Sustainability of Barrier Island Protection Policies under Changing Climates

JC Dietrich[1], DL Anderson[1], A Gharagozlou[1], JF Gorski[1]

[1]Dep't of Civil, Construction, and Environmental Engineering, NC State Univ

USCRP FY19 In-Progress Review
Virtual Meeting, 19 Nov 2020

This project aligns with FY19 USCRP Research Topic 11: Coastal Adaptation Pathways for Barrier Island Communities

1. Summarize the state-of-knowledge for adaptation methods of coastal communities
2. Develop conceptual models for determining alternative adaptation pathways
3. Test, revise, and validate approaches using open-source numerical models

We are making progress on all three objectives

- Working with the Town of Nags Head
- **David Ryan**, Town Engineer

In this presentation, we describe our initial model development

1. Objectives

Nags Head Nourishment 2019

Outer Banks Voice

Nourishment in 2011

- Largest locally funded nourishment to date
- 16 km of coast
- 3.5 million cubic meters

Major storms

- Irene (2011)
- Matthew (2016)
- Dorian (2019)
- Nor'easters

Nourishment in 2019

- 3.0 million cubic meters

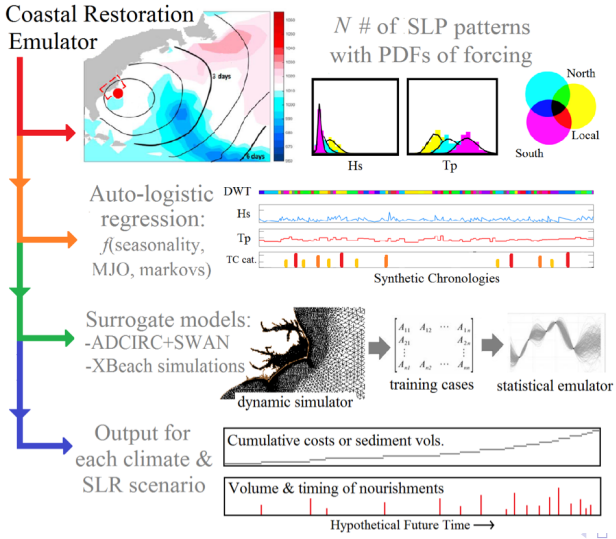
Whitehead, J. and White, H. B. (2017). "Adaptation planning in the Town of Nags Head: Vulnerability, Consequences, Adaptation, Planning Scenarios (VCAPS) Report."

- *[T]he most important and immediate next step, prior to engaging in any long range planning efforts and studies identified in the overall priority actions, will be to develop a suite of SLR scenario/probability distributions.*
- *The scenarios would not predict future changes, but describe future potential conditions in a manner that supports decision-making under conditions of uncertainty allowing the town to analyze vulnerabilities and impacts ....*
- *[T]hey could be utilized for long range planning such as development of an estuarine shoreline management plan, development of a long term shoreline management plan, and ... progressively improving the town's stormwater drainage infrastructure.*

Our emulator will consider scenarios for many climate forcings (not only SLR)

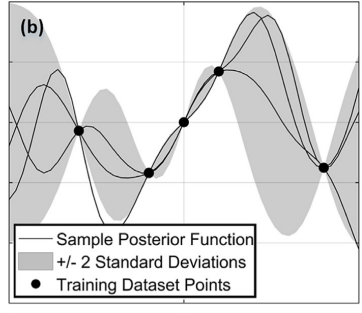
1. Objectives

Conceptual Diagram of the Proposed Emulator



2. Approach

What is a Surrogate Model?



K Parker, *et al.* (2019) *Coastal Engineering*, 150, 79–93.

