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Investigation of Surrogate Modeling Applications in Storm Surge Assessment[1]

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HURRICANE SANDY/NOAA

1- Al Kajbaf, A. and Bensi, M., 2020. Application of surrogate models in estimation of storm surge: A comparative assessment. *Applied Soft Computing*, p.106184.

Necessity of Predicting Storm Surge

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- Coastal storm surge hazard assessment has received increased attention due to major hurricane events in the last two decades.

- Robust hazard assessment requires accurate and efficient storm surge prediction models.

Hurricane Katrina/NOAA

Hurricane Jeanne /NOAA

Numerical models for Storm Surge Prediction

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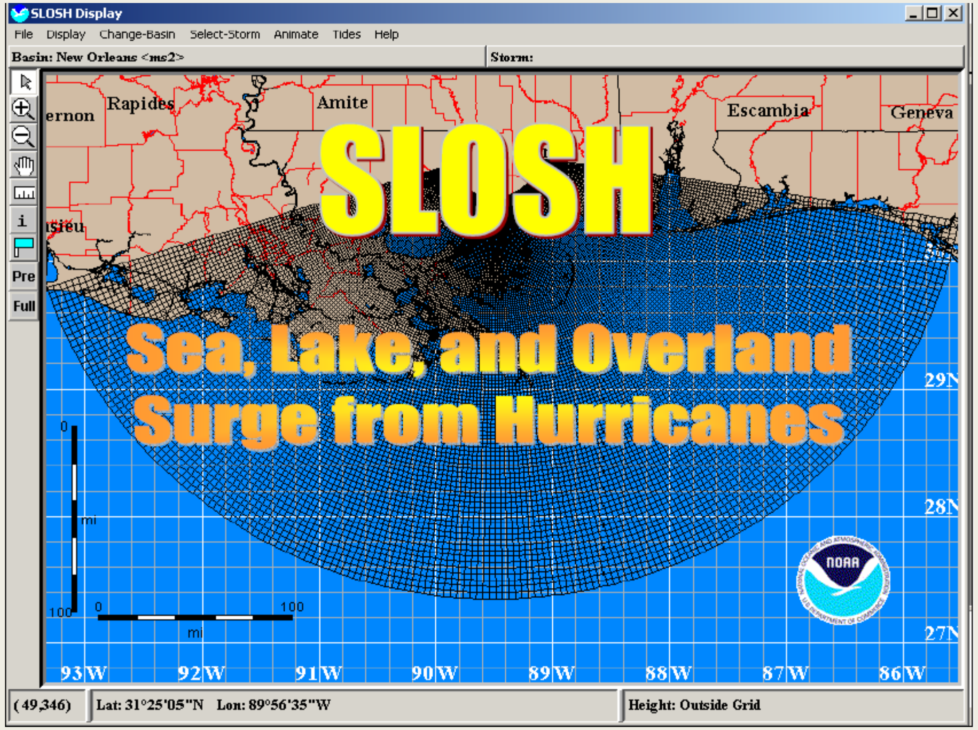
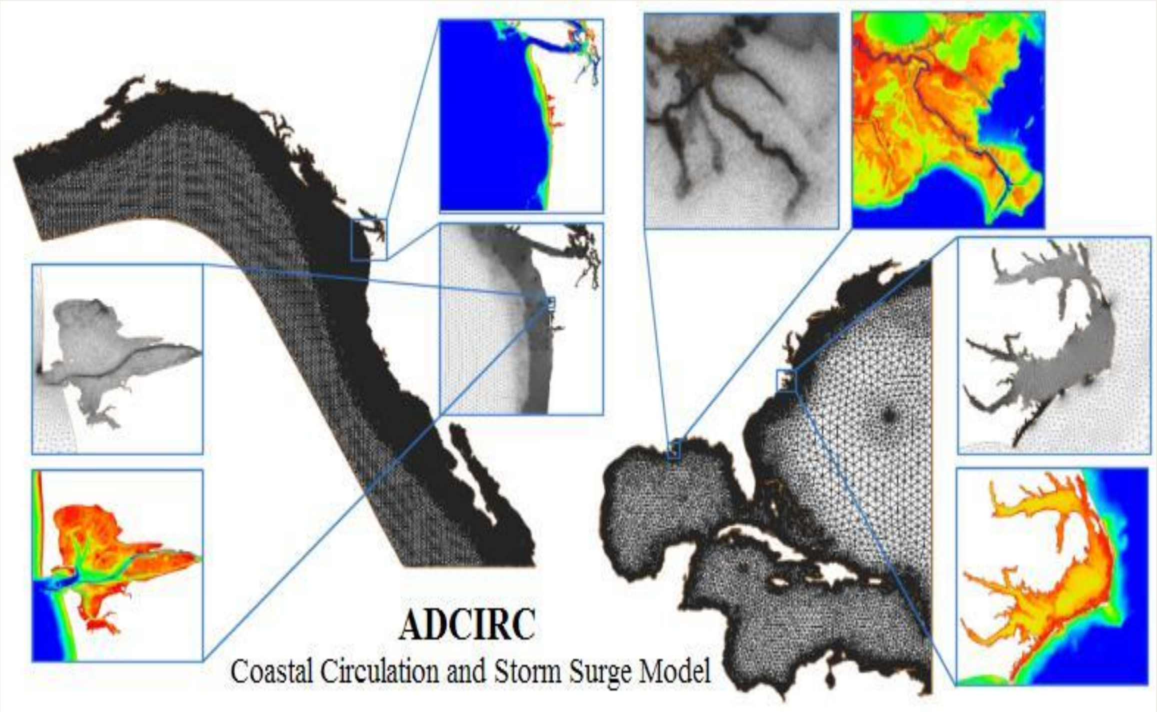
FEMA, U., 2003. USZ Army Corps of Engineers (2003)"SLOSH Display Training





US Army Engineer Research and development Center, USACE

- ✓ Computationally efficient and has been used for real-time storm surge forecasting.
- × Accuracy - generally within ±20% of peak storm surge.

- ✓ High fidelity finite element hydrodynamic model that can be setup at a fine spatial resolution to perform accurate simulation.
- × Computationally intensive to run.

Surrogate models for Storm Surge Prediction

- The computational expense associated with numerical models have encouraged the development of surrogate modeling methods.
- These methods provide a simplified functional relationship between input and response.
- The intent in utilizing these methods is to preserve the accuracy of the numerical model while providing a computational efficiency advantage.
- Surrogate modeling approaches that have been used for storm surge prediction include Artificial Neural Network (ANN), Support Vector Regression (SVR), and Gaussian Process Regression (GPR).

Gaps in Current State of Practice

- Most studies have only explored one method at a time and no study has compared all three methods.
- These studies evaluate the performance of the modeling approaches through aggregated error metrics.
- These aggregated metrics give incomplete and potentially optimistic measures of the performance of surrogate models.
- Aggregated metrics do not yield information about the error structure and its relationship to model parameters.

Purpose of this Study

- Develop and compare ANN-, GPR-, and SVR-based surrogate models for predicting peak storm surge as a function of hurricane parameters using synthetic data.

- Providing a comprehensive framework for comparison and assessment of the performance of surrogate models through:

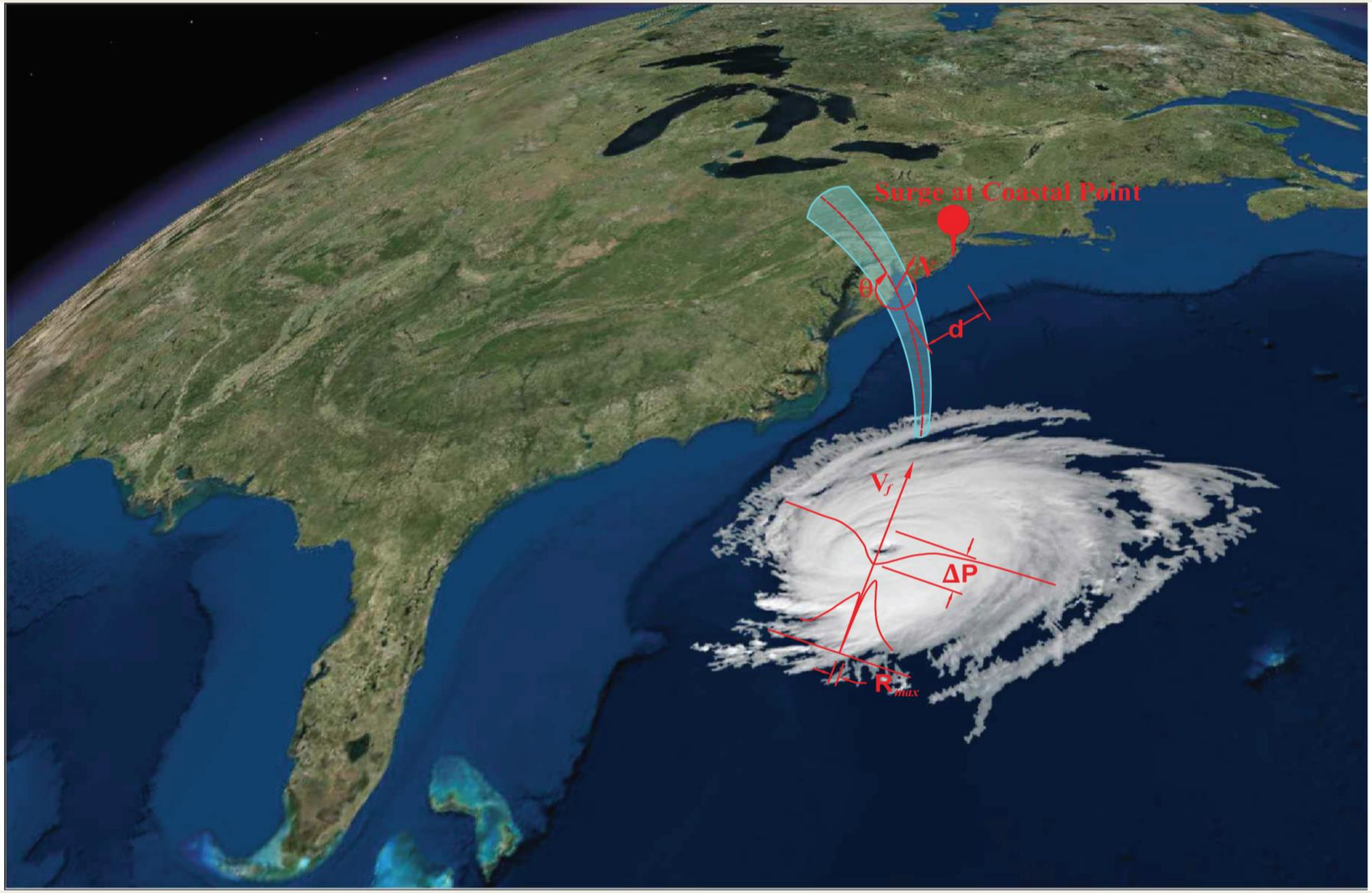
    - Investigating the stability of performance across training sample sizes.

    - Identifying systematic trends in errors.

