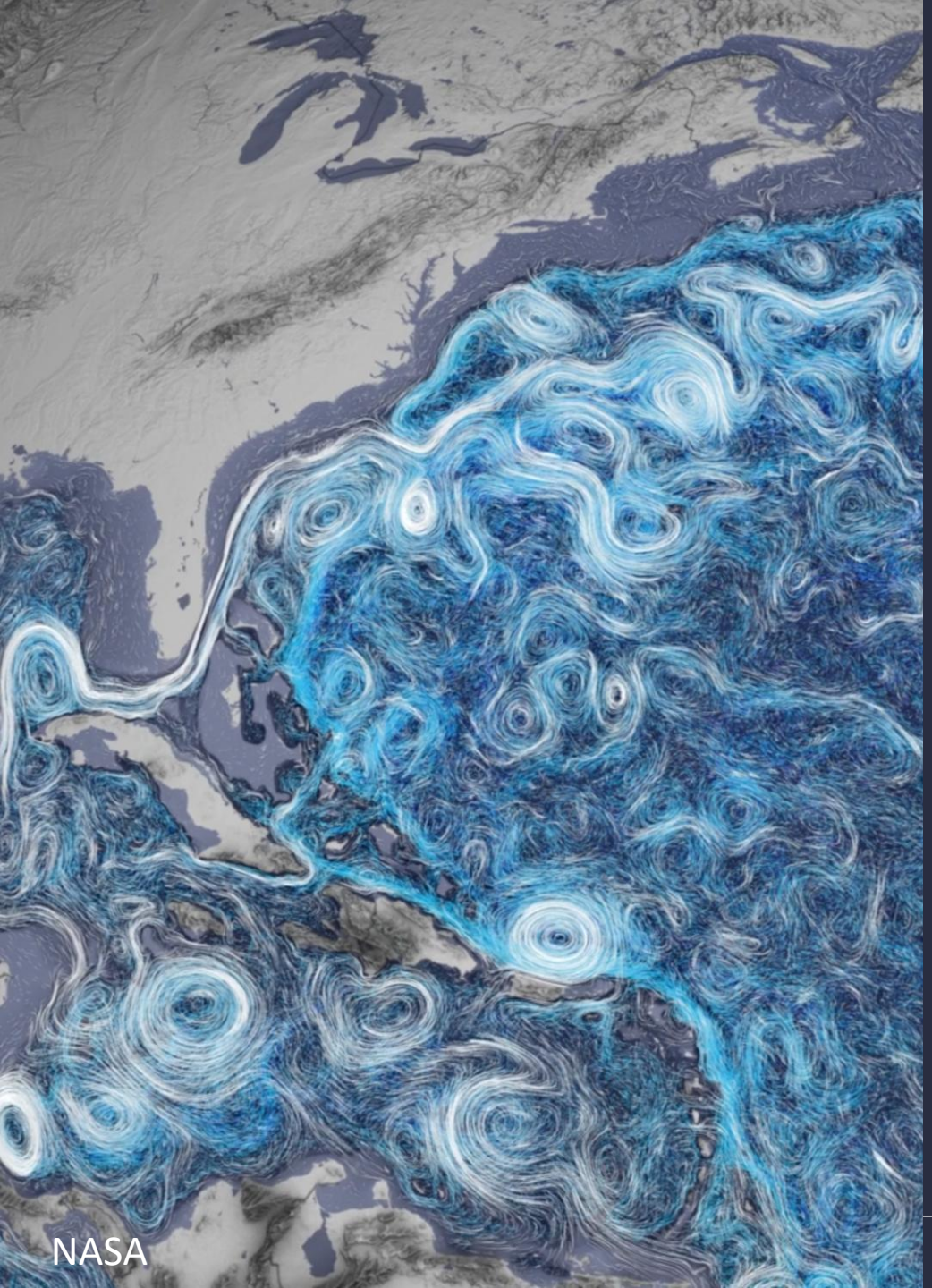

A Coupled 3D Ocean Circulation and Spectral Wave Model to Investigate Gulf Stream Effects on U.S. East Coast Waves and Water Levels

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Storm Surges and Coastal Hazards
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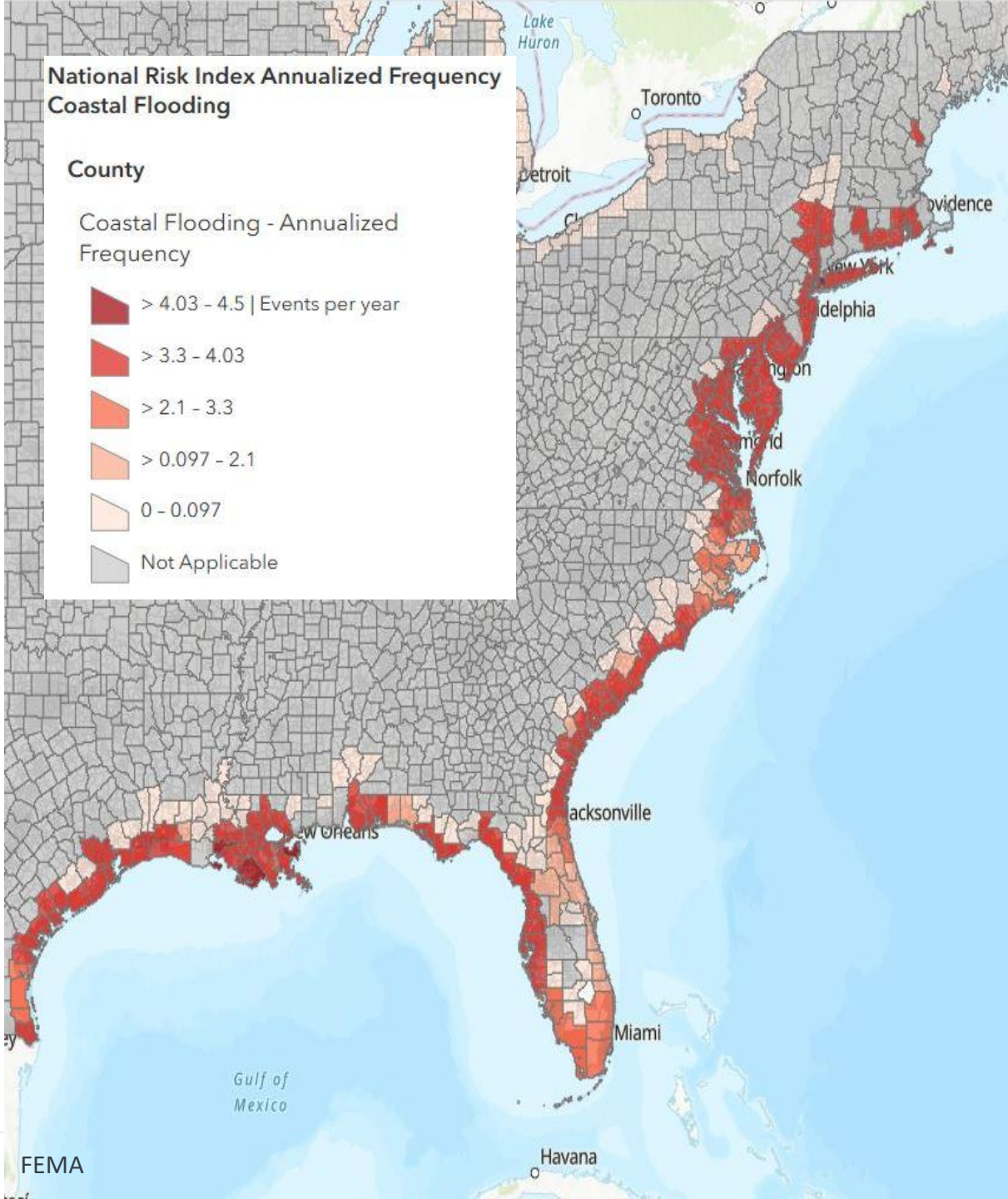
Motivation

- Accurate coastal flood prediction depends on how well we model water levels and waves.
- This requires models that capture processes across scales from the ocean to the coast.

