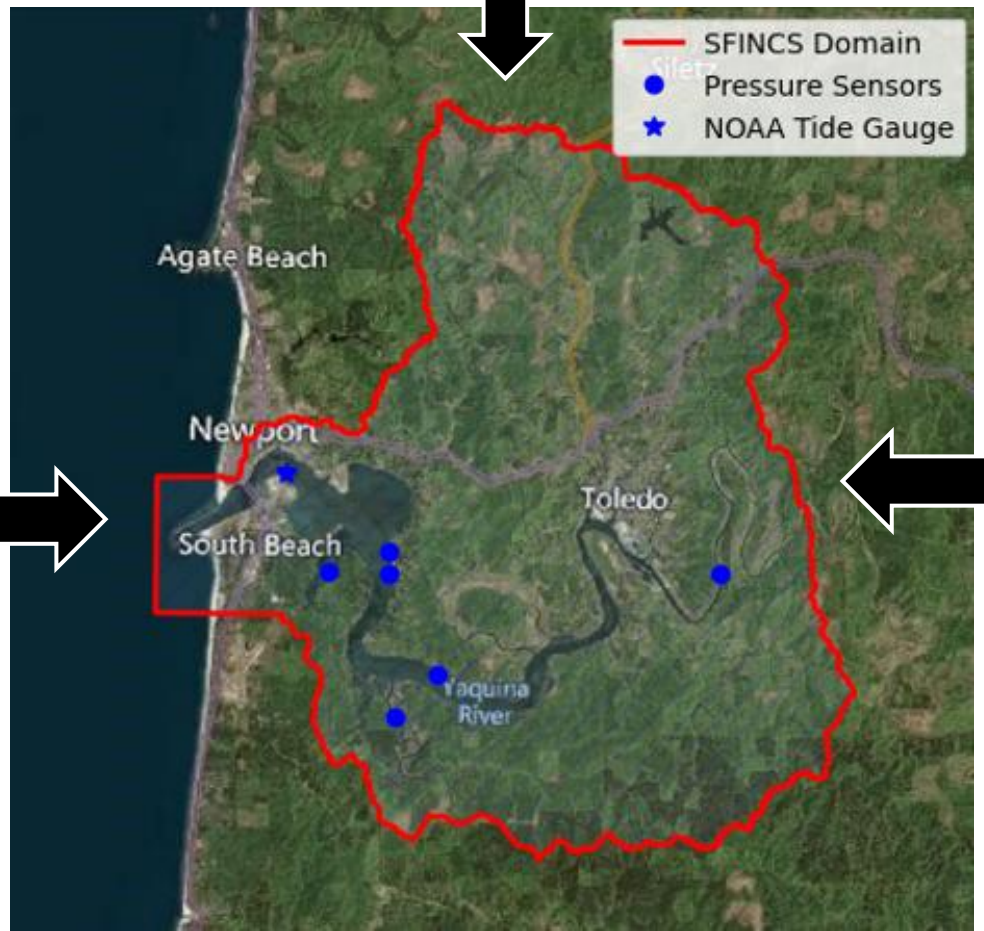
Anderson et al. (2019)

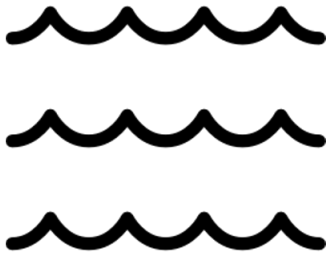
SFINCS

Leijnse et al. (2021)

Hydrodynamic Model Configuration

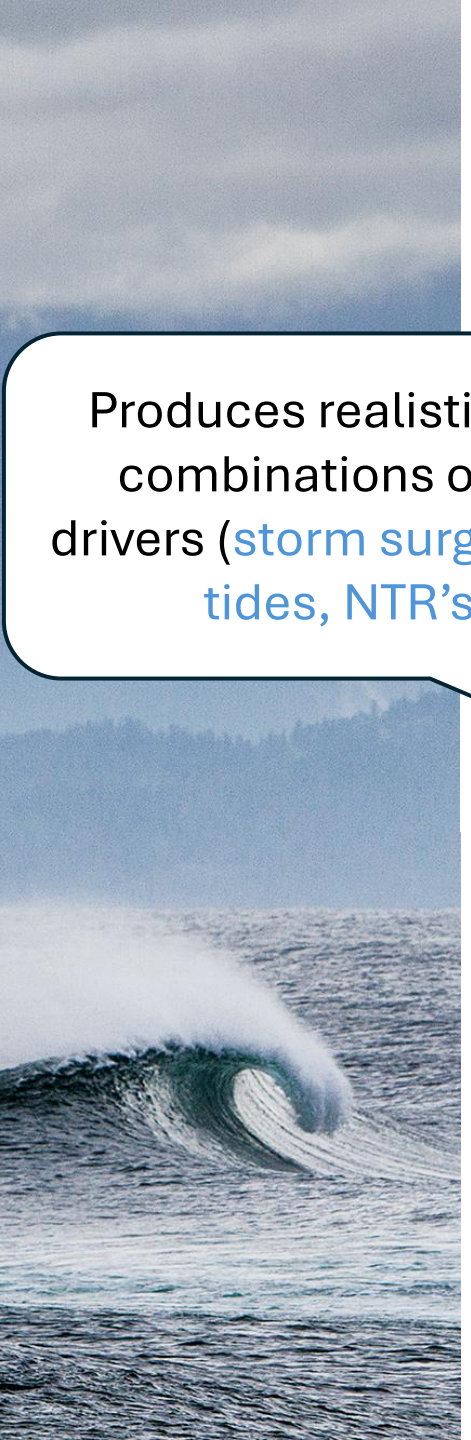
- Precipitation





- Tides
- Storm Surge
- Waves
- MMSLA

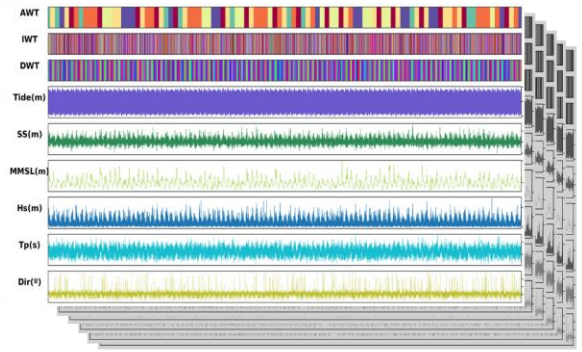
- River Discharge



MUSCLE

Produces realistic future combinations of flood drivers (storm surge, waves, tides, NTR's…)

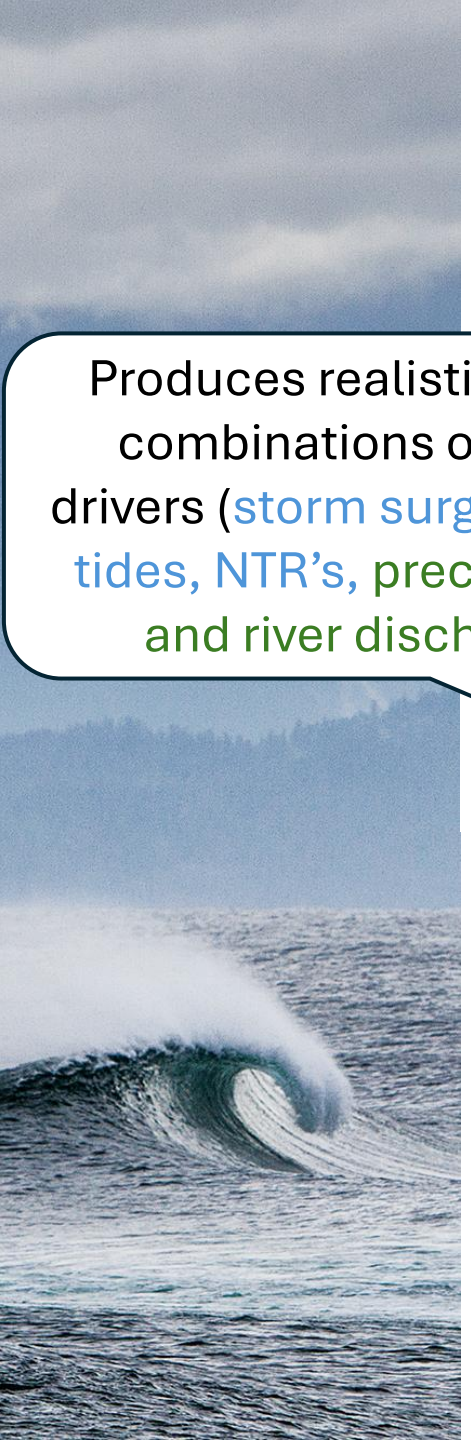
Stochastic Climate Emulator



MUSCLE

Anderson et al. (2019)

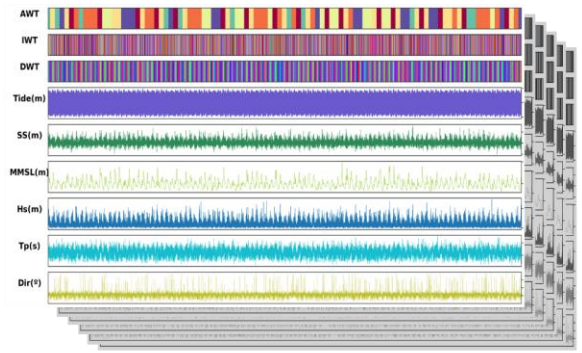
- MUSCLE was developed to simulate **coastal** flood drivers



MUSCLE with Discharge and Precipitation

Produces realistic future combinations of flood drivers (storm surge, waves, tides, NTR's, precipitation and river discharge)

Stochastic Climate Emulator

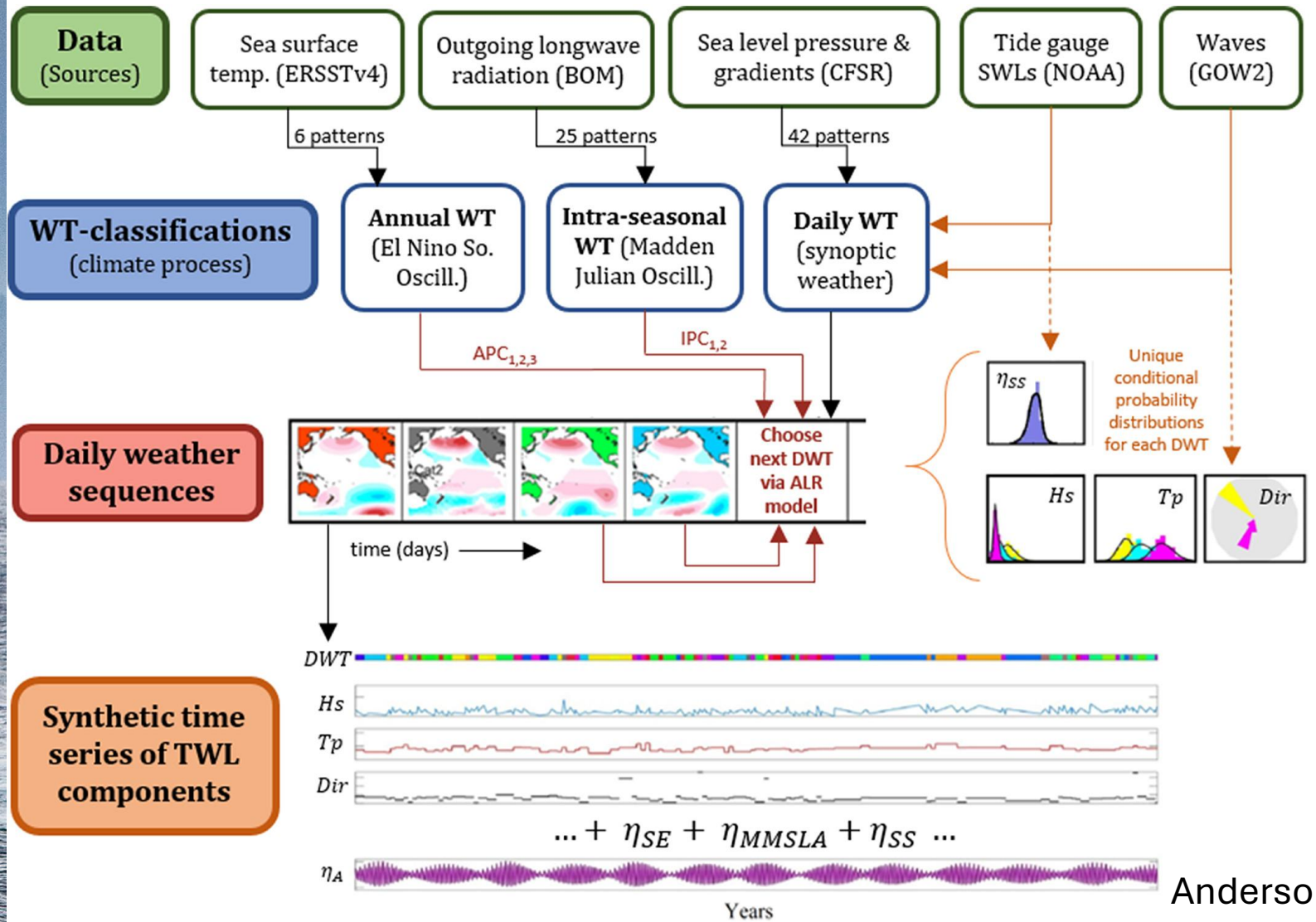


MUSCLE

Anderson et al. (2019)