A recent study compared surrogate models for predictions of dune erosion during storms

- Combine 100 synthetic storm events with a morphodynamic model
- That study used storms to predict beach/dune response

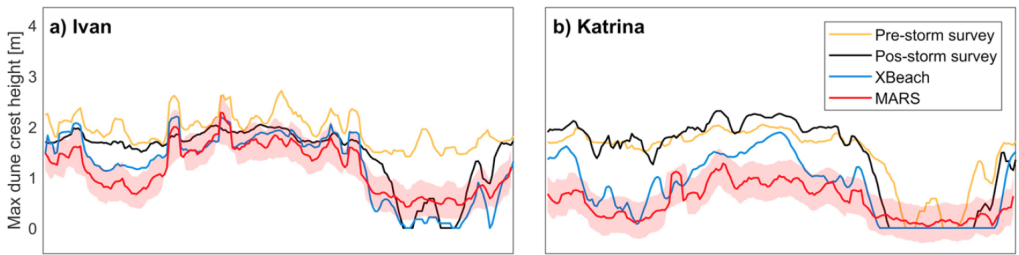
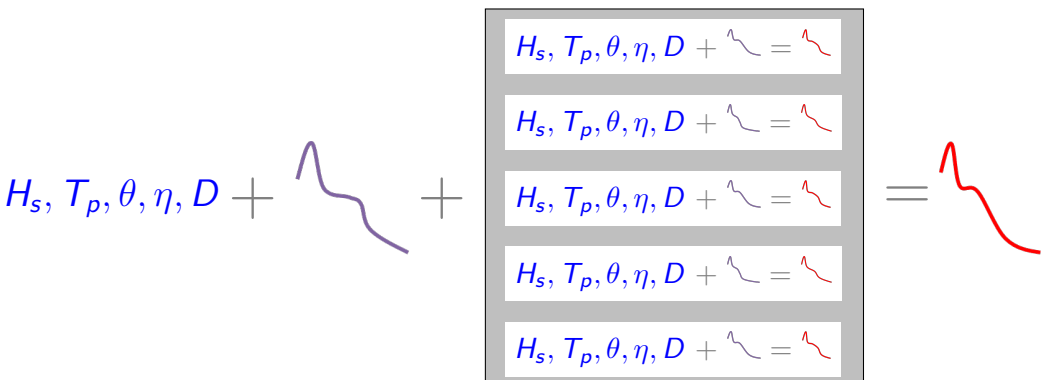


Figure 8: Comparison of maximum dune crest elevation as predicted by XBeach and MARS against survey data for hurricanes Ivan (a) and Katrina (b).

Santos *et al.* (2019), *JGR Earth Surface*.

We will use storms and initial beach/dune to predict beach/dune response

– We assess if a library of synthetic storms and idealized nourishment profiles produces an emulator with the ability to simulate realistic nourishment response to storm sequences



To do this, we need:

- Realistic (but not real) storms
  - Use hindcasts from the Wave Information Studies (WIS)
  - Compile 1000s of storm data into possible future scenarios
- Realistic (but not real) initial beach/dune profiles
  - Use surveys from Nags Head
  - Parameterize beach/dune geometry
- High-fidelity morphodynamic model to predict beach/dune response
  - Use the eXtreme Beach (XBeach) model
  - Develop a library of simulations using synthetic storms and beach profiles
- Connect everything in a surrogate model
  - Trained on library of process-based simulations
  - Replace the costly deterministic model

3. Execution Challenges

Connecting with the Town of Nags Head

We had two challenges related to our relationship with the Town of Nags Head:

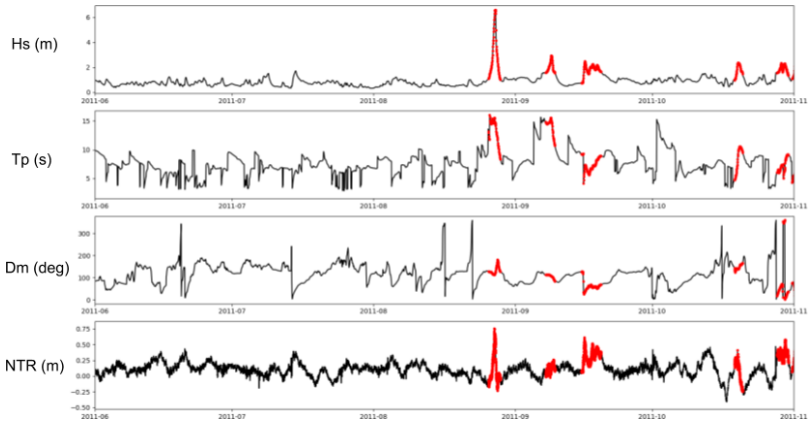
1. **Our collaborator Jess Whitehead took a new position**
   - Formerly the coastal communities hazards adaptation specialist for NC Sea Grant
   - Worked previously with the Town of Nags Head, participated in our USCRP pre-proposal, planned to facilitate connections to the town
   - Took position as chief resilience officer for NC Emergency Management
   - $\rightarrow$ *Thus we were slow to connect with the town*
2. **Nags Head hired a new coastal engineering firm**
   - Now working with Moffatt & Nichol
   - Surveys were transferred electronically in Jul/Aug 2020, then shared with us
   - $\rightarrow$ *Thus we have been working with the survey data for only about 3 months*

