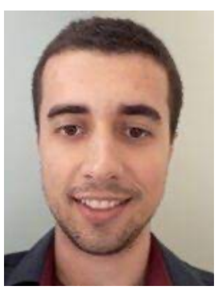
North Carolina Renewable Ocean Energy Program

Assessing the Risk of Hurricane Damage to Marine Hydrokinetic Devices

Anderson de Queiroz, Mohammed Gabr, and Joseph DeCarolis
Neda Jamaleddin, and Victor Faria



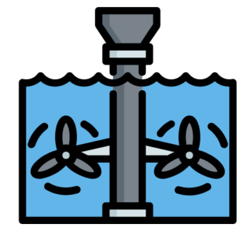


May 11th 2022

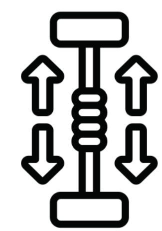
Introduction

- The US government has recently announced a 30 GW target for offshore wind energy deployment by 2030 and 110 GW by 2050 (WH, 2022). More locally, NC has defined as its objective to **reduce by 70%** its CO_2 emissions by 2030 and reach **carbon neutrality by 2050** (GANC, 2021).

- In the future marine hydrokinetic devices can contribute to a more **diversified** offshore renewable energy portfolio, helping to **reduce energy variability and improving system security** (Li et al, 2017; Faria et al, 2022). However, the **vulnerability** of these technologies to extreme events such as hurricanes has not been thoroughly studied.

