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Integrating Climate Projections and Hydrodynamic-Wave Modeling for Present and Future Compound Flood Risk

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We'd like to thank ONR: Mr. Daniel Eleuterio, Ph.D., Allison Penko, Ph.D., and NAS PAX River: Mr. Lance McDaniel, Alec Young

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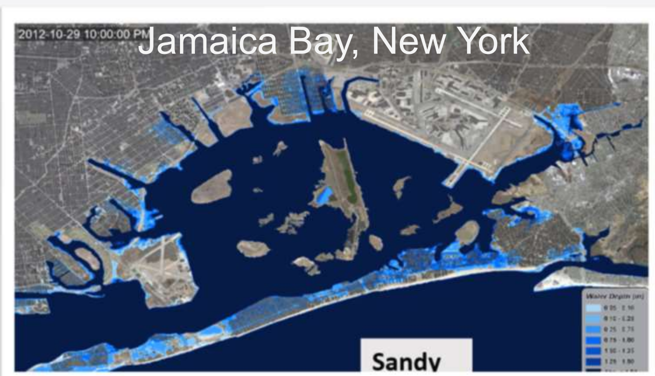
Outline

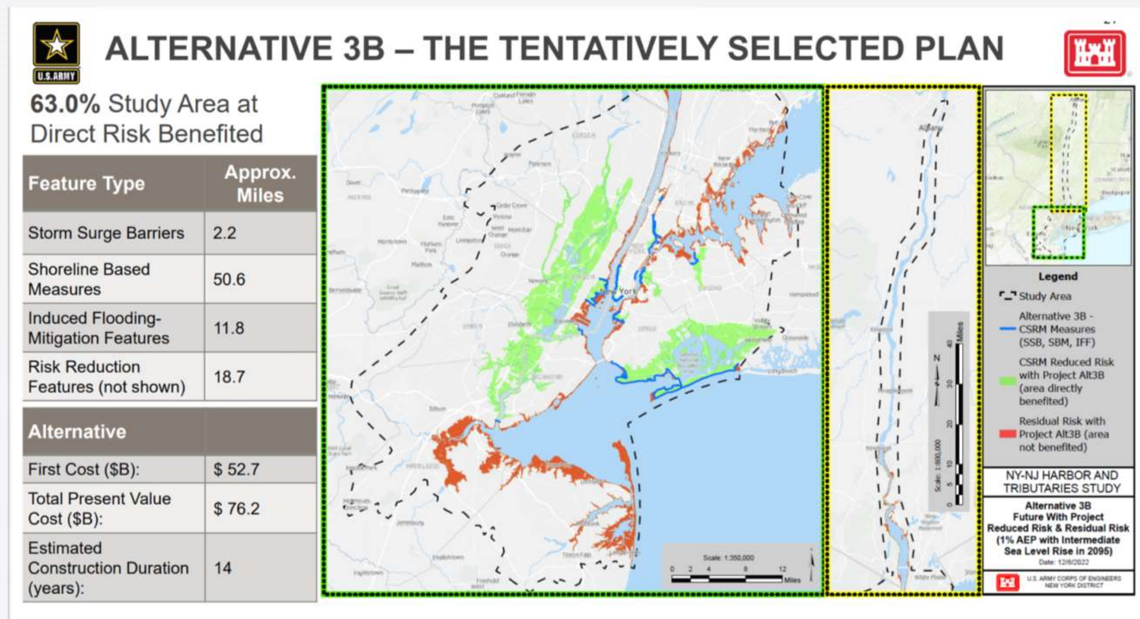
- Coastal storm risk management (CSRM) projects and vulnerability to compound flooding
- Types of compound flooding fluvial/surge, pluvial/surge, pluvial/overtopping/surge
- Quantifying rainfall and surge for TCs and ETCs now and in the future with climate change – Office of Naval Research Pilot study at Patuxent River Naval Air Station on Chesapeake Bay
- Modeling surge, waves, river discharge and rain on grid
- Bivariate analysis of compound flood with data only and with synthetic storms

Flood Risk Reduction Projects Leading to Bathtub Conditions

New York-New Jersey Harbor and Tributaries Study (NYNJHATS)

- The *HATS* study by the U.S. Army Corps of Engineers evaluates flood risk management for the NY-NJ harbor area.



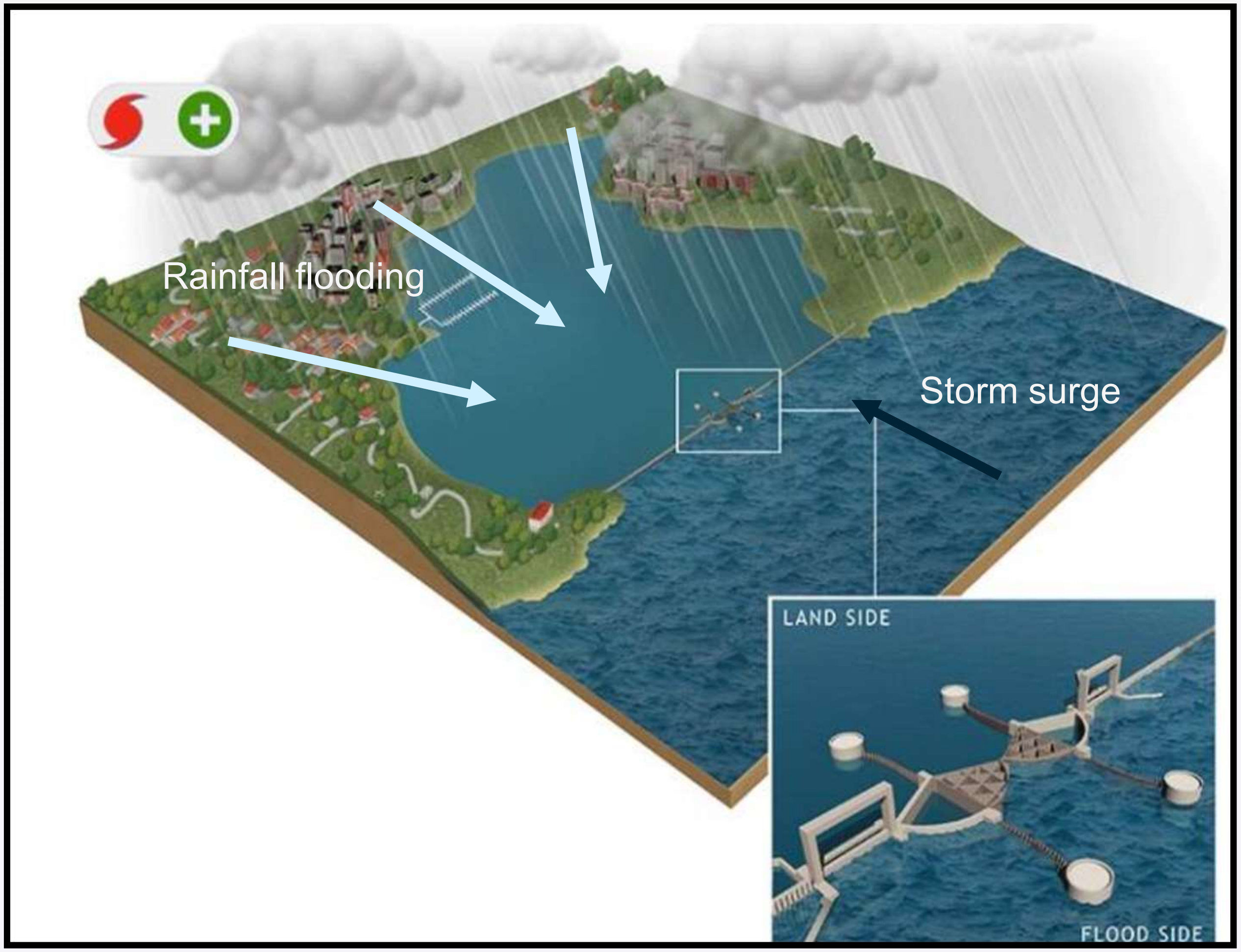


Feature Type	Approx. Miles
Storm Surge Barriers	2.2
Shoreline Based Measures	50.6
Induced Flooding-Mitigation Features	11.8
Risk Reduction Features (not shown)	18.7
Alternative	
First Cost ($B):	$ 52.7
Total Present Value Cost ($B):	$ 76.2
Estimated Construction Duration (years):	14

Source: https://www.nan.usace.army.mil/Portals/37/HATS_100yrIntSLR_Risk_wAlt3B_500dpi.pdf

Compound flood can potentially increase flood risk

- Will need to store or pump out rainfall runoff (pluvial)/fluvial discharge behind barriers
- Compound flood risk may increase with climate change (particularly where TCs become more frequent/intense)
- Dependency between rainfall and non-tidal residual increases the frequency of compound flood conditions by 2.5 to 3 times, or greater



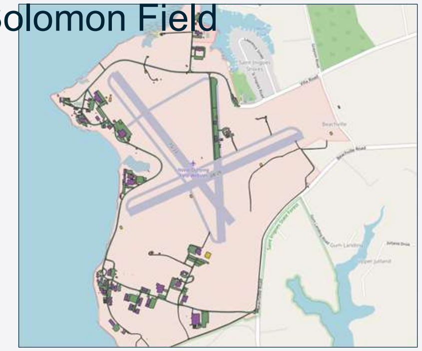
Takeaways for now,

- Compound flood is important to consider for design of flood risk reduction projects involving levee/berm-floodwall-gates-pump stations, and those types of projects are becoming more prevalent
- Independent assumptions for compound flood are non-conservative and a full dependency assumption is extremely over conservative
- Dependency is found with TCs at most locations (if not all) and this dependency may be increasing with time through increased frequency/intensity of TCs
- The TC record is too short to robustly evaluate statistics of compound flood
- Dependency for ETCs is unusual and site specific

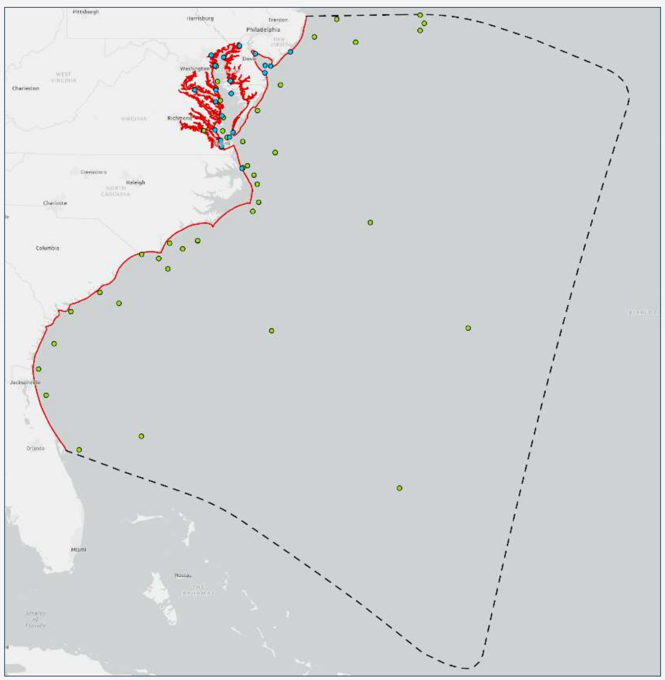
Coastal Flood Risk Assessment
Patuxent River Naval Air Station

- Develop/improve methods to quantify coastal flood risk for the naval air base considering changes to storminess.