Both challenges have been overcome

- Continue to strengthen relationship with **David Ryan**, Town Engineer

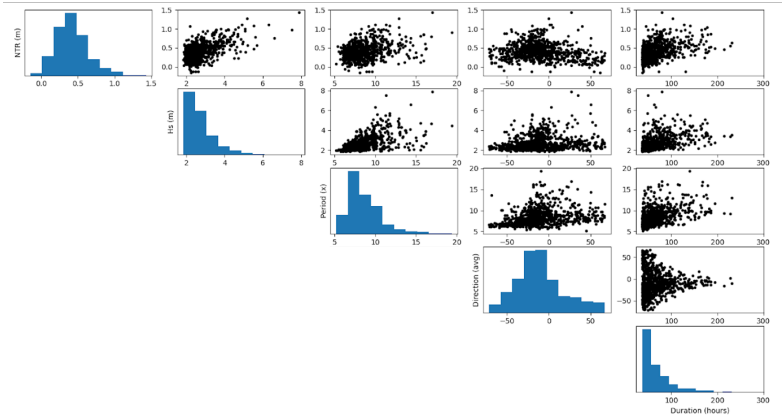
Using the WIS dataset, we examined 40 years and identified 800 storms

– For each storm, saved the parameters $H_s, T_p, \theta, \eta, D$



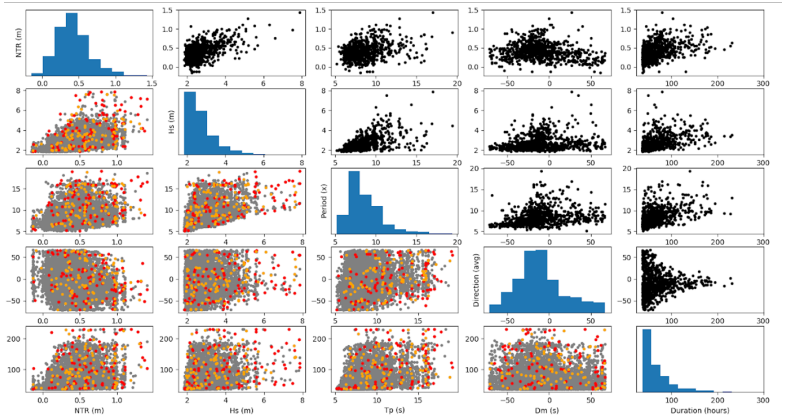
Then examine the relationships between the observed storms

- Sample the parameter spaces to obtain realistic (but not real) synthetic storms



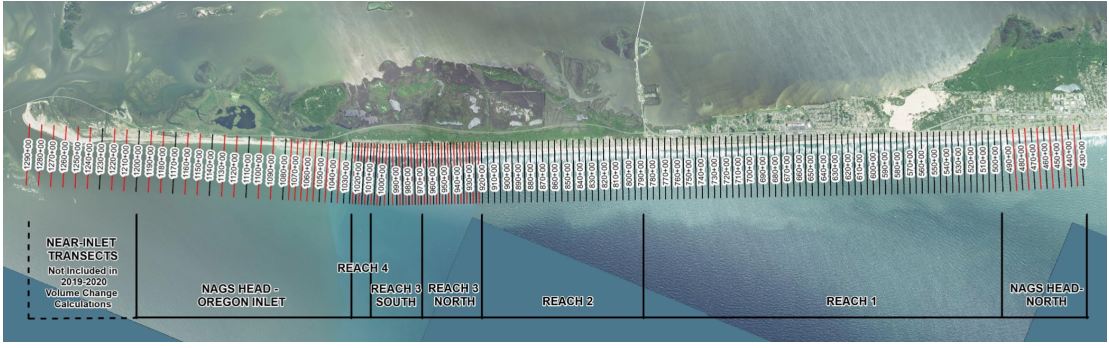
Then examine the relationships between the observed storms