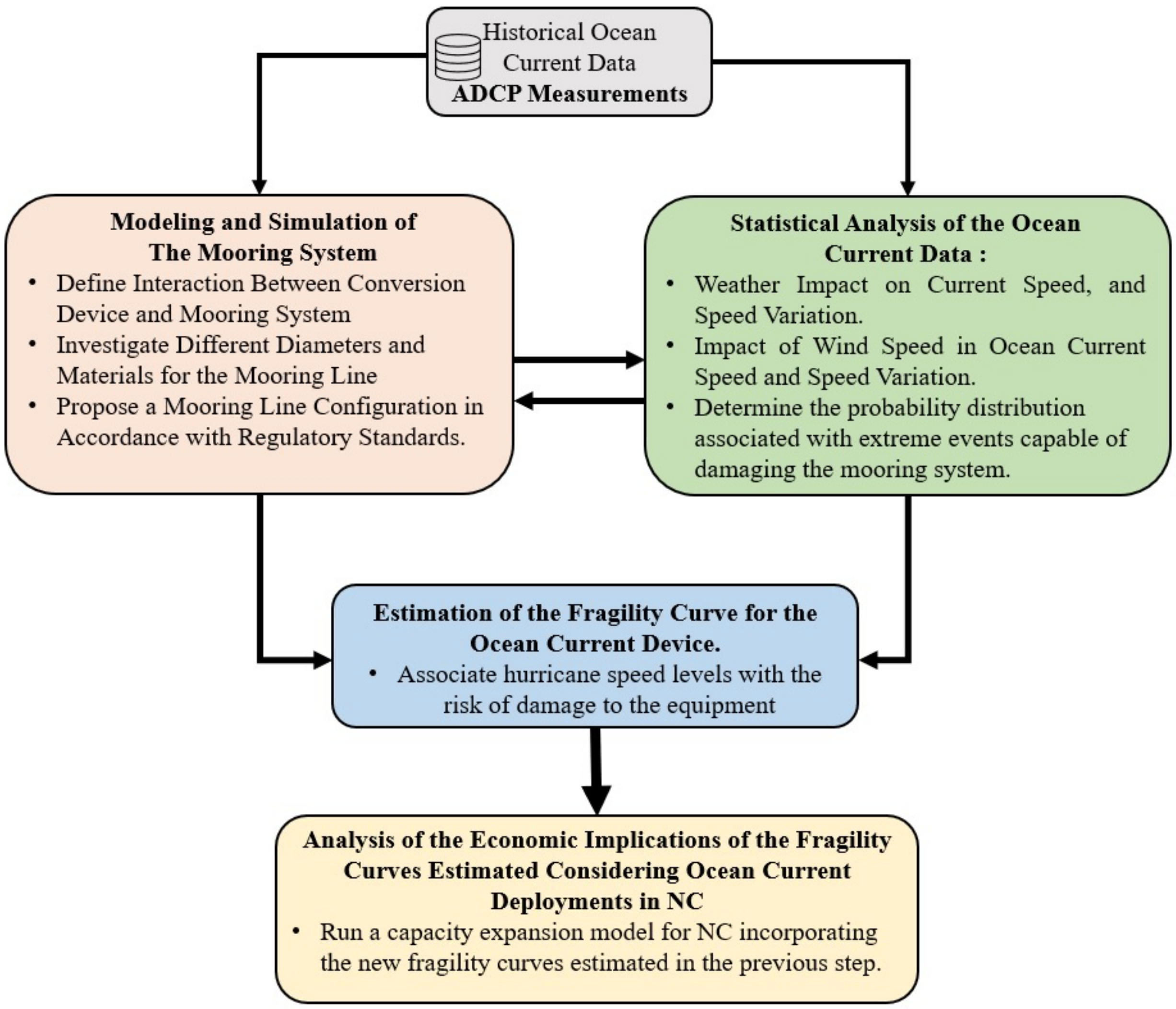


- This research proposes the use of **data analytics** and mechanical model simulations using the **Ansys-AQWA software** (ANSYS, 2013) to construct **fragility curve** estimates for ocean current devices, more specifically, their **mooring system**.



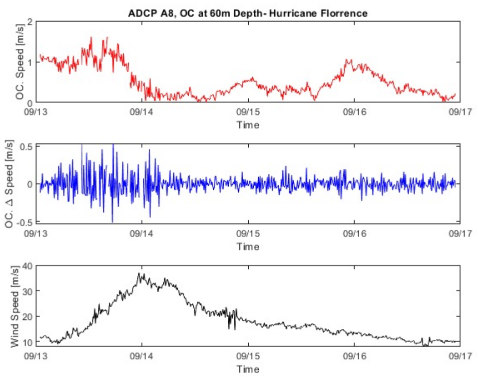
- These fragility curves associate **hurricane speed levels with the risk of damage to the equipment** and will be incorporated into a capacity expansion model for the NC energy system (DeCarolis et al, 2022) to assess how the economics of this device affects its development in the NC power grid.

Project Flow Diagram



Summary of Current Results

Statistics



$$(S_i, \Delta S_i) \sim Normal(\boldsymbol{\mu}, \boldsymbol{\Sigma}) \quad (1)$$

$$\boldsymbol{\mu_1} = \beta_1 + \beta_2 D_i + \beta_3 WS_i \quad (2)$$

$$\boldsymbol{\mu_2} = \beta_4 + \beta_5 D_i + \beta_6 WS_i \quad (3)$$

$$\Sigma_{11} \sim Gamma(0.1, 0.1) \quad (4)$$

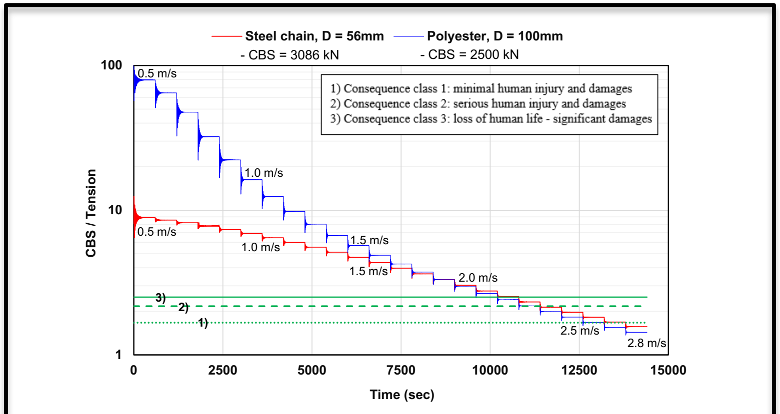
$$\Sigma_{22} \sim Gamma(0.1, 0.1) \quad (5)$$

$$\boldsymbol{\Sigma_{12}} = \boldsymbol{\Sigma_{11}} \times \boldsymbol{\Sigma_{22}} \times \rho \quad (6)$$