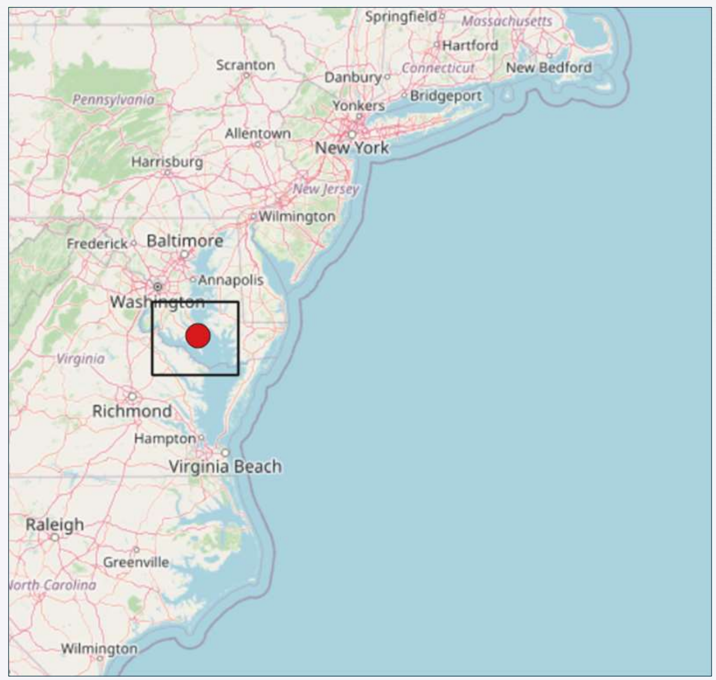
Solomon Field



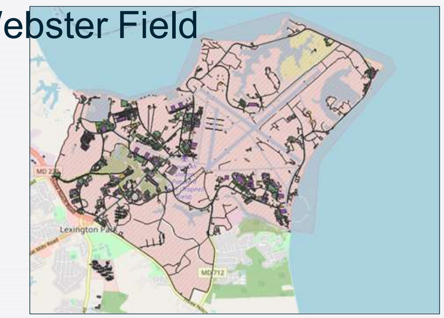
Model Domain



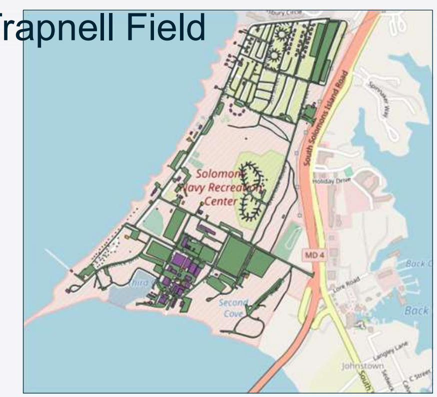
Area of interest



Webster Field

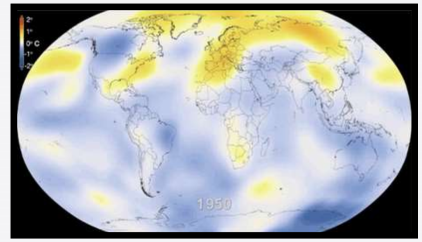


Trapnell Field



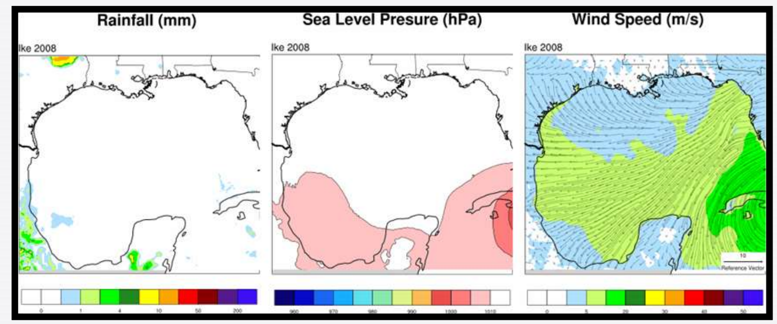
Compound Modeling Workflow

Reanalysis Datasets/CMIP6 data



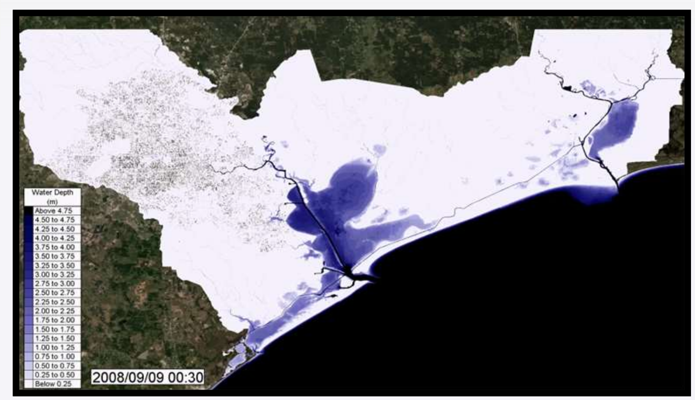
Provides boundary & initial conditions

Weather Models



Downscaled Rainfall,
Pressure, Surface Winds

Compound Flood Multiscale Models



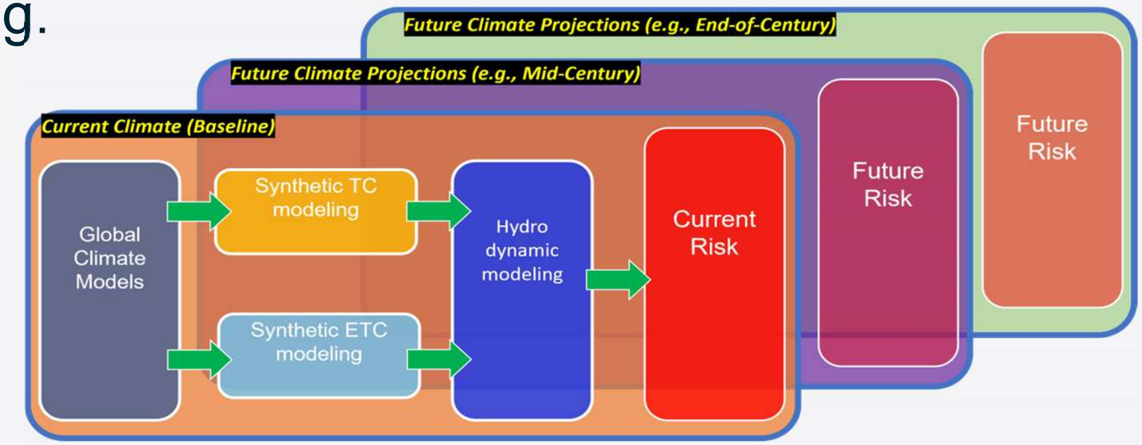
Flood levels, Velocities etc.

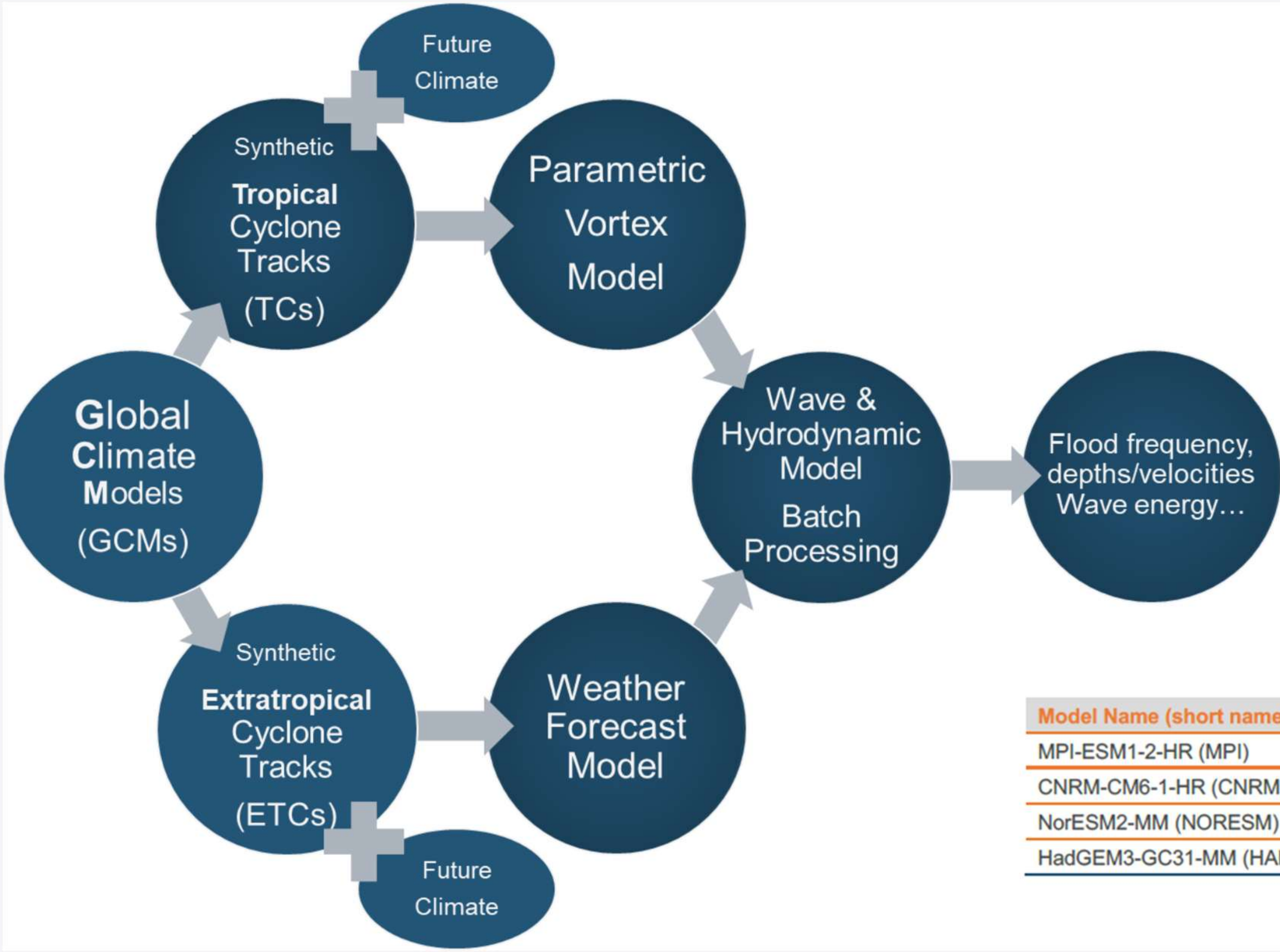
↓

Coastal Structure Design

Overall Patuxent River Project Approach for ONR

- Four GCMs used for CMIP6 SSP585 and SSP126 Scenarios for mid- and late 21st century periods.
- Produced single compound flood model (TELEMAC+TOMAWAC) to simulate: rainfall flooding, riverine flooding, tides, storm surge, wave setup, and flooding/drying.