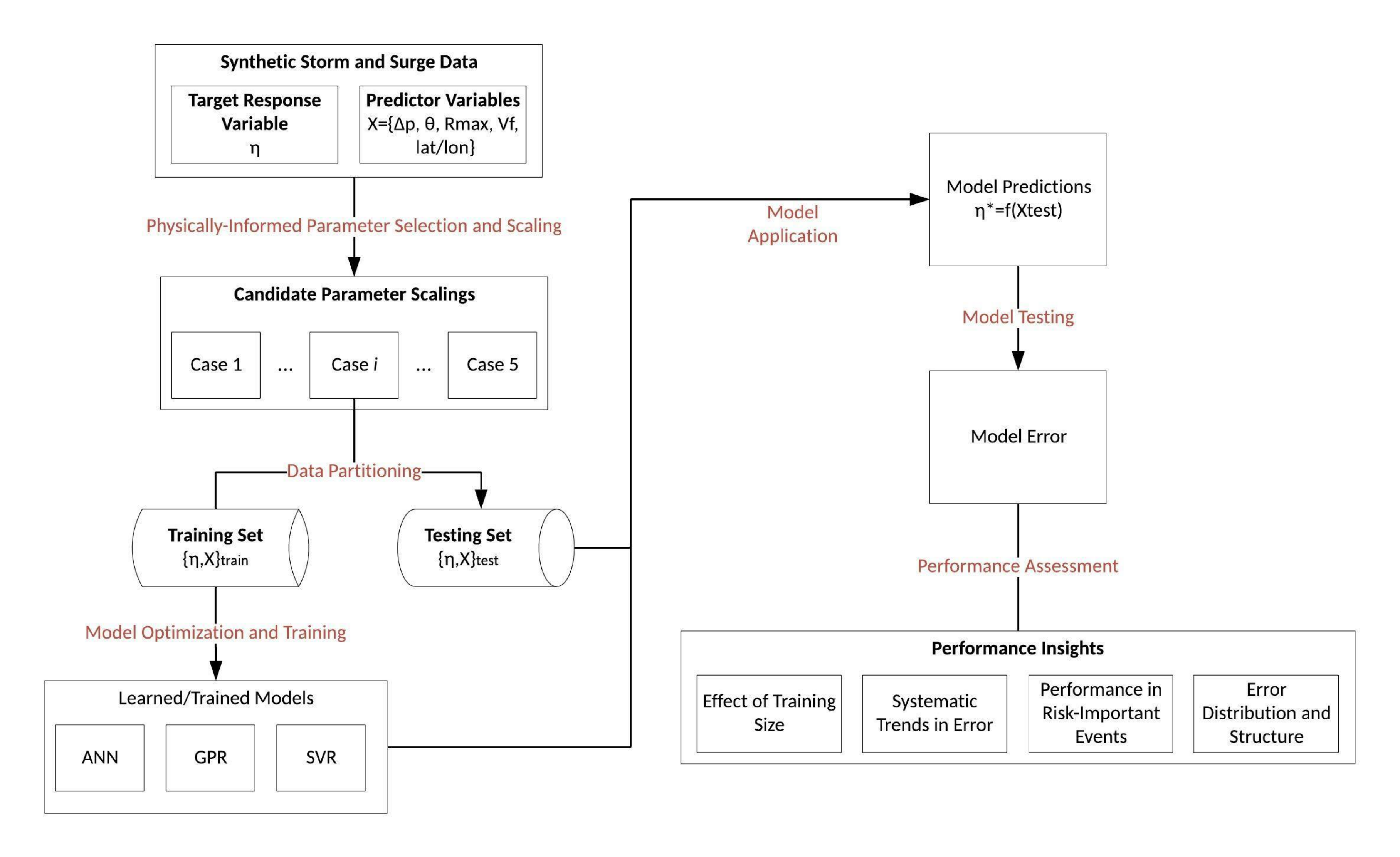
    - Assessing performance in predicting large target response quantities.

    - Characterizing the distribution of error.

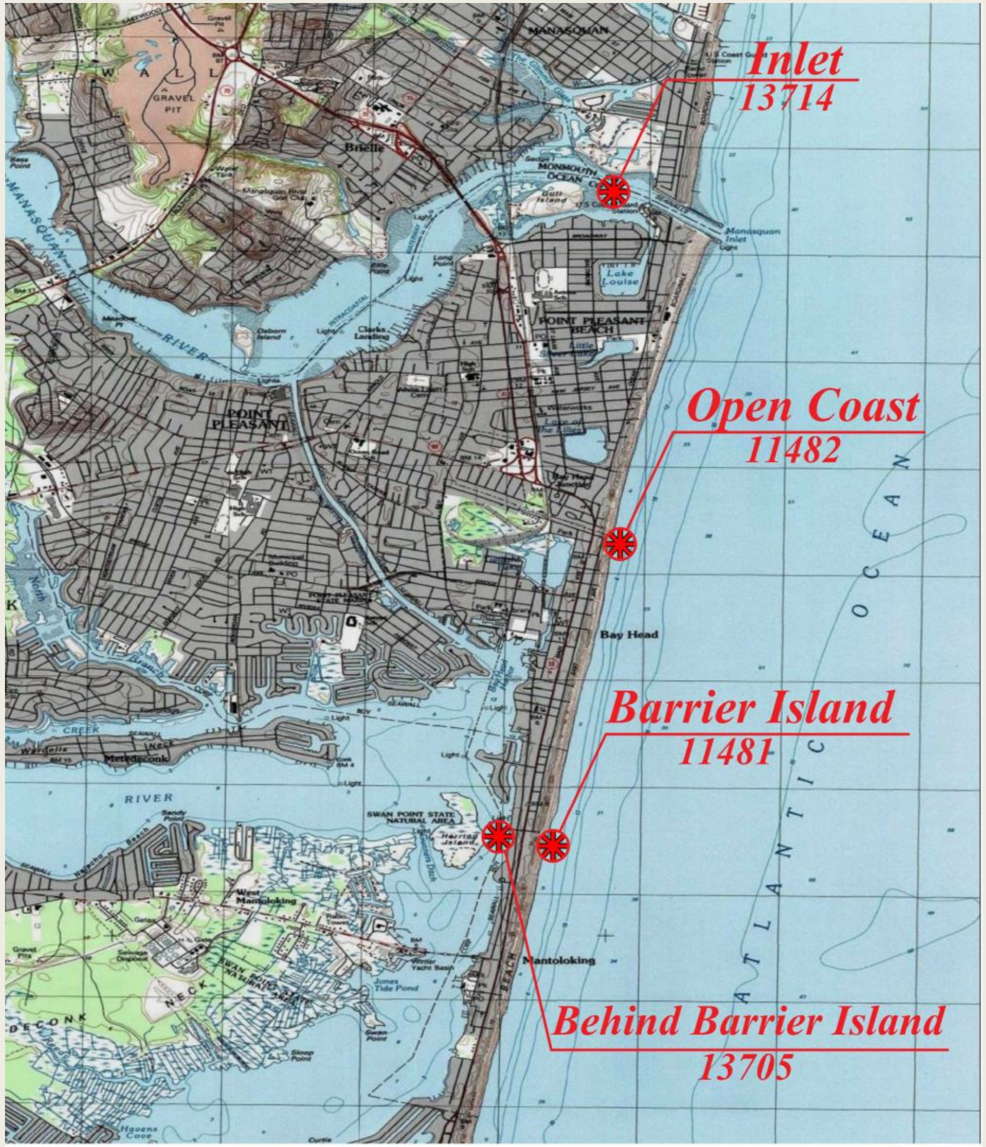
Storm parameterization from NACCS database



Study Framework

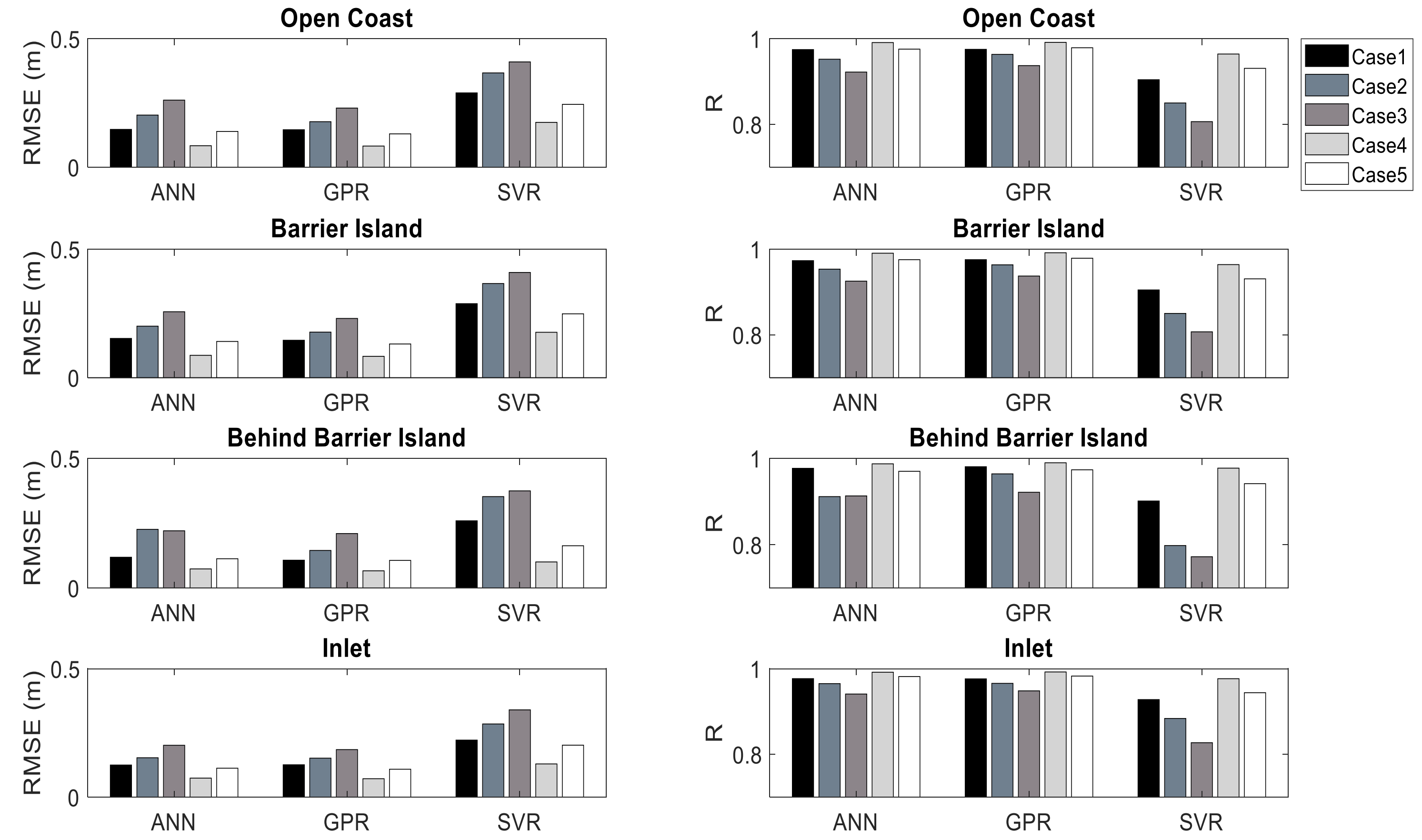


Location of points used in developing Models



Different Combinations of Input Parameters

Case	Input Parameter	Target Response
1	$\Delta P, R_{max}, V_f, \theta, lat_{ref}, lon_{ref}$	η_{NM}
2	$\Delta P, R_{max}, V_f, \theta, d$	η_{NM}
3*	$\Delta P, d/R_{max}, V_f, \theta$	η_{NM}
4*	$R_{max}, V_f, \theta, lat_{ref}, lon_{ref}$	$\eta_{NM}/\Delta P$
5*	$\frac{d}{R_{max}}, V_f, \theta$	$\eta_{NM}/\Delta P$



* J.L. Irish, D.T. Resio, M.A. Cialone, A surge response function approach to coastal hazard assessment. Part 2: Quantification of spatial attributes of response functions, Natural Hazards. 51 (2009) 183–205.

