Hurricane-Induced Wave Forcing and Associated Wetland Erosion Mechanisms in a Shallow Bay Environment

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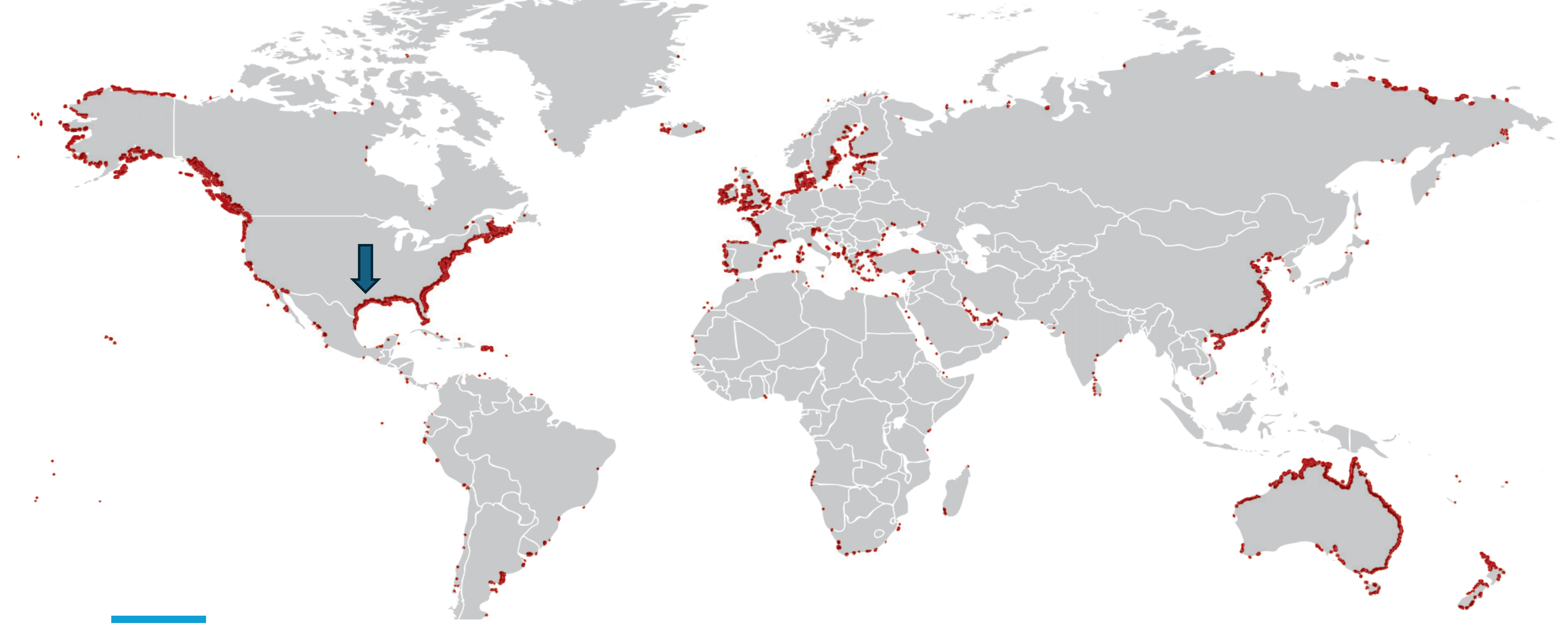
4TH INTERNATIONAL WORKSHOP ON WAVES, STORM SURGES, AND COASTAL HAZARDS
Incorporating the 18th International Waves Workshop

TXGLO



Data from Mcowen et al. (2017), image from FitzGerald and Hughes (2019)

Global distribution of salt marshes

Motivation and Significance

- Coastal wetlands buffer surge and waves
- Hurricanes rapidly redistribute sediment and reshape edges
- Managers need trustworthy, event-scale predictions