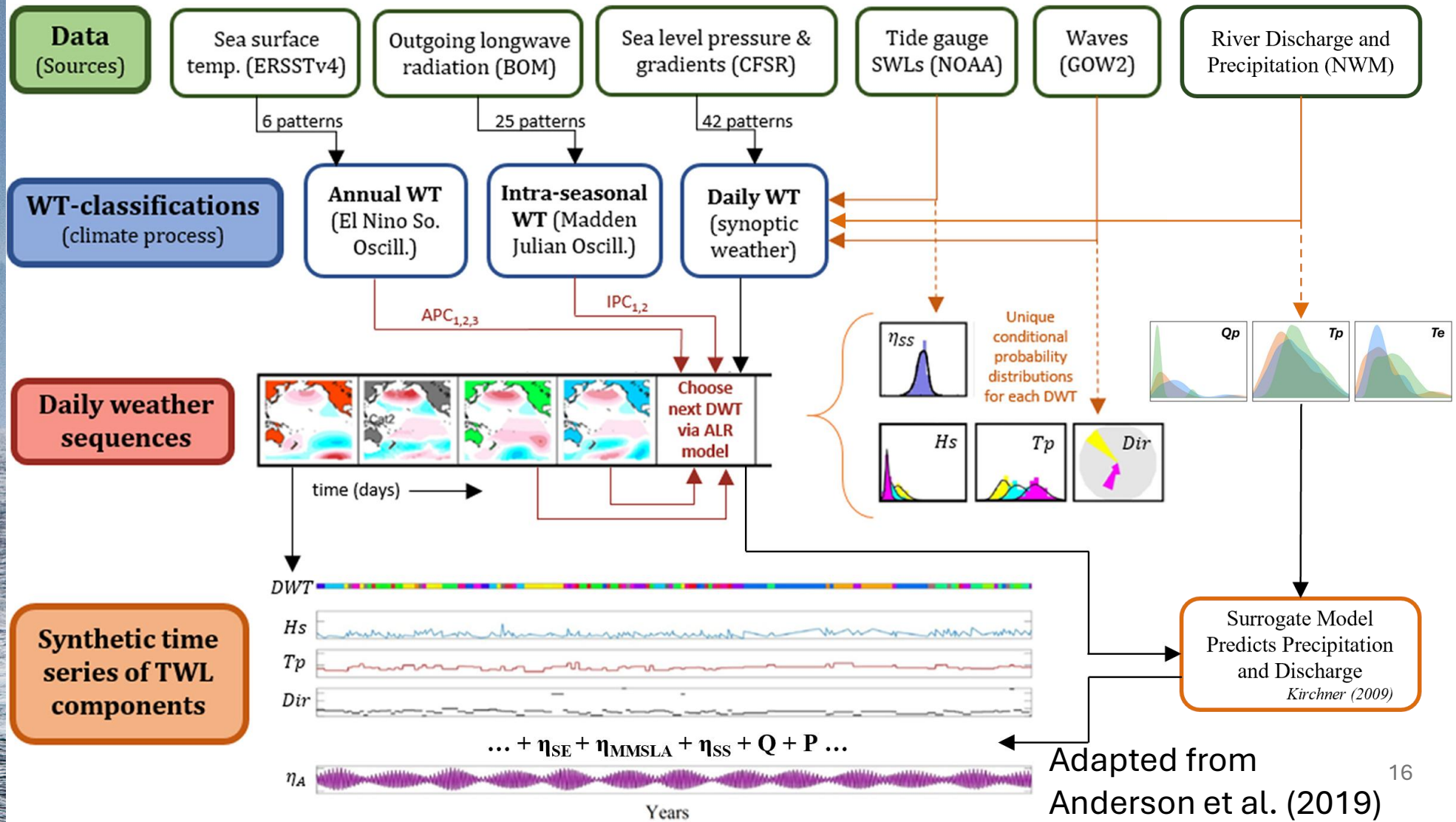
- MUSCLE was developed to simulate **coastal** flood drivers
- To accurately model compound flooding, we need to incorporate **overland** flood drivers into the climate emulator

Traditional MUSCLE Methodology



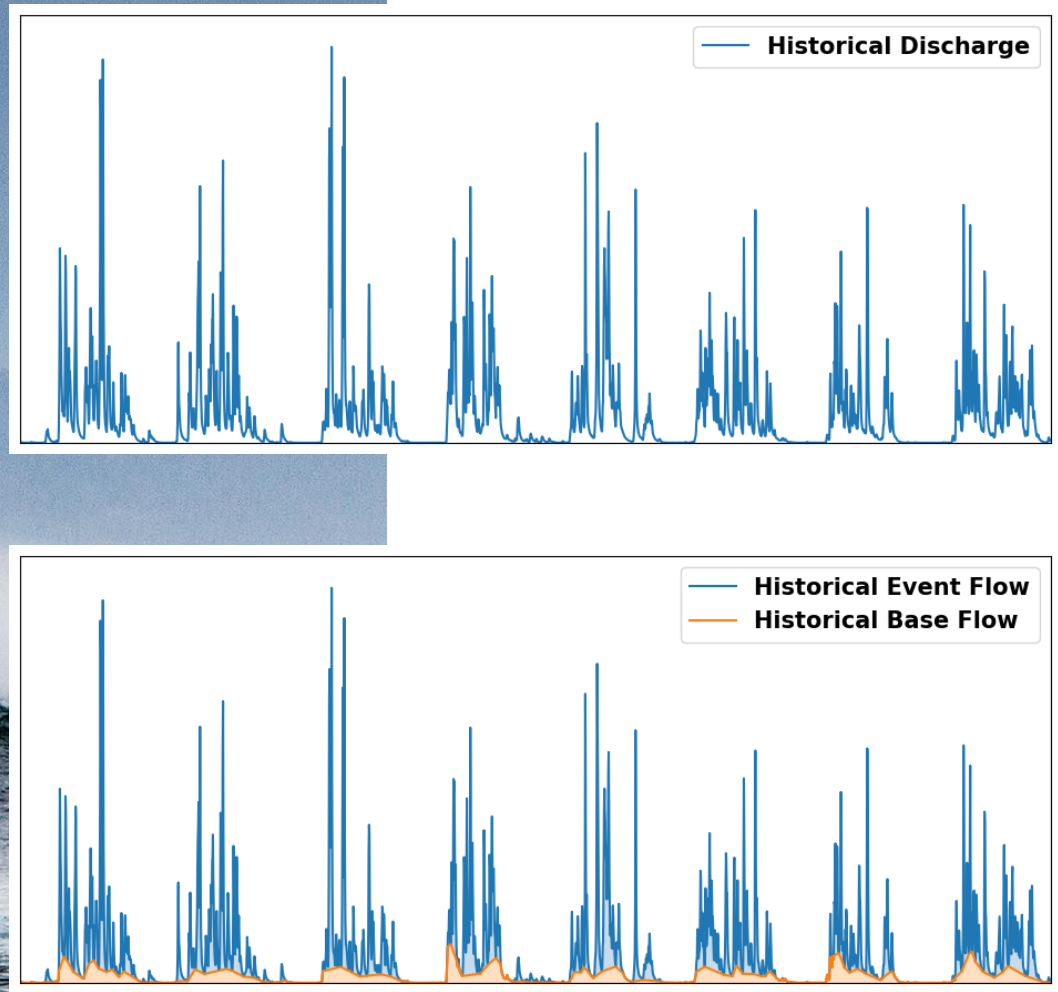
Anderson et al. (2019)

Incorporating Discharge and Precipitation into MUSCLE



Adapted from Anderson et al. (2019)

Incorporating Discharge and Precipitation into MUSCLE

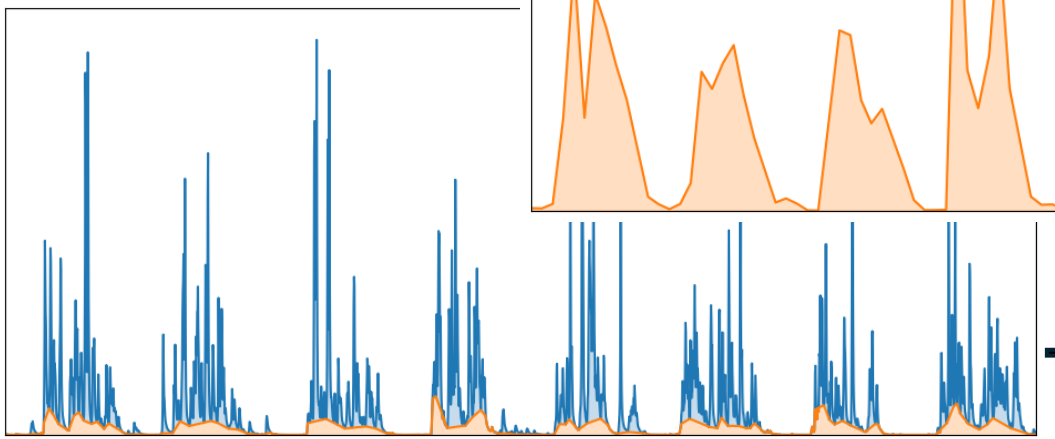


- Simulating discharge and precipitation starts with historical river discharge

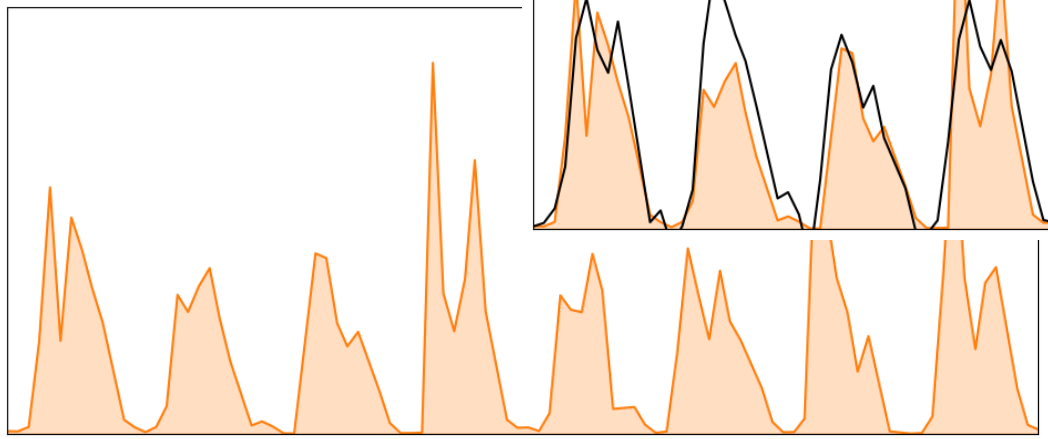
- Two methods for two signals
  - Episodic Event Flow
  - Background Base Flow