Error of Prediction and Surge Height vs. Storm Index Number

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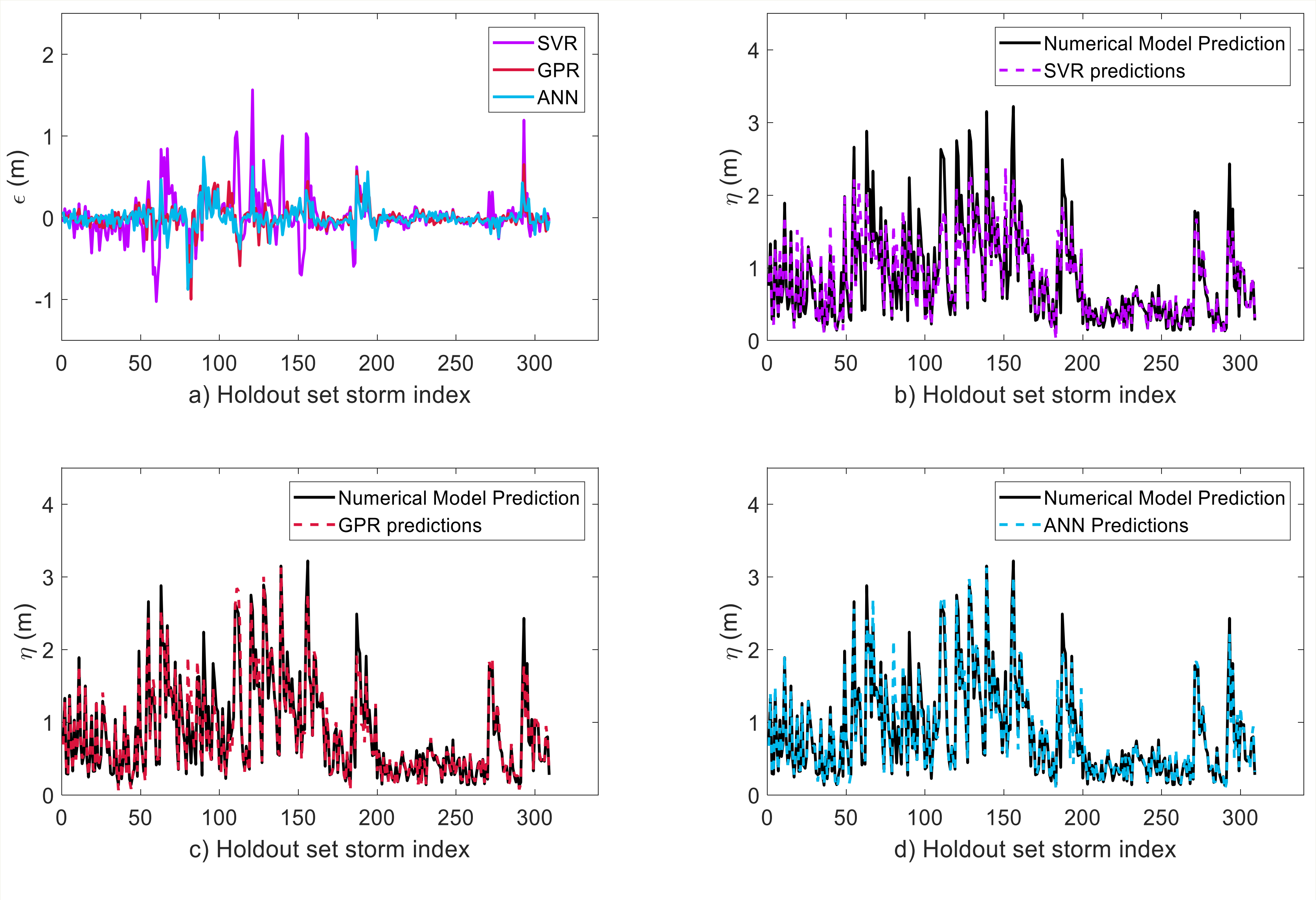
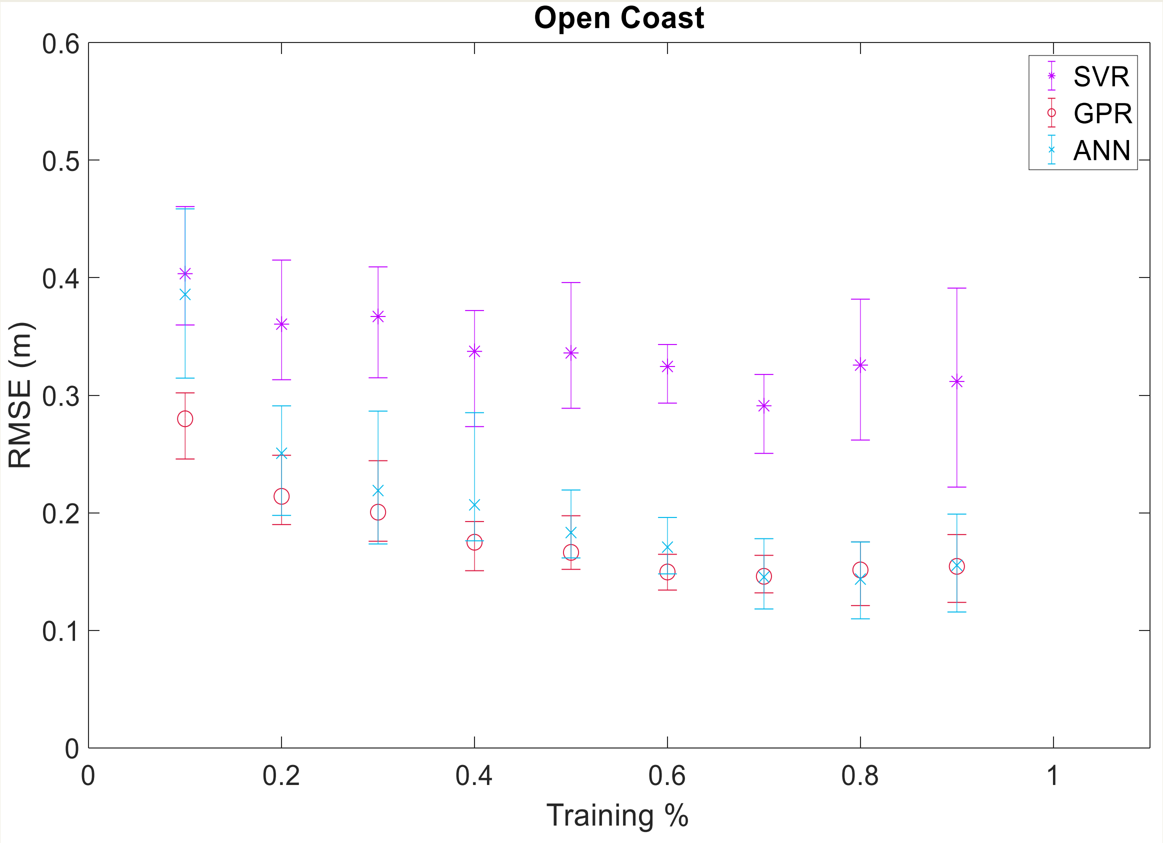
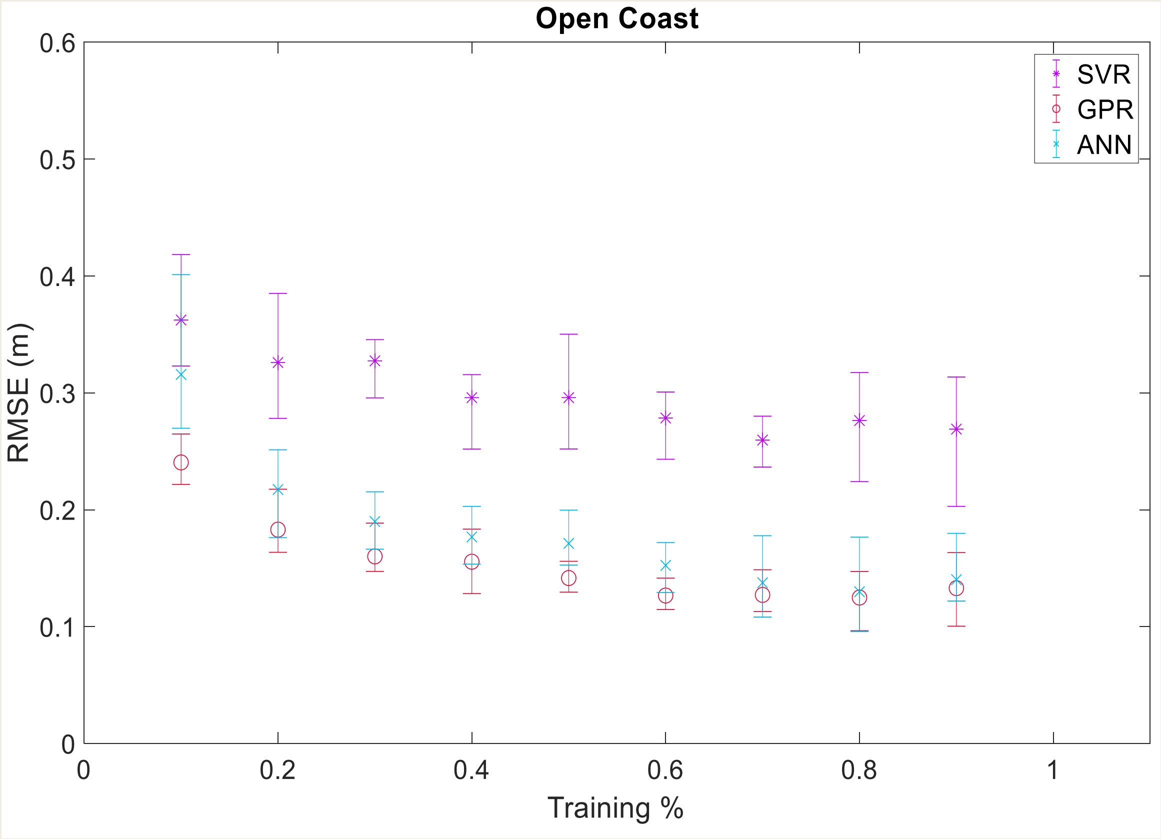