– Sample the parameter spaces to obtain realistic (but not real) synthetic storms



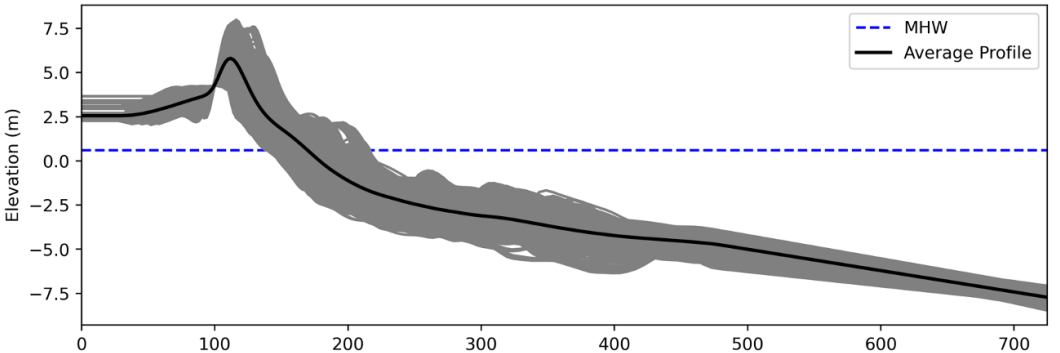
The Town of Nags Head conducts regular surveys of their nourishment project area

- Twice per year – every Jun/Jul and Oct/Nov
- Transects every 500 ft near the town, with wider spacing away from the nourishment
- This is a valuable dataset for seasonal storm effects and long-term erosion



Interpolated the real profiles from the entire coast and all surveys

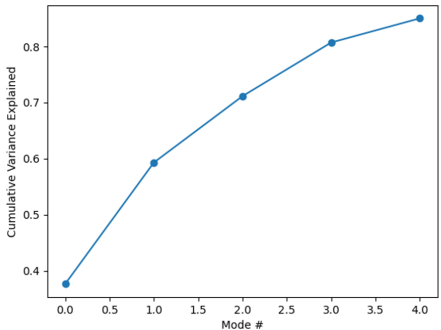
- Total of 15000 profiles



Next step is to parameterize these beach/dune profiles

To parameterize the profiles, we used **principal component analysis** (PCA)

- This is a way to reduce the dimensionality of the dataset
- Represent most of the variability with only a few modes and components
- This will reduce the number of simulations to train the surrogate model



4. Results

Principal Components for Nags Head Surveys

Each mode and component is related to variability in the profiles

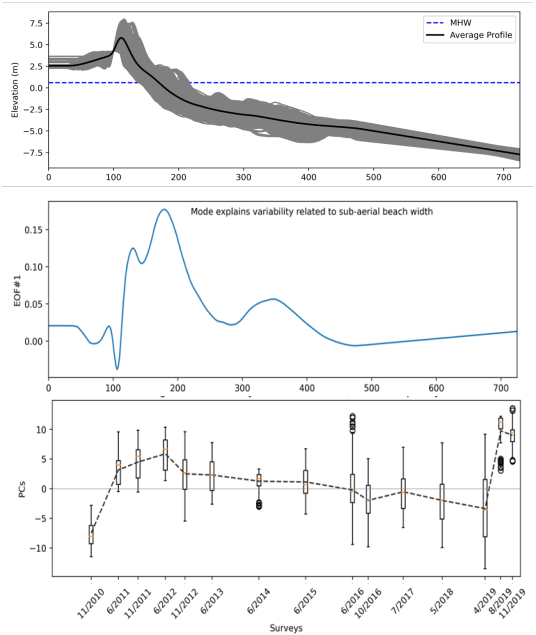
Mode 1 explains variability related to sub-aerial beach width

- Largest amplitudes at beach
- Component shows nourishments in 2011 and 2019, gradual erosion between