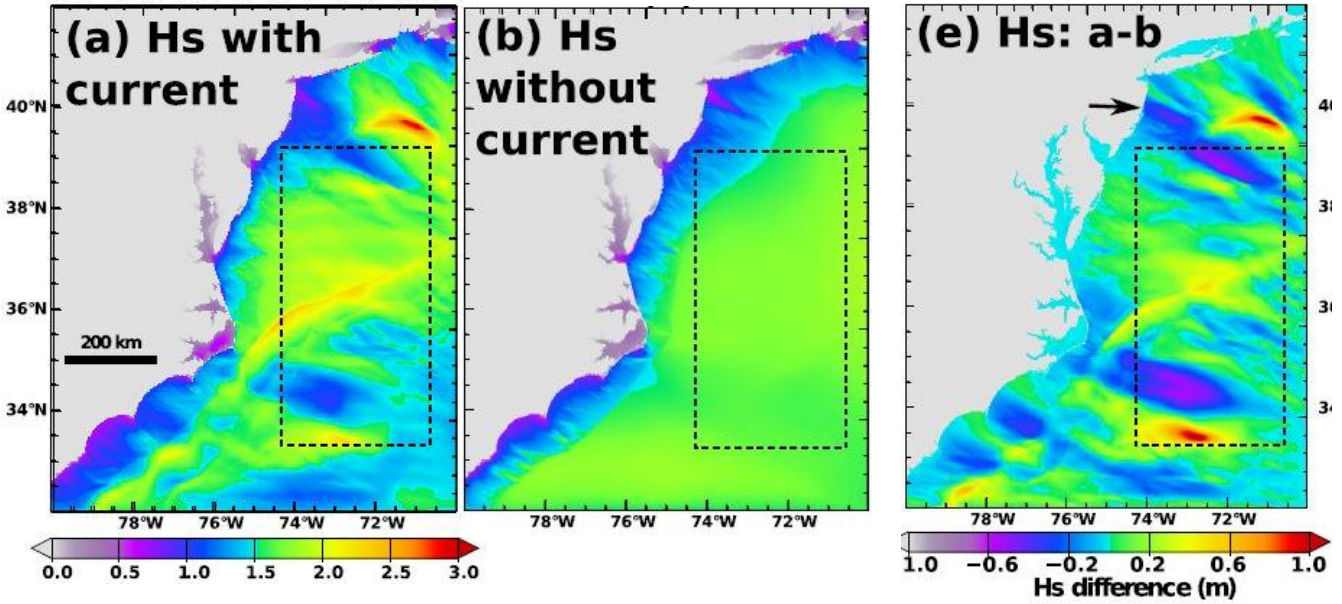


Motivation

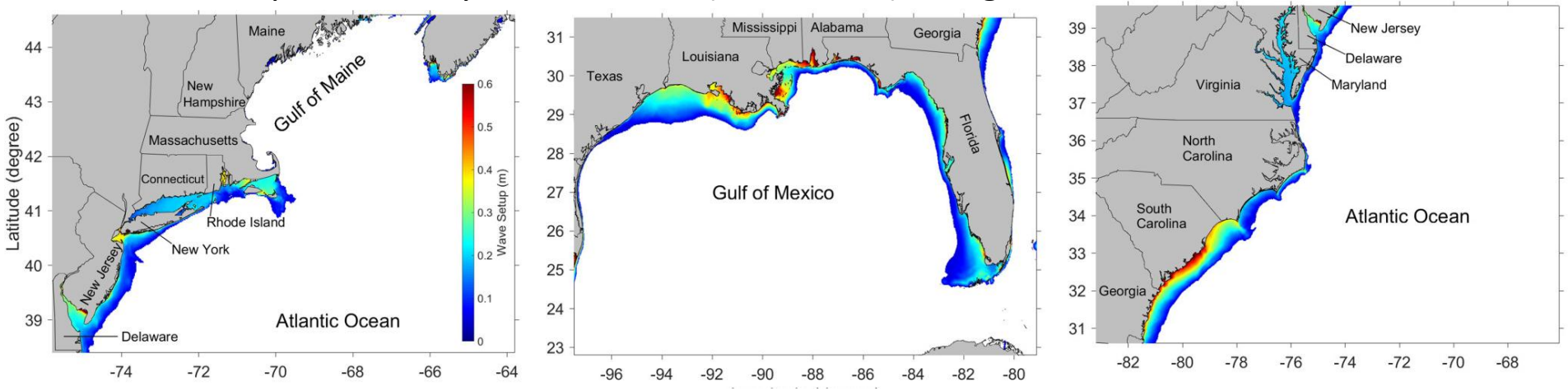
Key drivers

- Astronomical tides
- Storm surge (wind setup & inverse barometer effect)
- Baroclinic effects
- Wave-current interactions (coastal and deep ocean)
- Interactions among all processes

Impact of current on swells across the Gulf Stream on 18 September 2014, 6:00 UTC. Image from Ardhuin et al. 2017, JGR: Oceans



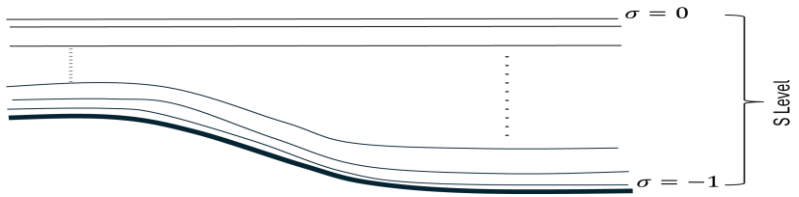
Maximum wave setup induced by historical TCs (1988-2015). Image from Marsooli and Lin 2018, JGR: Oceans



Objective: Validate and implement a coupled 3D baroclinic ocean circulation and spectral wave model (SCHISM + WWM) for modeling the effects of ocean currents in the western North Atlantic Ocean on coastal water levels and waves along the U.S. East and Gulf Coasts.

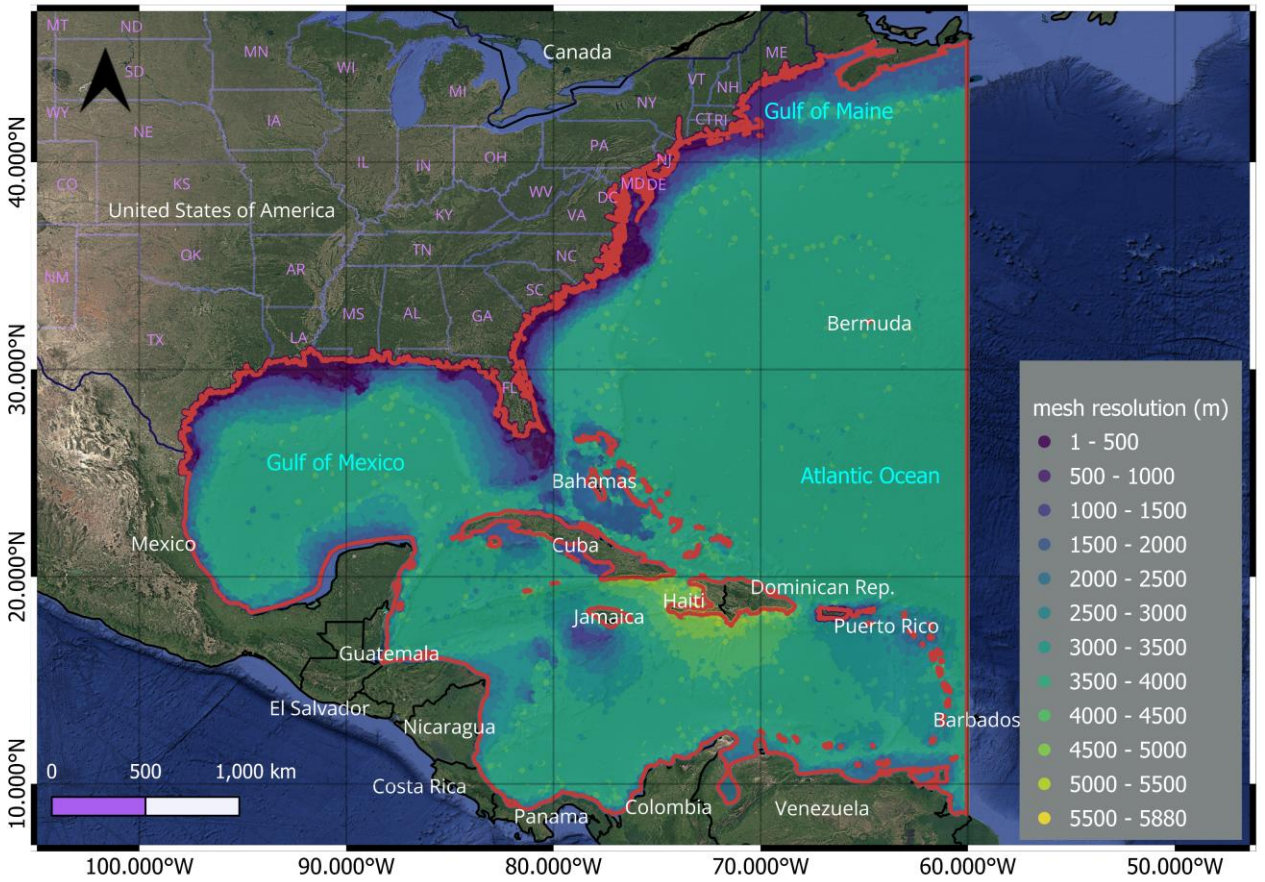
Methods: Computational Domain

- **Horizontal mesh resolution:** 2-6 km in the ocean; 1.5-2 km near coastlines; 600m in floodplains
- **Vertical resolution:** 20 sigma S layers



- Total of ~ 58 million nodes (2,926,236 nodes × 20 vertical layers)
- **Spectral Domain:** 50 frequency and 72 directional bins
- 150 s **time step** in SCHISM, 20-minute coupling with WWM

Unstructured mesh (NOAA 3-D Surge and Tide Operational Forecast System for the Atlantic Basin: STOFS-3D-Atlantic)



- **Simulation period:** December 2016 (November for spin-up simulation)

Methods: Boundary Conditions

- Tidal forcings (M2, S2, N2, K2, K1, O1, P1, and Q1)