Effects of Training/Testing Size on Model Performance

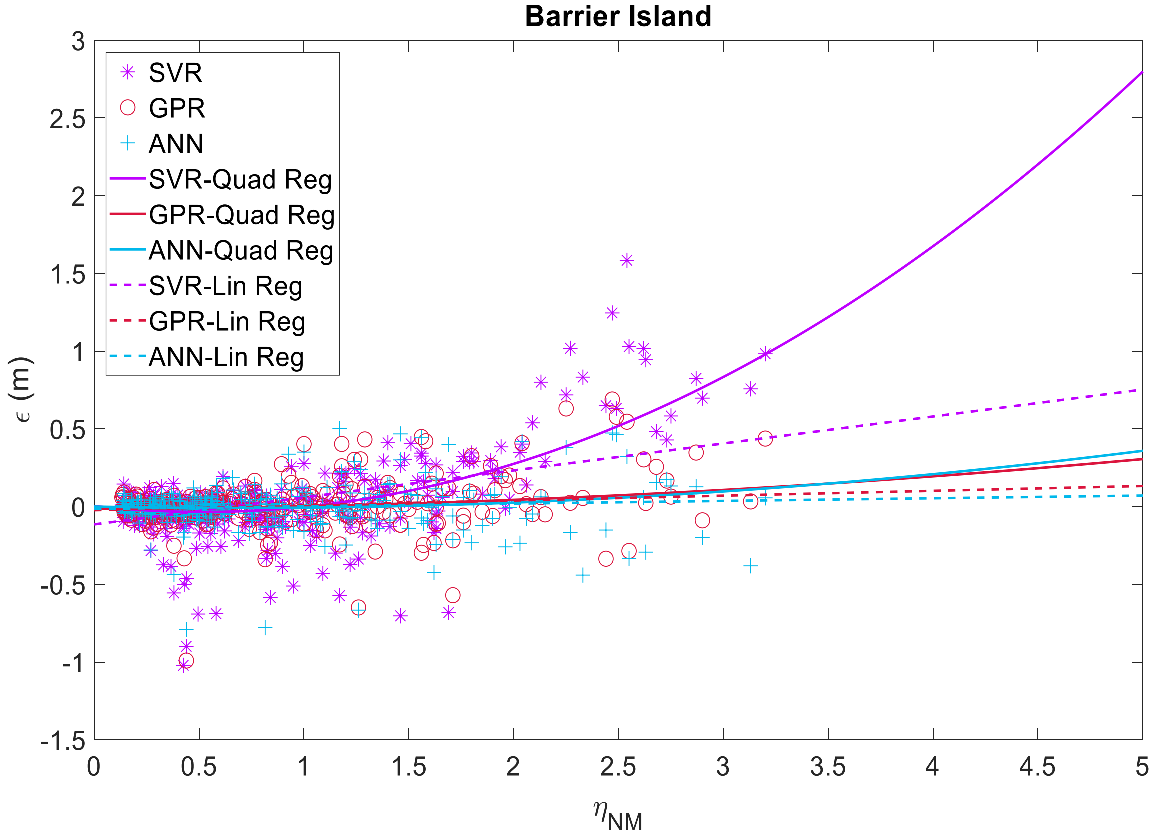




Case 1

Case 4

Systematic Trends in Error



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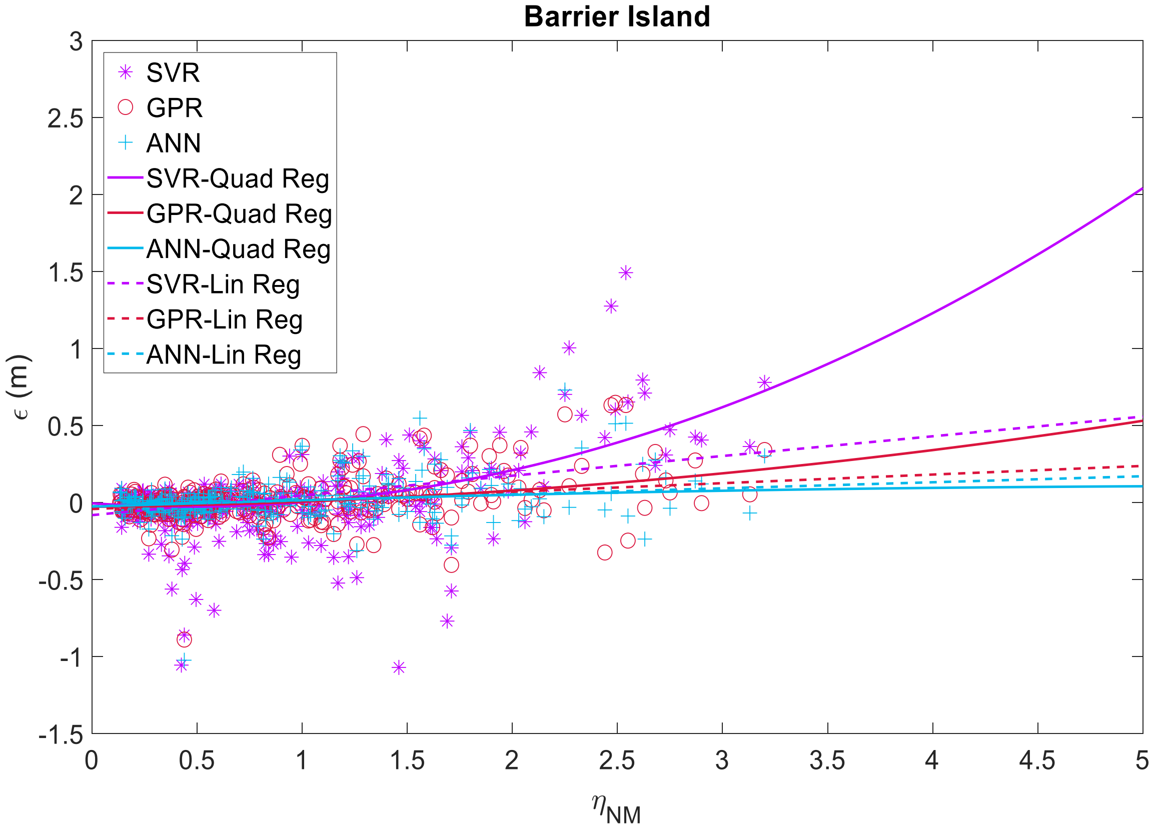
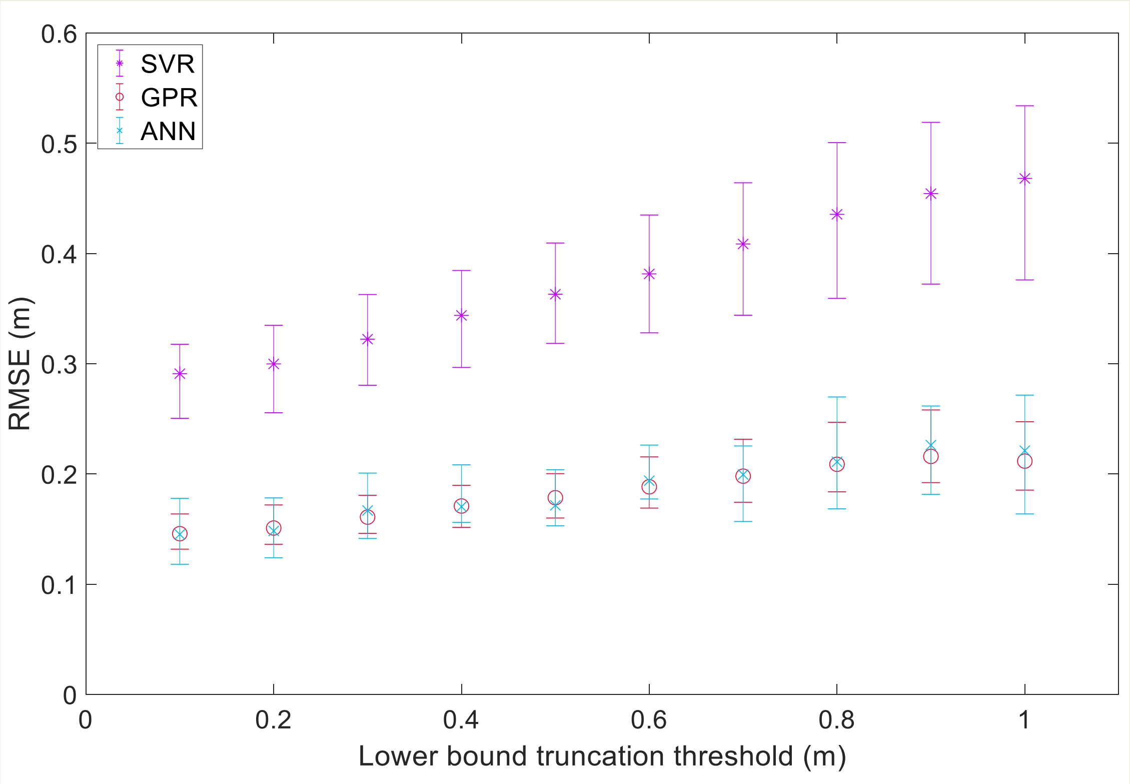
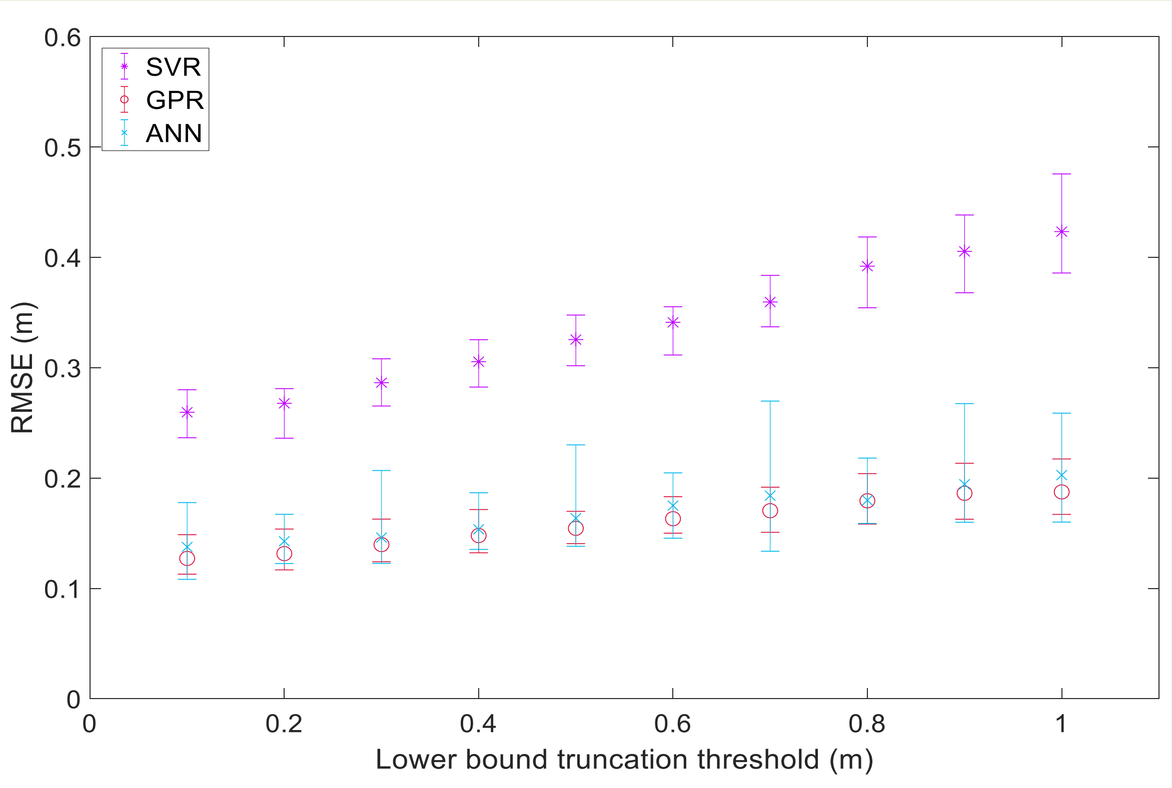


Case 4

Truncation before Testing





Case 1

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Truncation before Testing

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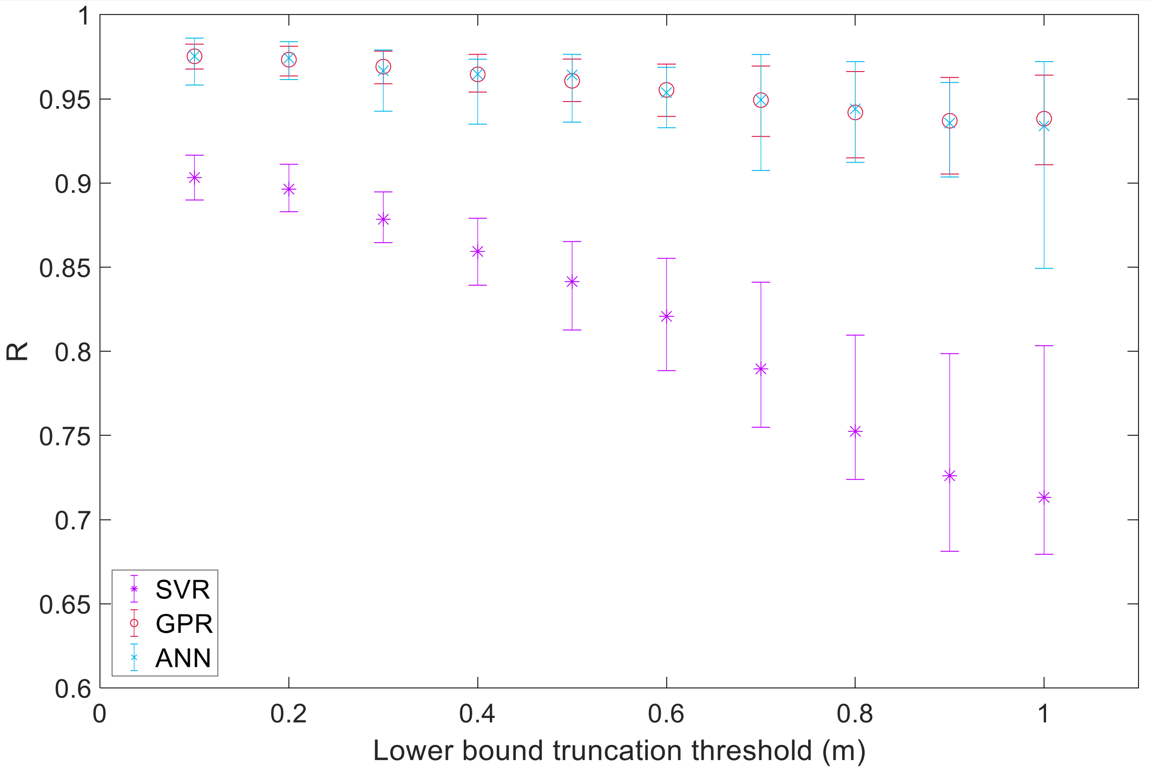