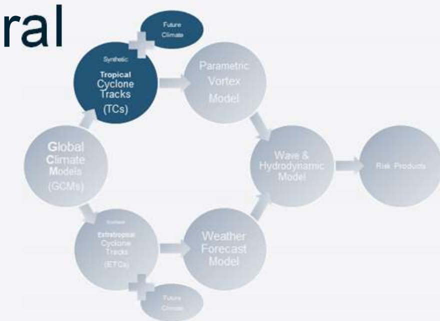




Model Name (short name)
MPI-ESM1-2-HR (MPI)
CNRM-CM6-1-HR (CNRM)
NorESM2-MM (NORESM)
HadGEM3-GC31-MM (HADGEM)

Bloemendaal et al (2020)

- Data from IBTrACS and ERA5
- Run STORM – Markov Chain Monte Carlo (MCMC) statistical approach to generate representative synthetic storms and their intensity for several thousand years



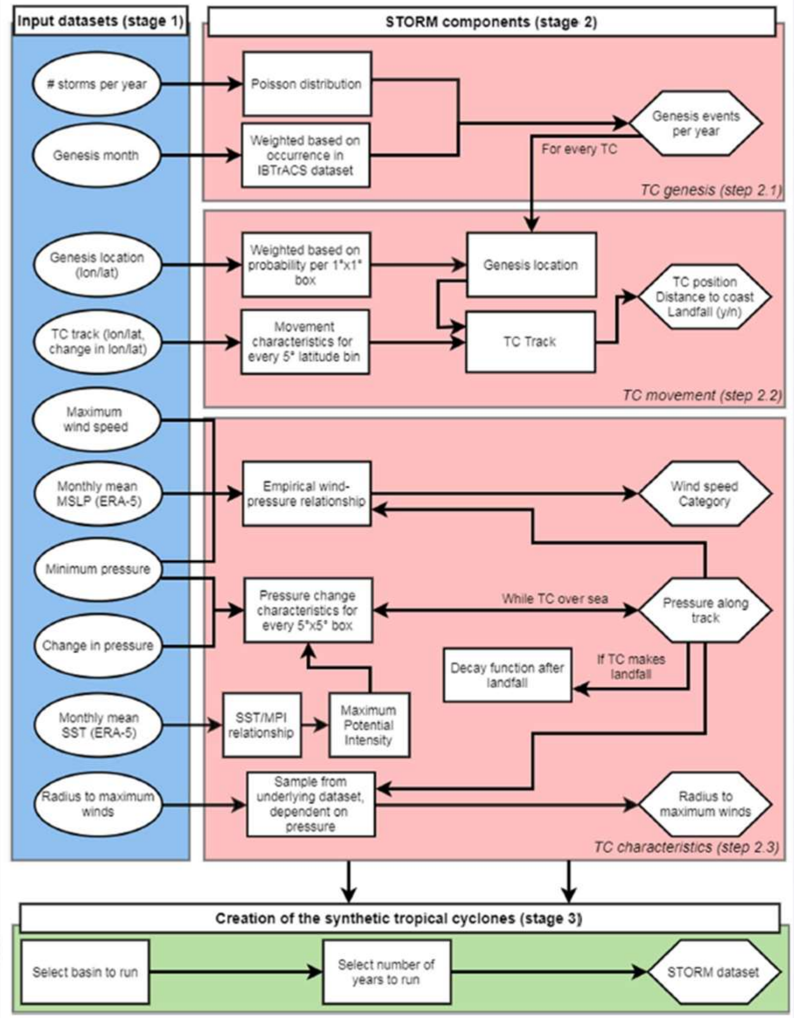
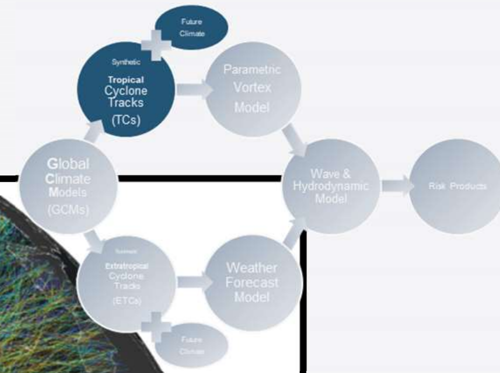


Fig. 2 Flowchart with the extracted IBTrACS tropical cyclone (TC) characteristics (stage 1; in blue), the STORM components (stage 2; in red), and the creation of the synthetic tropical cyclones (stage 3; in green). Round boxes represent input data, square boxes represent the methodological steps taken to process this input data, and hexagonal boxes represent the output data.

Synthetic TC Tracks Generated Using STORM



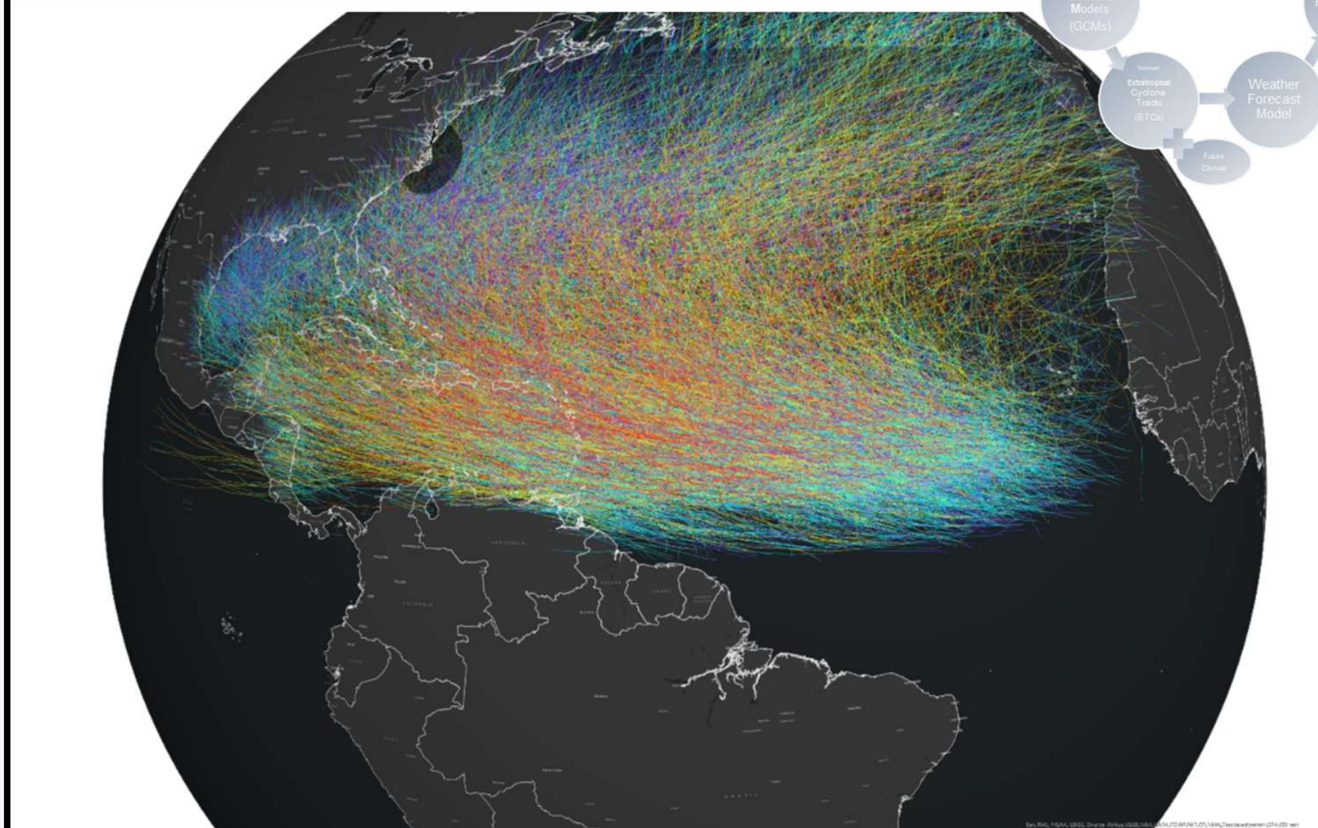
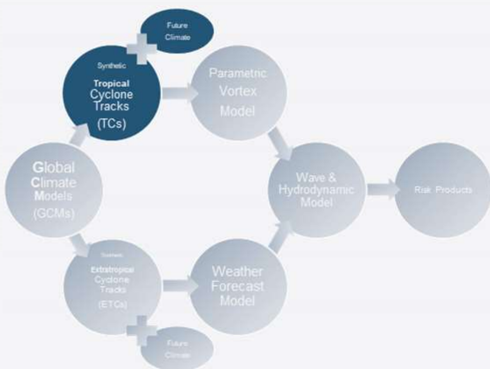


Figure 6: Developed synthetic tropical cyclone tracks using the CNRM GCM for the late 21st Century in the SSP585 scenario for a period of 7,000 years. The color of the track indicates minimum sea level pressure along the track.

STORM and the Delta Approach for Synthetic Tracks in the Future

(Bloemendaal et al 2022)



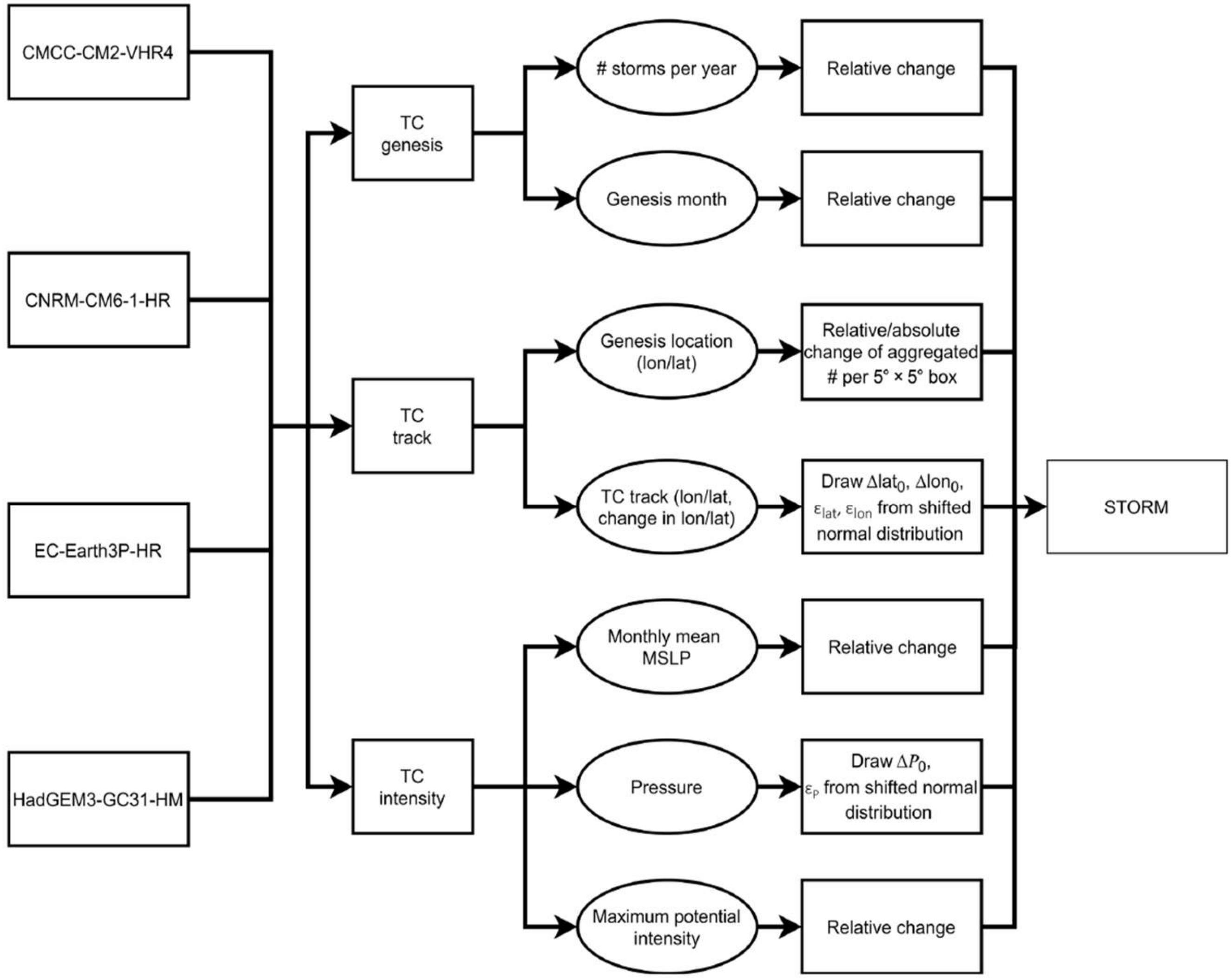
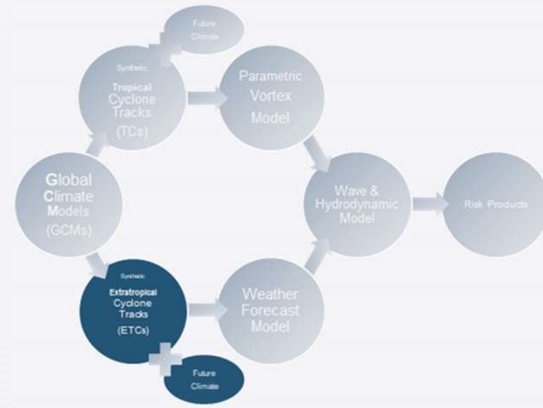


Fig. 6. Overview of the propagation of the delta into the STORM model.