FES 2014

- Water velocities
- Temperatures
- Salinity

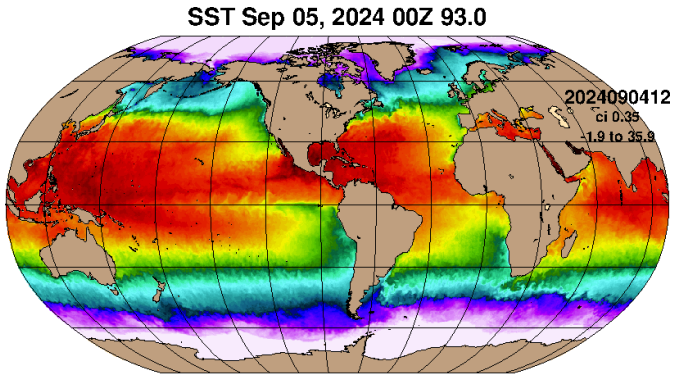
HYCOM

SCHISM

Water surface elevation and velocities; winds

WWM

Radiation stress; surface roughness



https://www7320.nrlssc.navy.mil/

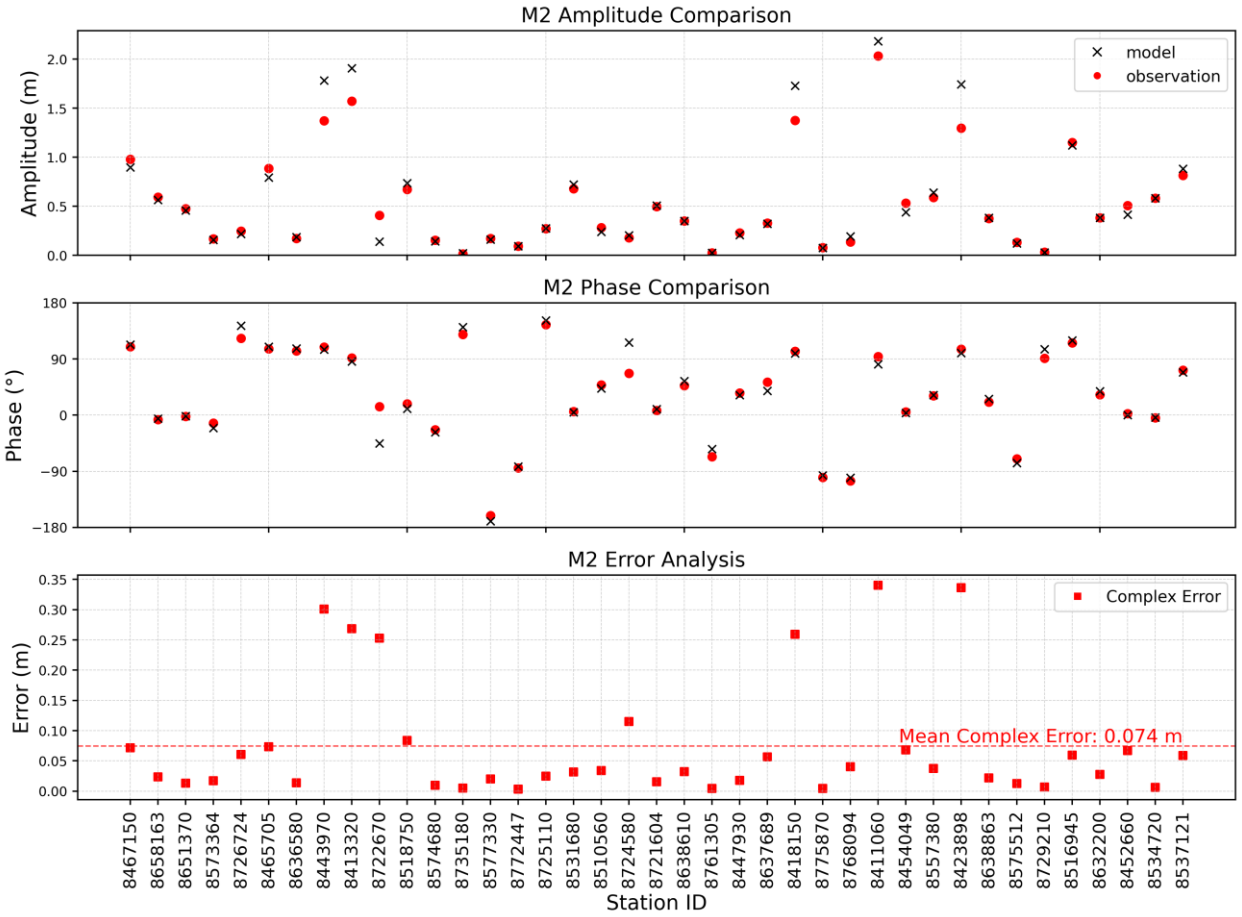
ERA5

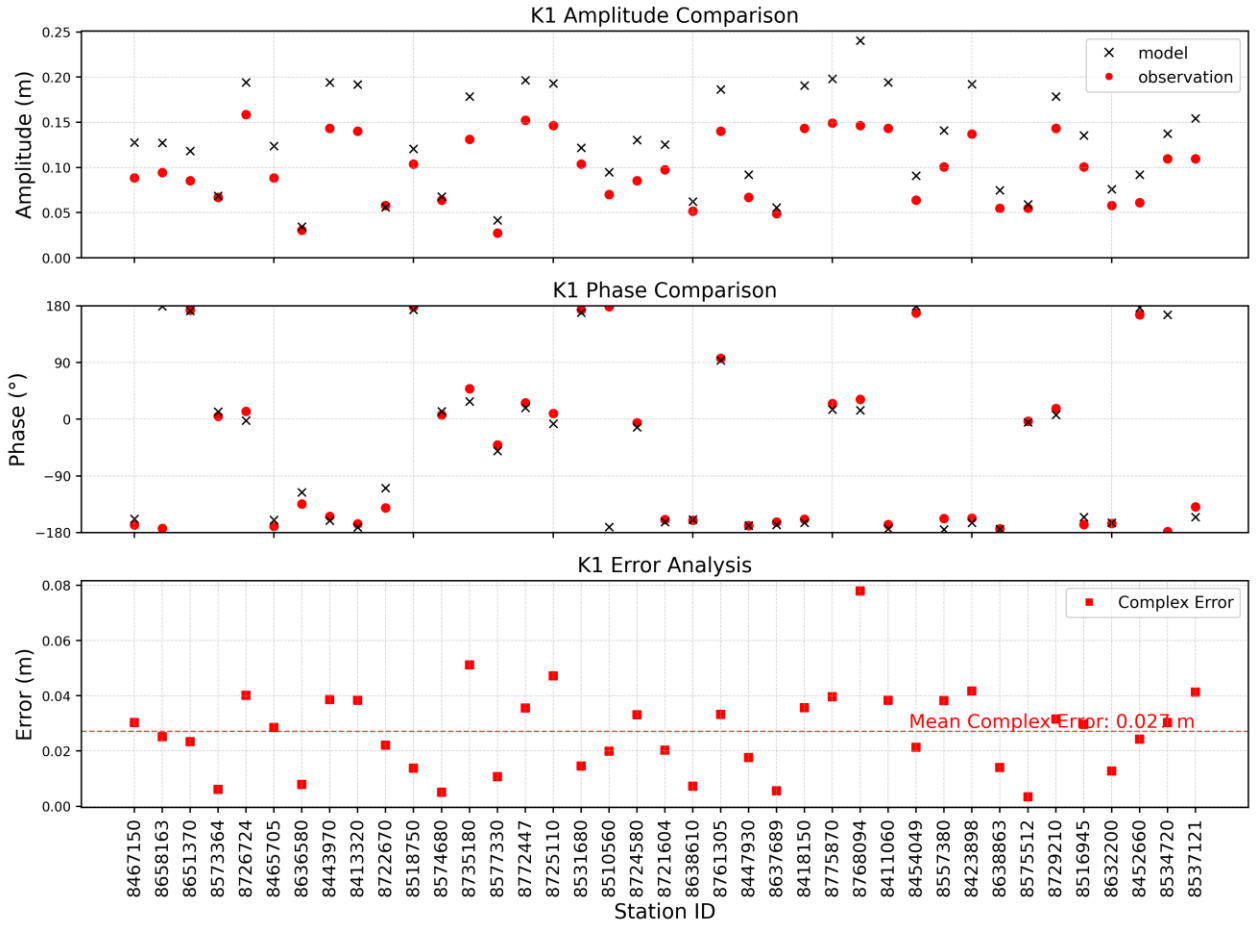