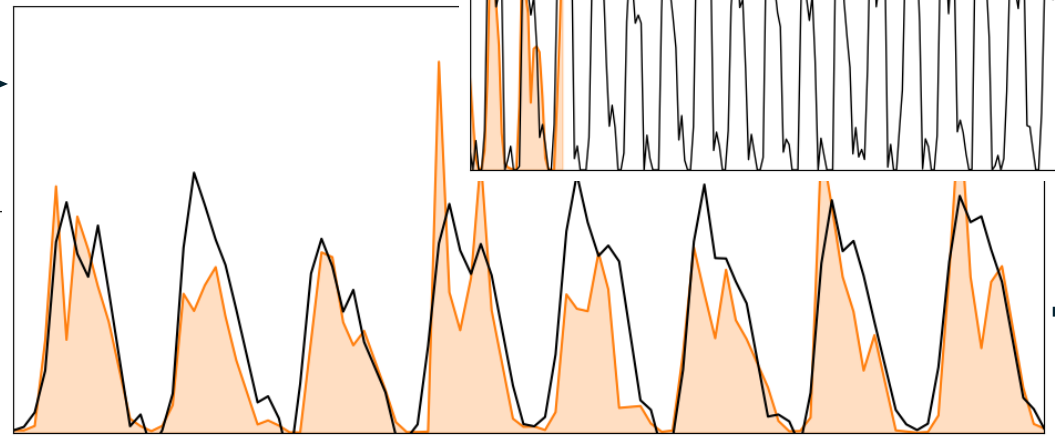
Incorporating Discharge and Precipitation into MUSCLE

Fit a multivariate regression model to historical base flow

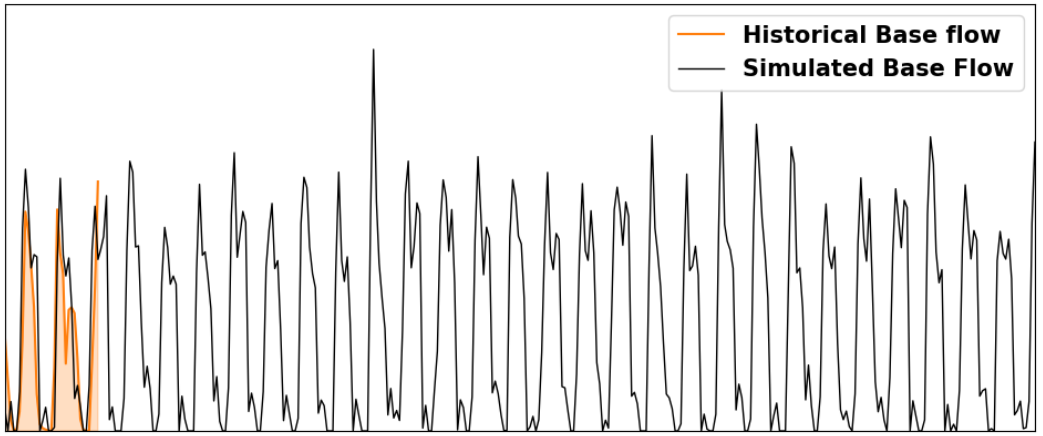


Separate base flow and event flow (zoomed in)



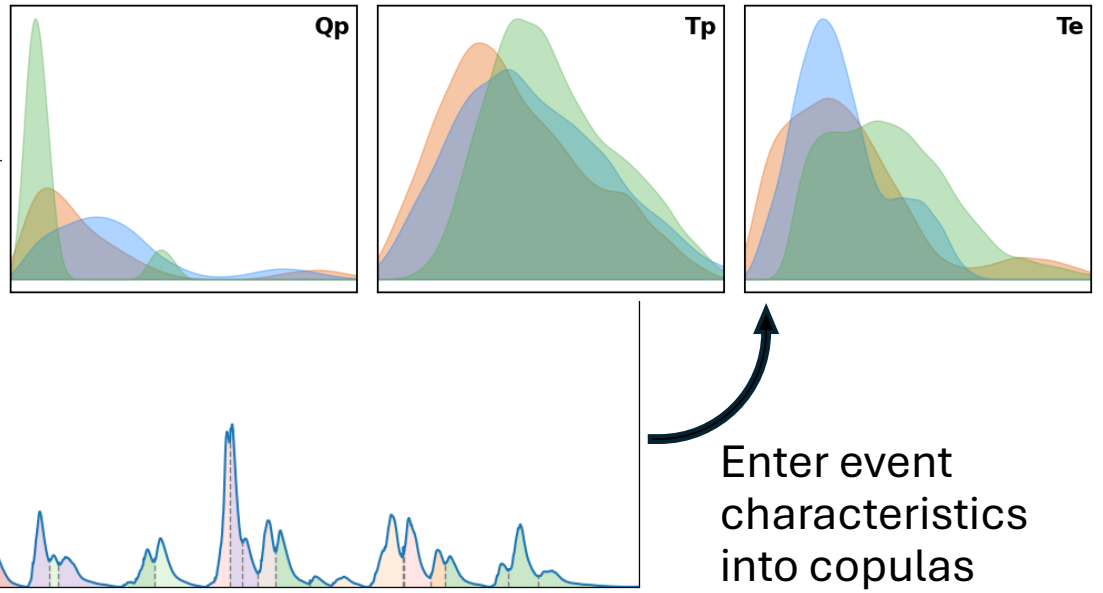


Simulate future base flow



Incorporating Discharge and Precipitation into MUSCLE

Attribute event characteristics (peak and duration) to weather types



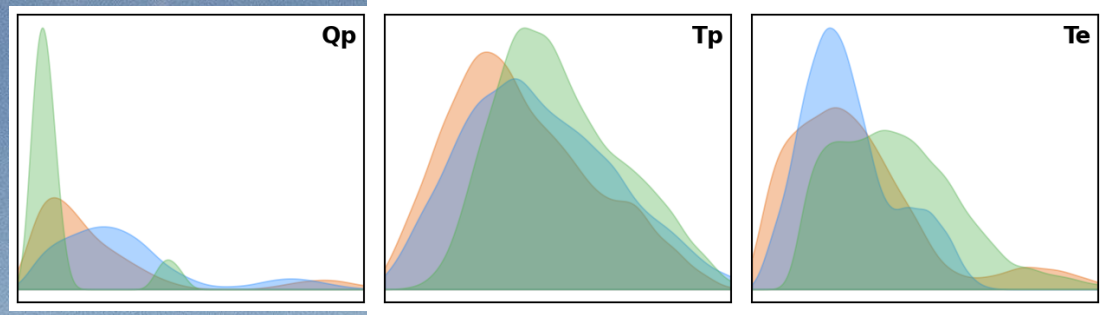
Enter event characteristics into copulas

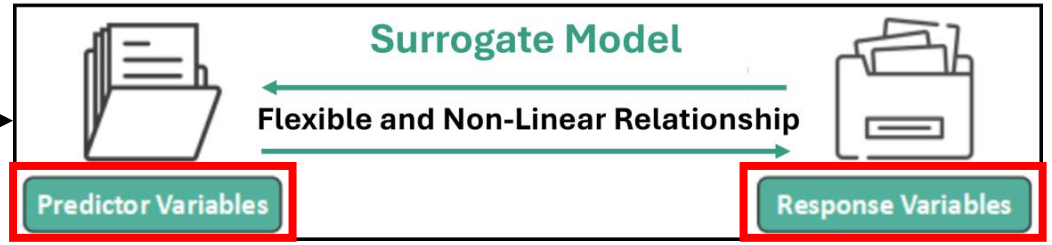
Separate base flow and event flow

Event Characteristics:

- Time to Peak (Tp)
- Peak Discharge (Qp)
- Time from Peak to End (Te)

Incorporating Discharge and Precipitation into MUSCLE





Predictor Variables:

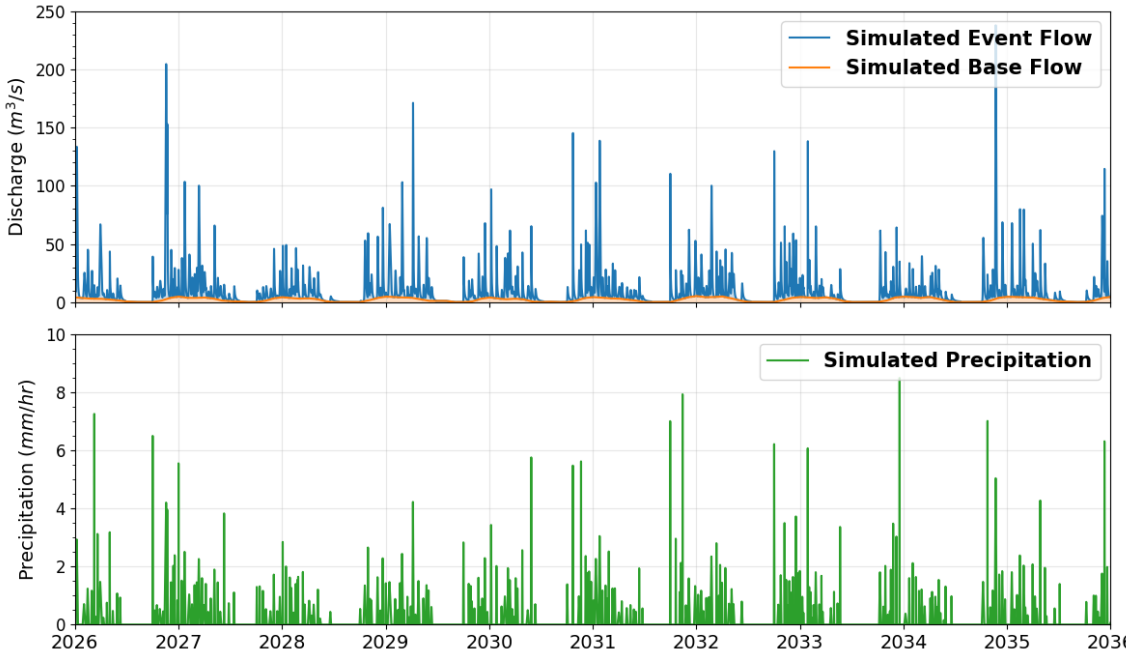
- Time to Peak (Tp)
- Peak Discharge (Qp)
- Time from Peak to End (Te)

Response Variables:

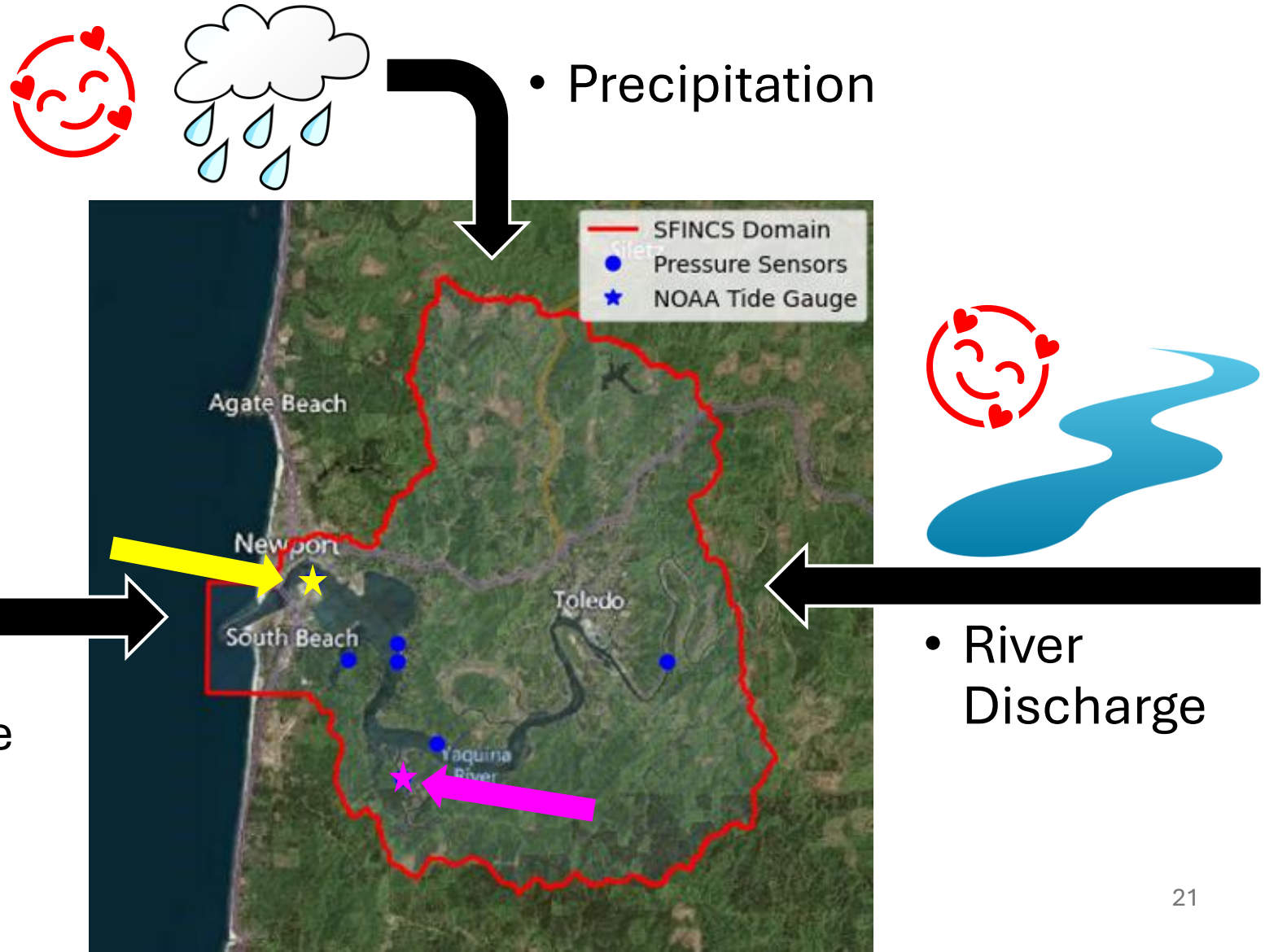
- Precipitation Duration
- Peak Precipitation

$$\frac{dQ}{dt} = (P - E - Q)aQ^{b-1}$$

Kirchner (2009)