Historic ETC Detection



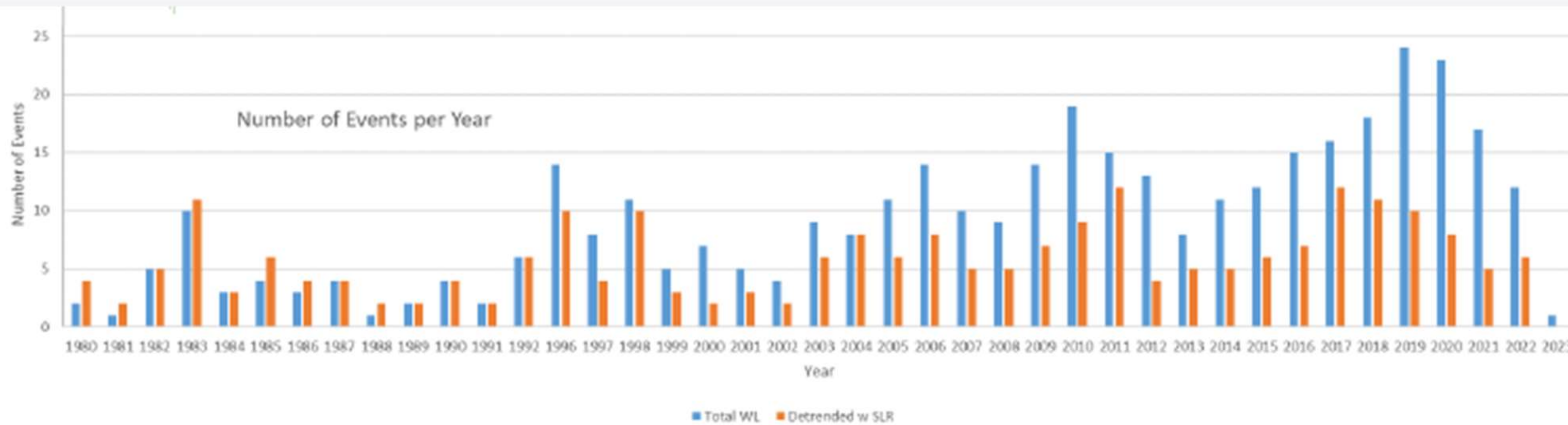


Figure 10: ETC detection illustration. Top panel shows the time series of the NAO and SOI indices. Bottom panel shows the number of identified ETC events per year identified via the storm windowing approach.

Future ETCs with Climate Change

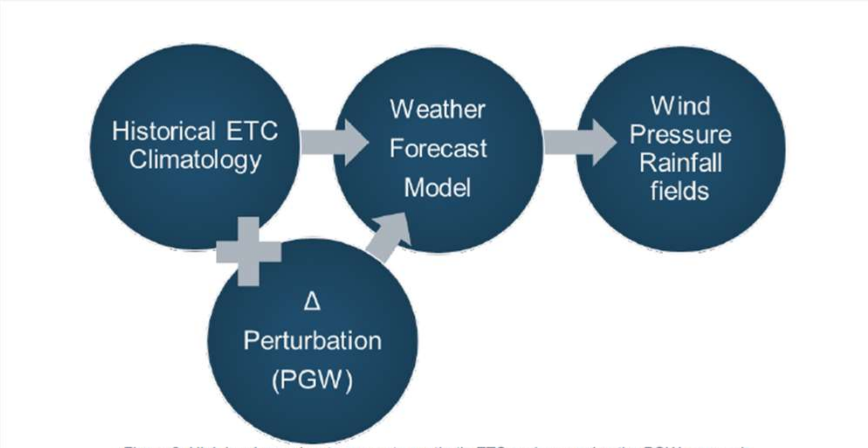
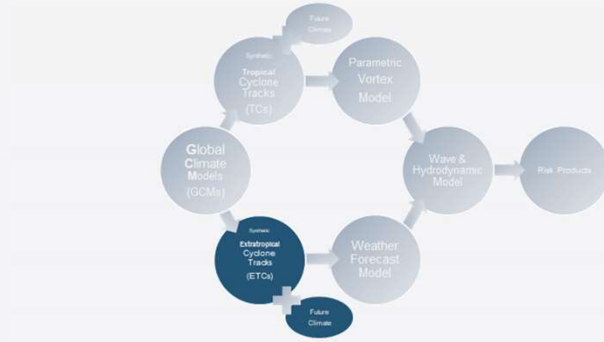
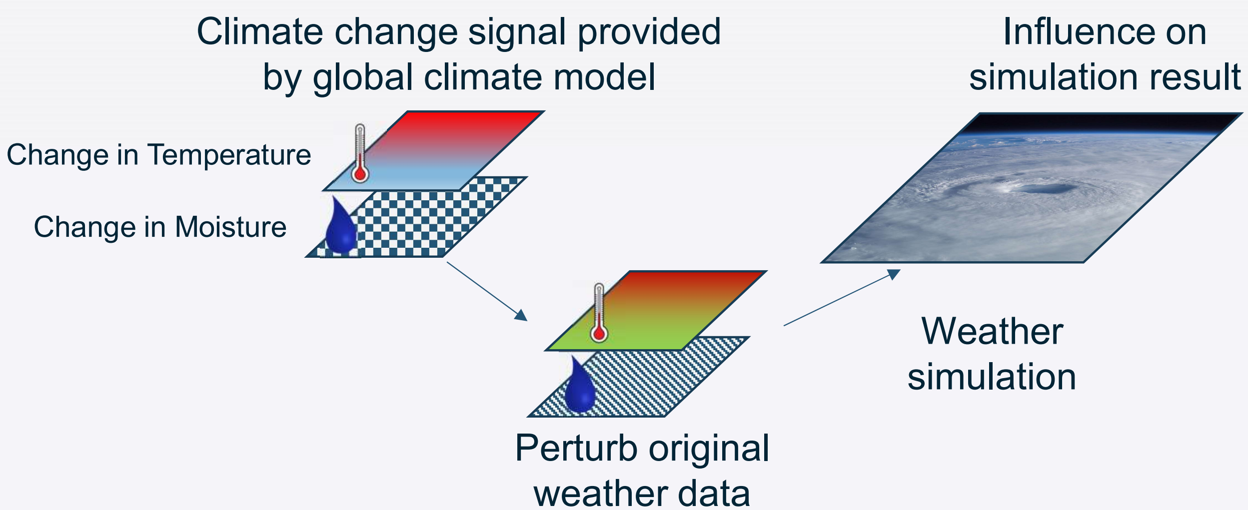


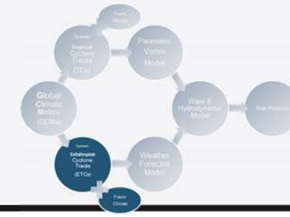
Figure 8: High level overview to generate synthetic ETC cyclones using the PGW approach.



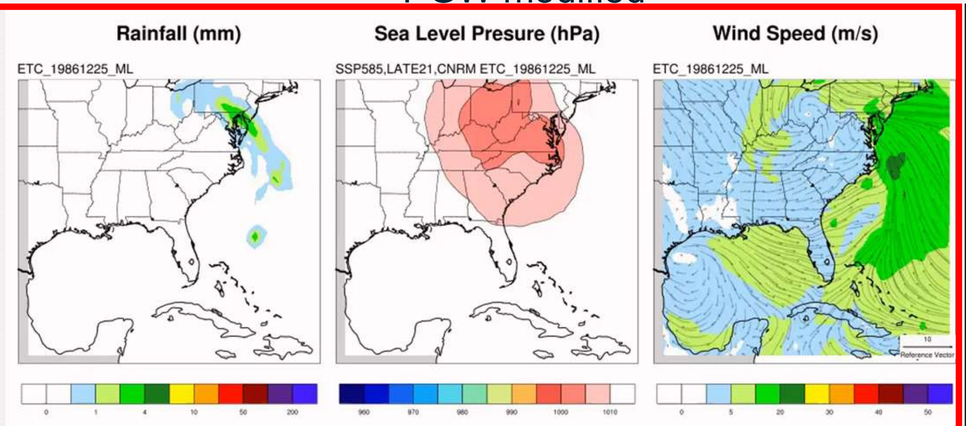
Future Atmosphere = (Historical Atmosphere) + (Delta)



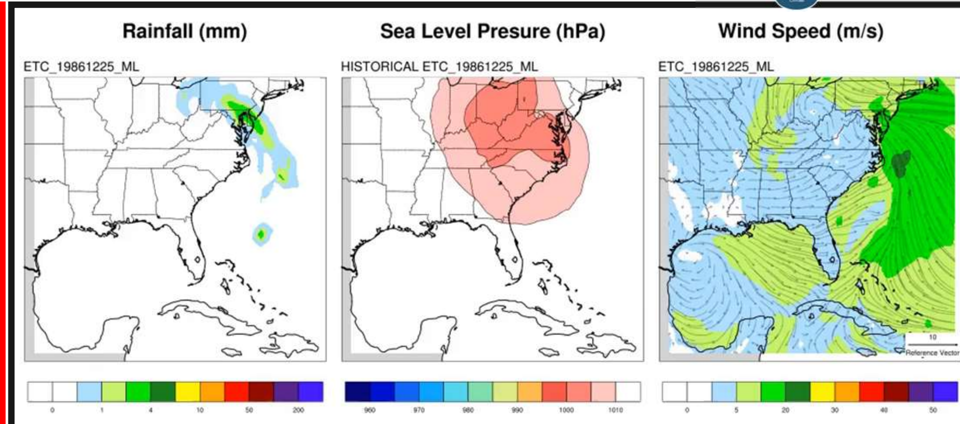
Weather Research Model (WRF) Application