- Wind
- Pressure

ERA5

- Frequency-direction energy spectrum

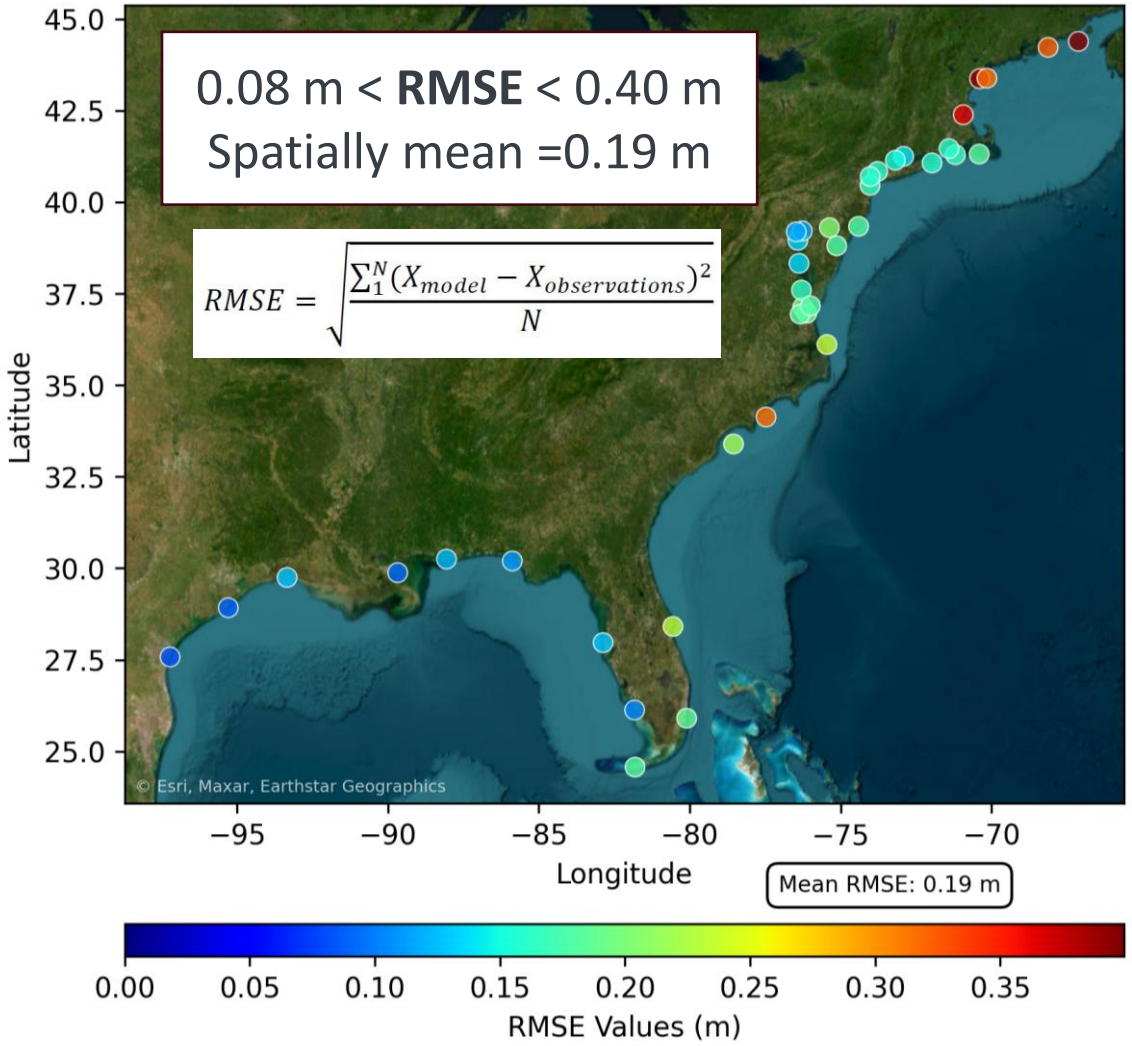
Validation: Tide Amplitude and Phase

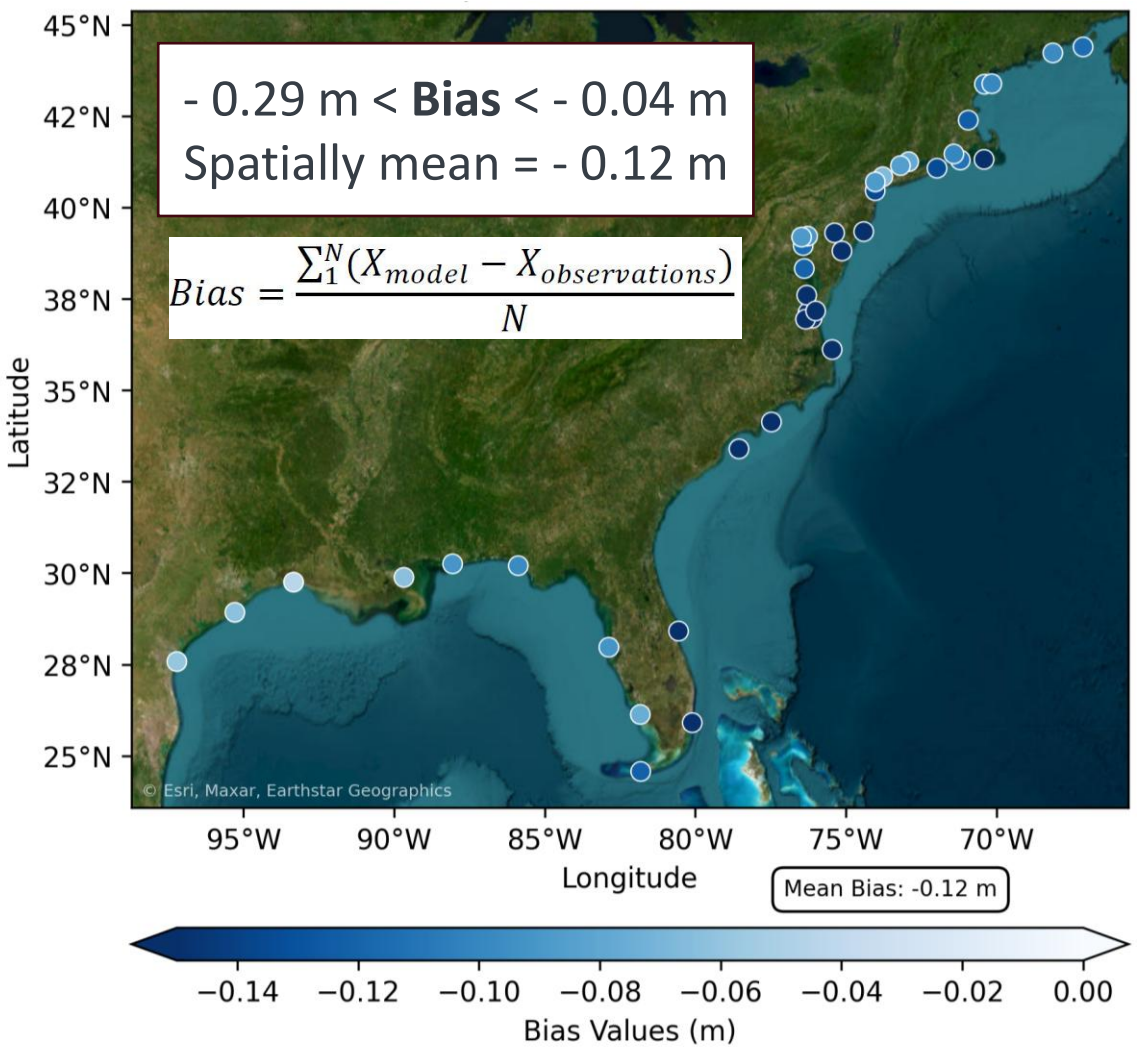




Complex error: $RMSE = \left(0.5 * \left((A_0 cosP_0 - A_m cosP_m)^2 + (A_0 sinP_0 - A_m sinP_m)^2\right)\right)^{1/2}$