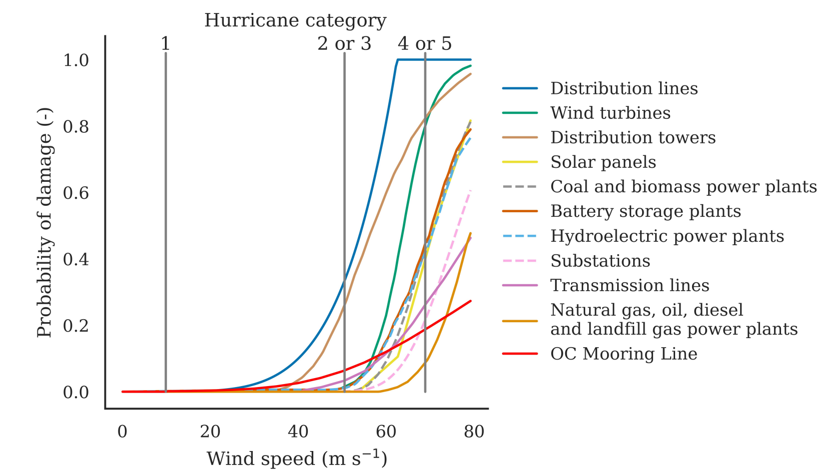
$$\rho \sim Uniform(-1, 1) \quad (7)$$

$$\beta_i \sim Normal(0, 100) \quad (8)$$

Mechanical Model Simulations



Fragility Curve Estimate



Statistical Analysis

Figure 1. ADCP Locations and Average Daily Ocean Current Speed from 2009 to 2013 considering the MABSAB model (Gong, et al. 2015)

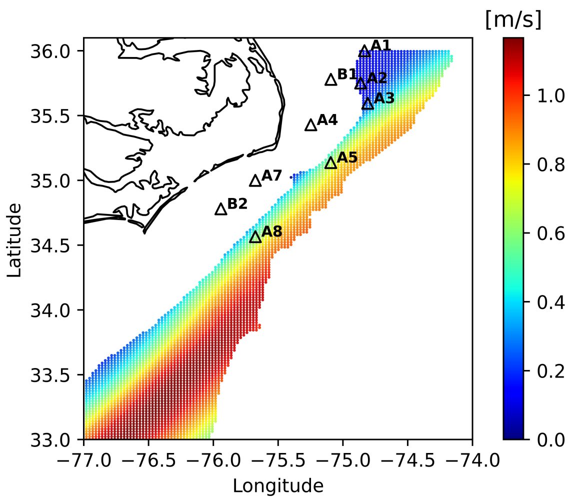
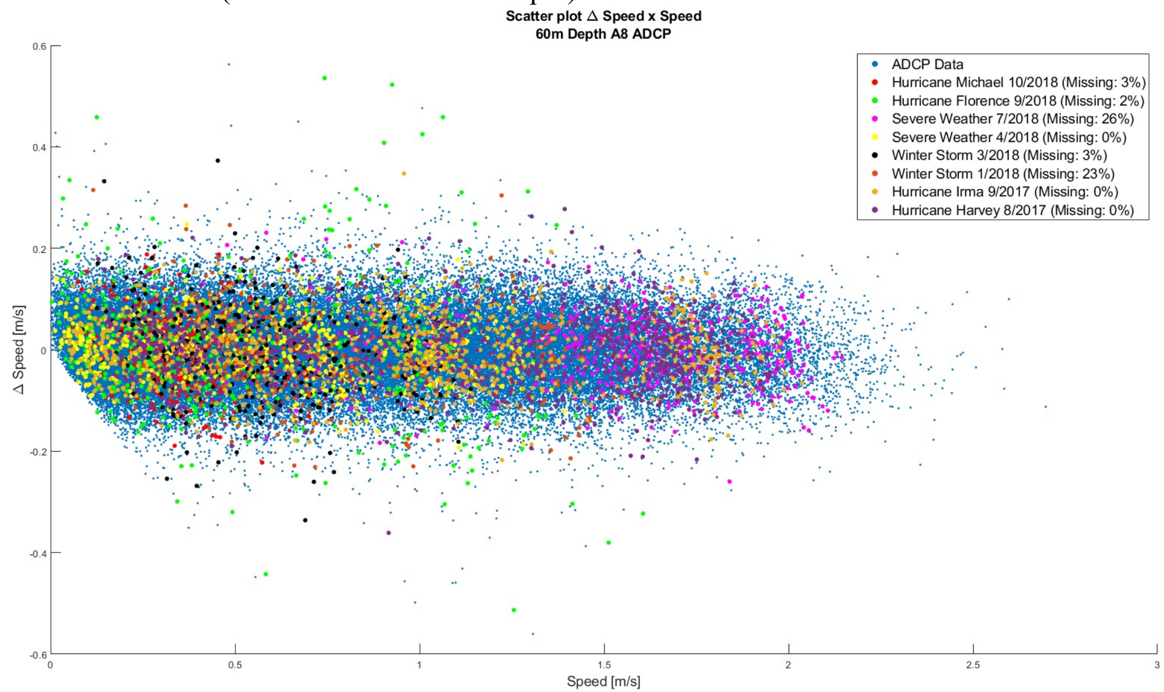
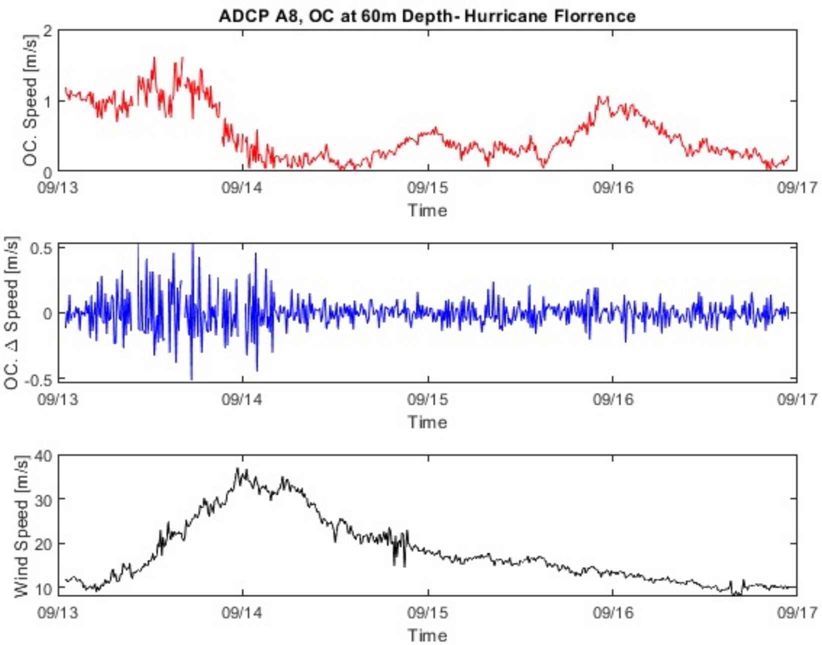