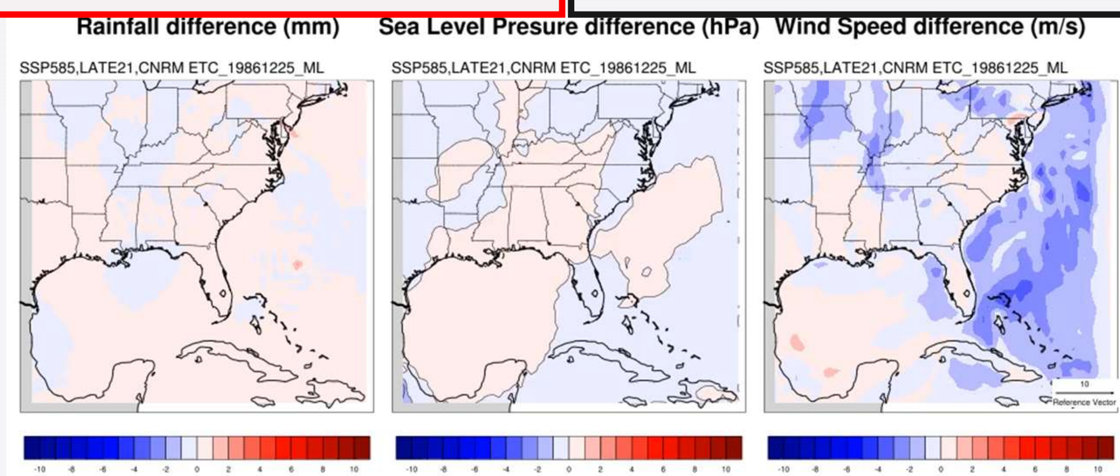
PGW modified



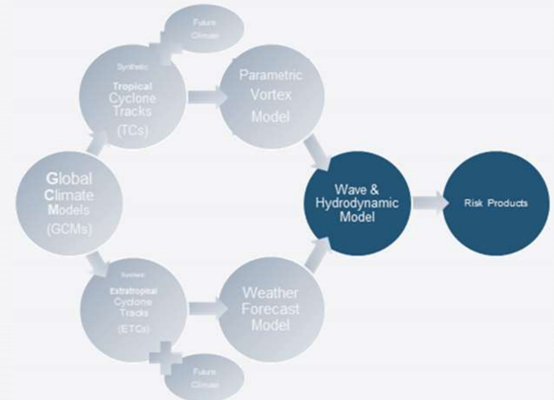
Historical

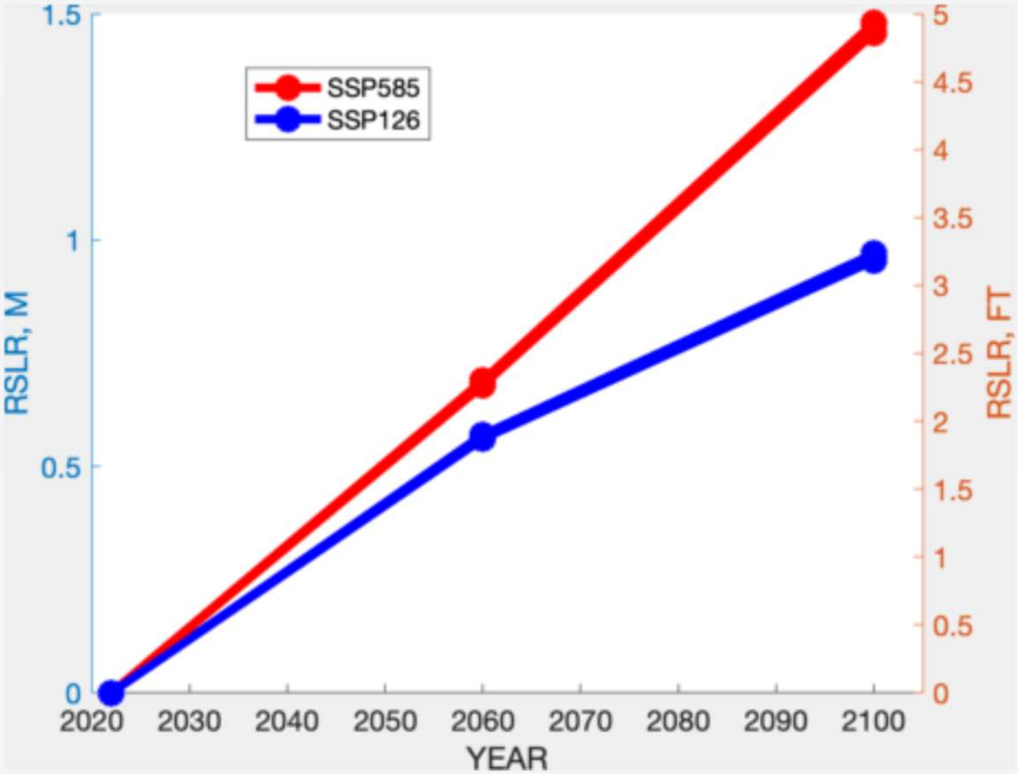


Difference
PGW – historical



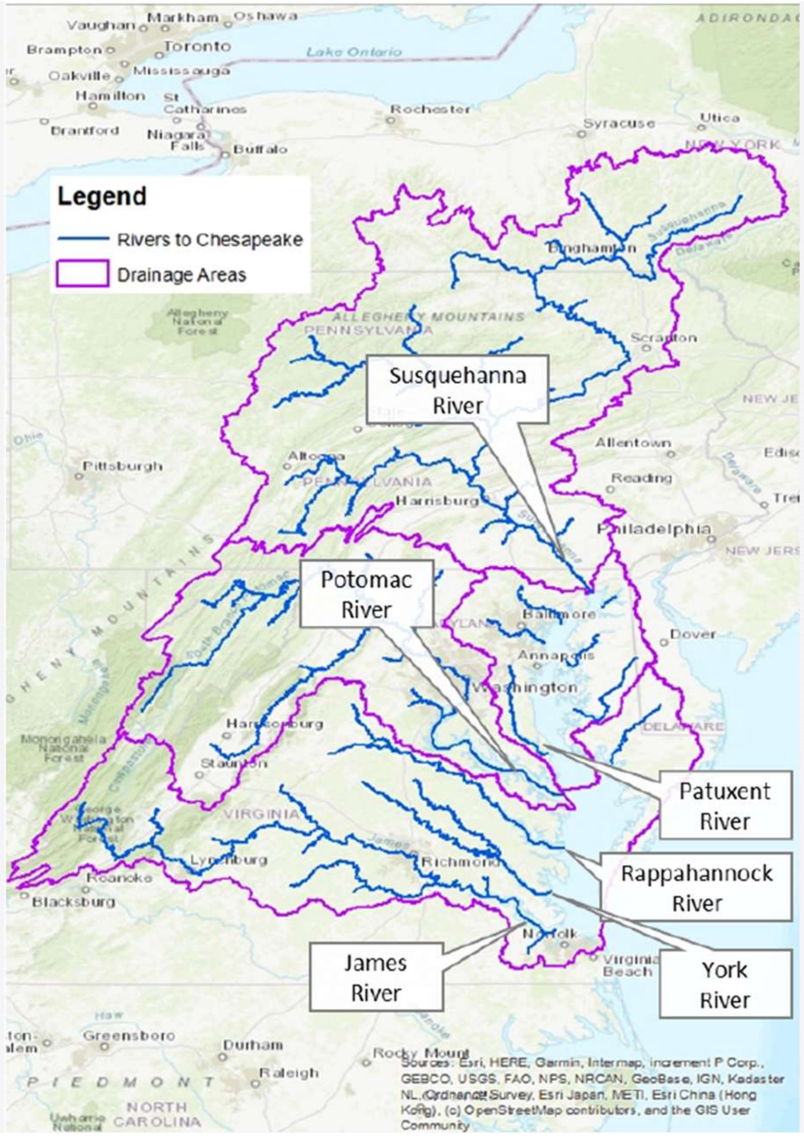
Sea Level Rise

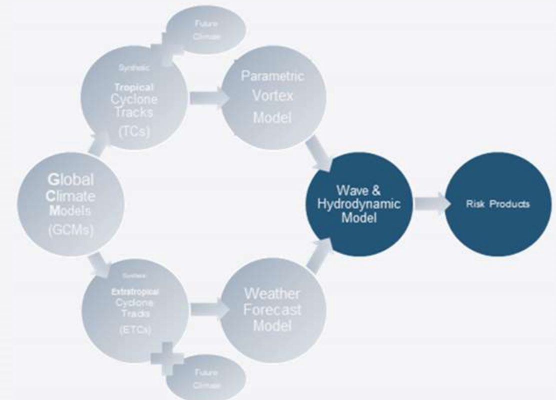




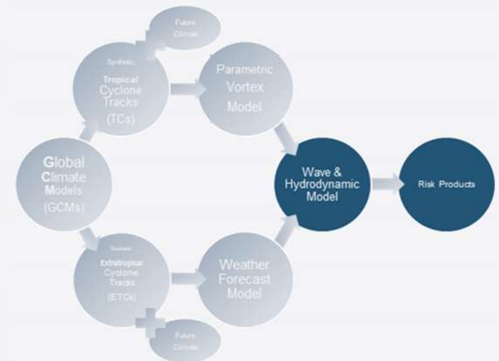
Pathway	2065 (mid-21st)	2100 (late-21st)
SSP126	0.57 m (1.87 ft)	0.97 m (3.18 ft)
SSP585	0.69 m (2.26 ft)	1.48 m (4.86 ft)