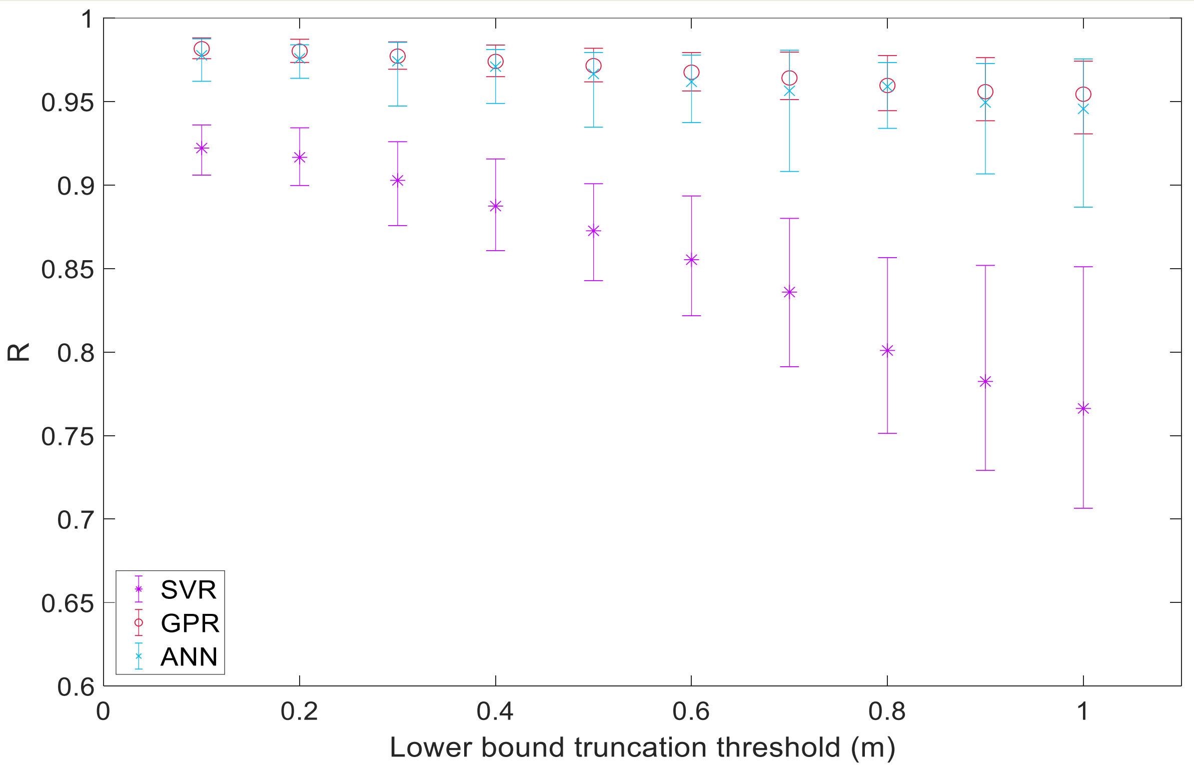

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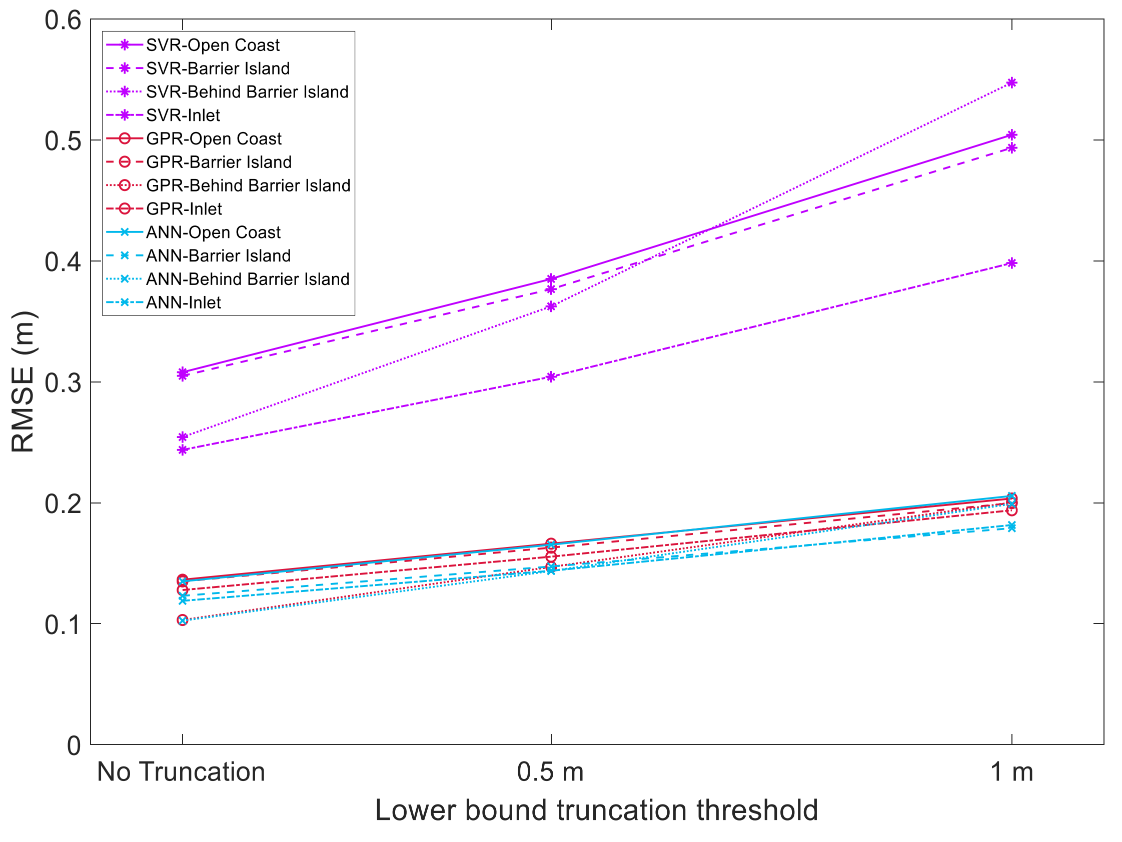

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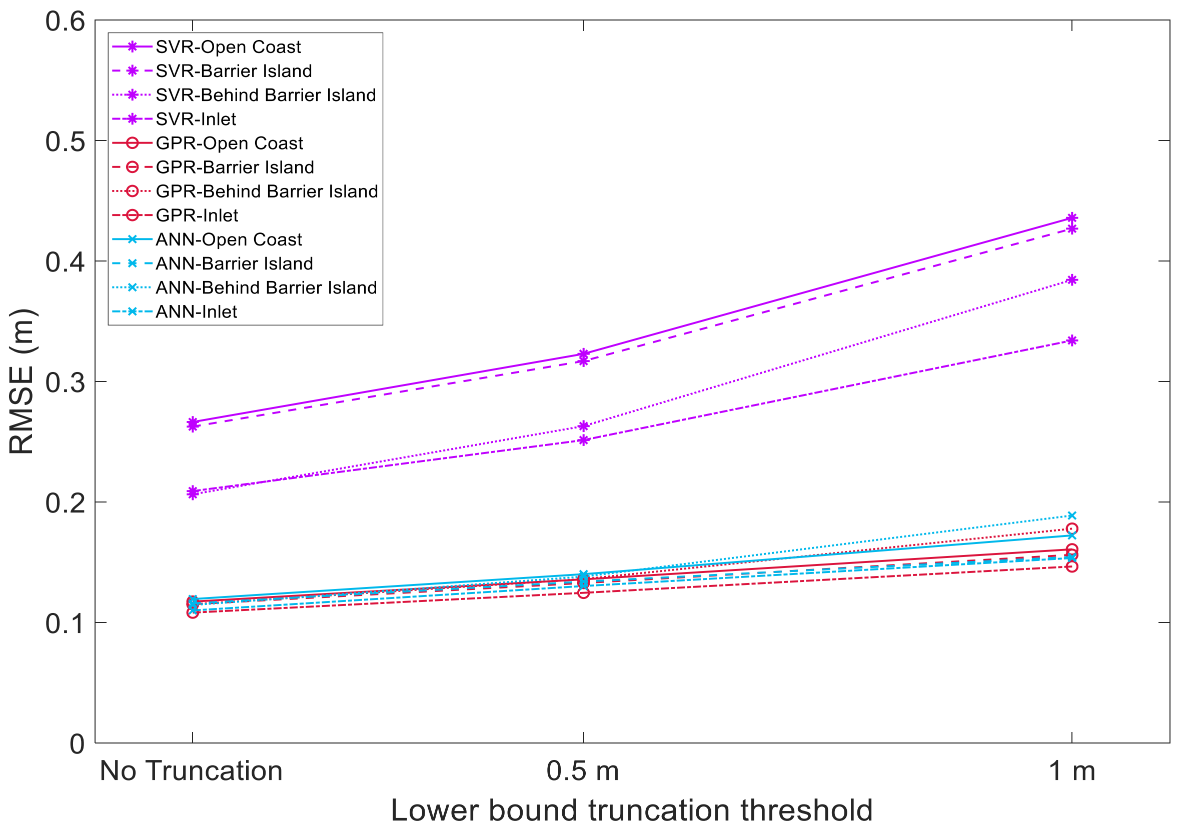

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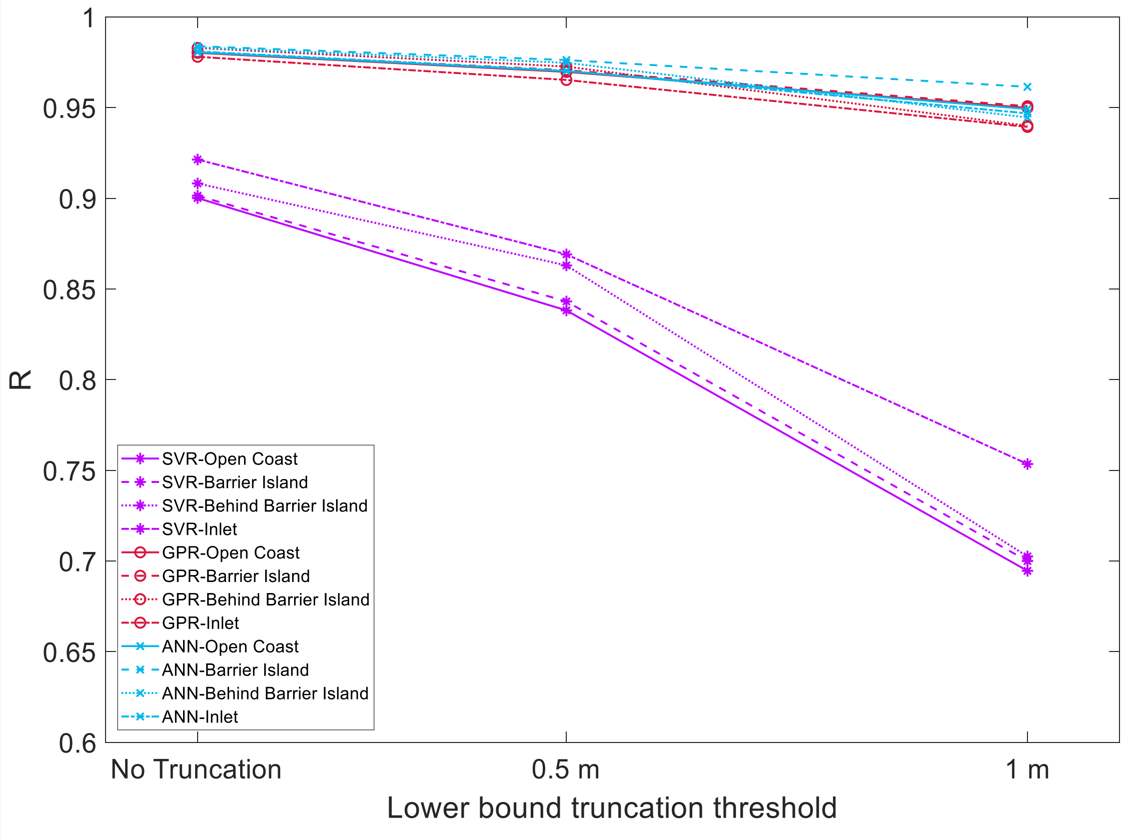

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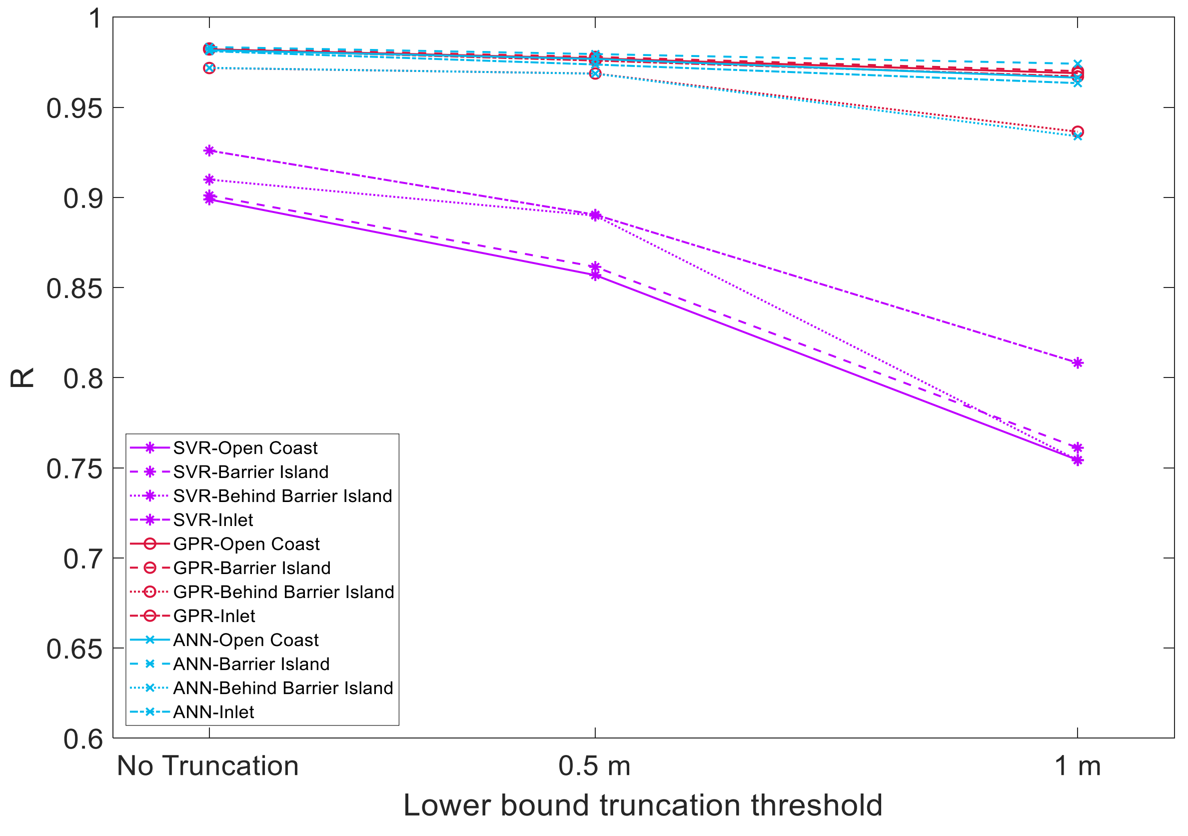