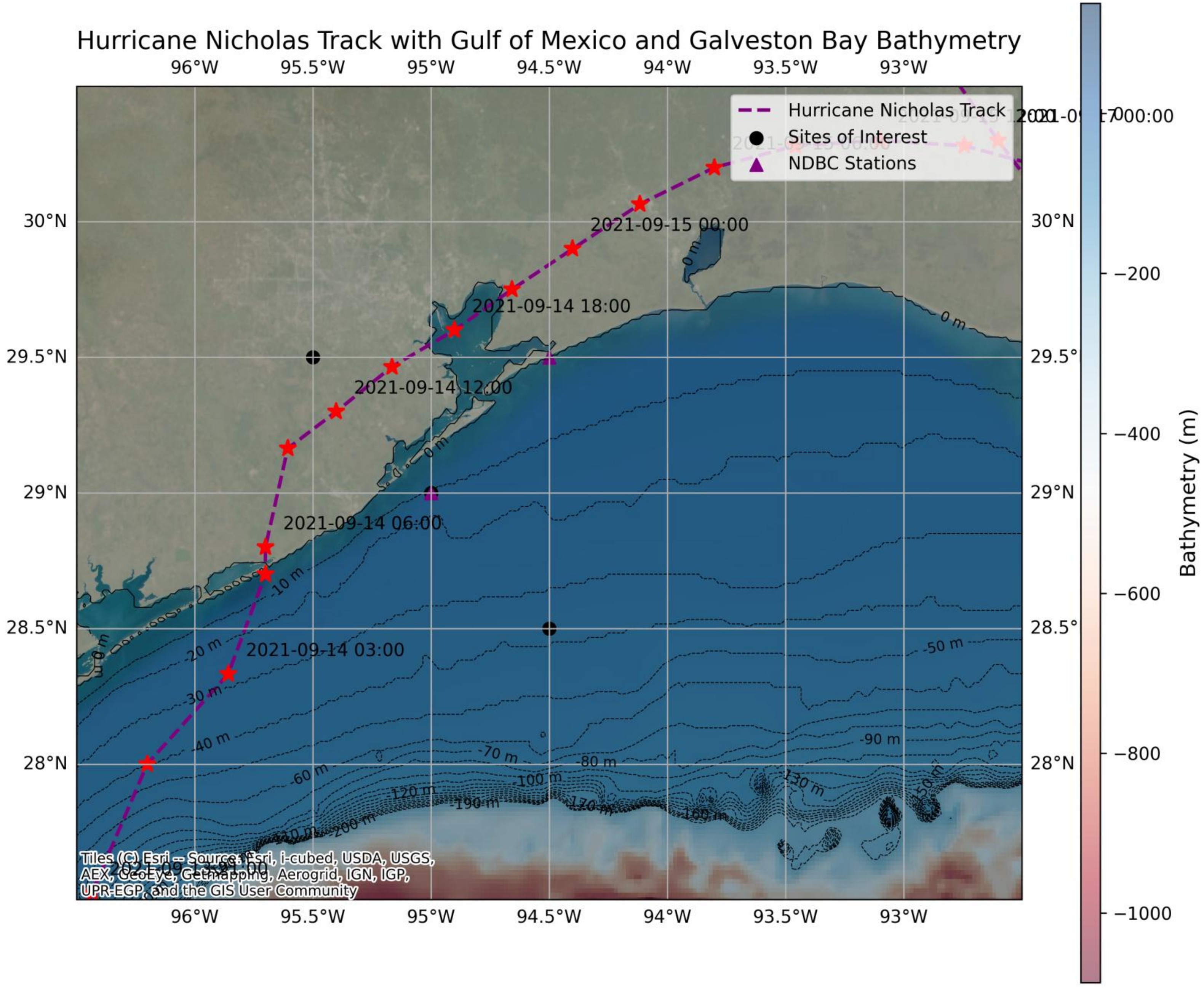
Study area & event

- Micro-tidal West Galveston Bay, Texas, U.S.

  (avg depth ~1.8 m)