Mode 2 explains variability related to dune and surfzone trough / bar

- Aeolian growth of dune over time

We consider first five modes



4. Results

Principal Components for Nags Head Surveys

Each mode and component is related to variability in the profiles

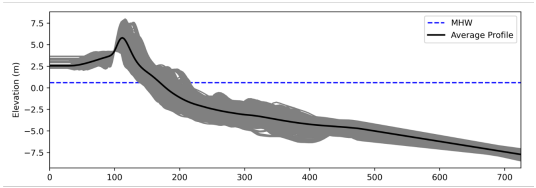
Mode 1 explains variability related to sub-aerial beach width

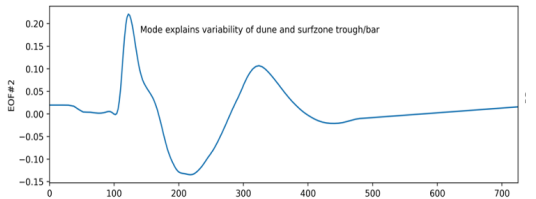
- Largest amplitudes at beach
- Component shows nourishments in 2011 and 2019, gradual erosion between

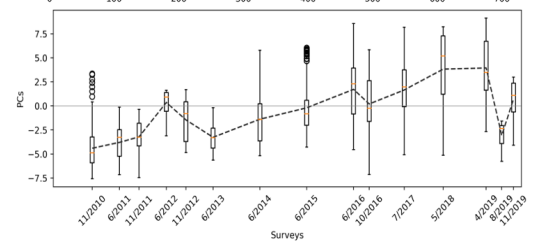
Mode 2 explains variability related to dune and surfzone trough / bar

- Aeolian growth of dune over time

We consider first five modes

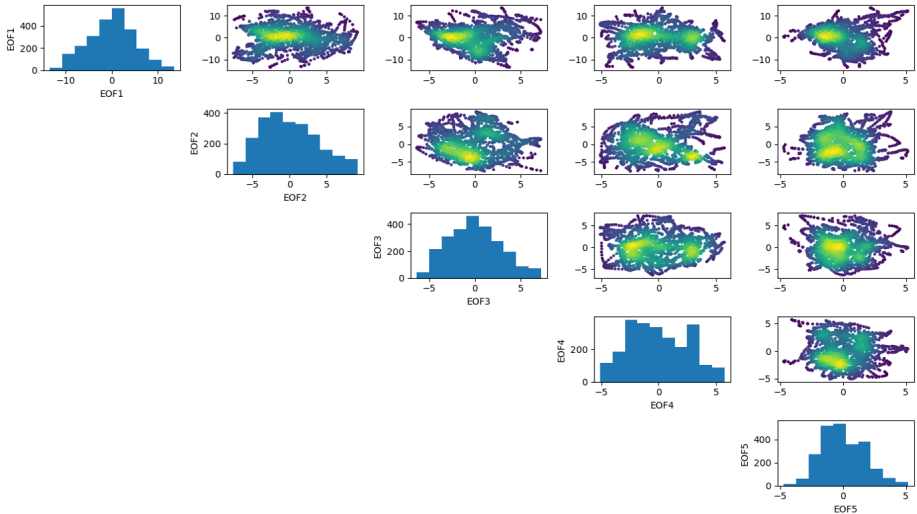






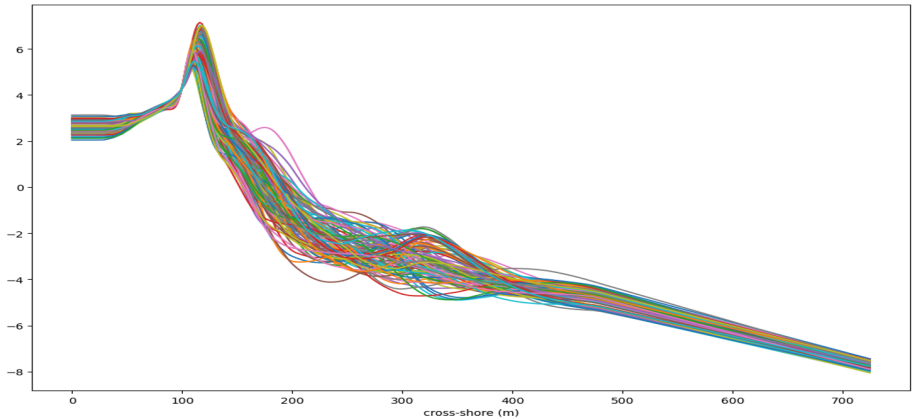
4. Results

Sampling of Components from Five Modes



Use principal components to construct realistic profiles

- Sample the weight for each component, then add weighted components into one profile
- Leads to **150 realistic profiles** for the Nags Head nourishment