Figure 2. Scatter Plot of Current Speed and Current Speed Difference (Δ_s) at Consecutive Time Steps for ADCP A8 **(April-2017 to November-2018)**, and Corresponding Weather Related Events. (Measurements at 60m Depth).



Statistical Analysis

Figure 3. Ocean current speed, speed variation and wind speed for ADCP A8 during Hurricane Florence (current measurements made at 60[m] depth).



$(S_i, \Delta S_i) \sim Normal(\boldsymbol{\mu}, \boldsymbol{\Sigma})$	(1)	$\beta_i \sim Normal(\alpha_i, \sigma_i)$	(9)
$\boldsymbol{\mu_1} = \beta_1 + \beta_2 D_i + \beta_3 WS_i$	(2)	$\alpha_i \sim Normal(0{,}100)$	(10)
$\boldsymbol{\mu_2} = \beta_4 + \beta_5 D_i + \beta_6 WS_i$	(3)	$\sigma_i \sim Gamma(0.1{,}0.1)$	(11)
$\Sigma_{11} \sim Gamma(0.1{,}0.1)$	(4)		
$\Sigma_{22} \sim Gamma(0.1{,}0.1)$	(5)		
$\boldsymbol{\Sigma}_{12} = \boldsymbol{\Sigma_{11}} \times \boldsymbol{\Sigma}_{22} \times \rho$	(6)		
$\rho \sim Uniform(-1{,}1)$	(7)		
$\beta_i \sim Normal(0{,}100)$	(8)		