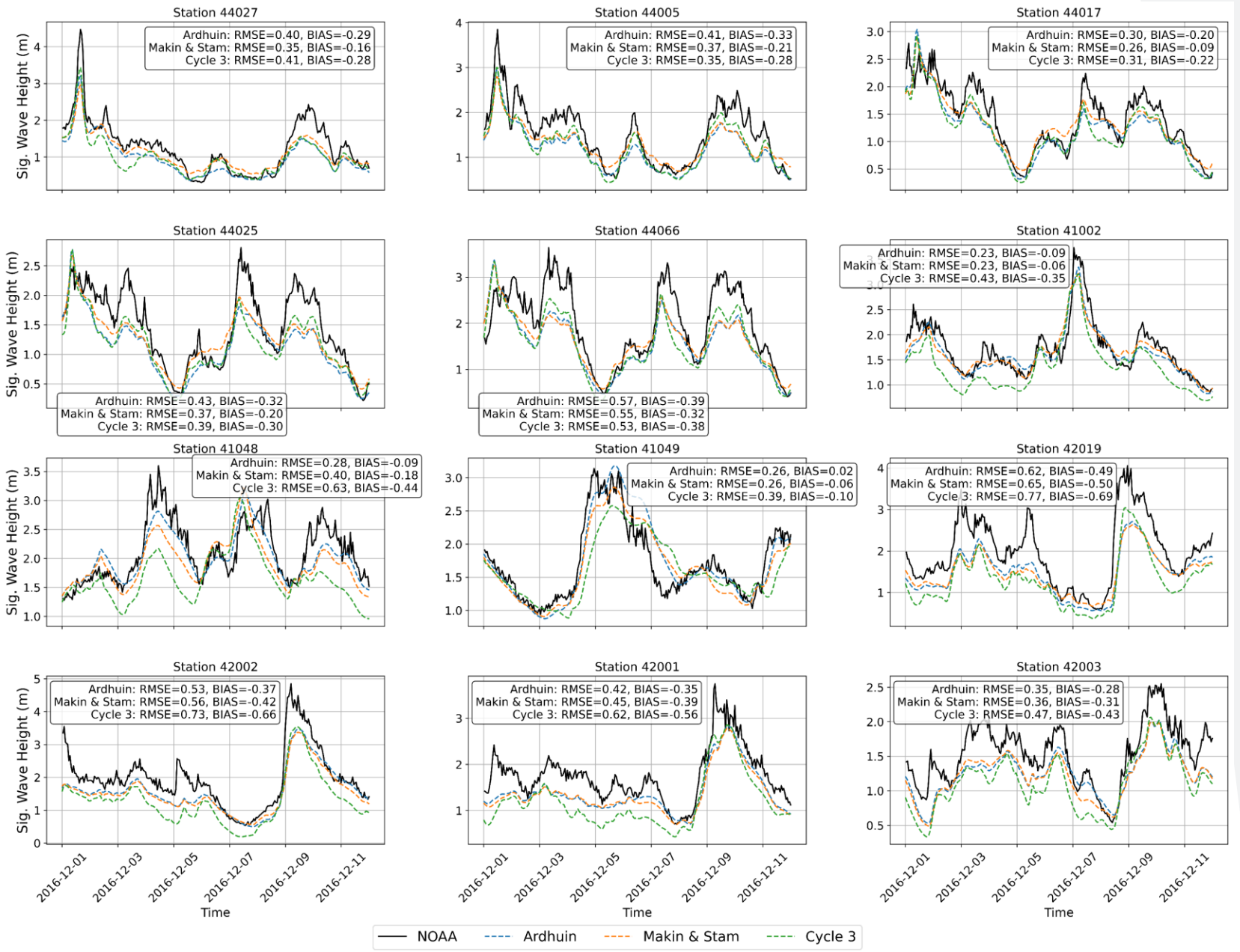
Validation: Total Water Level





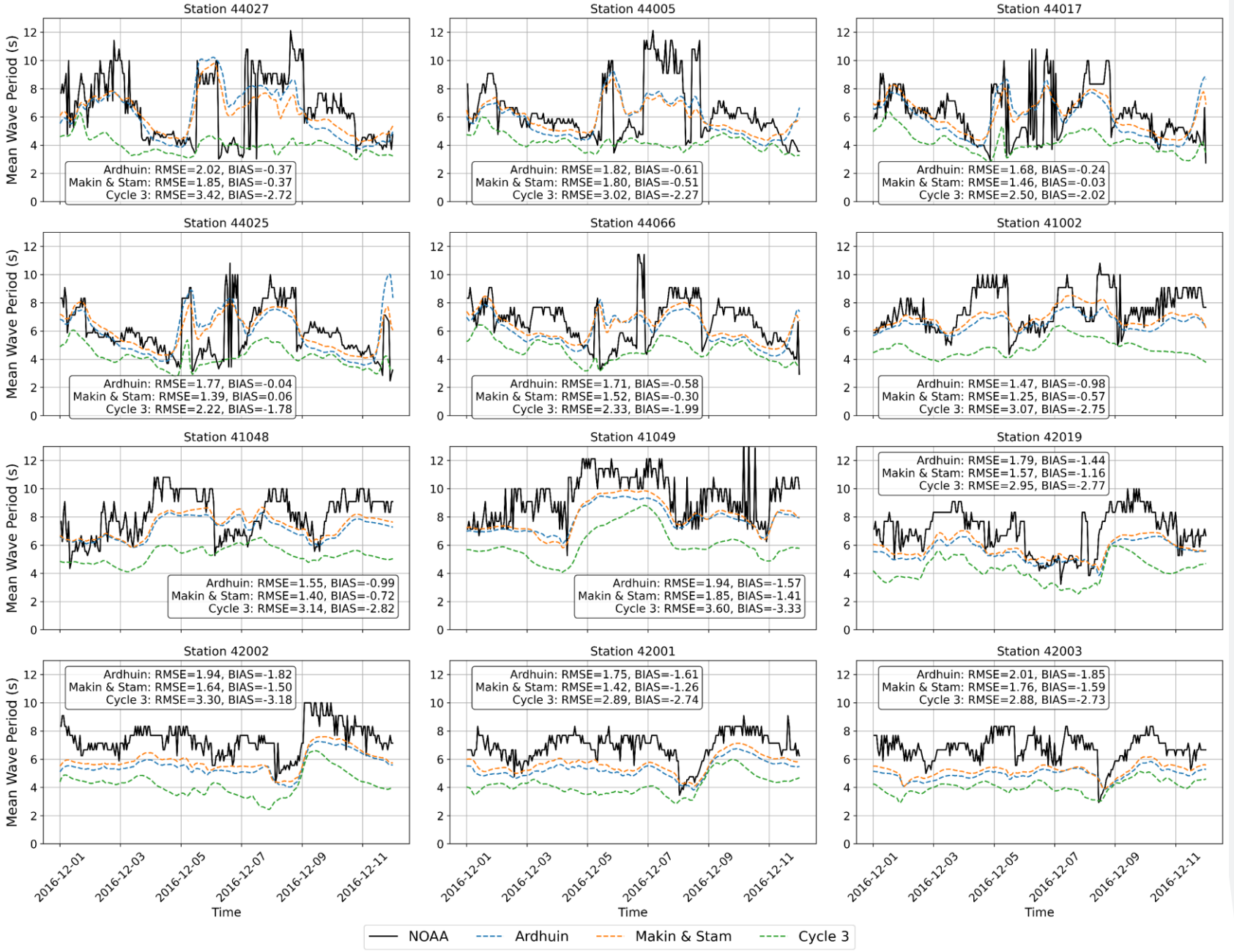
Validation: Wave Height

- "Ardhuin" performed better at most locations, including all stations in the Gulf of Mexico (stations 41048, 42019, 42002, 42001,42003).
- In deep waters beyond the continental shelf (such as stations 41048, and 41049), "Ardhuin" performs better in capturing extreme wave height peaks.



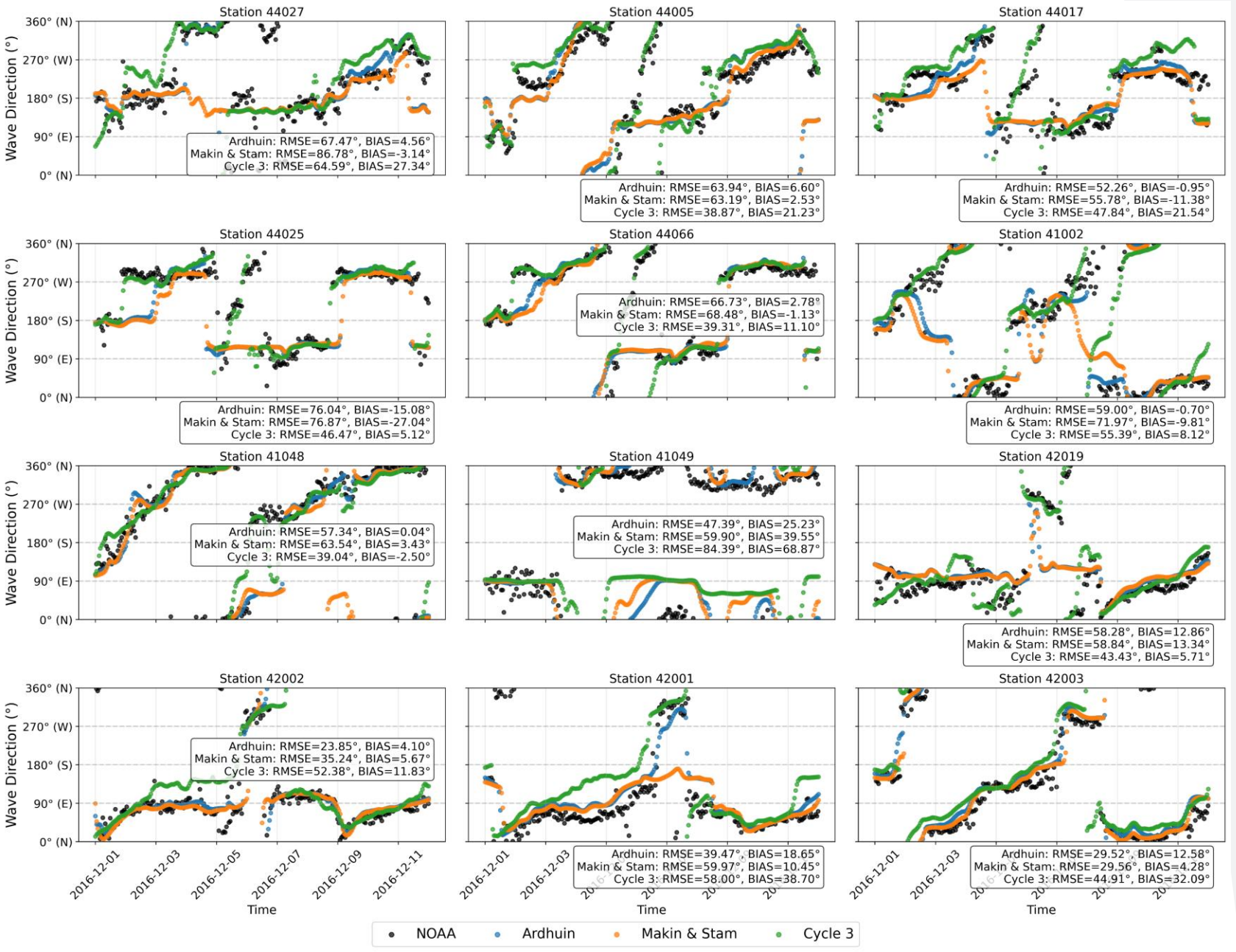
Validation: Wave Period

- "Makin and Stam" performs better in terms of RMSE and bias in all stations.
- "Cycle Three" substantially underestimates wave periods across all stations.
- In general, all models show limitations in capturing rapid transitions in wave period.