We use these realistic storms and profiles to run **150 XBeach simulations**

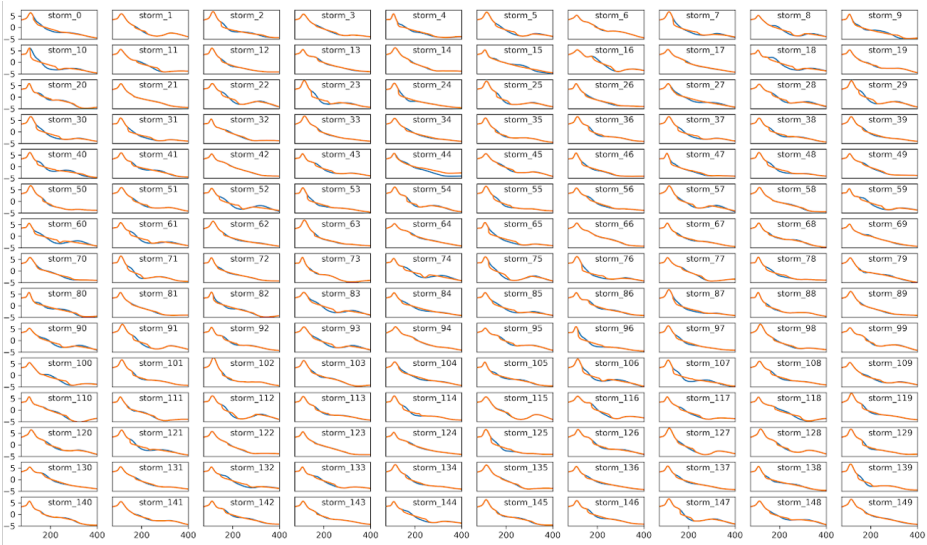
- Each profile was used to create a 2D domain
  - Size of 5 km by 2 km (500 cells by 243 cells)
  - Alongshore uniform profile
- Each storm was applied as boundary forcing for one profile/domain
  - Wave heights H_s, periods T_p, and surge η applied with triangular approach
  - Constant forcing for wave directions θ
  - Variable storm durations D as sampled

Computational requirements were less than expected

- Each simulation takes 2 to 6 hr on 28 cores
- Using resources at NC State, Gharagozlou completed the simulations in less than a week

4. Results

Library of Simulations



4. Results

Library of Simulations

4. Results

Library of Simulations

We use these XBeach simulations to train a surrogate model

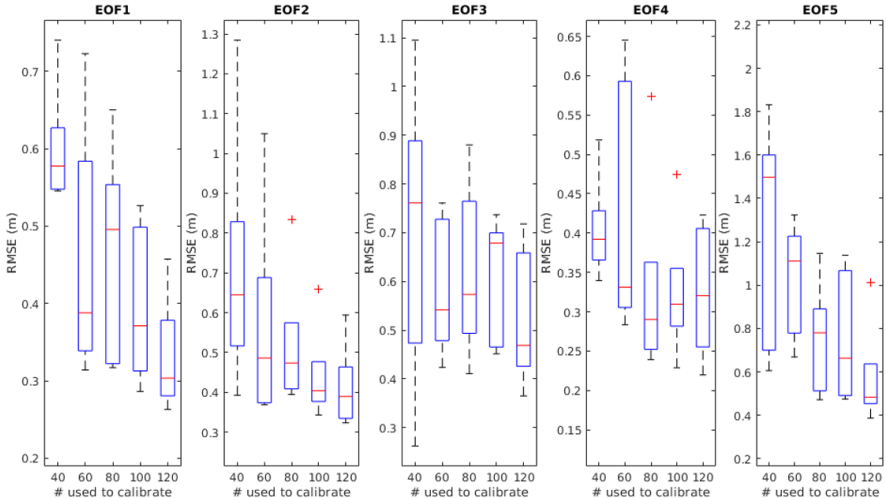
- This statistical model will replace our process-based (XBeach) model for future profiles