Modeling Challenges

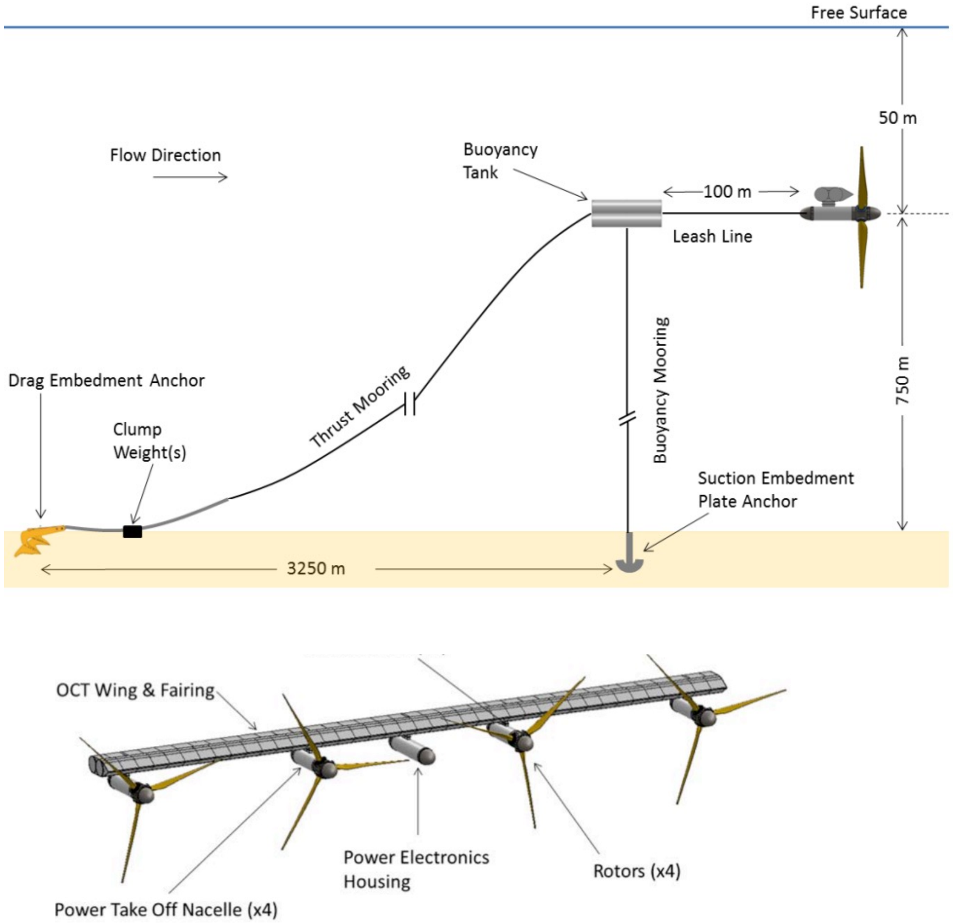
- Limited amount of data representing extreme events.
- High percentage of missing data during extreme conditions.

Possible Improvements in Model (1-8)

- Estimate the probability distributions of multiple site locations simultaneously and create shared prior parameters instead of assuming independent uninformative priors (9-11).
- Define the data uncertainty/variance (Σ) as a function of the extreme conditions explored.

Mooring System Analysis

Figure 4. RM4 device configuration and dimension, Neary et al (2014).



Mooring System Analysis

Figure 6: CBS/Tension versus time for steel chain mooring line with D=56 mm and polyester mooring line with D = 100 mm.