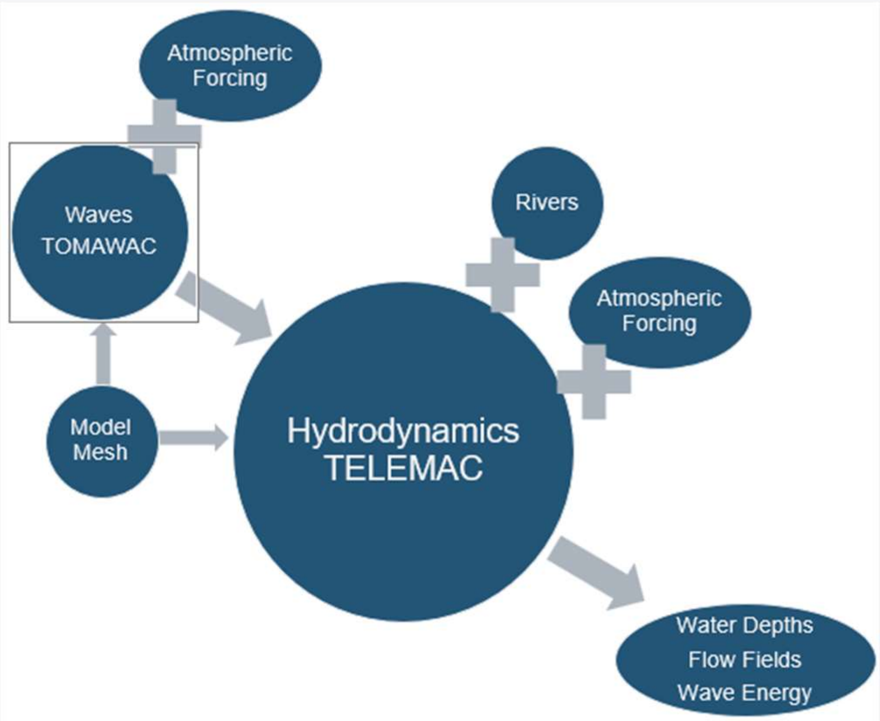
Evaluate Fluvial Impacts

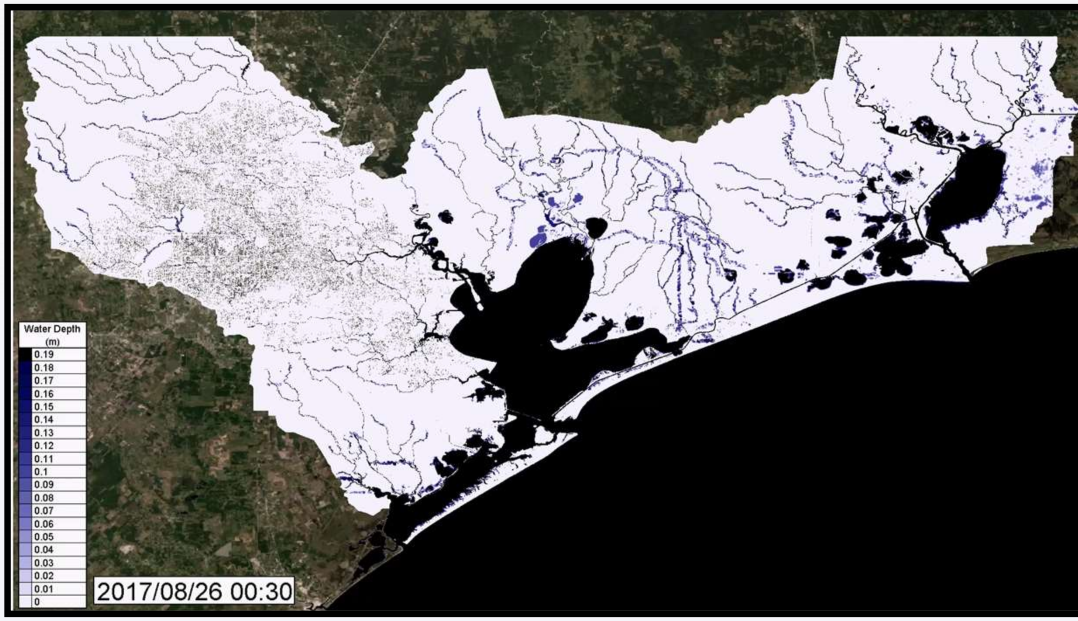




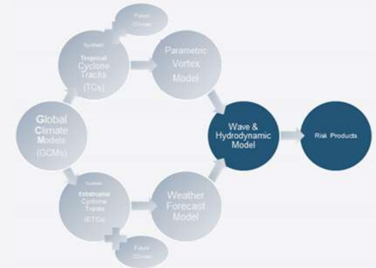
Apply Hydrodynamic-Wave Model

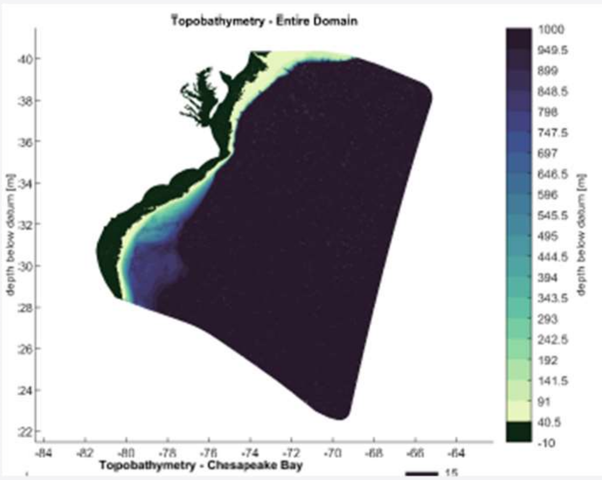


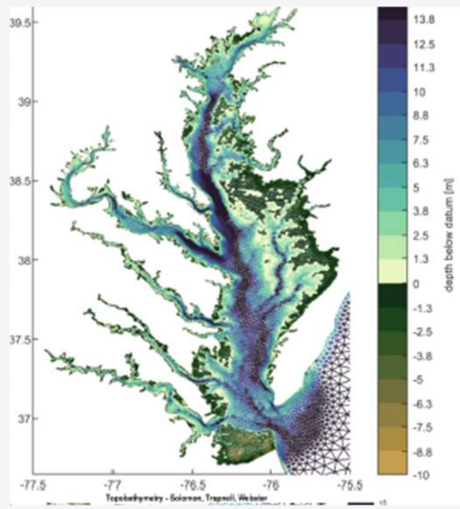


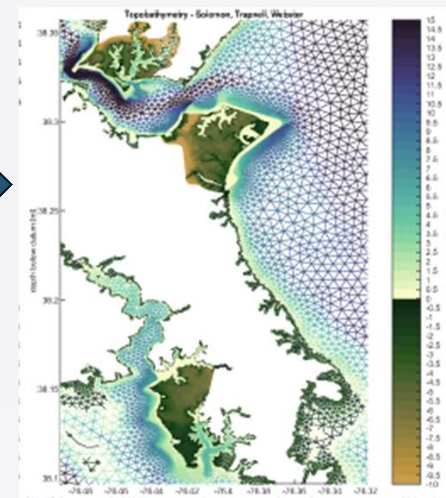


TELEMAC-TOMAWAC Model Domain and Mesh









Model	Resolution Range (m)	Mesh Size (# Elements)
HD	15-6000	230k
Wave	750-20000	26k

Number of Storms Simulated

Scenario Period		Number of Synthetic Storms					
		Historical	CNRM	NORESM	HADGEM	MPI	
Historical (1979-2022)		997	-	-	-	-	
SSP126	Mid-21st	-	696	999	792	968	
	Late 21st	-	1,000	998	1,000	951	
SSP585	Mid-21st	-	994	832	986	810	
	Late 21st	-	999	602	997	977	Total
Total		997	3,689	3,431	3,775	3,706	15,598

Scenario Period		Number of Synthetic Storms					
		Historical	CNRM	NORESM	HADGEM	MPI	
Historical (1979-2022)		383	-	-	-	-	
SSP126	Mid-21st	-	383	383	-	-	
	Late 21st	-	383	383	-	-	
SSP585	Mid-21st	-	383	383	-	-	
	Late 21st	-	383	383	-	-	Total
Total		383	1,532	1,532	0	0	3,447

Results

- Evaluation of compound flood with recorded and reanalysis data (NOAA and AORC) – TCs show dependence but too few
- Analysis with synthetic TCs alone to evaluate compound flood

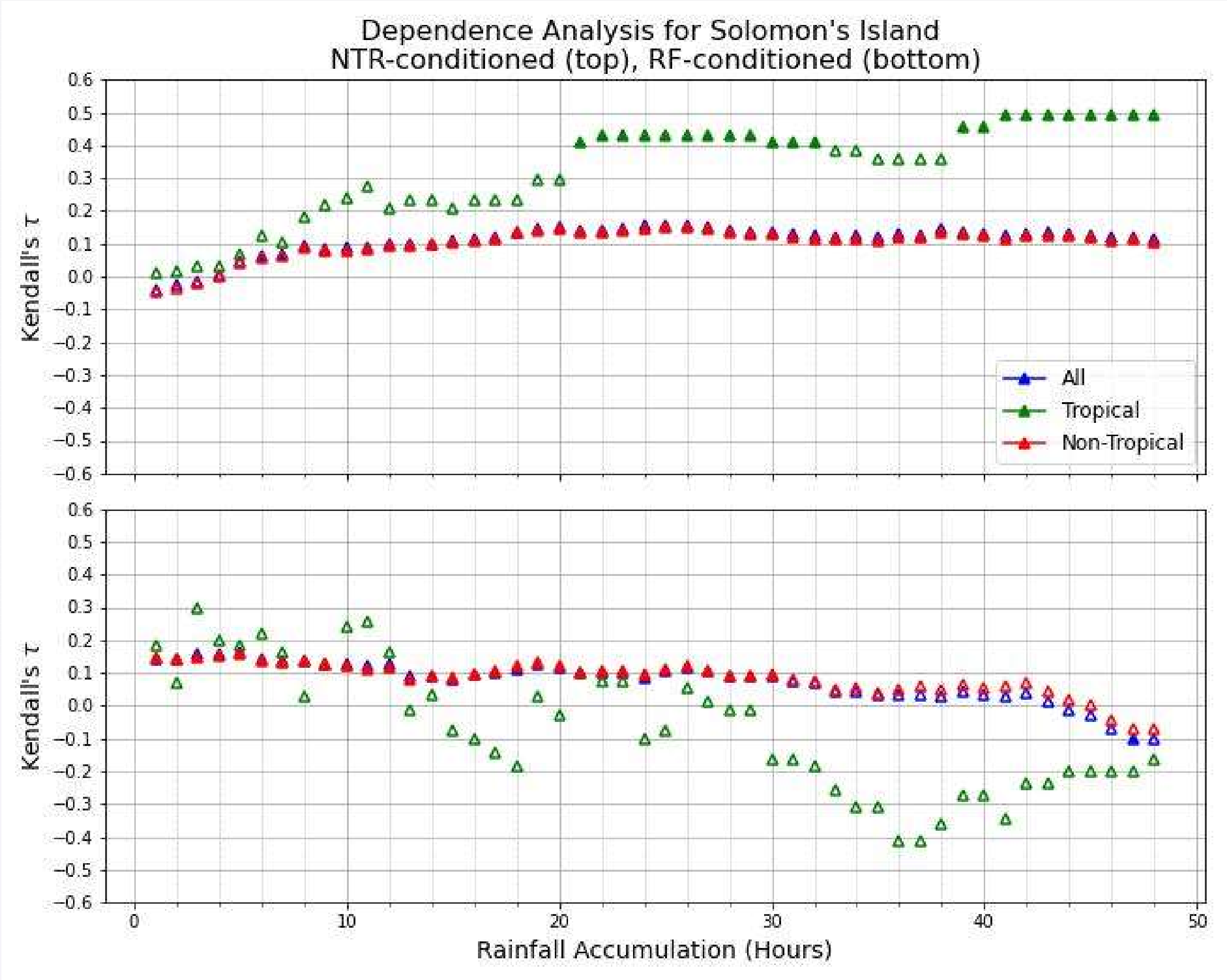
Data Gathering for Data-based Bivariate analysis

- Require a long time series of water levels & daily accumulated rainfall (collocated as closely as possible)
  - Nearby NOAA gages
  - Analysis of Record for Calibration (AORC)

- Require Hurricane track data to determine if storms are tropical or non-tropical
  - HURDAT2