Case 4

Truncation before Training

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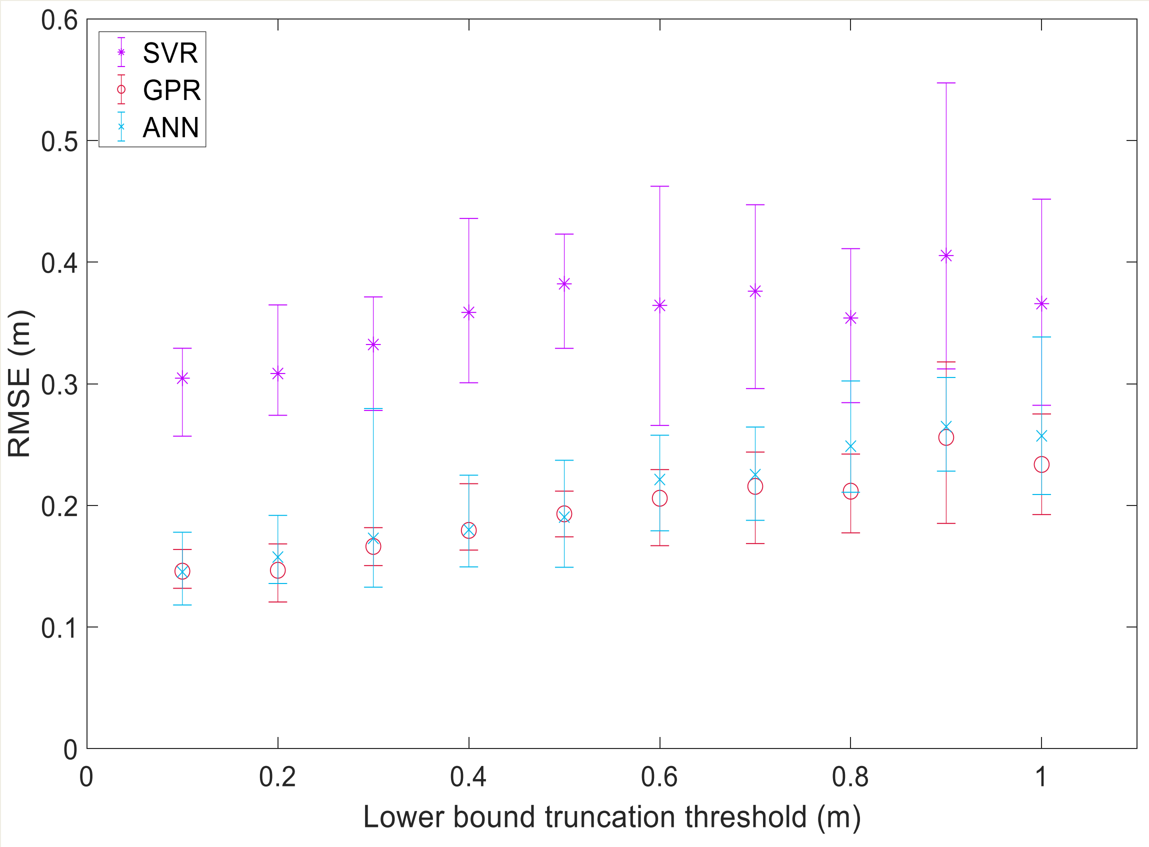

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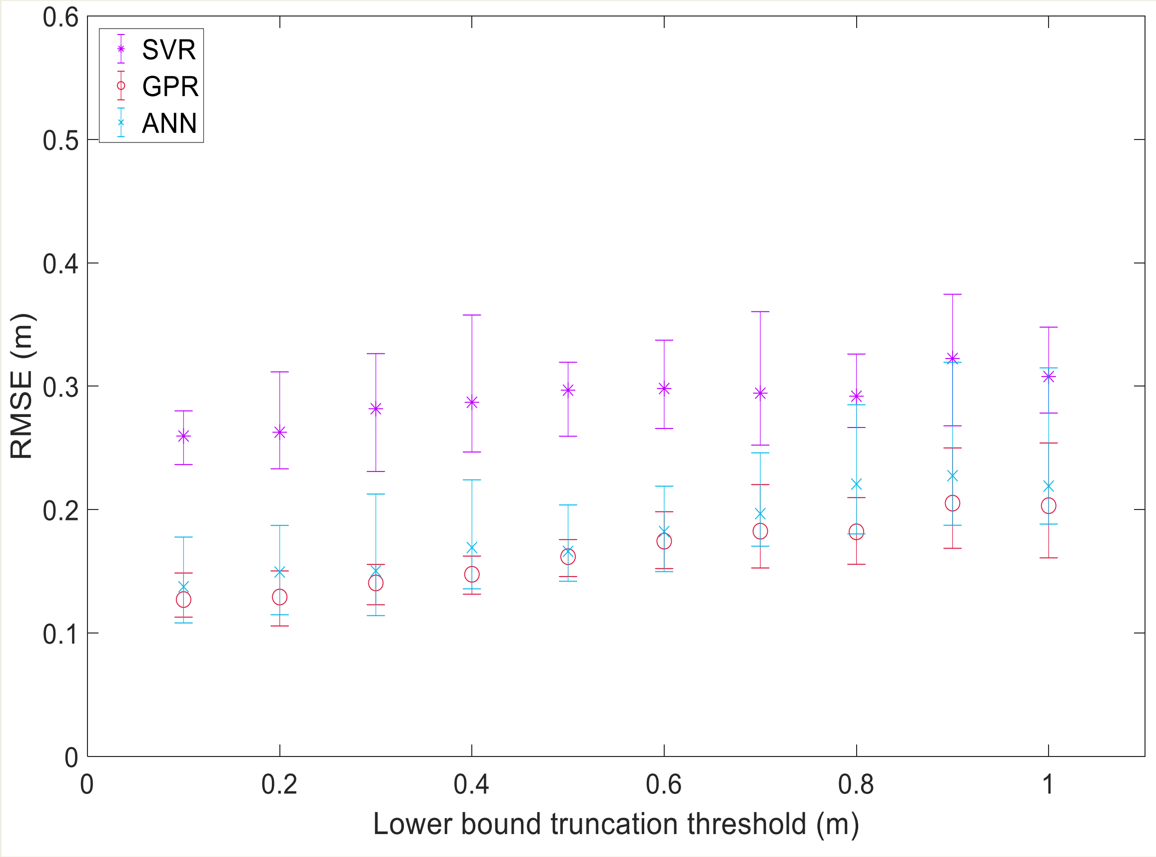

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Truncation before Training

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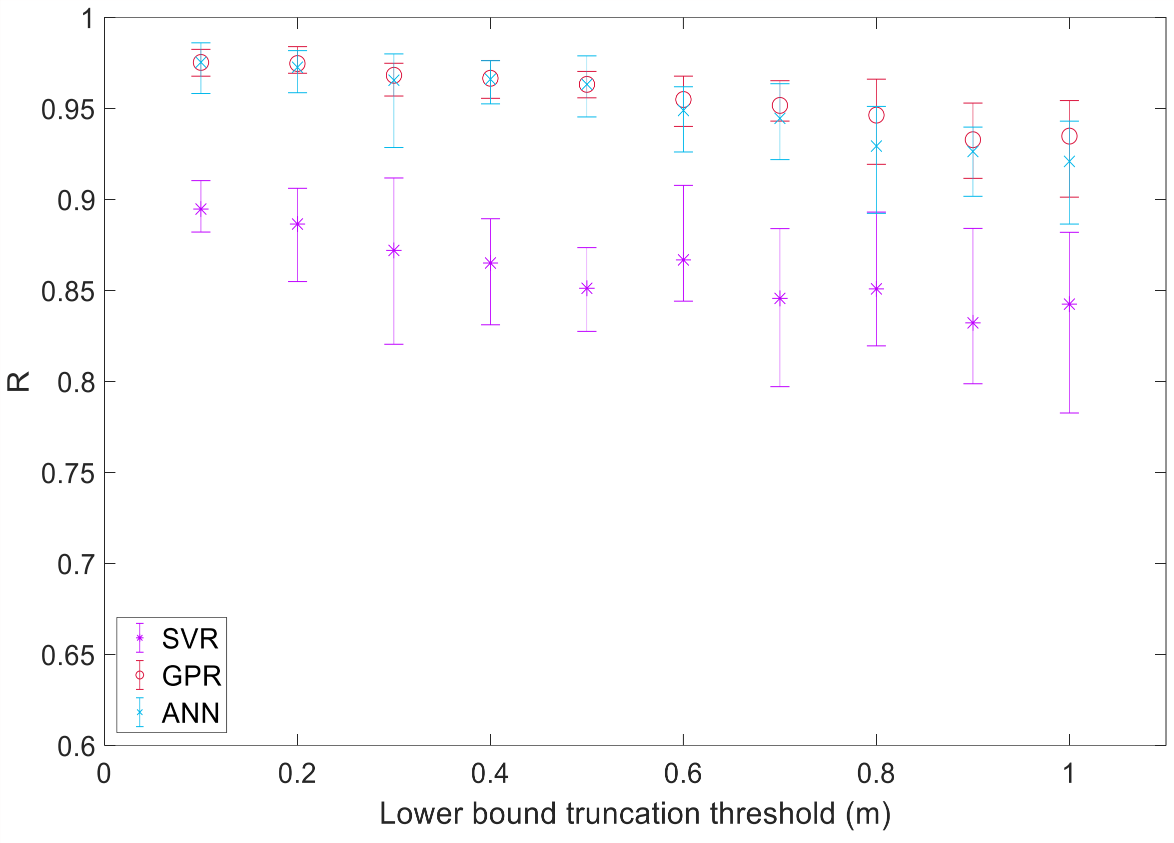
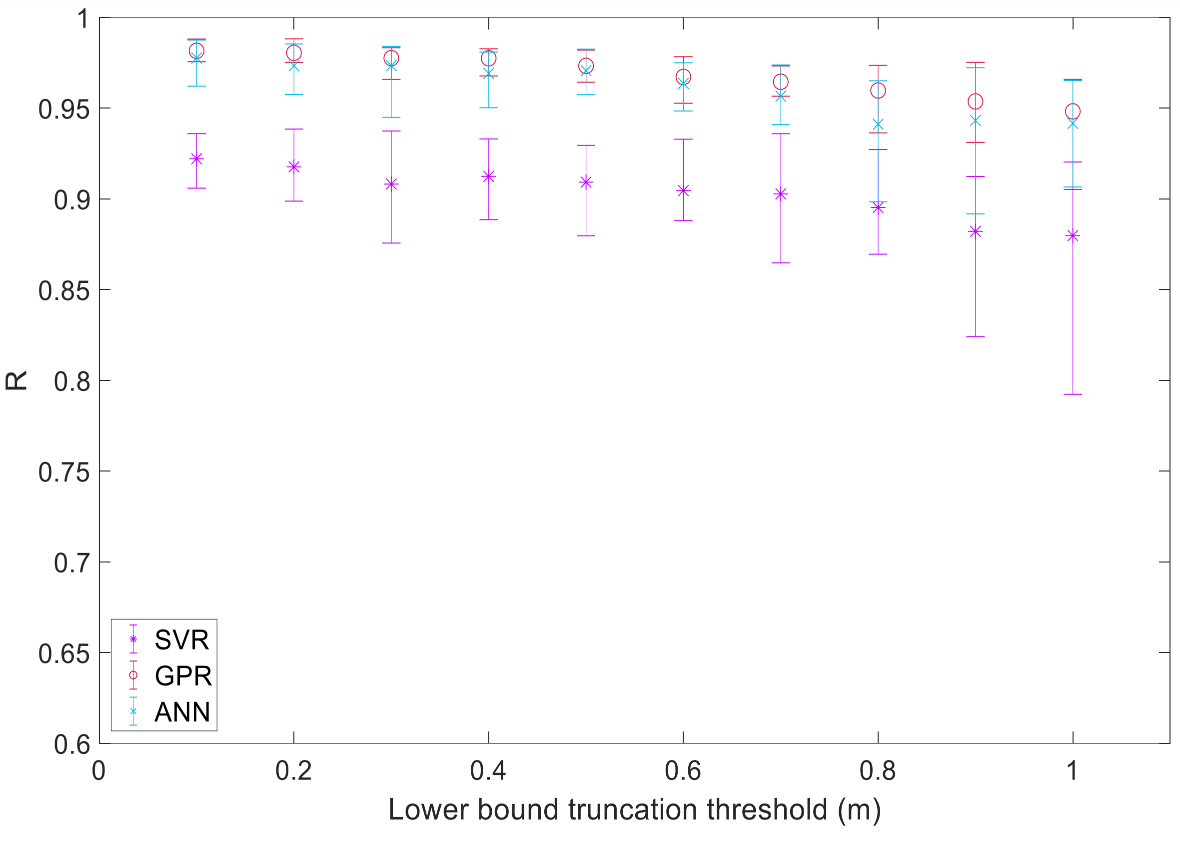
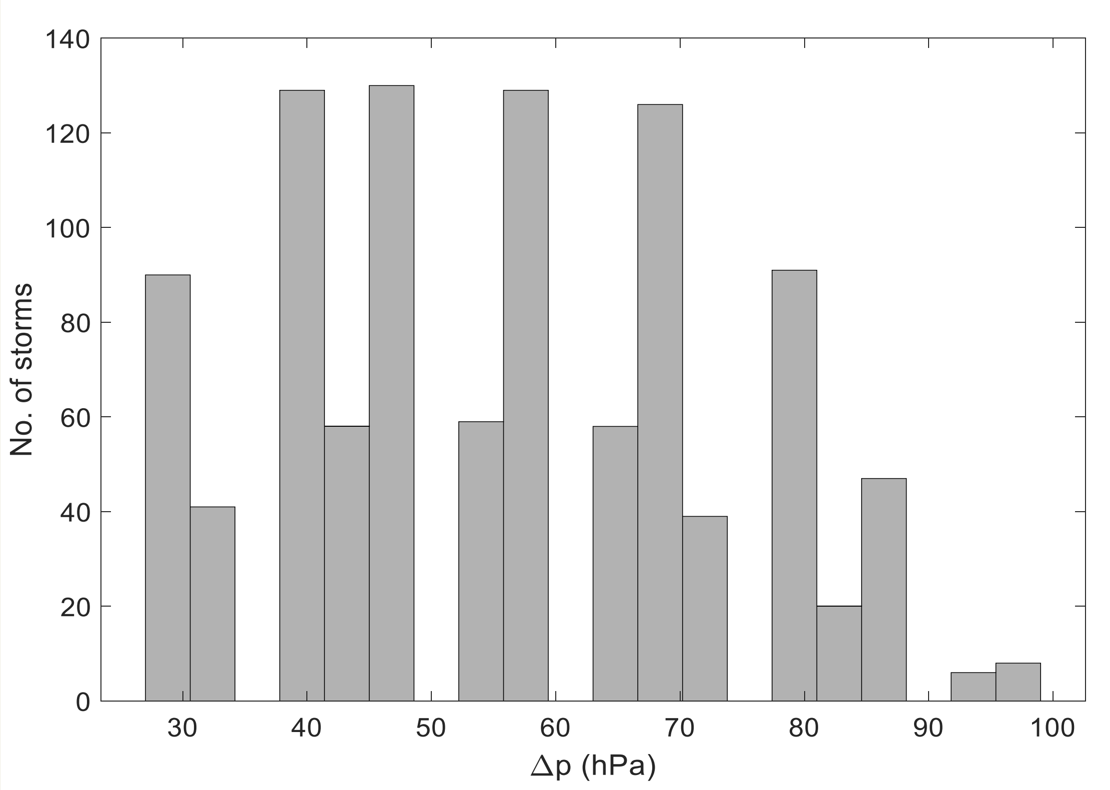