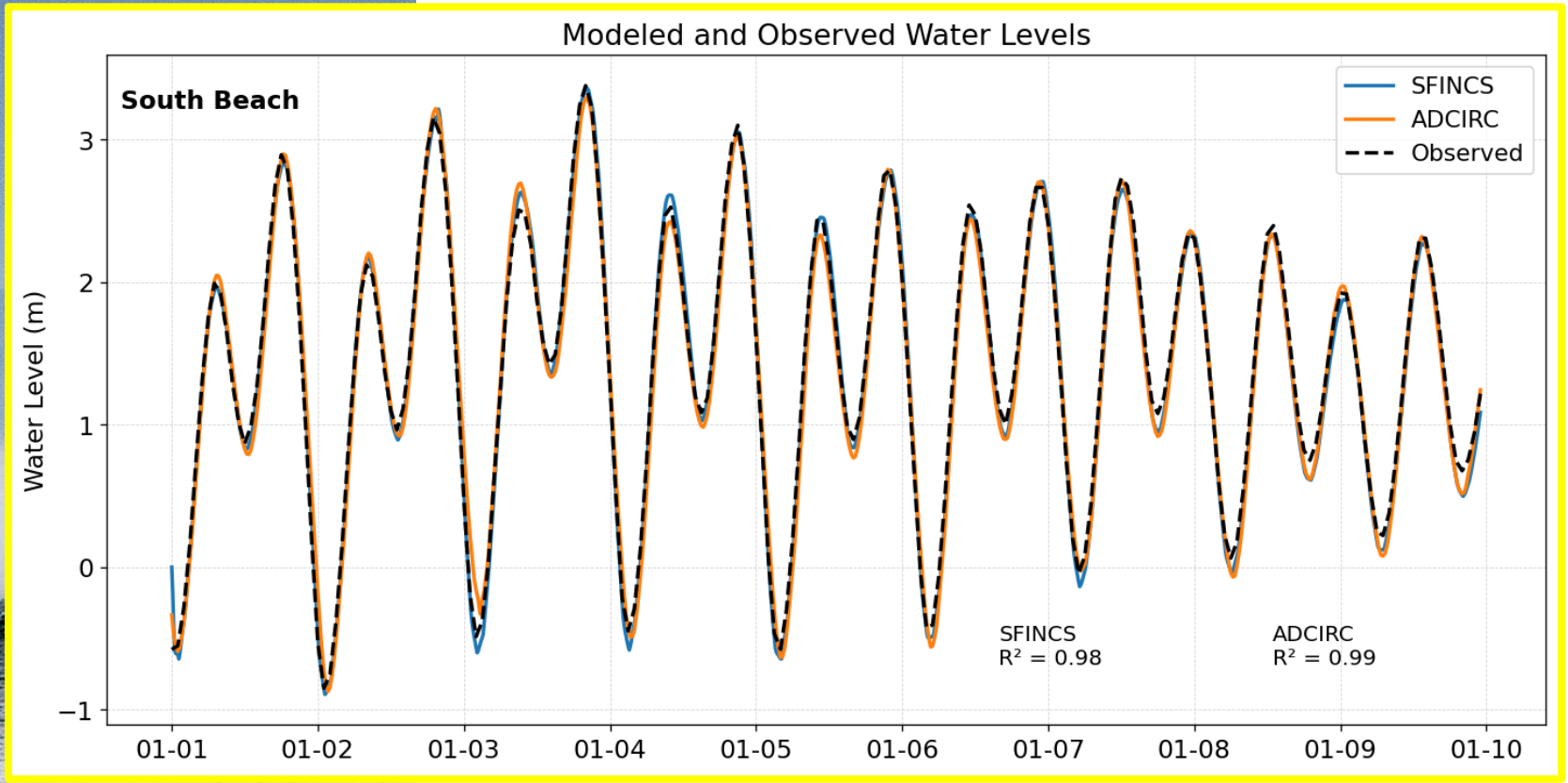


Hydrodynamic Model Configuration



- Precipitation
- Tides
- Storm Surge
- Waves
- MMSLA
- River Discharge

Model Validation



- January 2022 storm event
- **SFINCS: ~3 minutes**
- **ADCIRC: ~6 hours**

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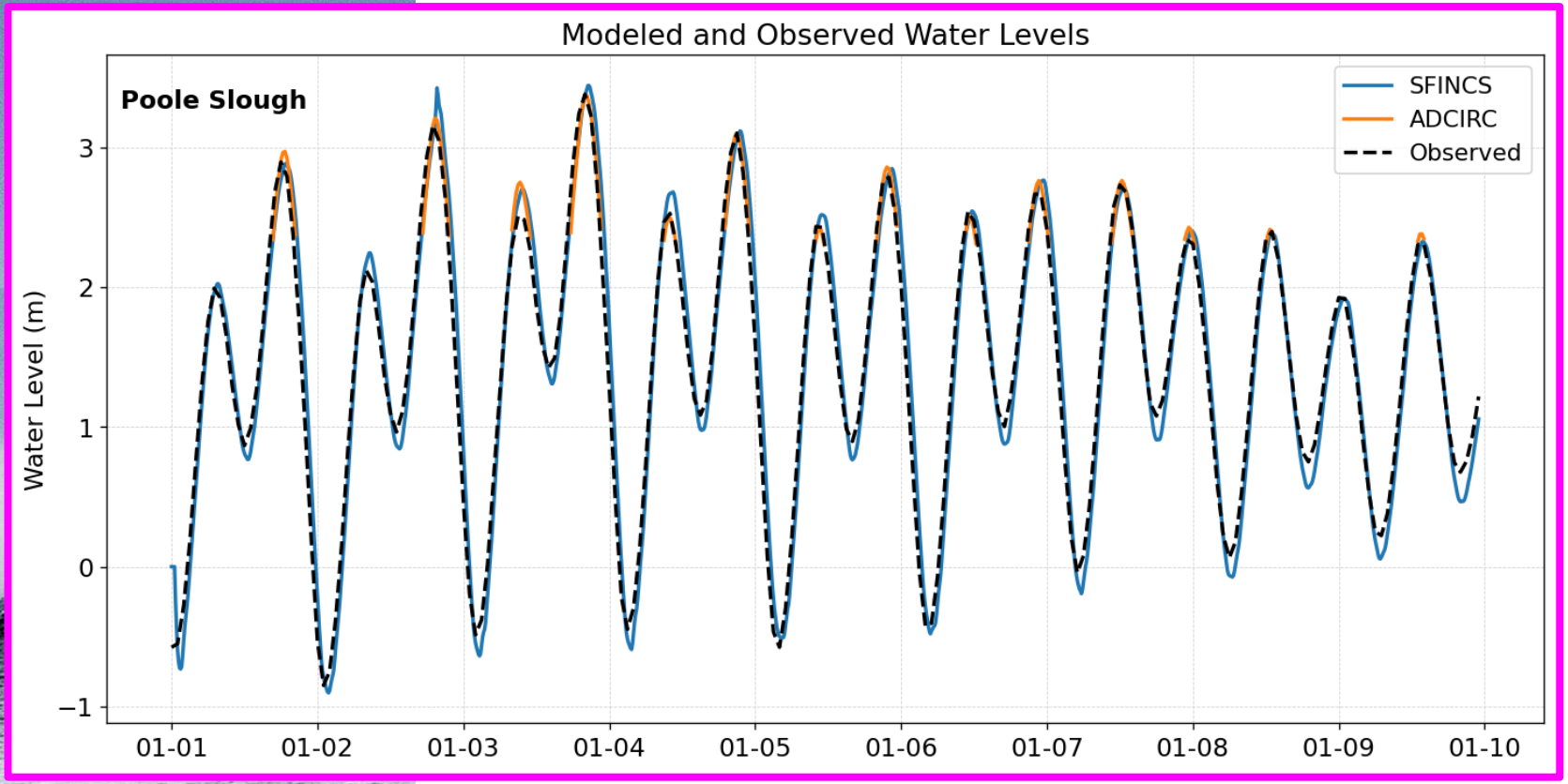