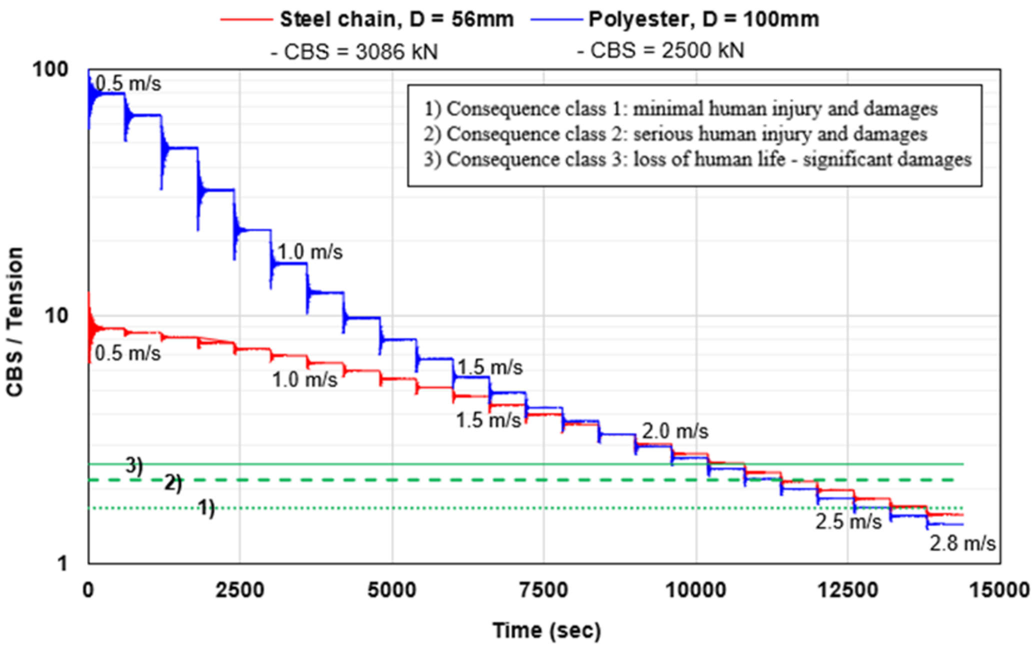
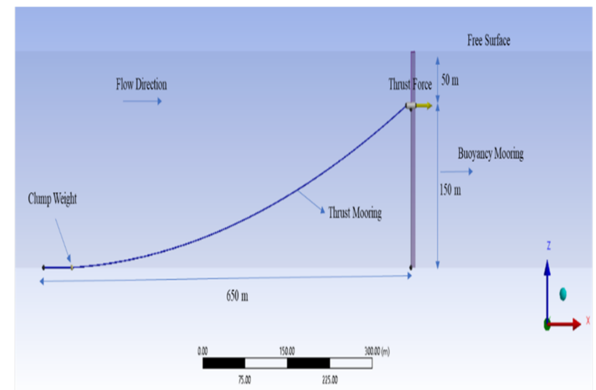


Figure 5: Simplified Configuration for the Mooring System of RM4- ANSYS Diagram

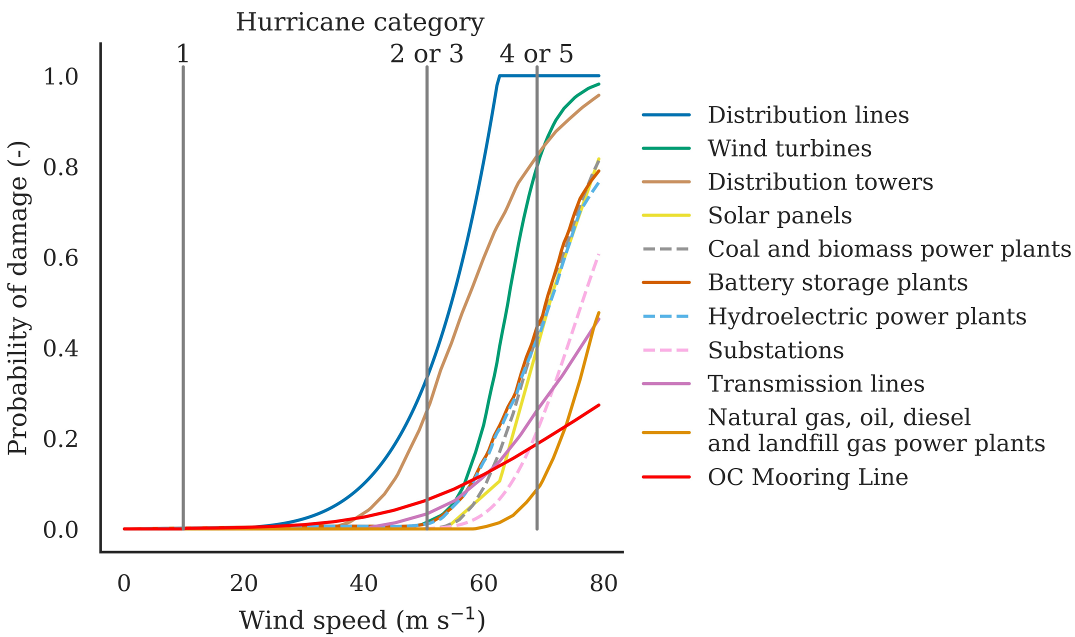


Possible Improvements/Next Steps

- Improve the modeling/analysis of the mooring system for the RM4 design, using the ANSYS AQWA software to determine the response of the thrust **and buoyancy mooring lines** under the dynamic wind, wave, and current loading.
- Investigate the possibility of using several lines as a strategy for failure management.