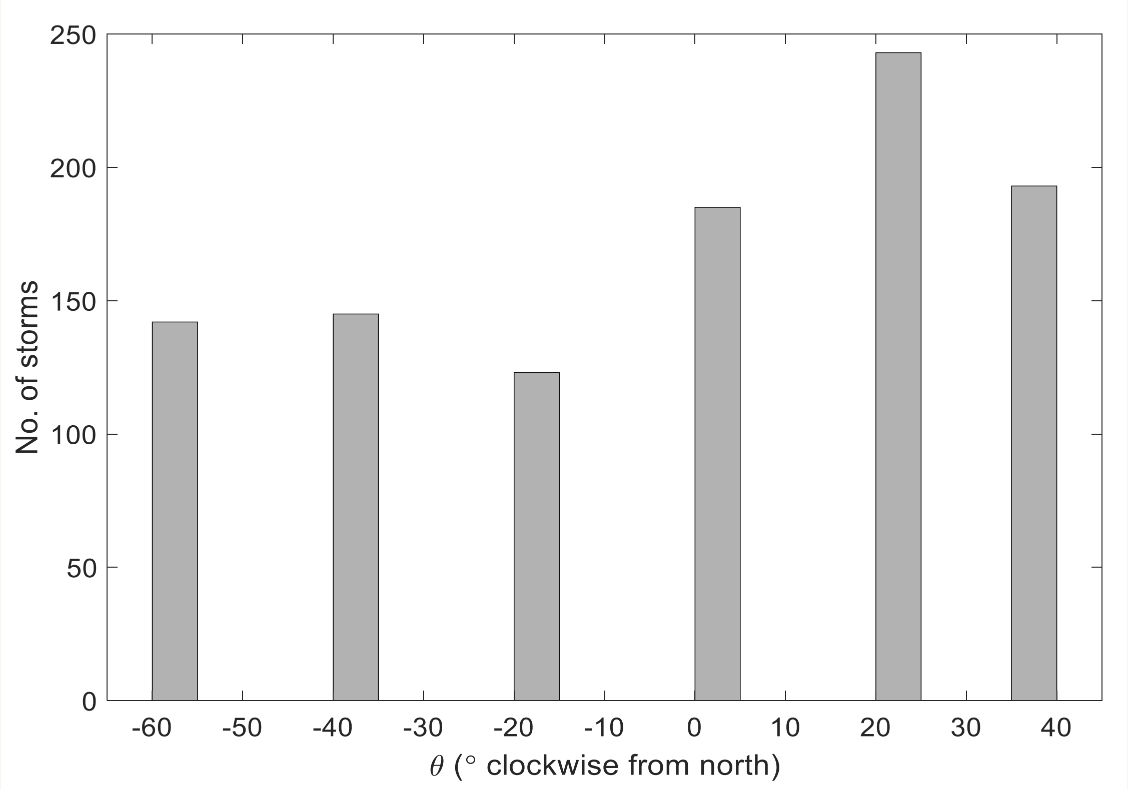


Case 1

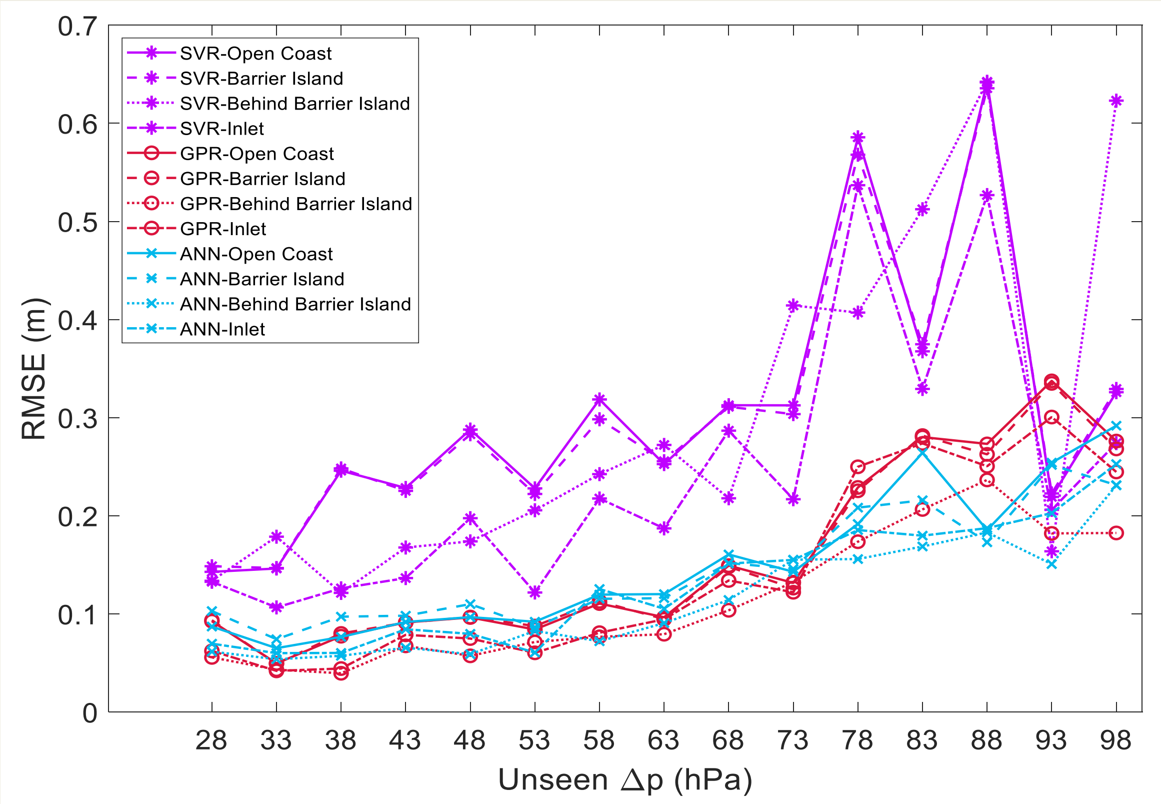
Case 4

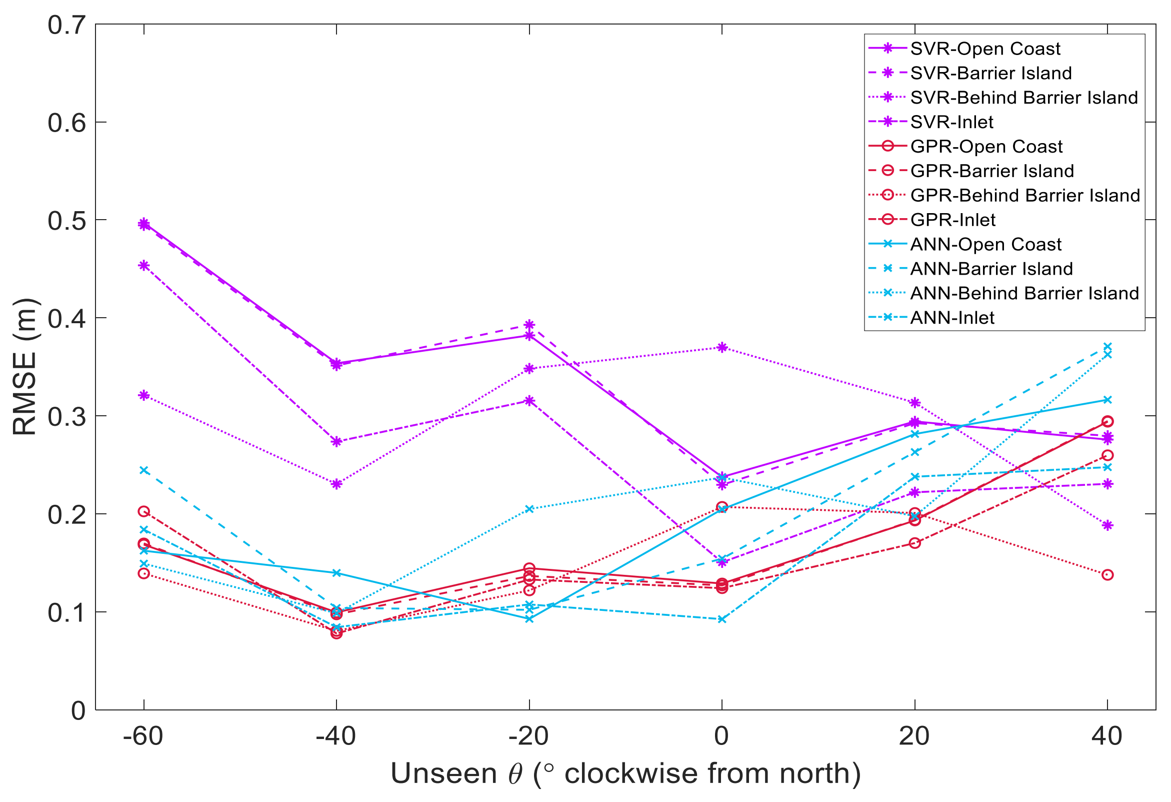
Predicting Surge at Unseen Storm Parameters