- January 2022 storm event
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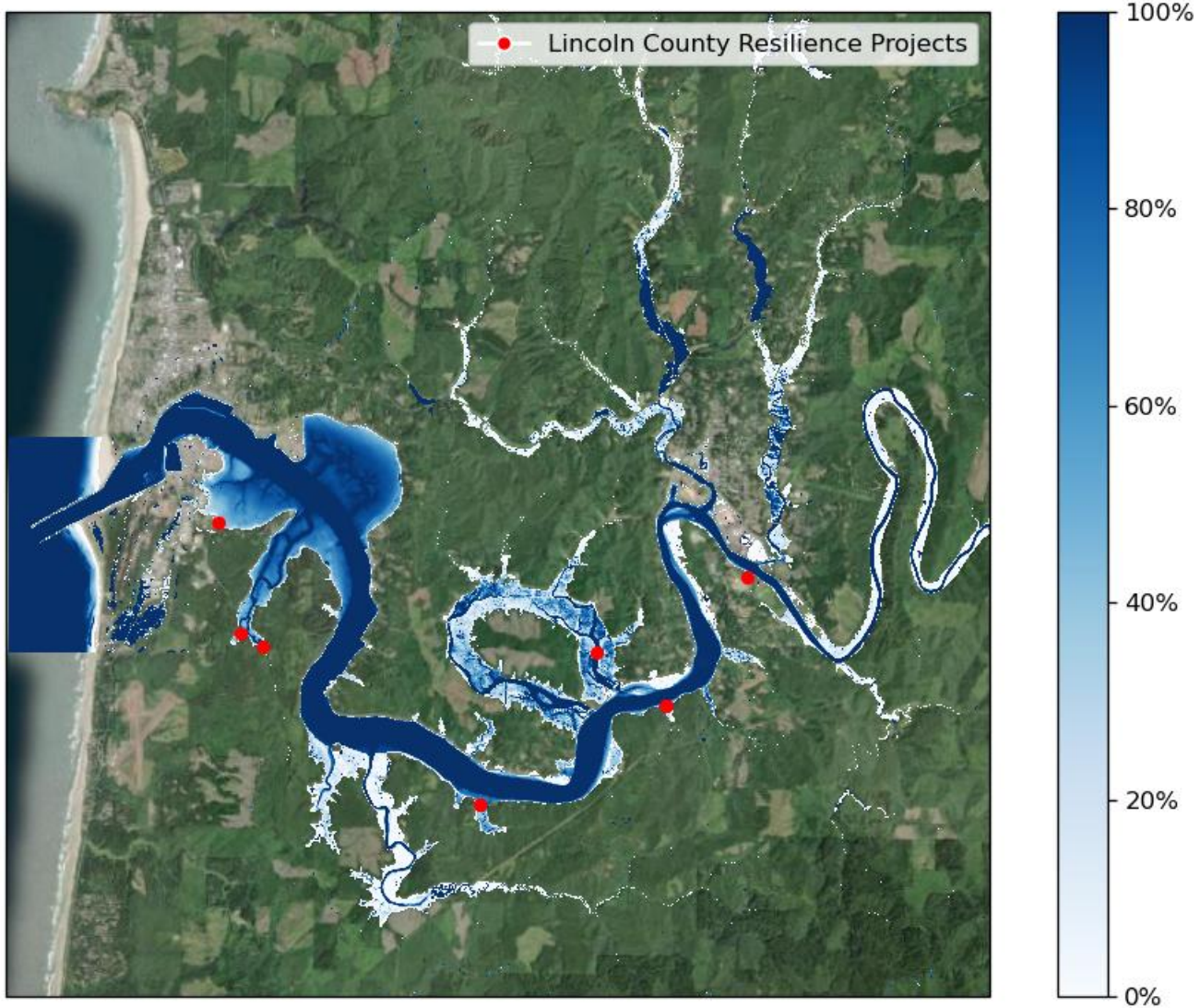
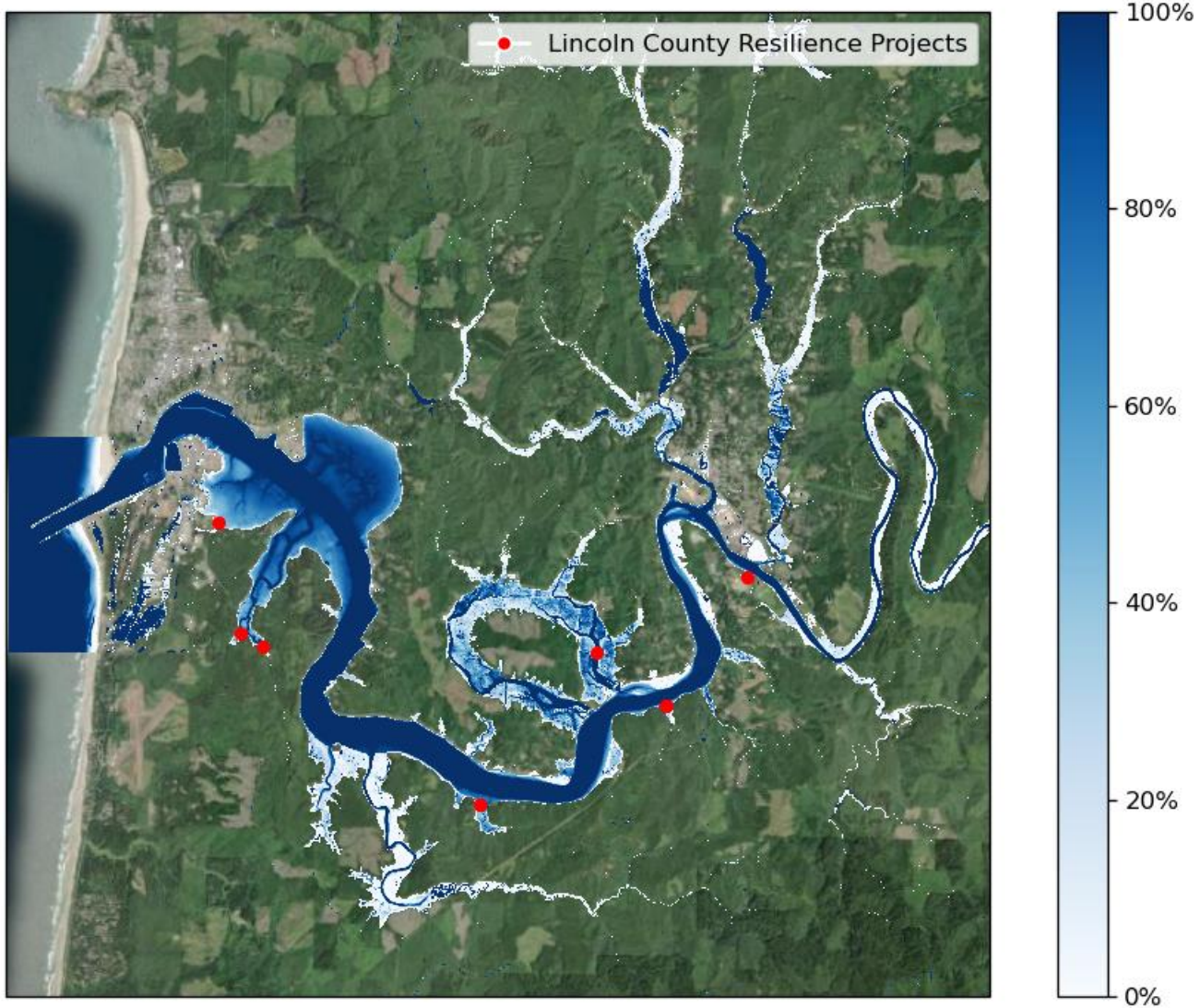
Historical SFINCS Simulation



- 5-year long simulation
  - 2010-2014
- Boundary conditions from observations and reanalysis products

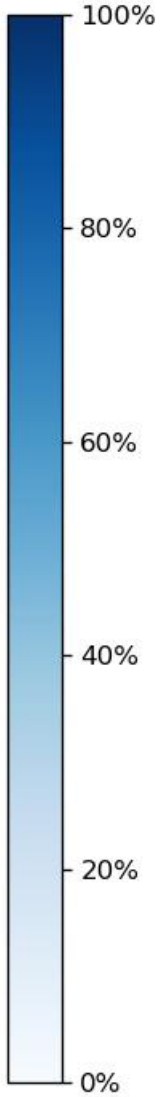
Synthetic SFINCS Simulation



- 5-year long simulation
- Boundary conditions from MUSCLE
  - Today's climate

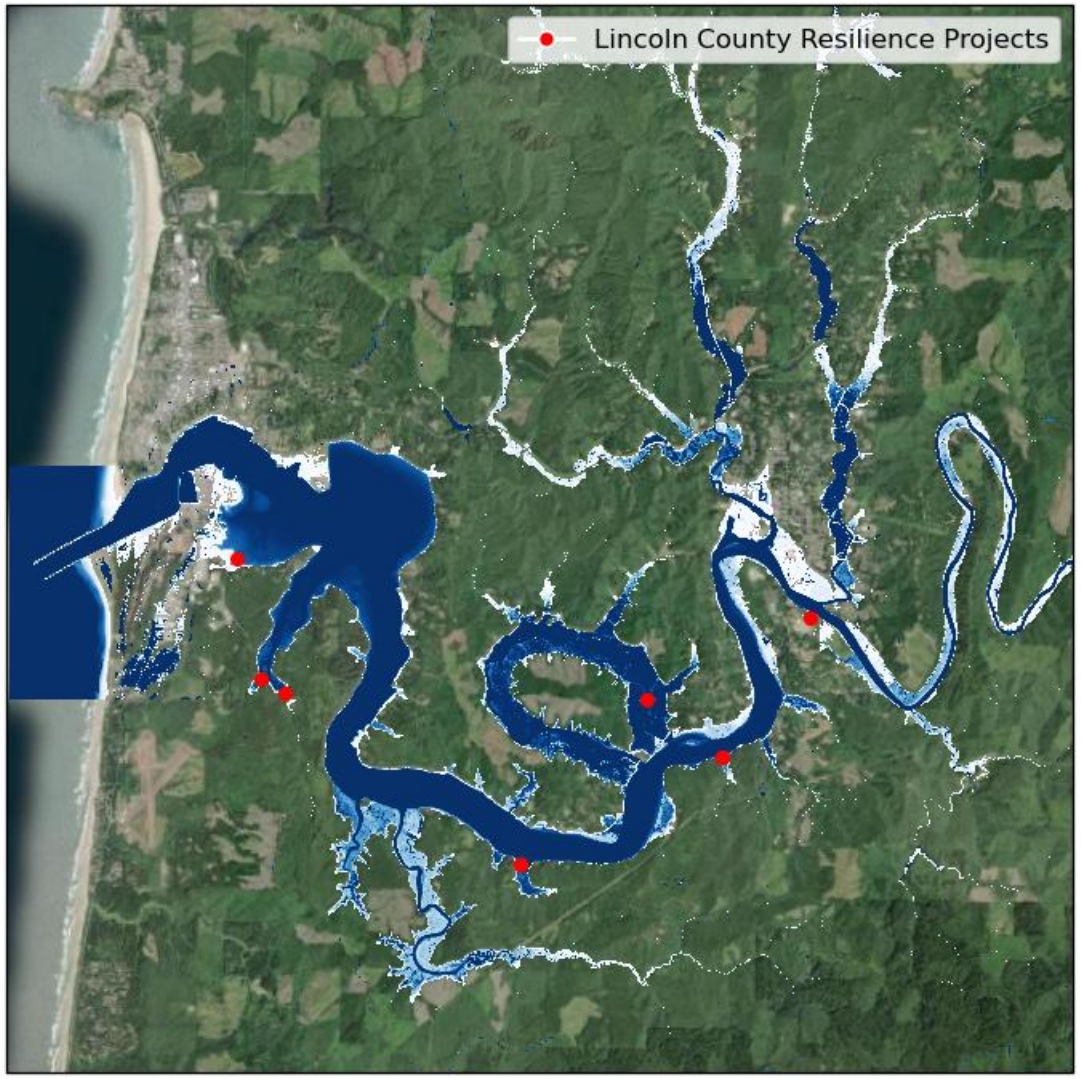
r11i1p1f2 realization from UKESM for the SSP370

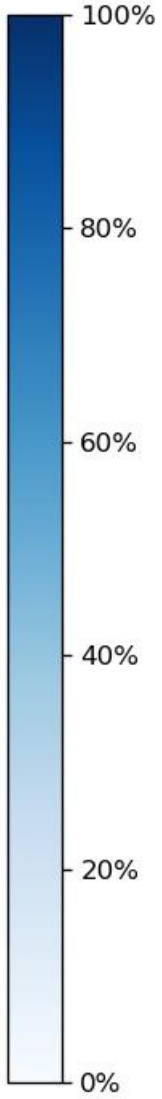
Synthetic SFINCS Simulation



- 5-year long simulation
- Boundary conditions from MUSCLE
  - Future climate
- r11i1p1f2 realization from UKESM for **SSP370**

Synthetic SFINCS Simulation





- 5-year long simulation
- Boundary conditions from MUSCLE
  - Future climate
- r11i1p1f2 realization from UKESM for **SSP370**
- +1.0m of SLR

Ongoing Research

- Apply MUSCLE to simulate all compound flood drivers, including discharge and precipitation, over **decadal to centennial timescales**, at hourly and 5-m resolution, for present day and a wide range of future climates.

- Co-develop Decision-Relevant Flood Products:
  - Create actionable flood maps and metrics in collaboration with stakeholders to **support community resilience** planning.