We select a **Gaussian Process Regression** (GPR) model

- Also known as Bayesian non-parametric regression, or Kriging
- Should scale better than other surrogates when many dimensions are used as inputs
- Used (successfully) for other coastal problems, including storm surge predictions
- We may consider other surrogates at a later time

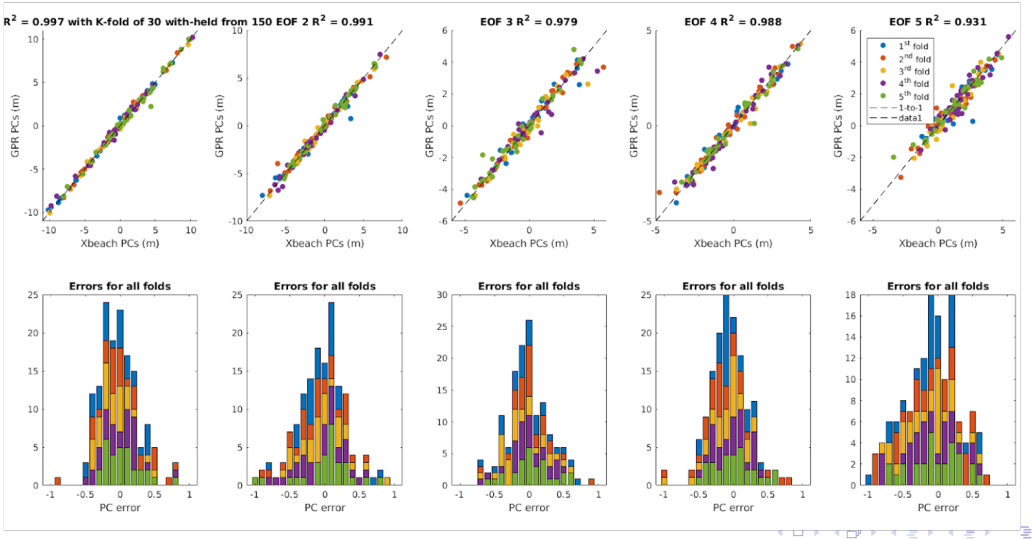
4. Results

Surrogate Model Convergence



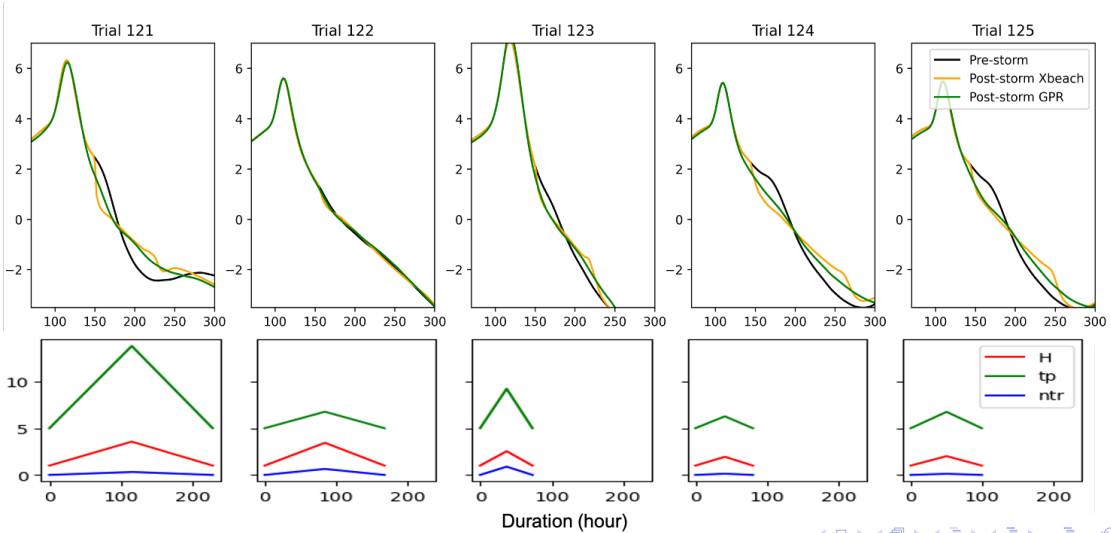
4. Results

Surrogate Model Validation to Withheld Profiles



4. Results

Examples of Surrogate Model Validation to Withheld Profiles



5. Project Deliverables

In-Progress

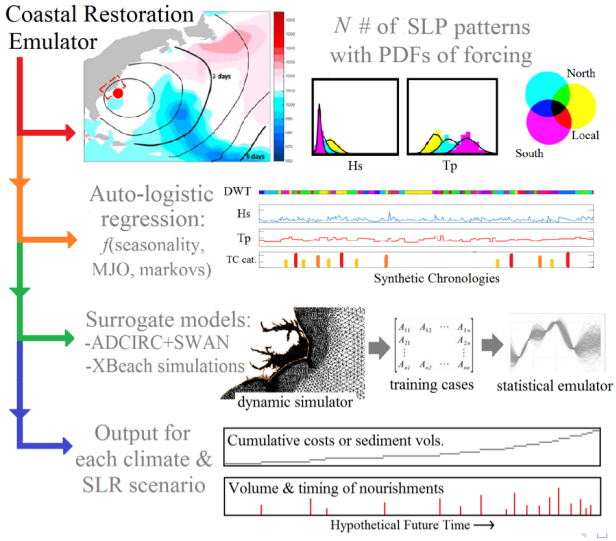
So far, we have advanced in two key aspects of our model development

1. **Identification of storms for the climate emulator** (not shown)
   - Attributes for each weather pattern from historical wave data and storm tracks
   - Isolate storms from the CFSR global sea level pressure fields
   - Categorize based on strength
2. **Connect storm data with beach/dune profiles for first try at surrogate model**
   - Identified 800 real storms from 40 years of WIS hindcast data
   - Sampled to create 150 realistic storms
   - Analyzed surveys of real beach/dune profiles from Nags Head
   - Used PCA to create 150 realistic profiles
   - Created a surrogate model for storm-driven erosion of nourished beaches
   - Good match between statistical/surrogate and process/XBeach models

Interim results are promising!

6. So What?

Conceptual Diagram of the Proposed Emulator



7. Stakeholder Engagement

Working with the Town of Nags Head

Our engagement has been with **David Ryan**, Town Engineer for Nags Head

- Conversations by email, phone call in late Jun
- Very appreciate of his willingness to share survey data, nourishment reports
- Those data have allowed us to jump forward during the last 3 months