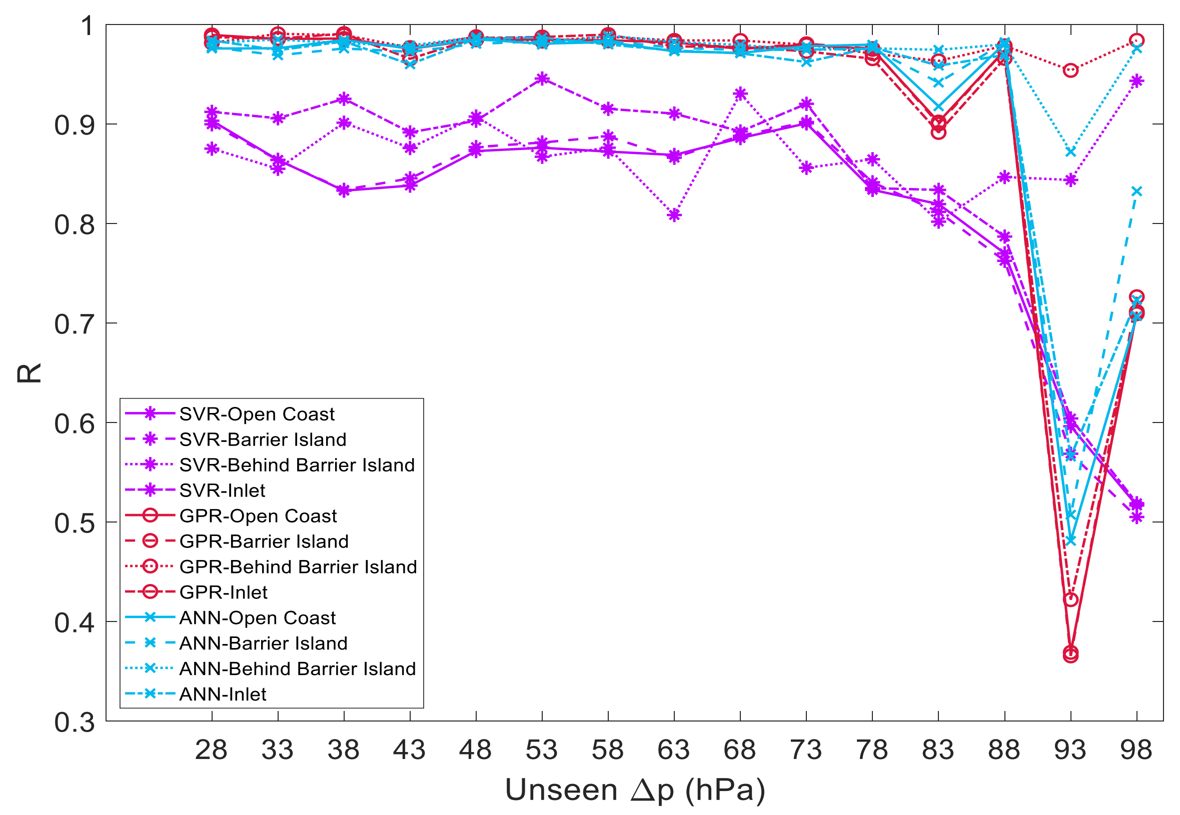


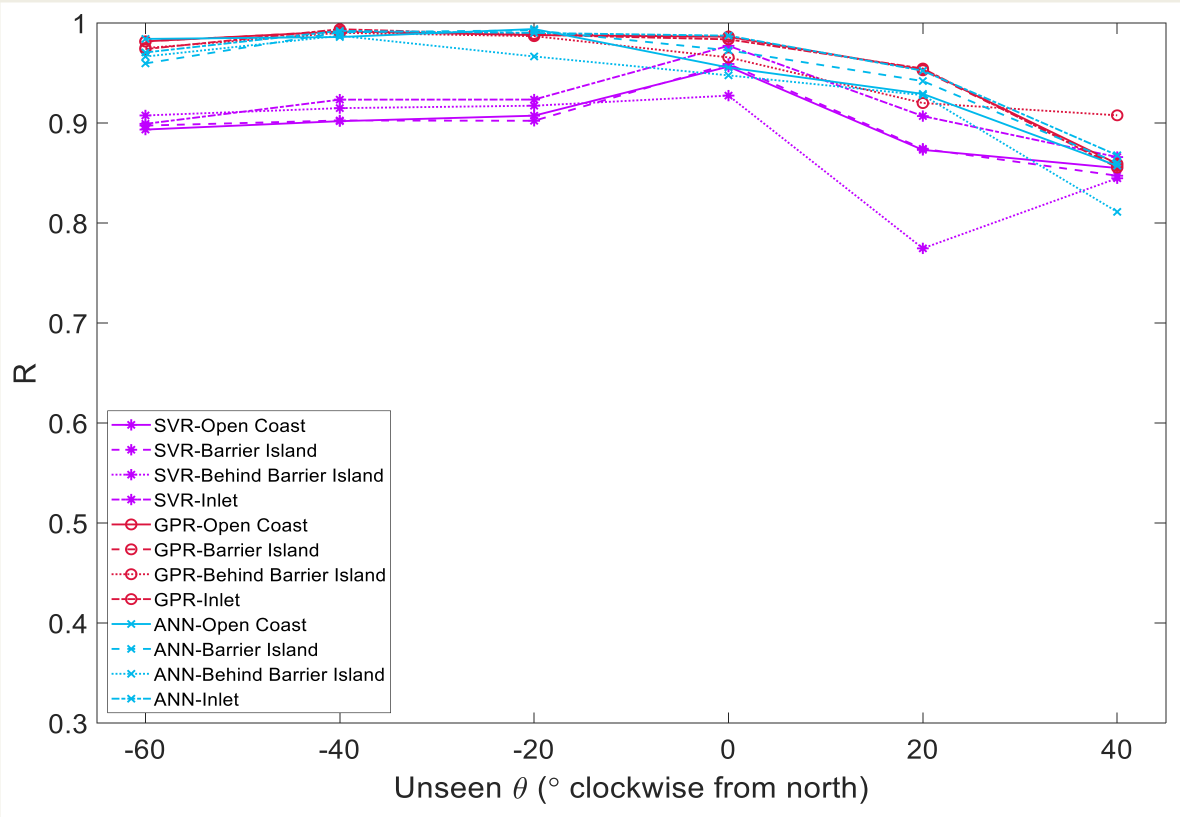
Predicting Surge at Unseen Storm Parameters



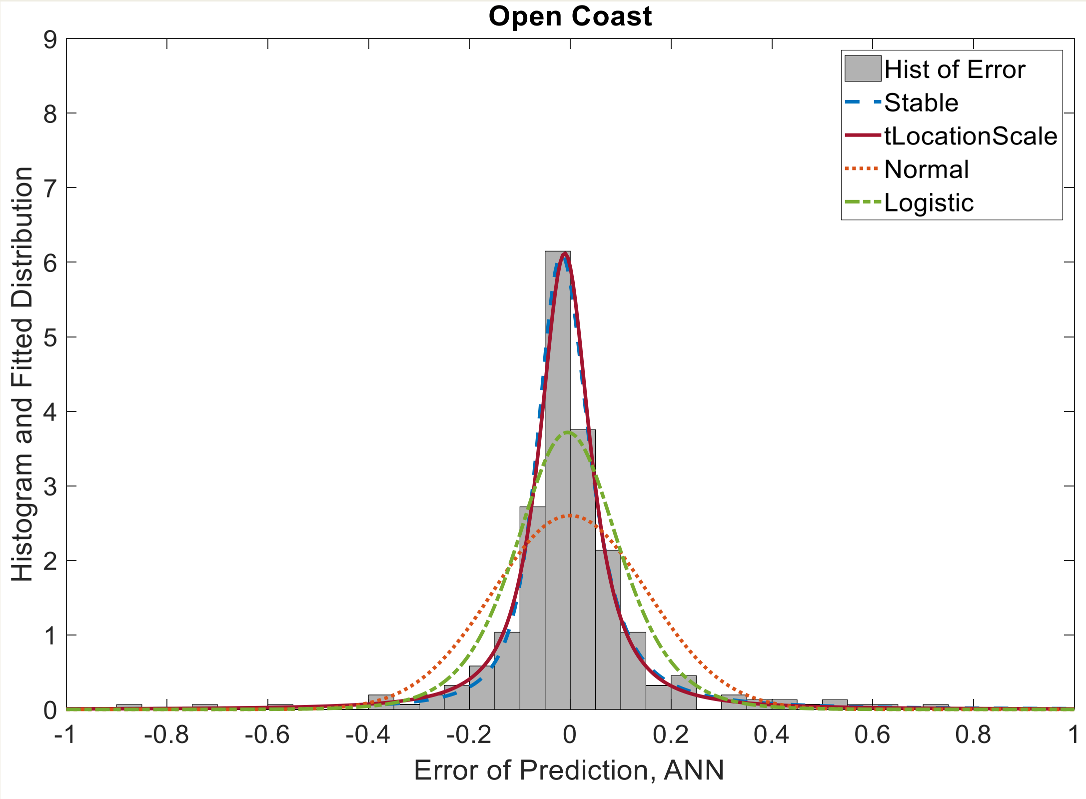


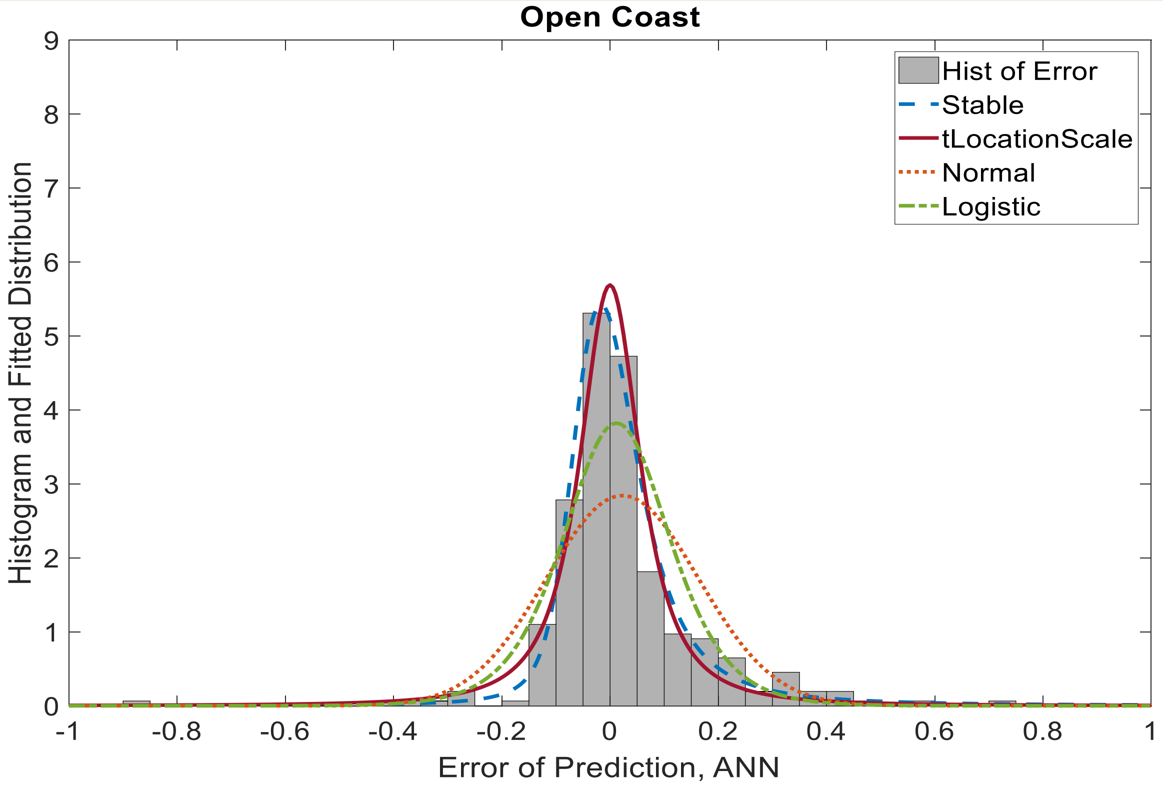
Predicting Surge at Unseen Storm Parameters





Distribution of Error





Case 1

Case 4

Results Summary

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- Improvements to surrogate model performance may be achieved through physically informed scaling of certain quantities.

- The accuracy of the tested surrogate models may be significantly affected by the target surge height.

- The size of the dataset available for training affects performance differently across the modeling methods considered.

- Results suggest that the inclusion of many surge heights close to zero brings down the aggregated error metrics and may give an optimistic perspective regarding performance of surrogate models.

- The distribution of error is not necessarily Normal and needs to be fully characterized to have a more completed understanding of errors that can be used in hazard curve development and risk mitigation studies.

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