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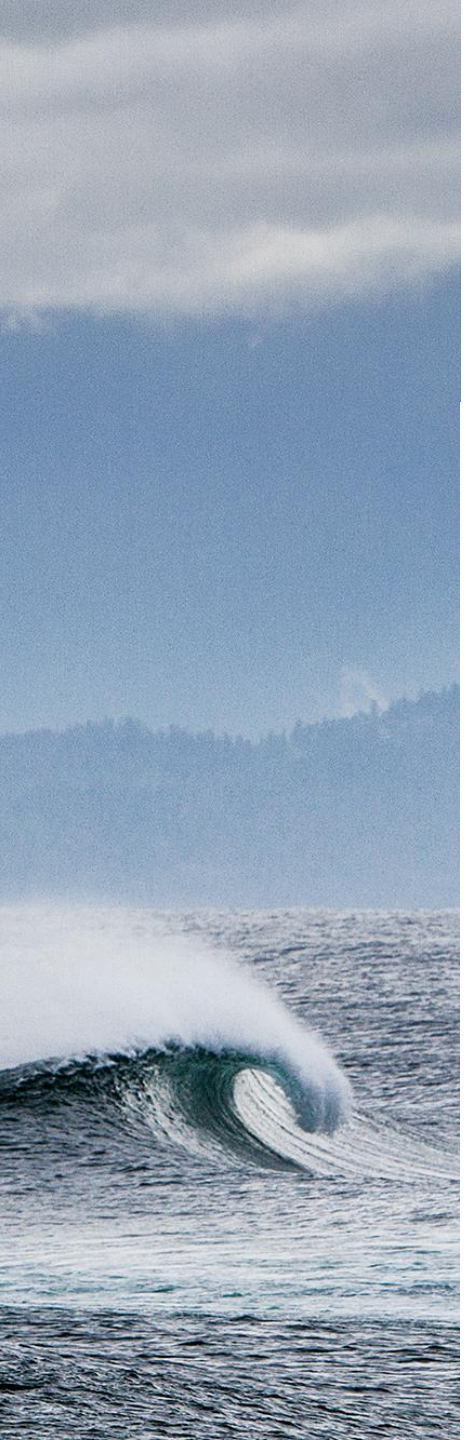
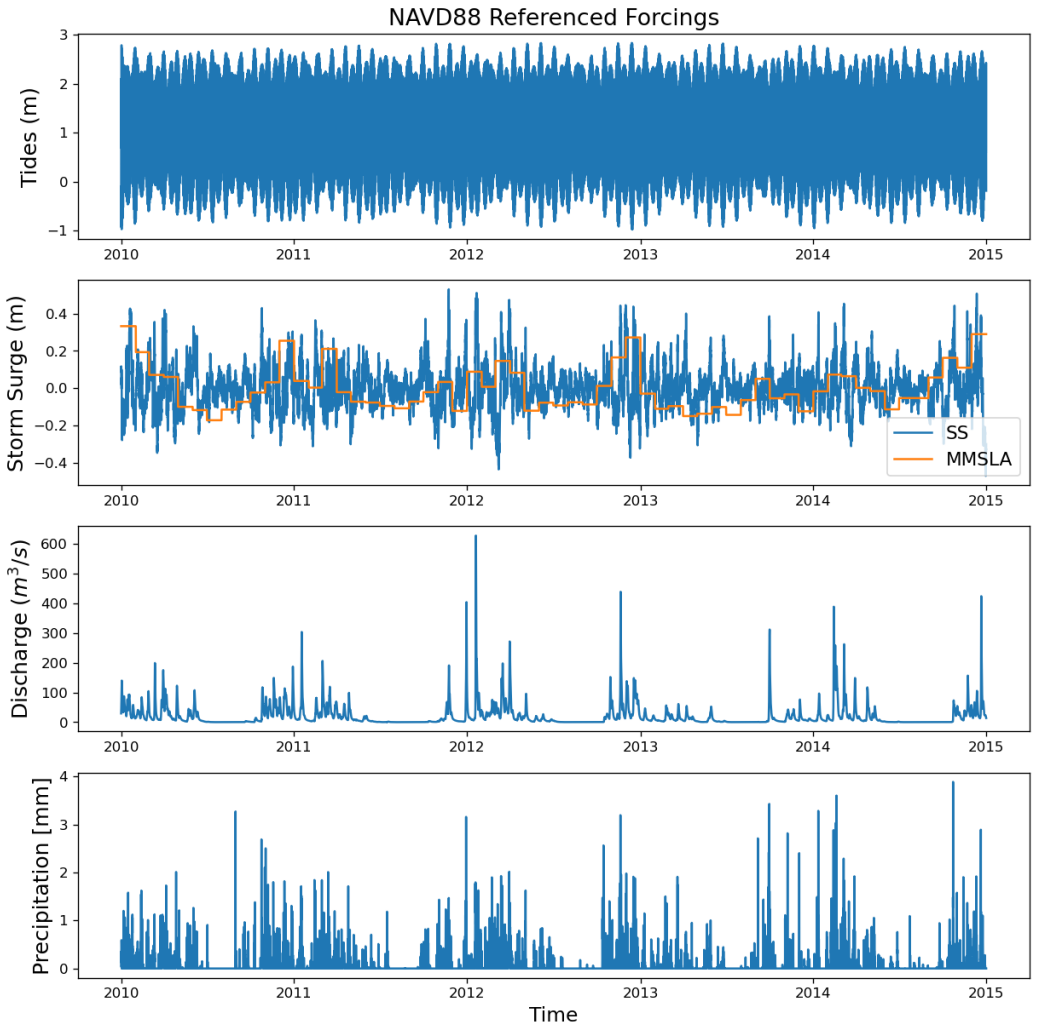
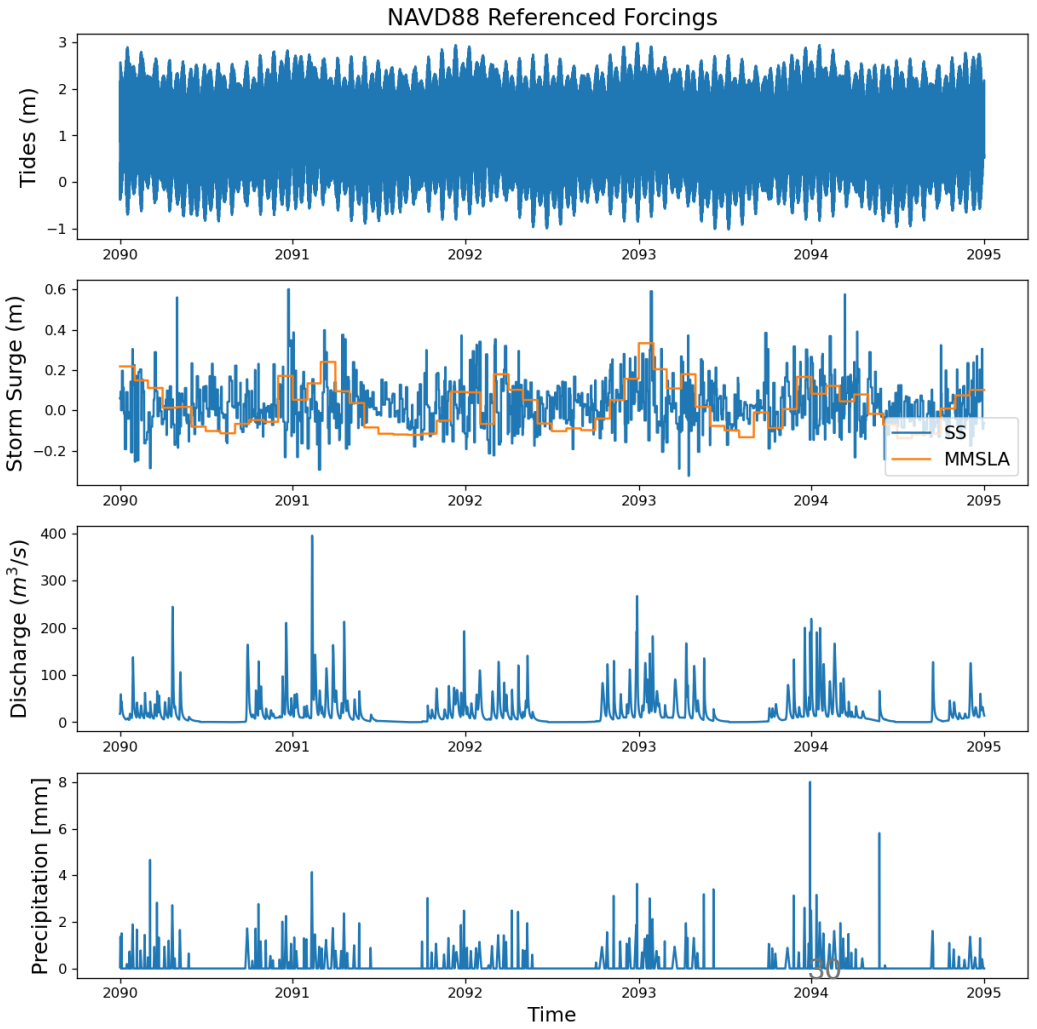
Extra Slides

- Forcings
- Methodology
- Surrogate Model Validation
- GCM Information



Forcings


NAVD88 Referenced Forcings
Tides (m)
Storm Surge (m)
SS
MMSLA
Discharge (m^3/s)
Precipitation [mm]
Time


NAVD88 Referenced Forcings
Tides (m)
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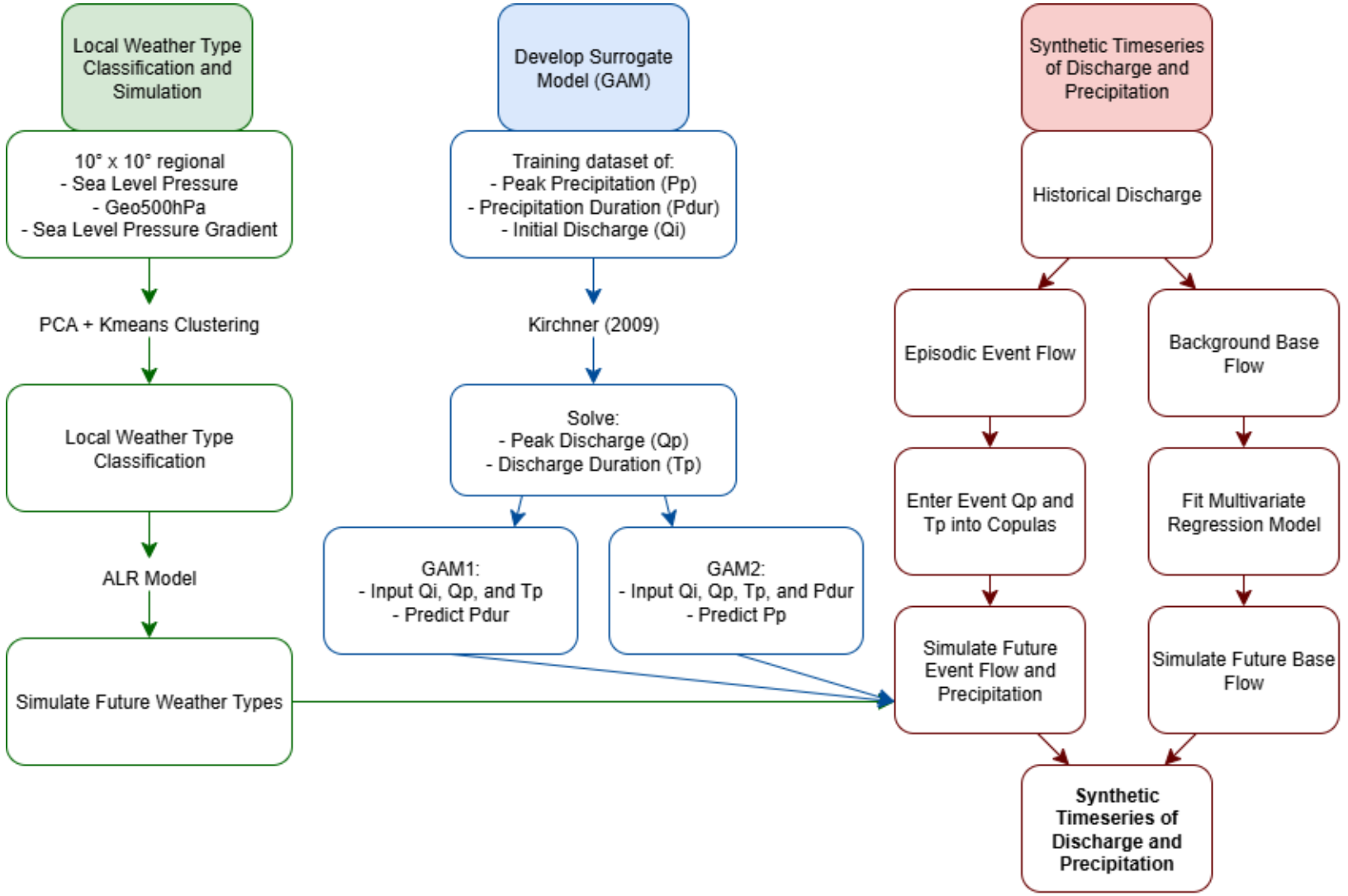
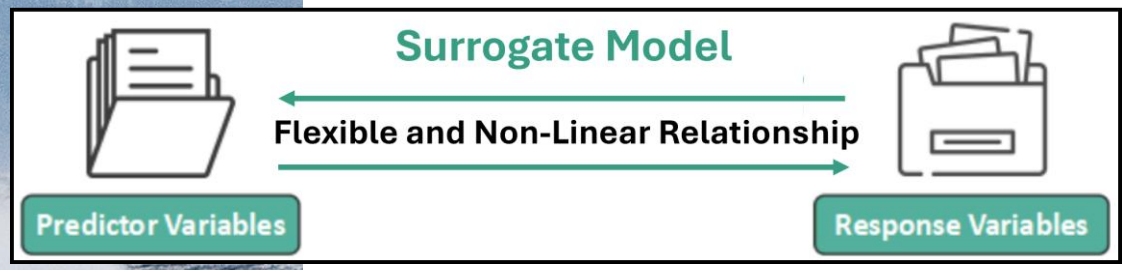
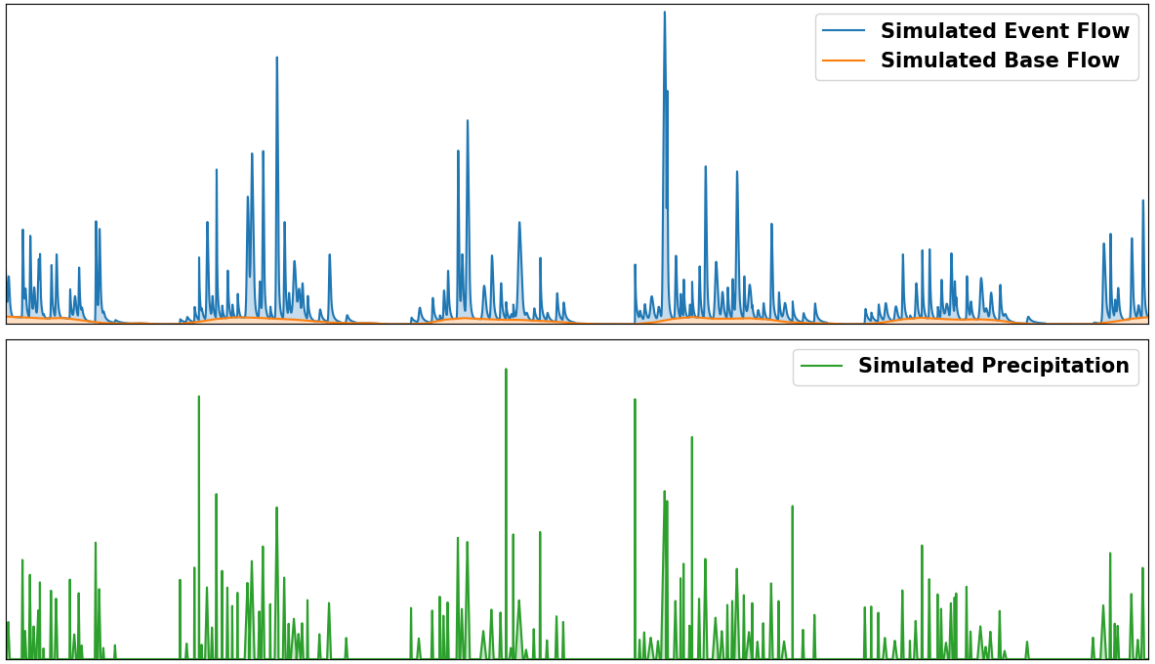
Methodology