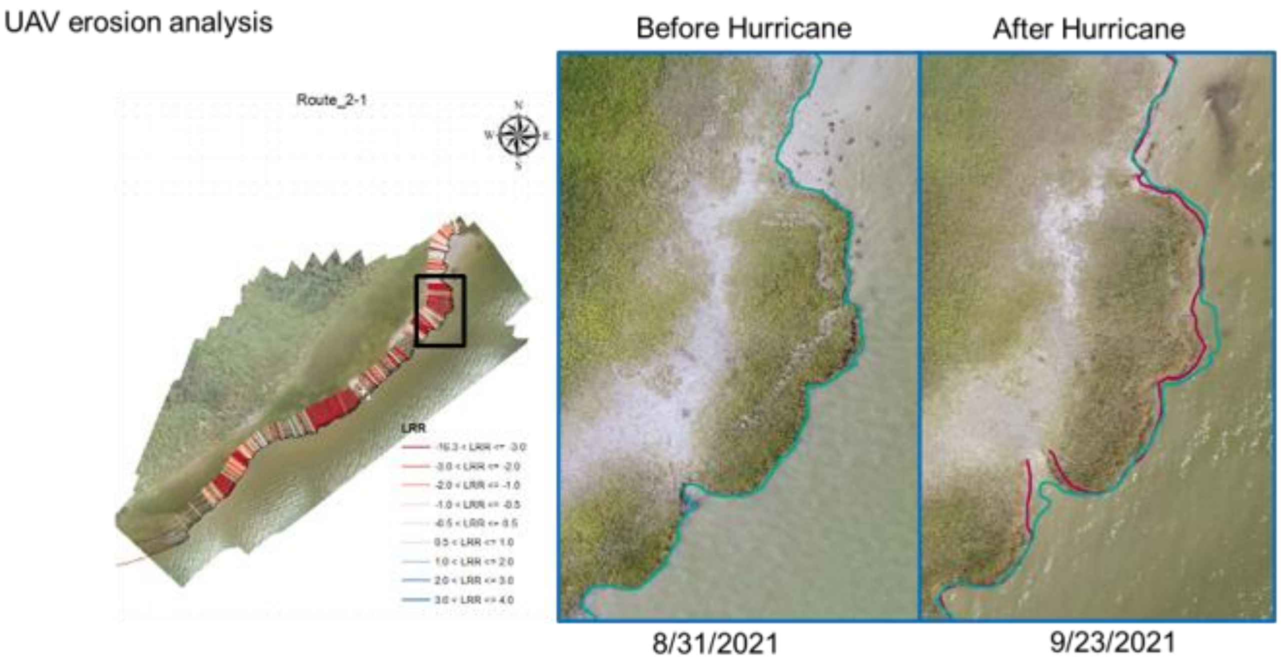
- Nicholas landfall Sep 14, 2021; pre/post survey window Aug 31–Sep 16

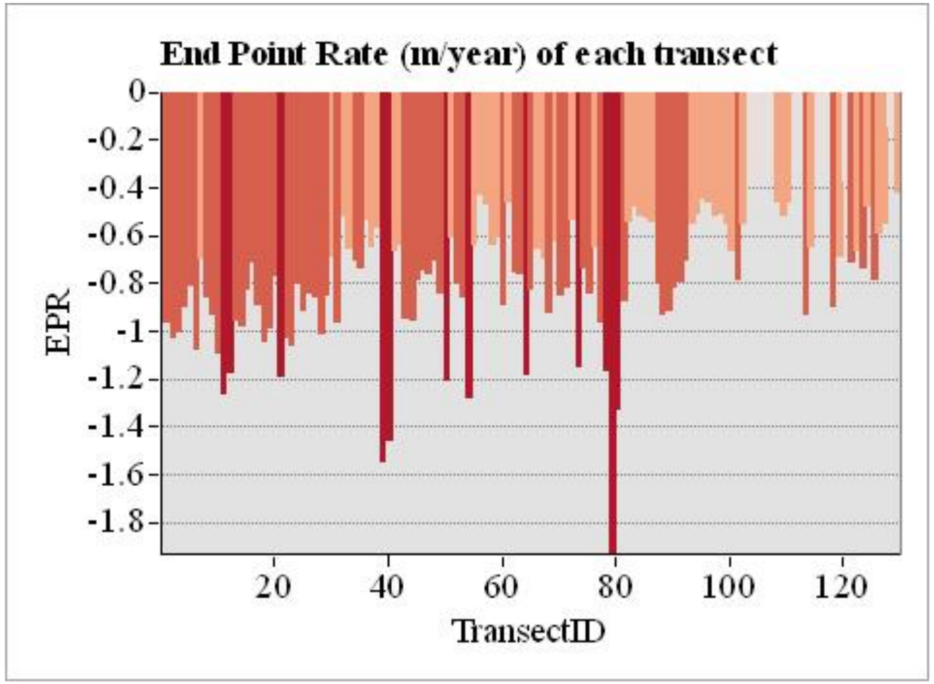
- Marsh edges exposed to northerly winds and short fetch



Observations

- 4 pressure transducers (2–16 Hz); 1 OBS near bed
- Aug 31–Sep 23 deployment across the event window
- UAV SfM orthomosaics pre/post; PIV/DSAS shoreline change