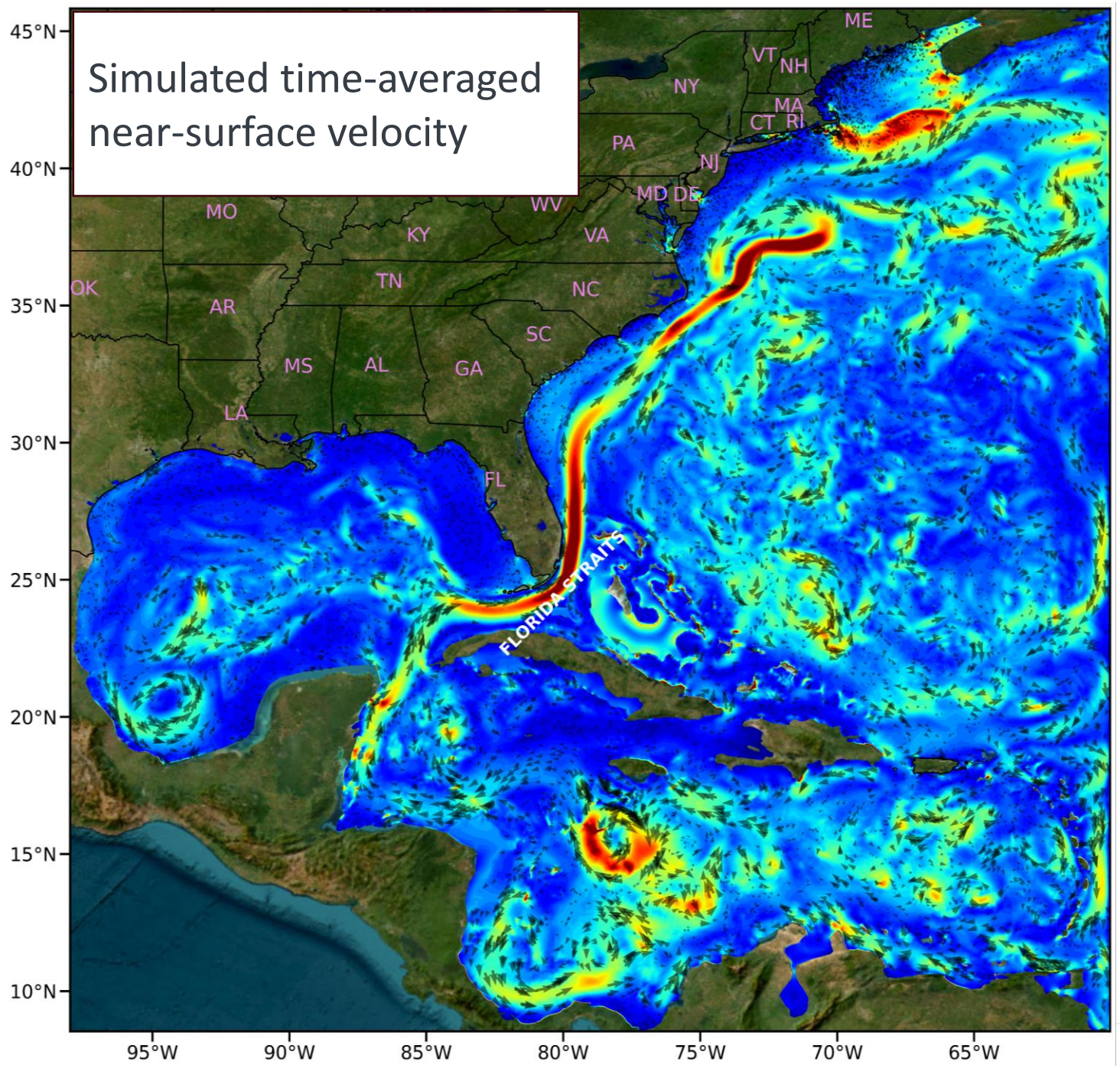


Validation: Wave Direction

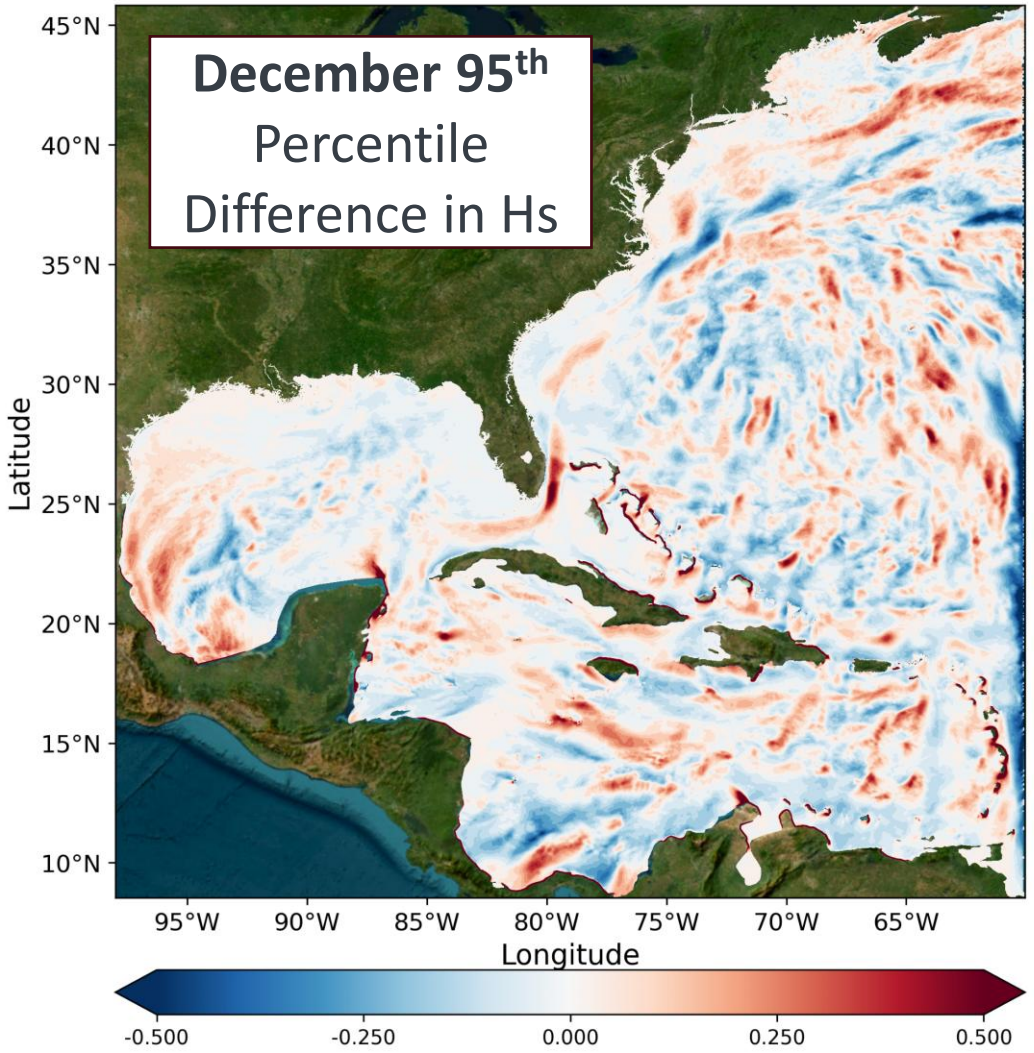
- "Cycle Three" performs well at many stations (44027, 44005, 44017, 44025, 44066, 41002, 41048, and 42019).
- "Ardhuin" performs better at stations 41049, 42001, and 42003.

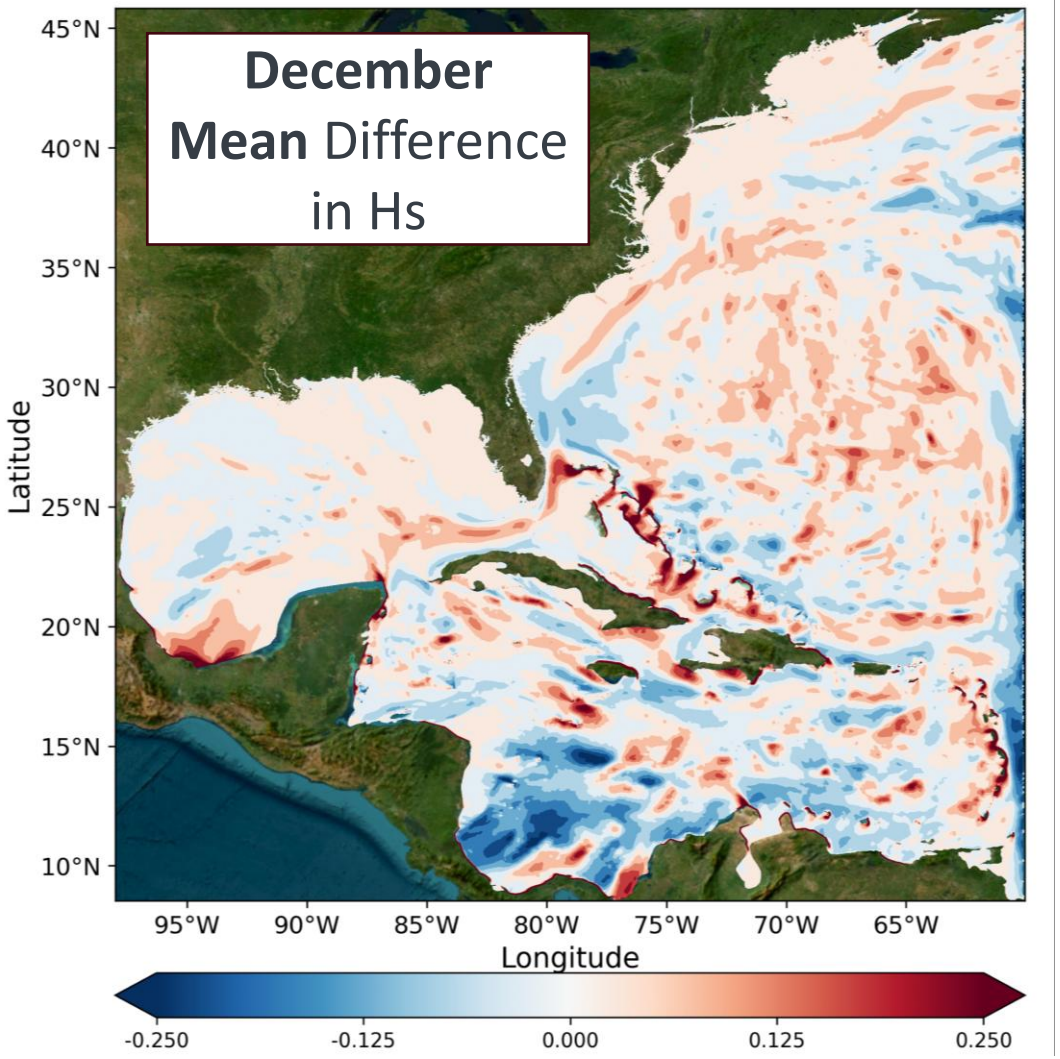


Simulated time-averaged near-surface velocity



Difference in Hs ("with currents" minus "without currents")