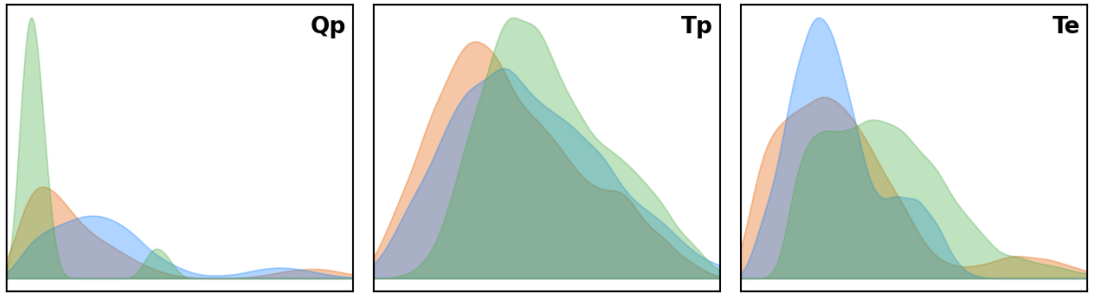


Methodology – Event Flow Cont.

- Sample synthetic discharge event characteristics (peak and duration)
- Predict associated precipitation peak and duration from event characteristics

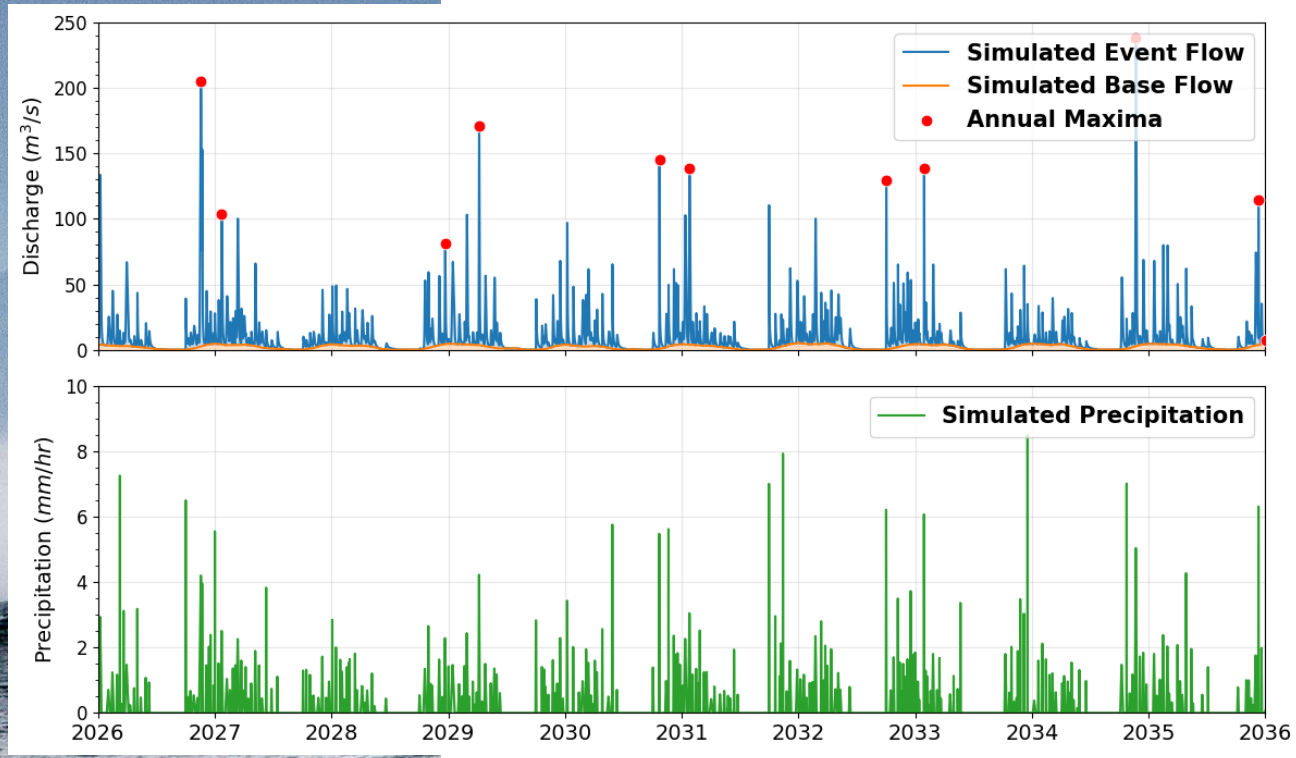


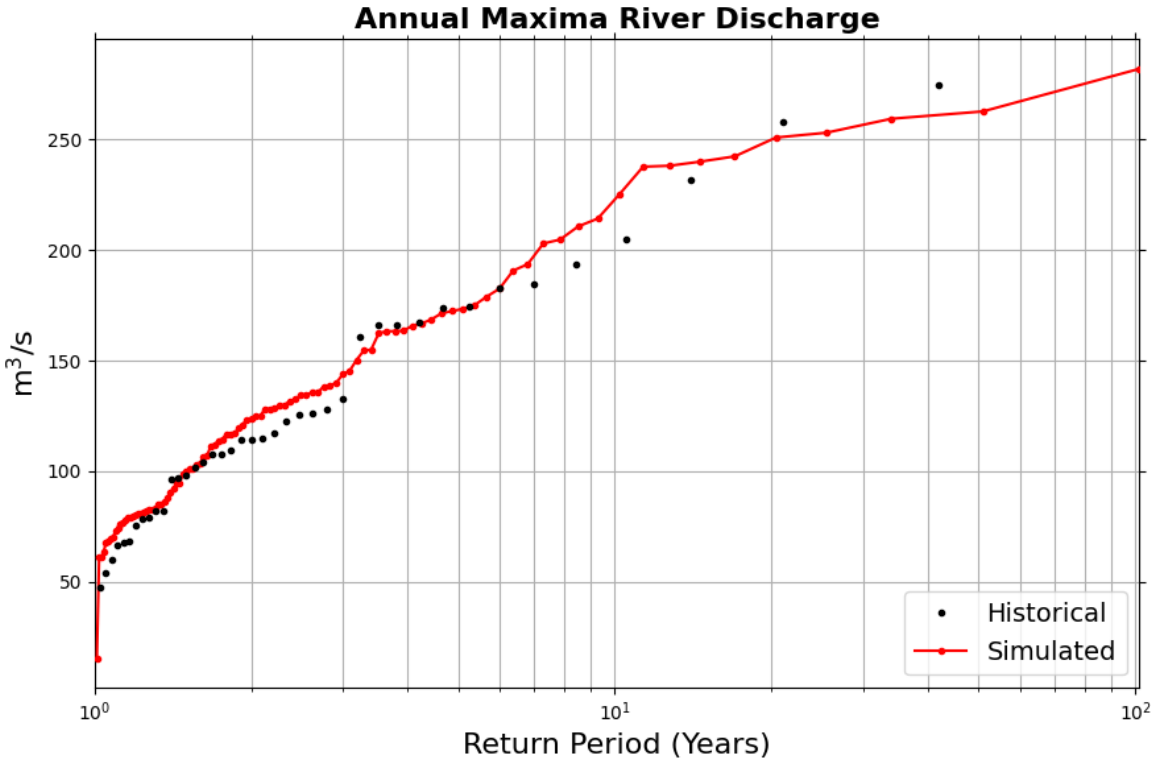




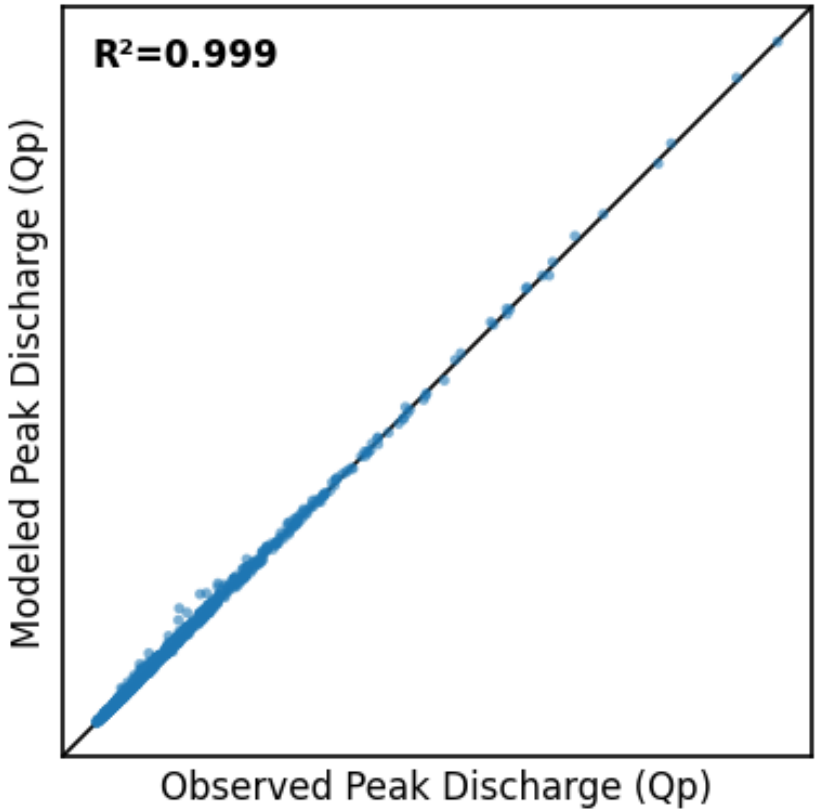
Following Kirchner (2009), simulate realistic timeseries of discharge and precipitation from copula samples and surrogate model response variables