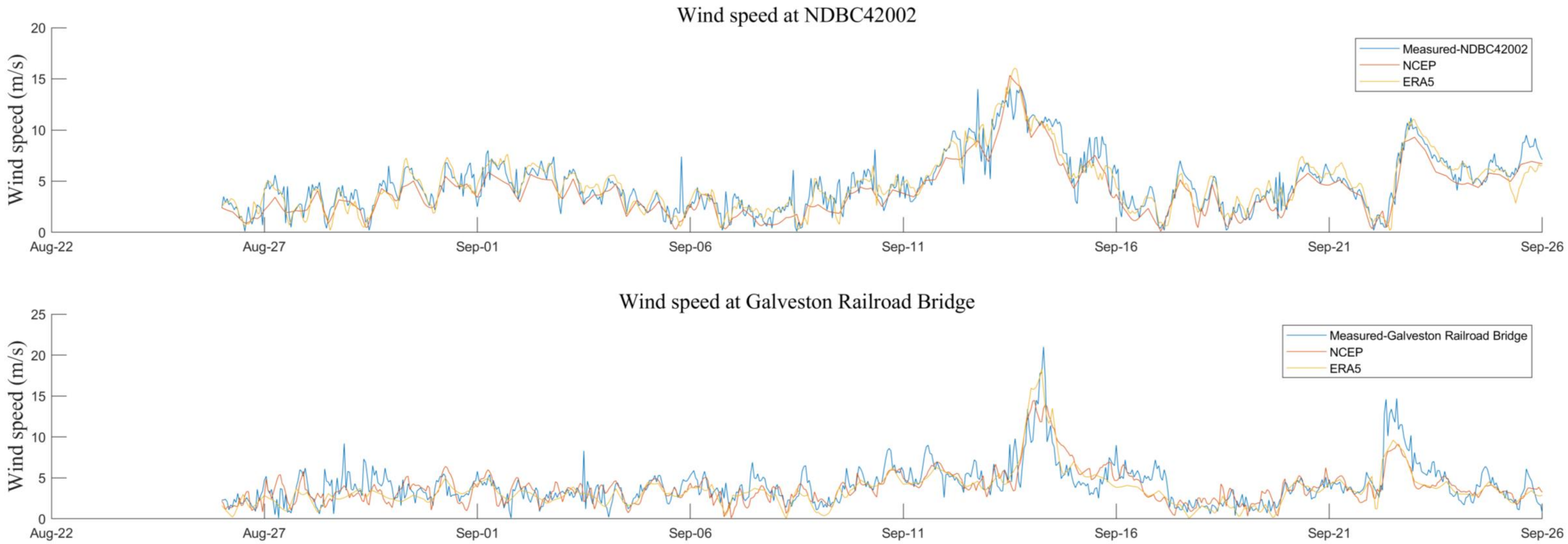




Analysis results from
Digital Shoreline Analysis System (DSAS)