Now we need to cycle back to him

- Get his input on the design of the next iteration of our surrogate model
- What other parameters should be included? What outputs will be helpful?

Long-term goal is to open to other communities

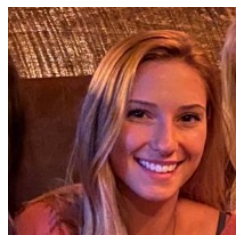
- Support barrier island protection policies

8. Summary Metrics

Student Training and ASBPA Virtual Conference

This project has supported the training of:

- **Dr. Dylan Anderson**, ORISE Fellow at FRF, full-time NCSU post-doc starting Jan
- **Alireza Gharagozlou**, PhD student, nearing graduation in Spring 2021
- **Jessica Gorski**, BS student, nearing graduation in Spring 2021

This project has supported one conference presentation:

- A Gharagozlou, *et al*, *ASBPA 2020 National Coastal Conference*, 13-16 October 2020.

Our future plans will focus in three key aspects of model development

1. **Refine the surrogate model**
   - This first iteration is promising, but it lacks complexity
   - Add parameters to better represent time history of each storm?
   - Add parameters to better represent variability of beach/dune profiles?
   - What are the errors between surrogate and true morphodynamics?
2. **Connect to a climate emulator**
   - Expand the capabilities from Dylan's PhD work
   - Add tropical cyclones and nor'easters
   - Represent sequences of realistic storms
3. **Apply the framework for predictions of long-term erosion**
   - What is the performance of a beach nourishment over a decadal time scale?
   - Can we inform management decisions?

10. USCRP and You

Proud to Participate in USCRP

How can the USCRP help you to advance and/or communicate your research findings?

- Need to better plug into expertise at USCRP member agencies
  - Other datasets to consider?
  - Other models/tools to try?
- Need feedback
  - **Thanks for your attention!**