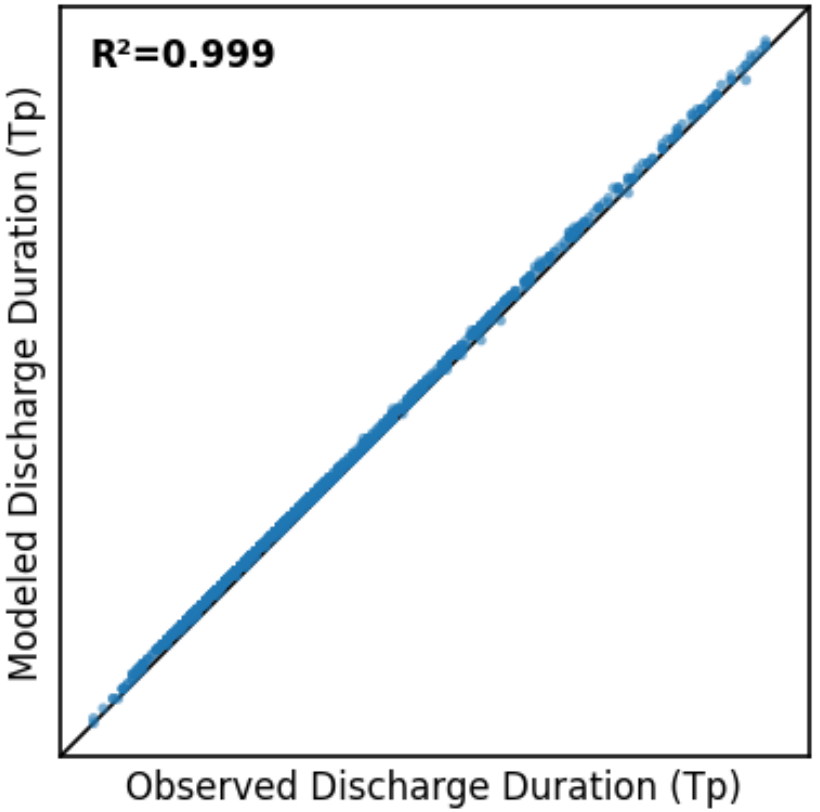
MUSCLE Simulated Discharge and Precipitation





Surrogate Model





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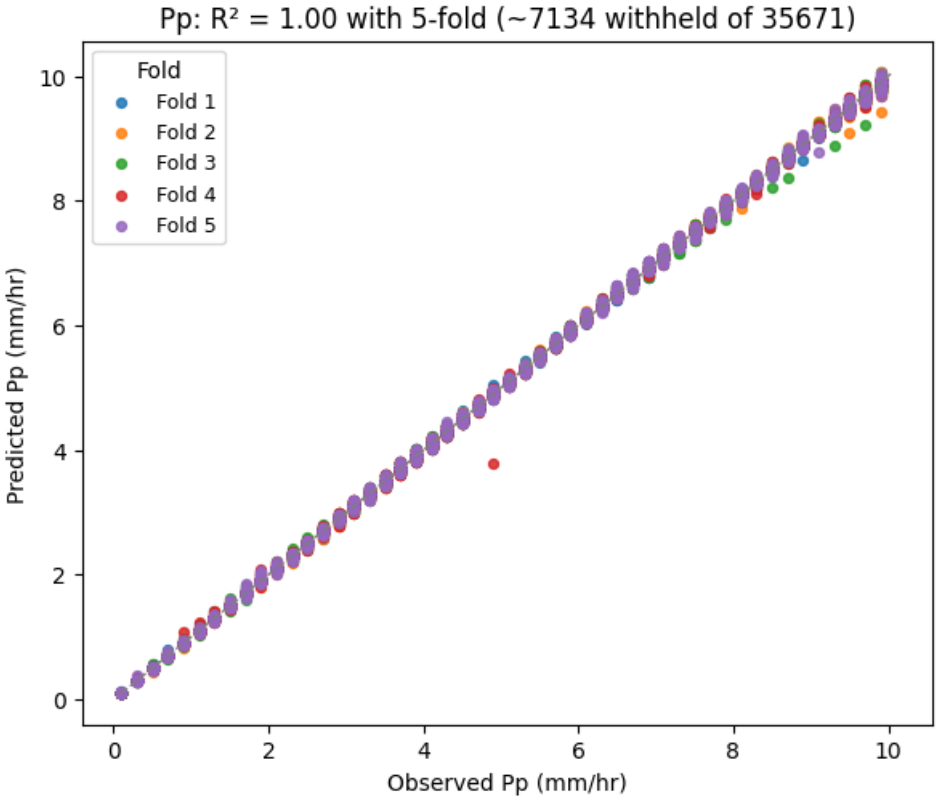
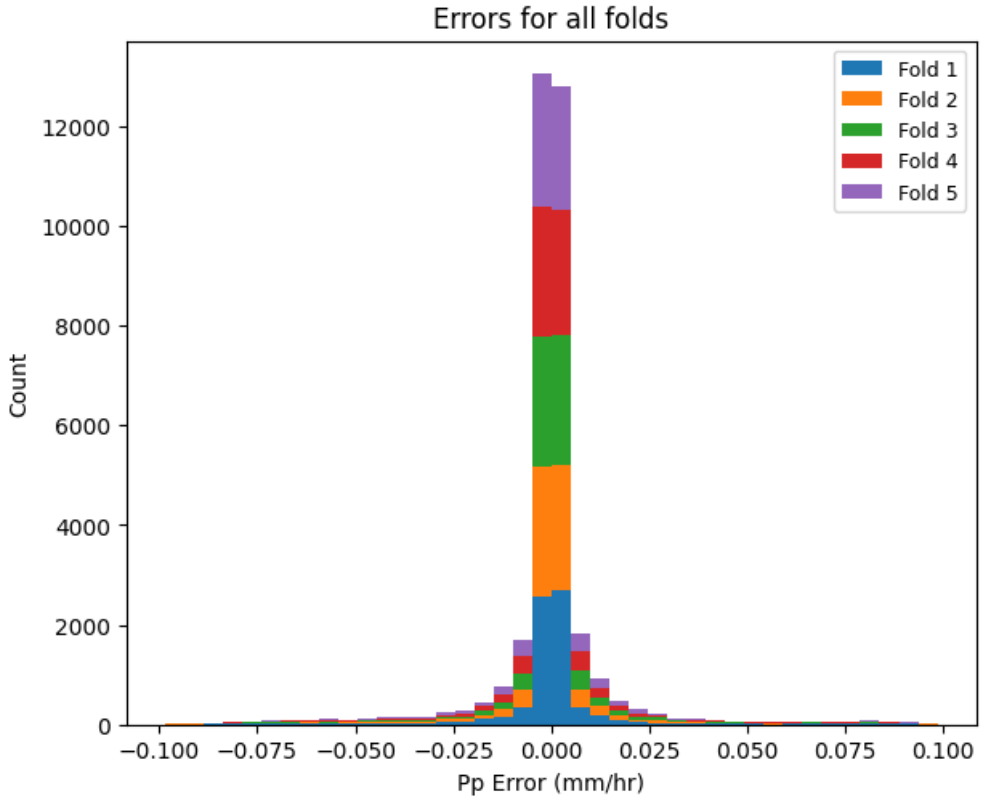
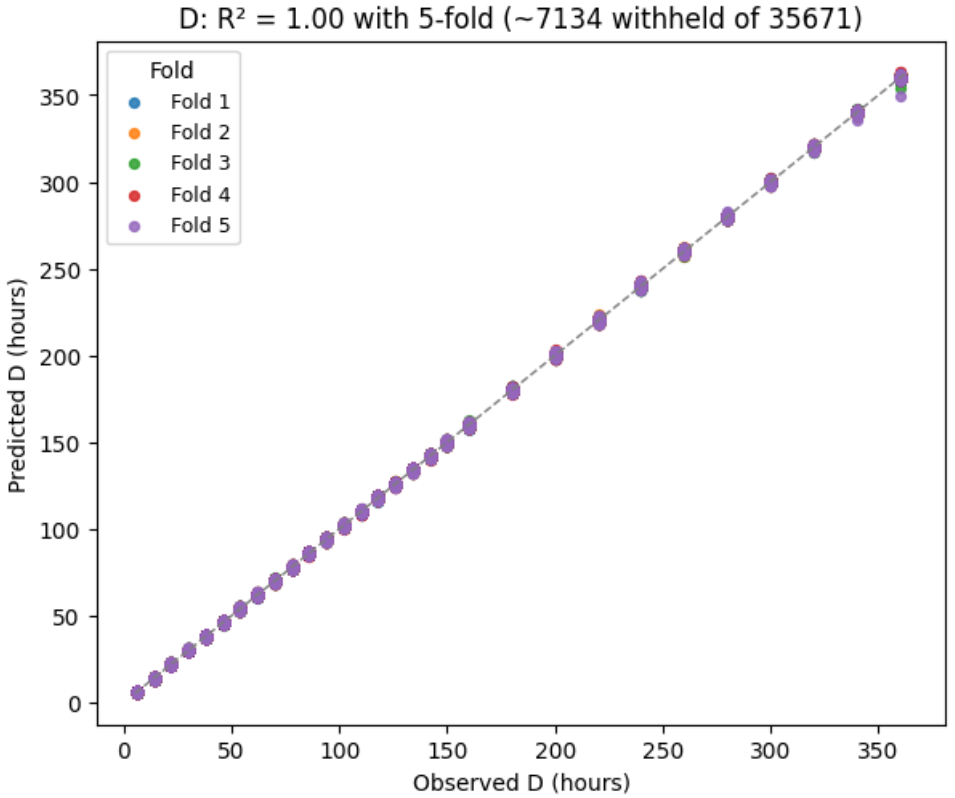
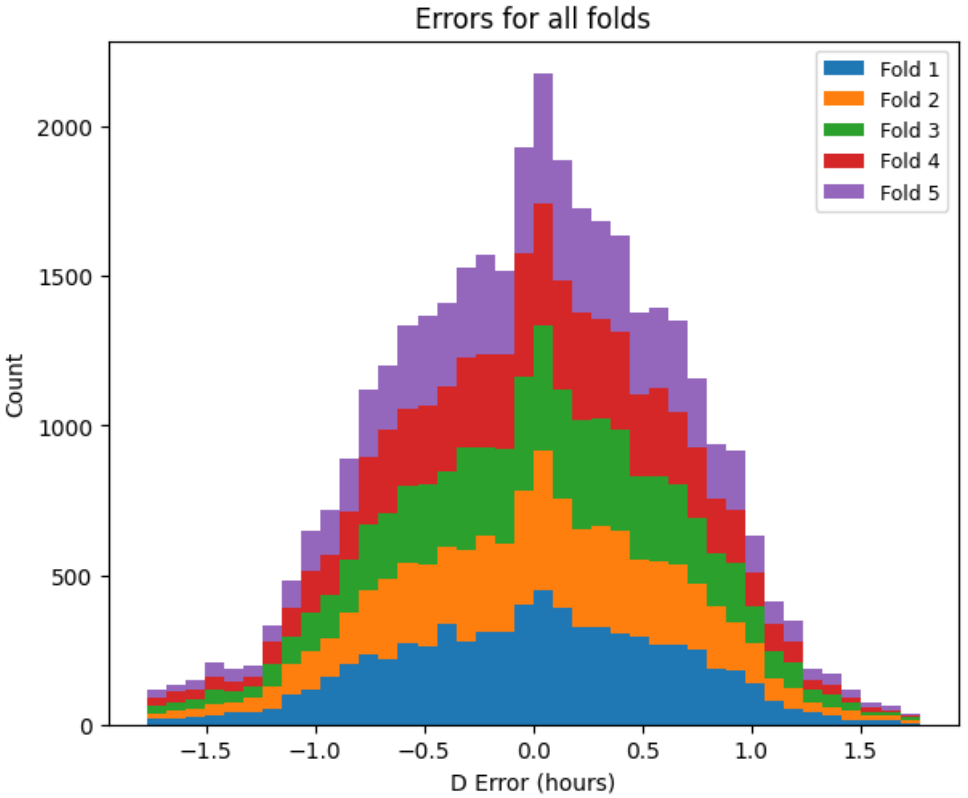




Surrogate Model





GCM Info

- SSP370 is a plausible future scenario where plausible emission forcing amounts could have a measurable effect on ENSO.
- r11i1p1f2 best showcased changes to future AWTs.
- Hybrid PCs for the AWTs and the annual PCs. These are computed by multiplying the model SSTA data into the observed (ERSSTv5) EOF patterns.