Fragility Curve Estimate

Figure 7: Fragility curve for different technologies (O. Current Mooring Line in Red)



Construction Procedure

- From the Bayesian model, for each wind speed, we have an estimate for the probability distribution of the ocean current variables ($S, \Delta S$).
- By integrating this PDF under the regions that exceed the limits of the mooring system we can determine the y-axis values (probability of failure) for the fragility curve of the mooring system.

Possible Improvements

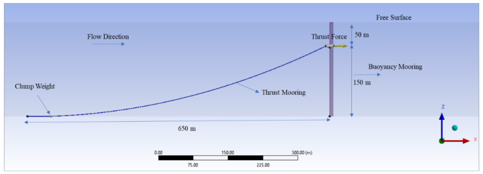
- Assess the uncertainty in the estimate of the fragility curve of the mooring line.
- Build fragility curves considering other extreme events.

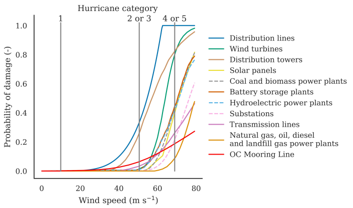
Key insights

- The statistical analysis of extreme ocean current events is very complex due to the limited amount of high-resolution data, and missing measurements (loss of information).

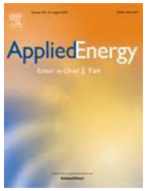
- A detailed description/analysis of the mooring system of the RM4 design is not provided in its Sandia documentation (Neary et al, 2014). By improving our ANSYS AQWA model, incorporating more connection elements and investigating different materials and line diameters we can provide critical information for the improvement of this technology and other marine energy technologies.

- While fragility curves have been developed for wind turbines, transmission and distribution lines, and conventional power plants, no such curves exist for ocean current energy. This existing research gap inhibits our ability to analyze the susceptibility of marine hydrokinetic devices to damage from hurricanes and other extreme events. Our research objective to fill this gap, providing an initial modeling analysis.





Contributions & Accomplishments



de Faria, V.A.D., de Queiroz, A.R., DeCarolis, J.F., (2022a) Optimizing Offshore Renewable Portfolios Under Resource Variability, Applied Energy (***under review***)

de Faria, V.A.D., de Queiroz, A.R., DeCarolis, J.F., (2022b) Scenario Generation and Risk-averse Stochastic Portfolio Optimization Applied to Offshore Renewable Energy Technologies, IEEE Transactions on Power Systems (***under review***)

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MARINE ENERGY TECHNOLOGY SYMPOSIUM

Faria, V., Jamaleddin, N., de Queiroz, A.R. and Gabr, M. (2022) Assessing the Risk of Hurricane Damage to Marine Hydrokinetic Devices, Marine Energy Technology Symposium

NSF

Galik, C., de Queiroz, A.R., Arumugam, S., Edwards, E. (2022) Collaborative Research: SAI-R. Institutions, Markets, and Policies-Assessing Complex Trajectories for energy and water Infrastructure Deployment (IMPACT-ID), National Science Foundation, Strengthening American Infrastructure (SAI) - NSF 22-564 (***under review***)

Planned Future Work

1. Extend mooring system modeling/analysis to determine responses of the thrust and buoyance lines multiple configuration under dynamic wind, wave, and current loading
2. Expand the algorithm for Fragility Curve Estimation strengthening the Bayesian Markov Chain Monte Carlo procedure
3. Link inputs from 1 and 2 to explore the potential economics to the NC power system under extreme events via Tools for Energy Modeling Optimization and Analysis (Temoa)

Thank You!

North Carolina Renewable Ocean Energy Program