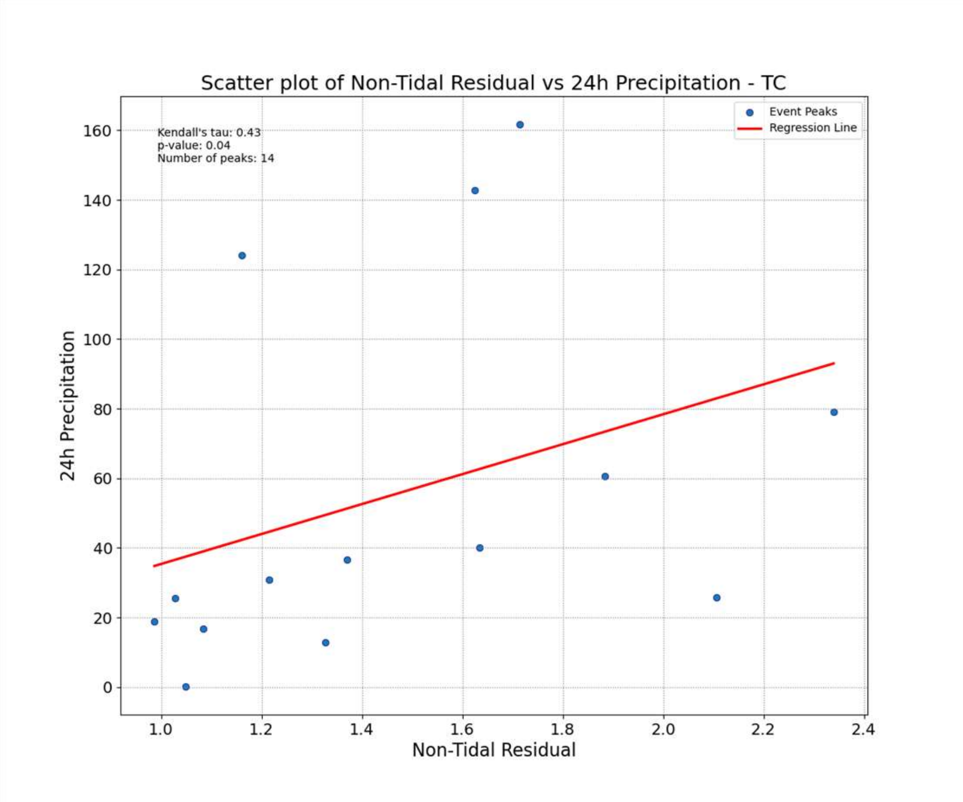
Dependence Analysis Plot

Tau>0.2 to 0.3 shows dependence



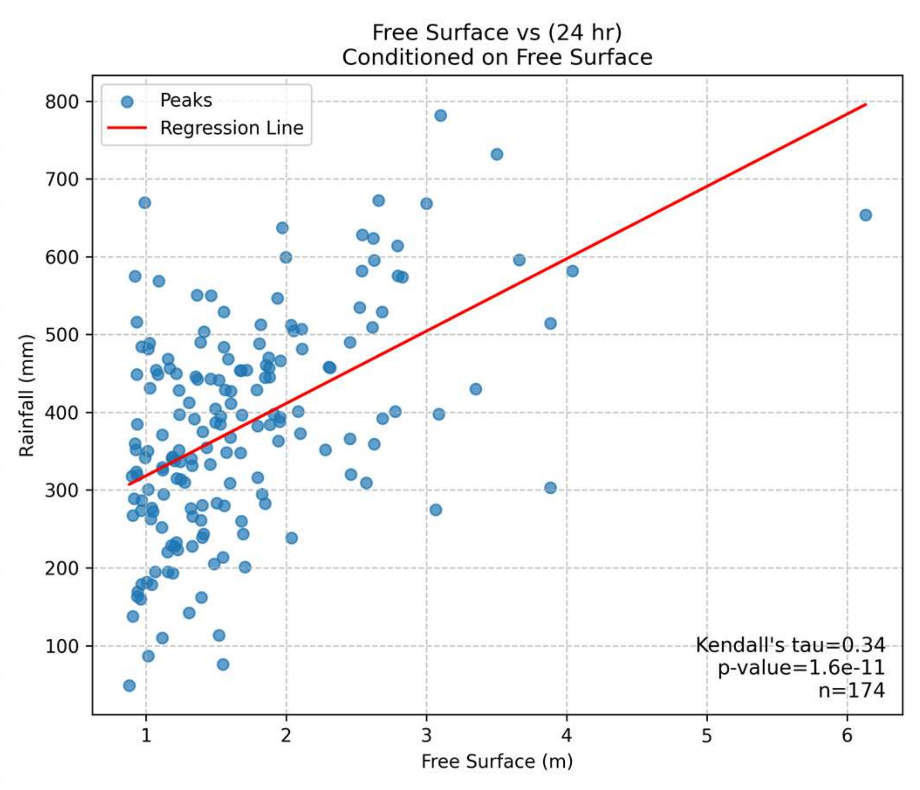
Tau Correlations - TC Peaks (Measured Data)

NTR (Water level) -Conditioned

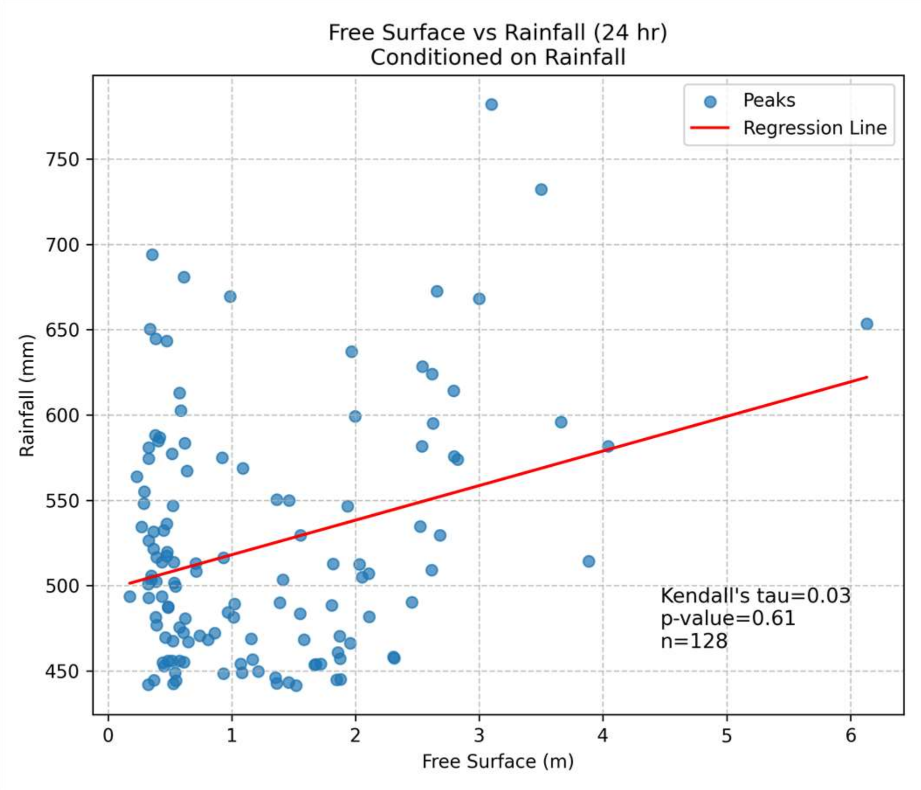


Existing (synthetic data)