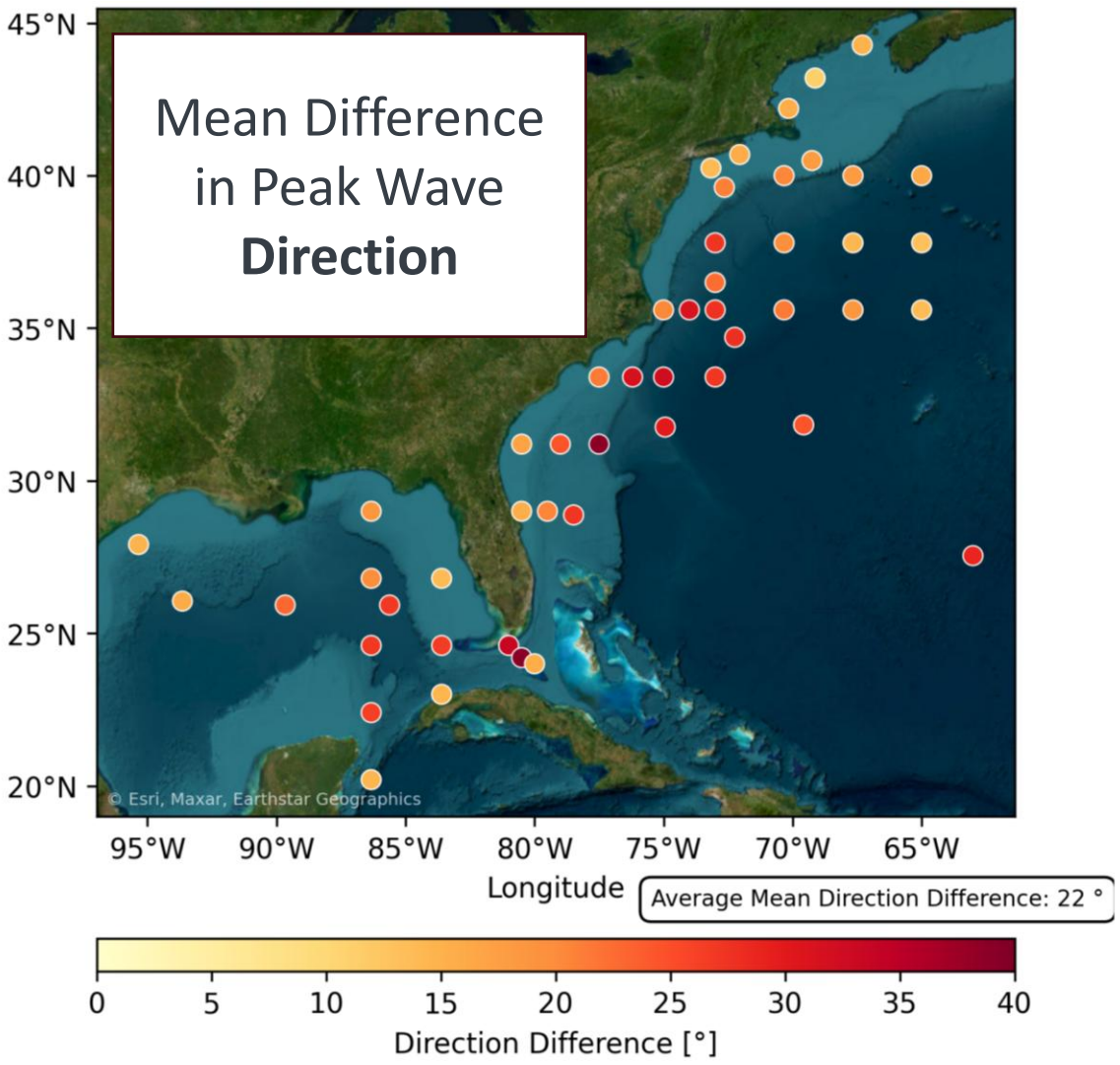


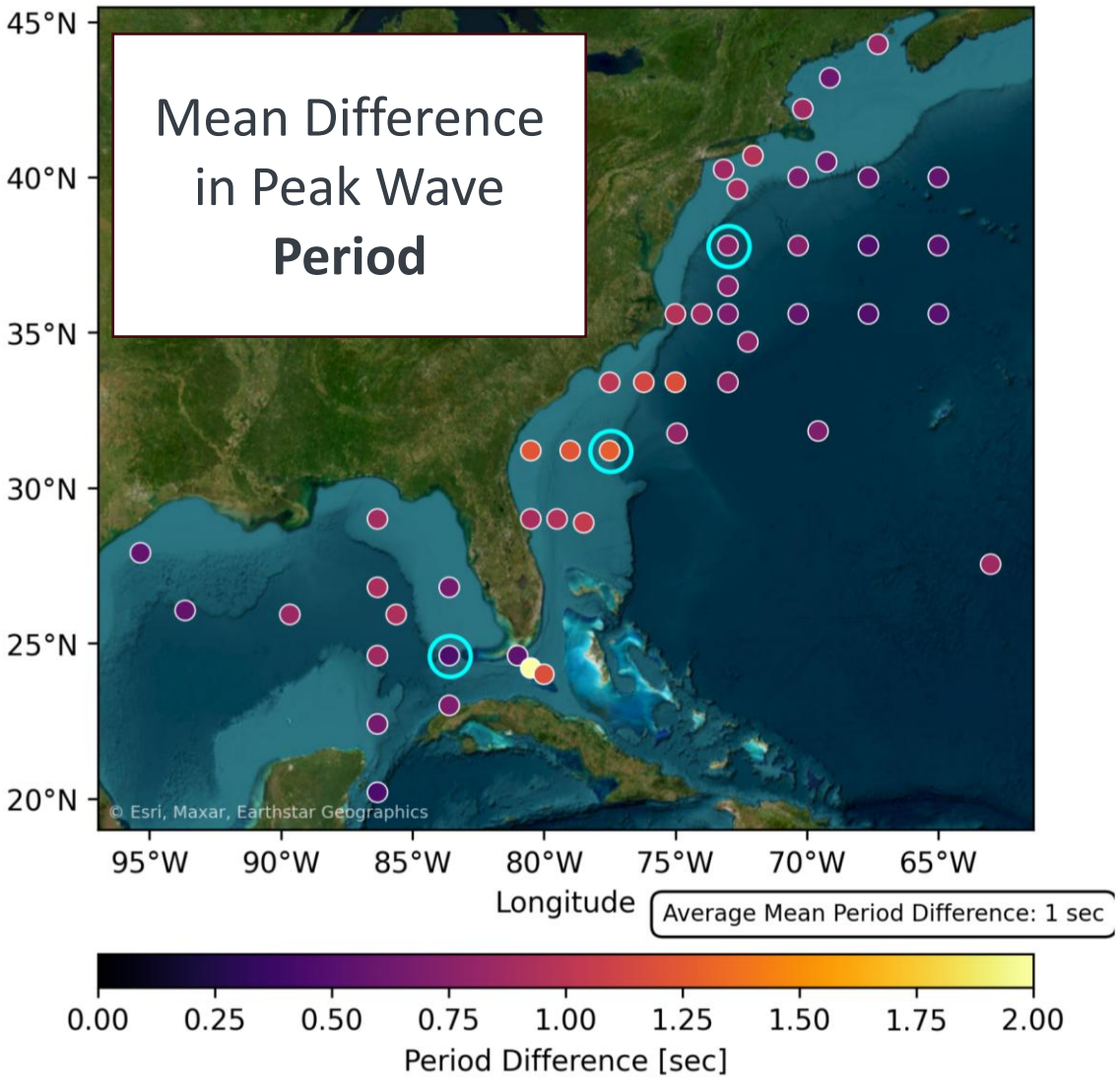


Negative differences: currents dampen wave heights

Positive differences: currents amplify wave heights

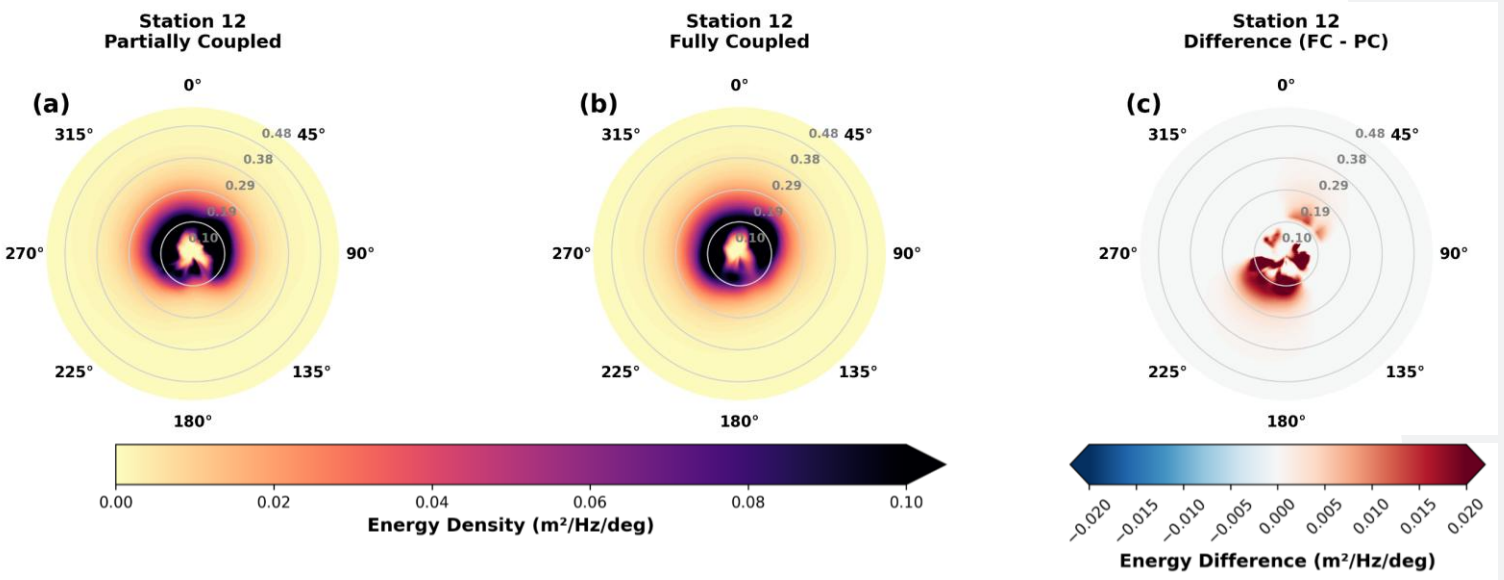
Difference in Peak Direction and Period

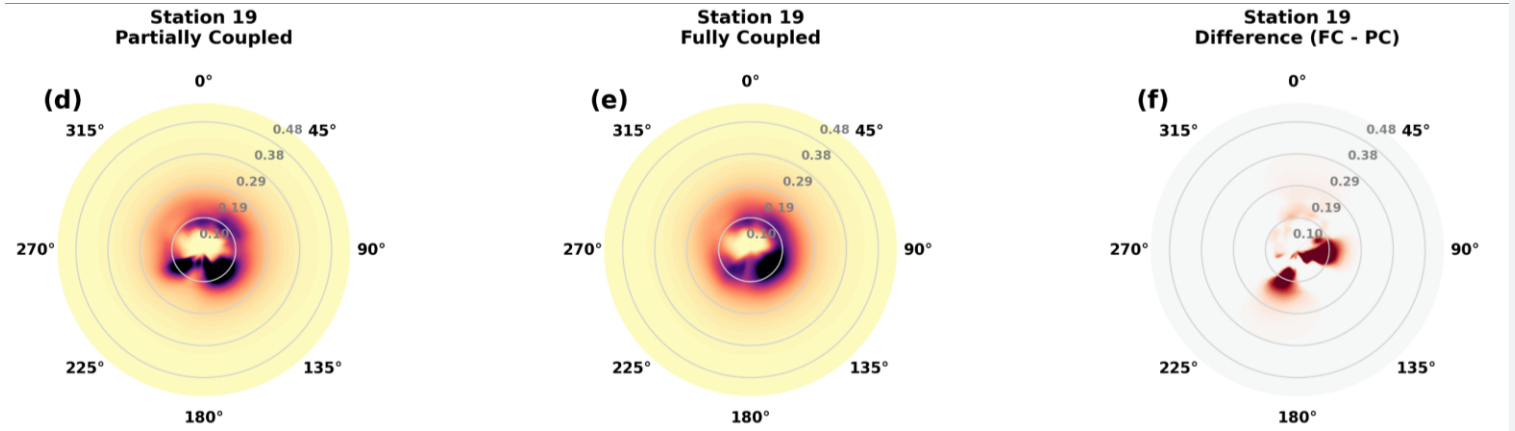


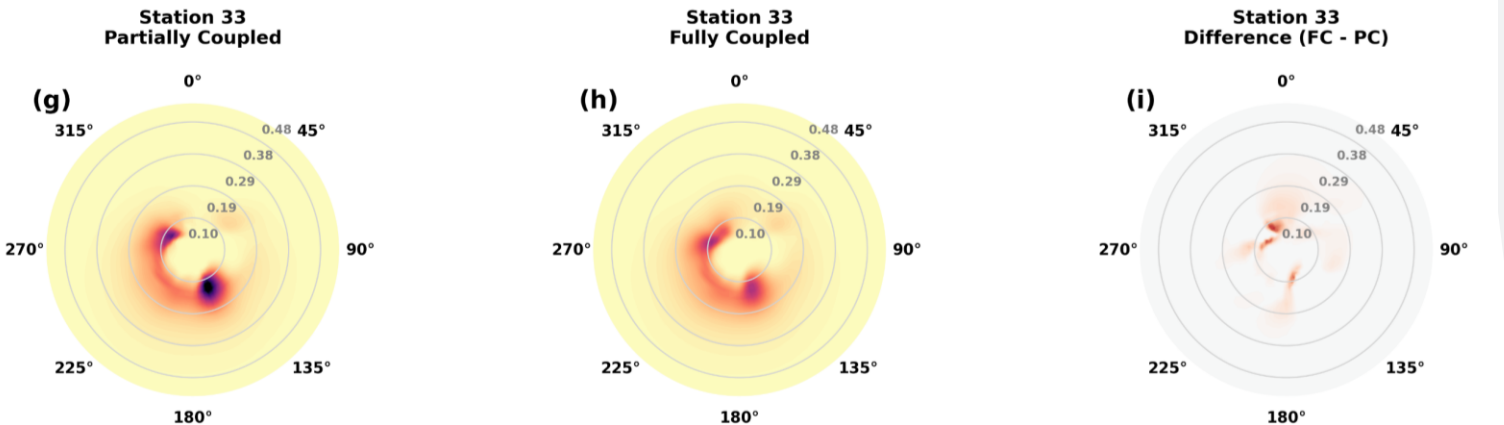


Difference in Energy Spectrum

- Currents substantially influence the distribution of wave energy in the frequency-direction domain.
- The magnitude and pattern of these changes vary significantly between locations depending on their local waves and currents.







Summary:

- The study validated a three-dimensional baroclinic fully coupled circulation and spectral wave model for the western North Atlantic basin (coupled SCHISM-WWM III)
- Substantial ocean current effects on wave heights were found in most regions of the basin.
- The largest effects are to alter the characteristics of waves within and in the vicinity of the Gulf Stream, but regions far from the Gulf Stream are still influenced.
- The effects of currents on wave spectrum, including peak wave period and direction, would have important implications for coastal hazards (e.g., shoreline change).

Next step:

- To quantify the direct and indirect (through changes in waves) effects of ocean current on coastal water levels and flooding.

Thank You!

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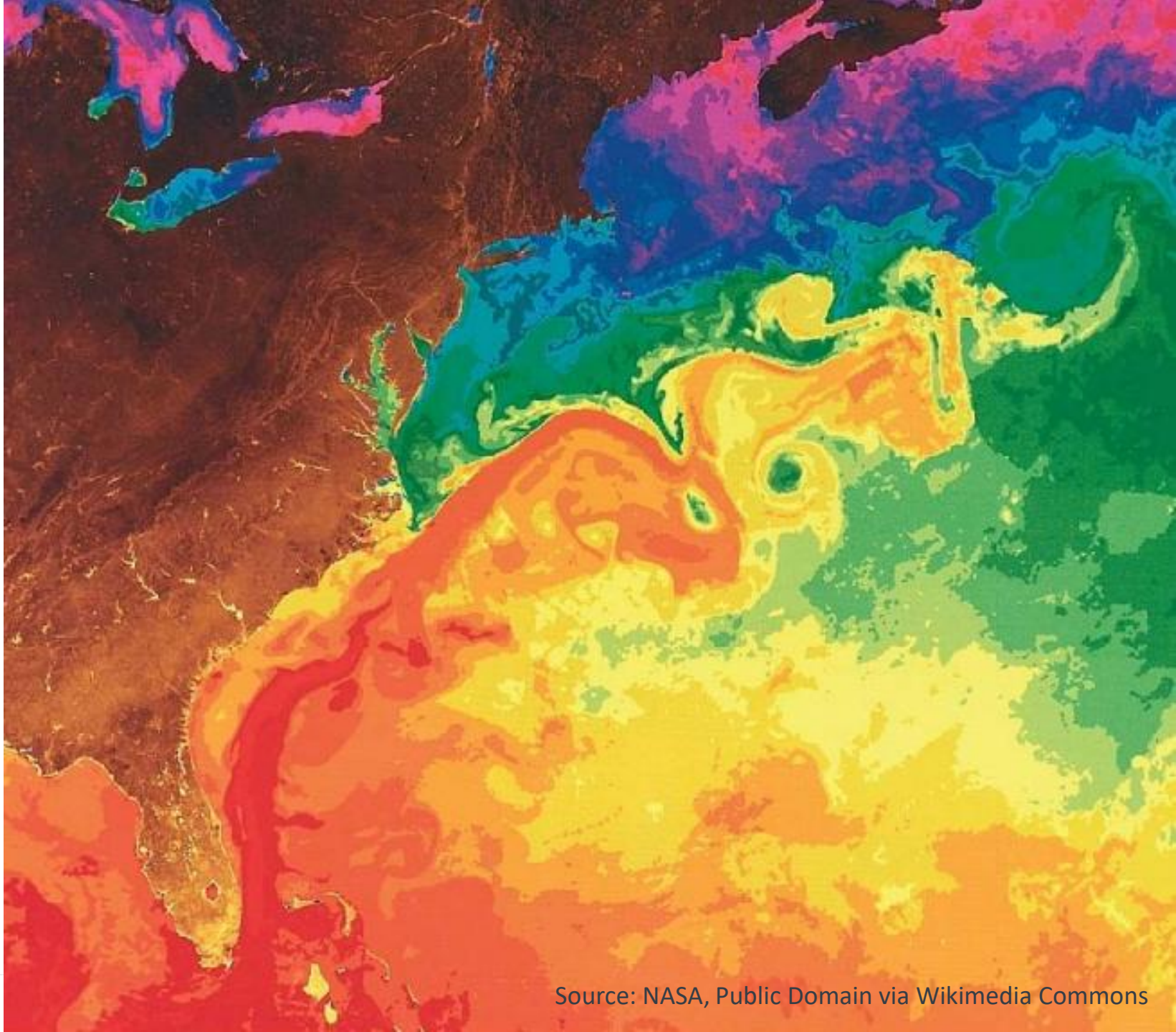

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