Water Level

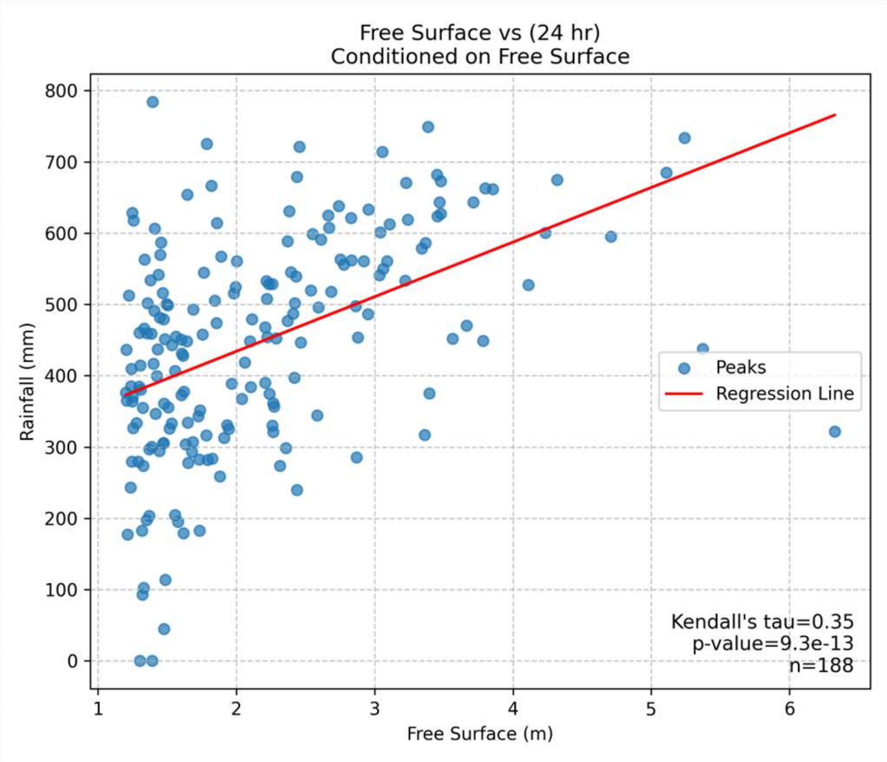


Rainfall

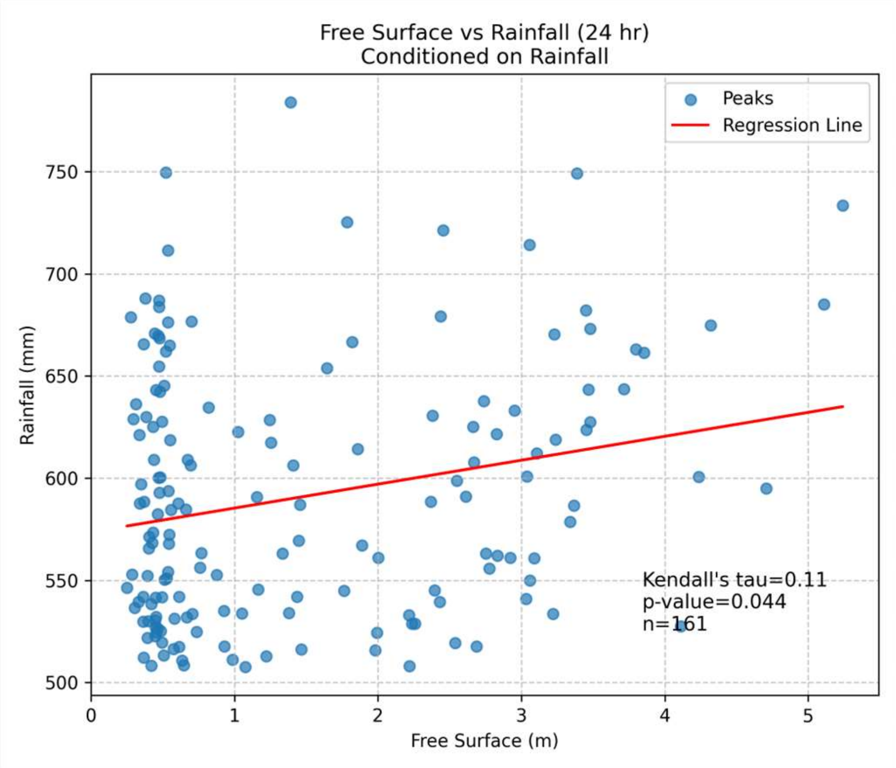


Late Century

Water Level

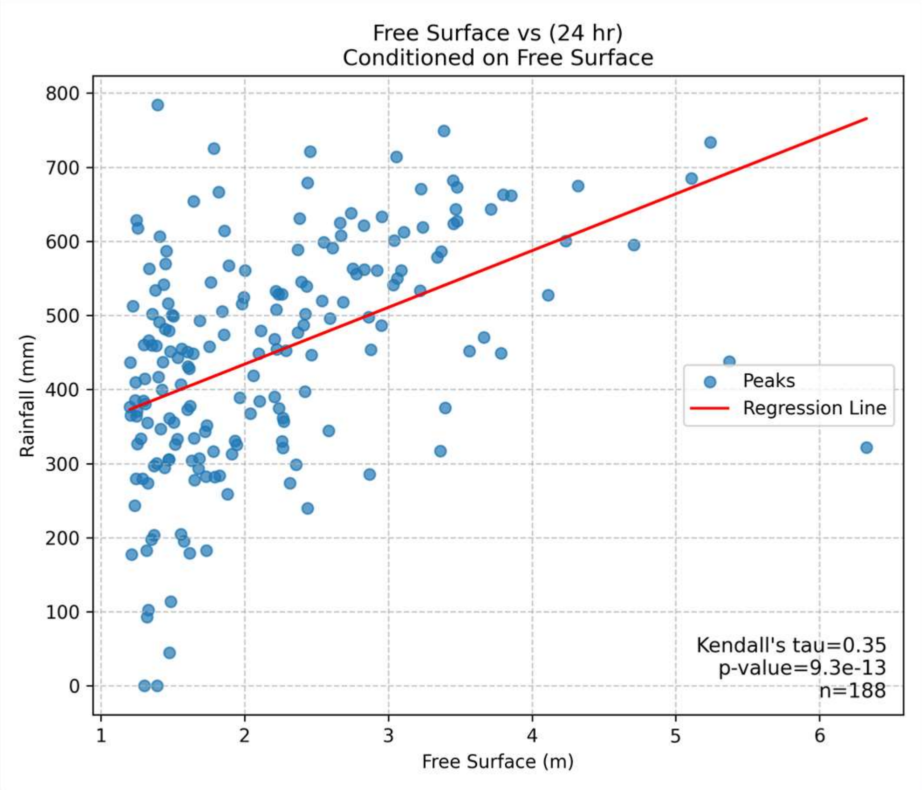


Rainfall

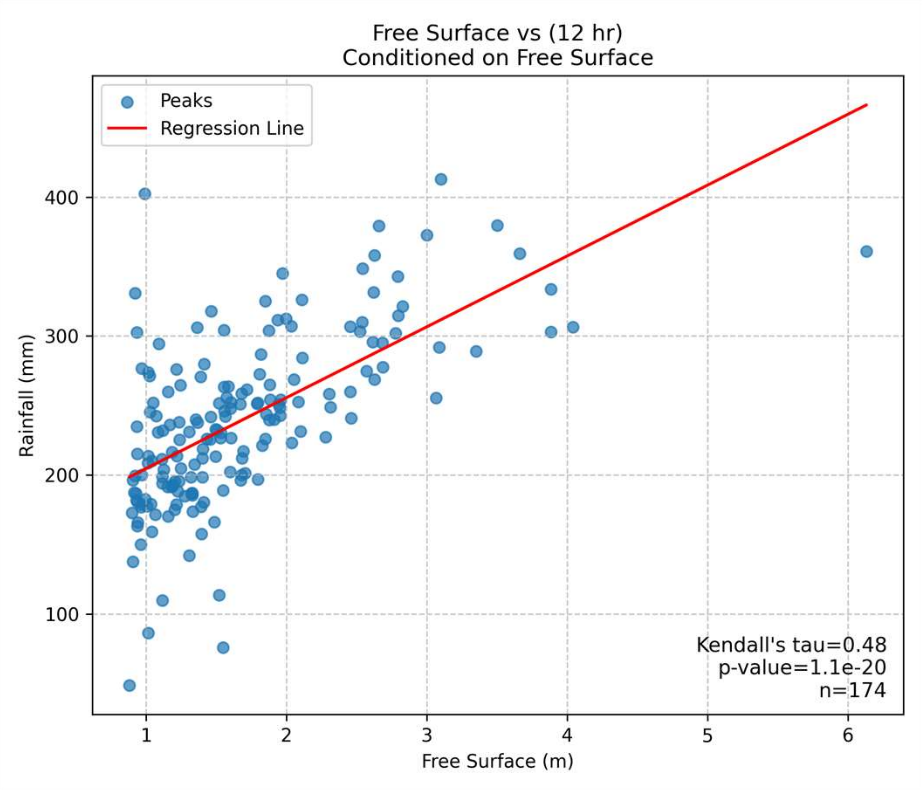


Late Century

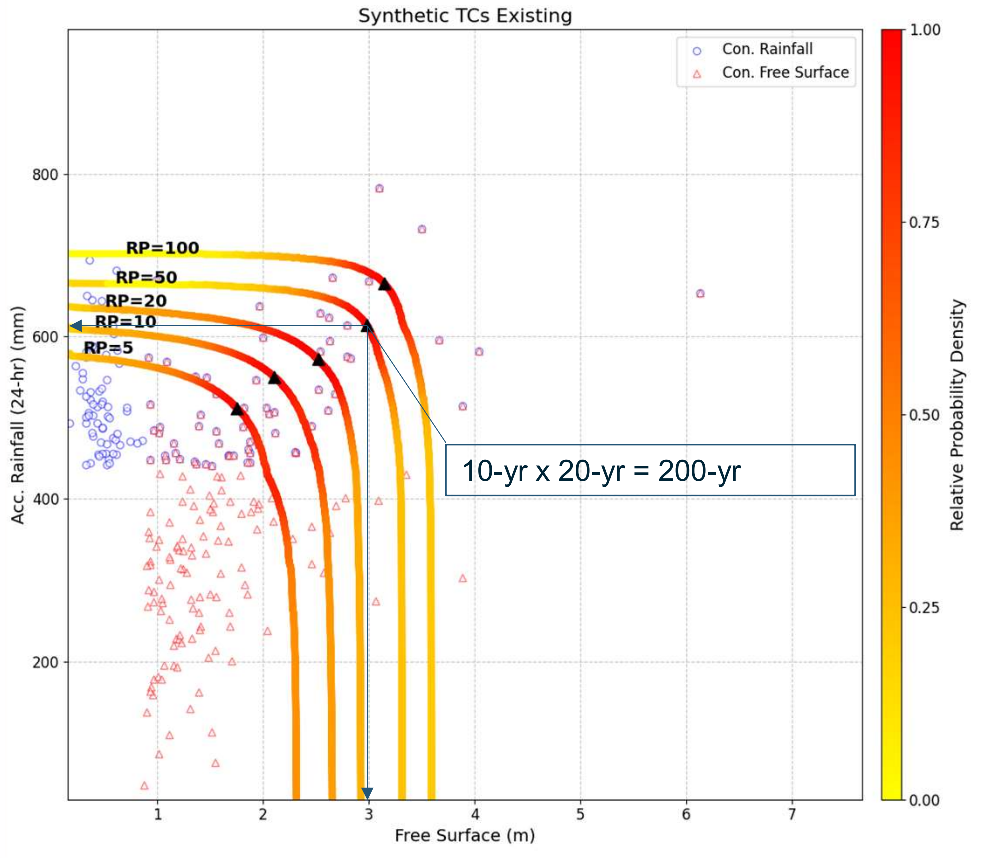
Water Level – 24 hr

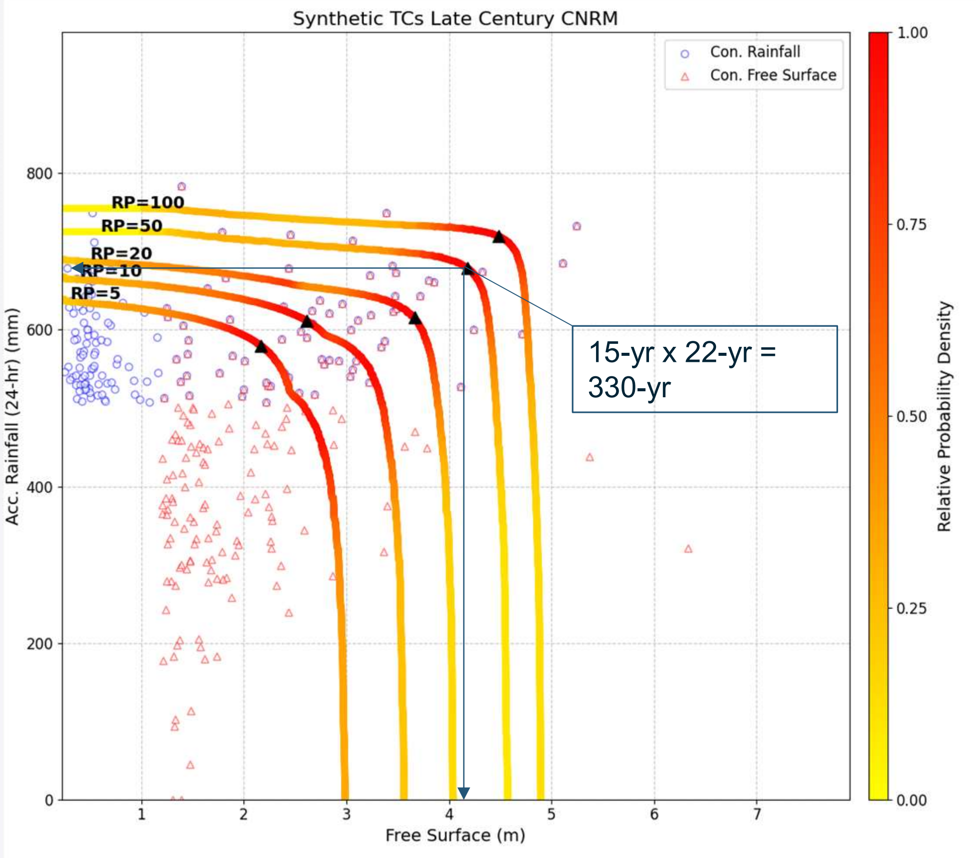


Water Level – 12 hr

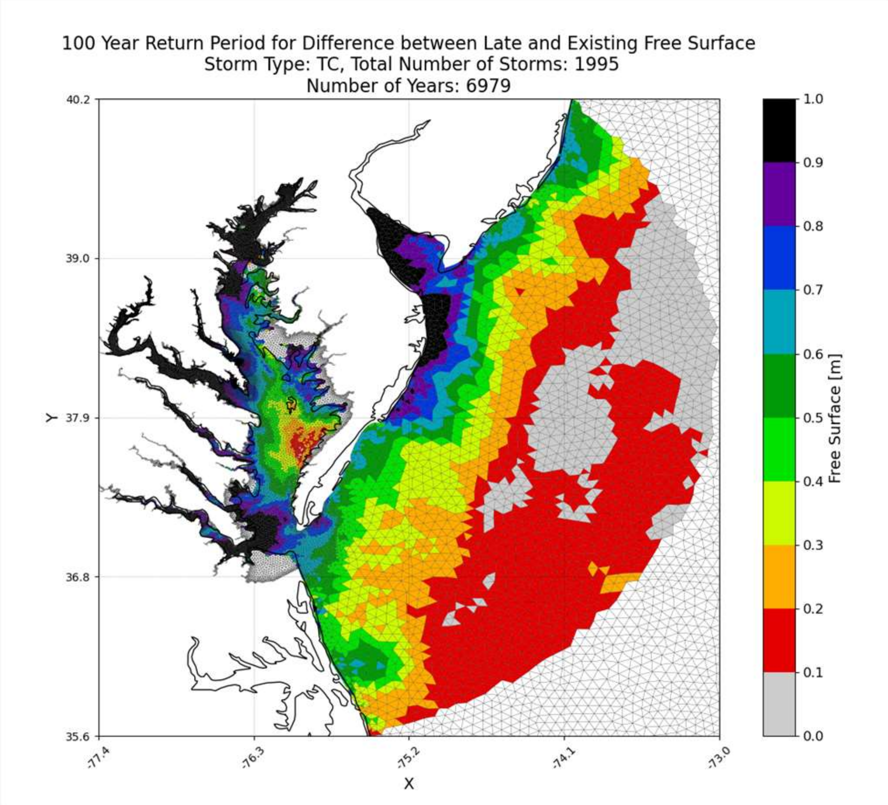


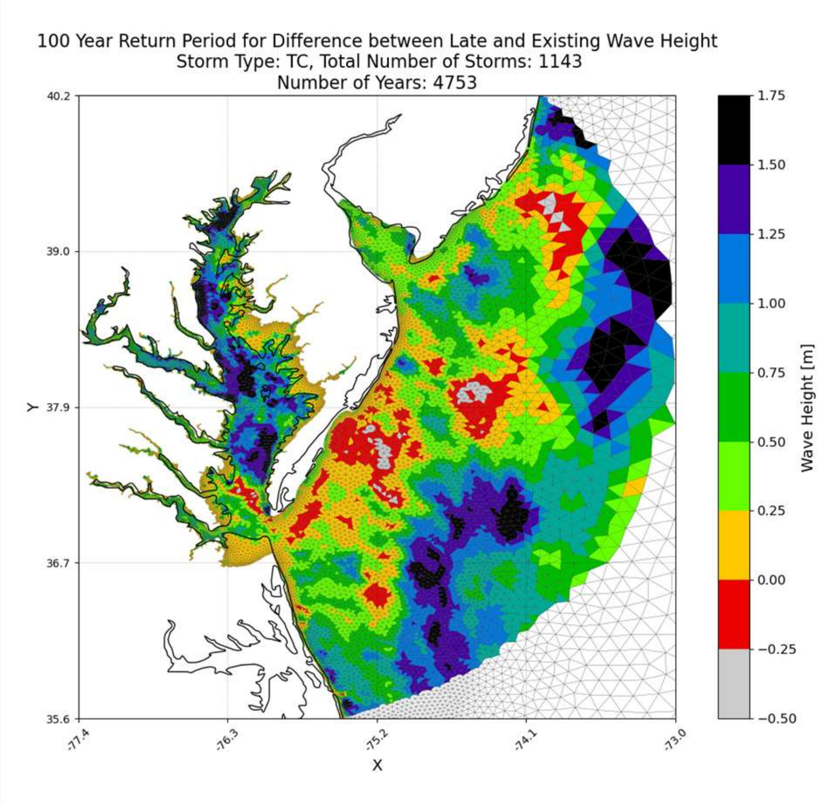
Copula Plots from Bivariate Analysis for Compound Probability





Predicted Change in 100-yr Return Period Water Levels and Waves from Existing to Late Century





Thank you for listening…

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