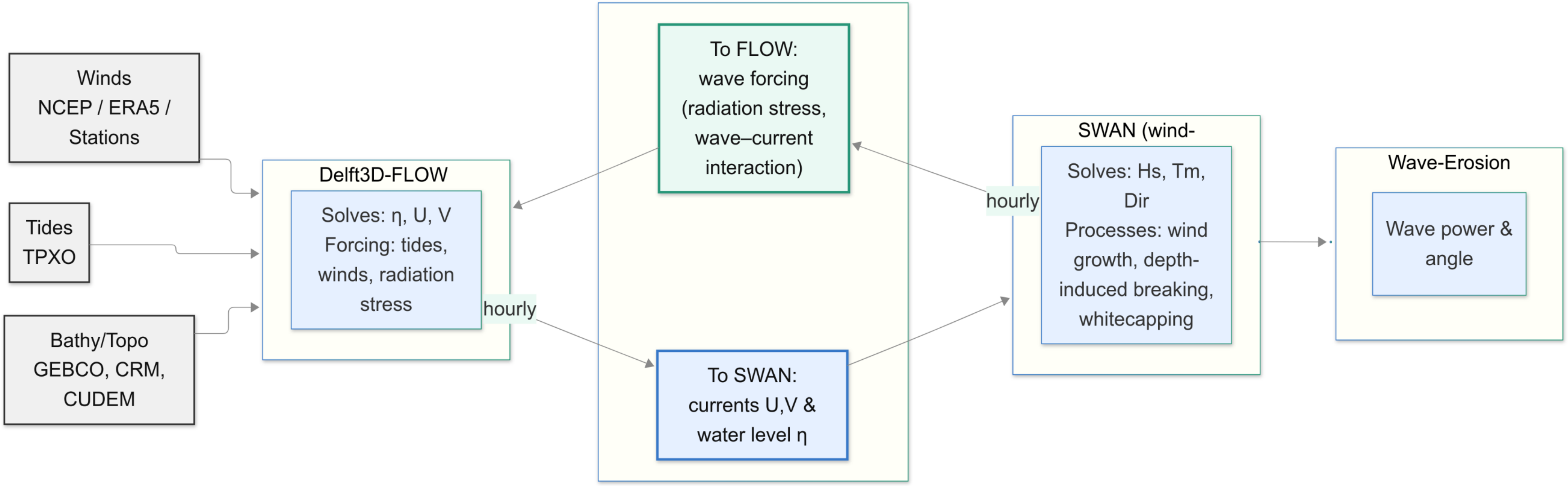
Wind forcing comparison for Modelling

- ERA5 vs NCEP vs local stations
- Both under-estimate peak winds; NCEP tracks peaks better
- Offshore buoy trends align; local structure matters in-bay



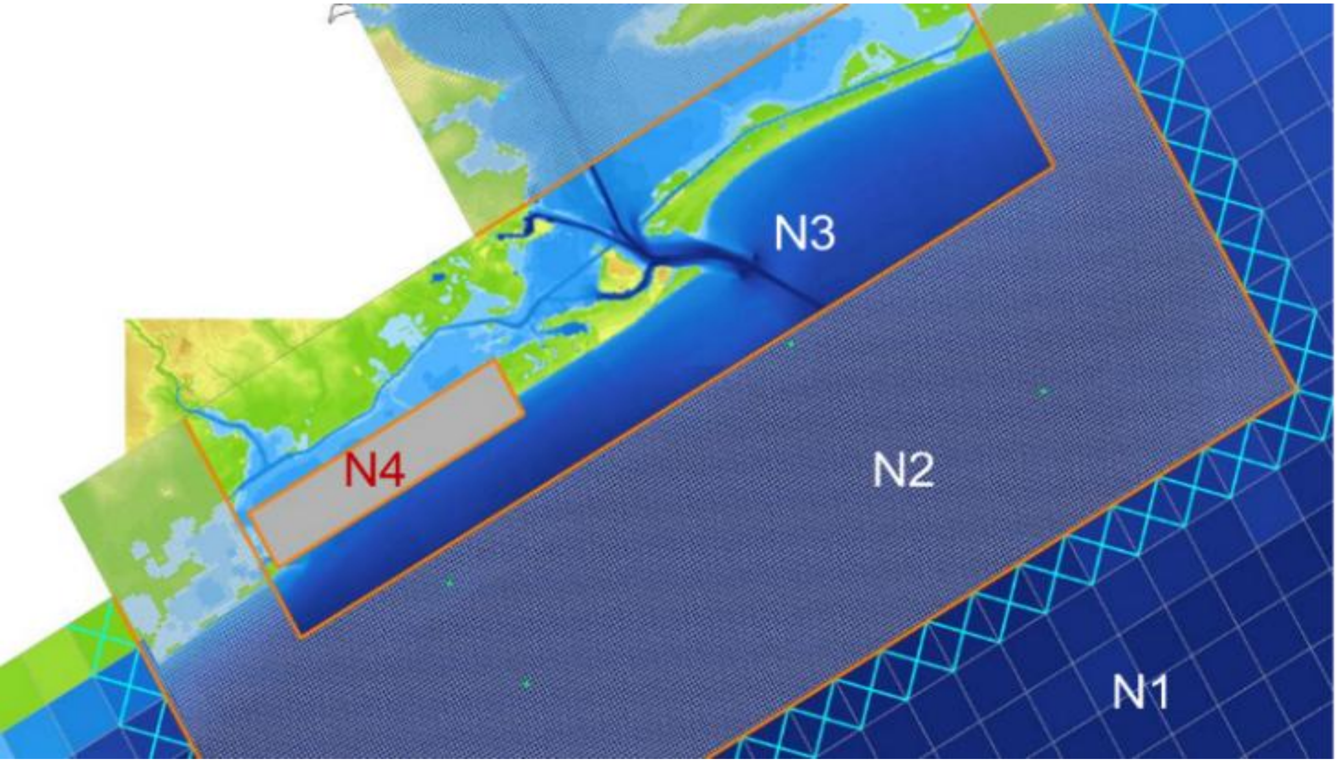
Model framework

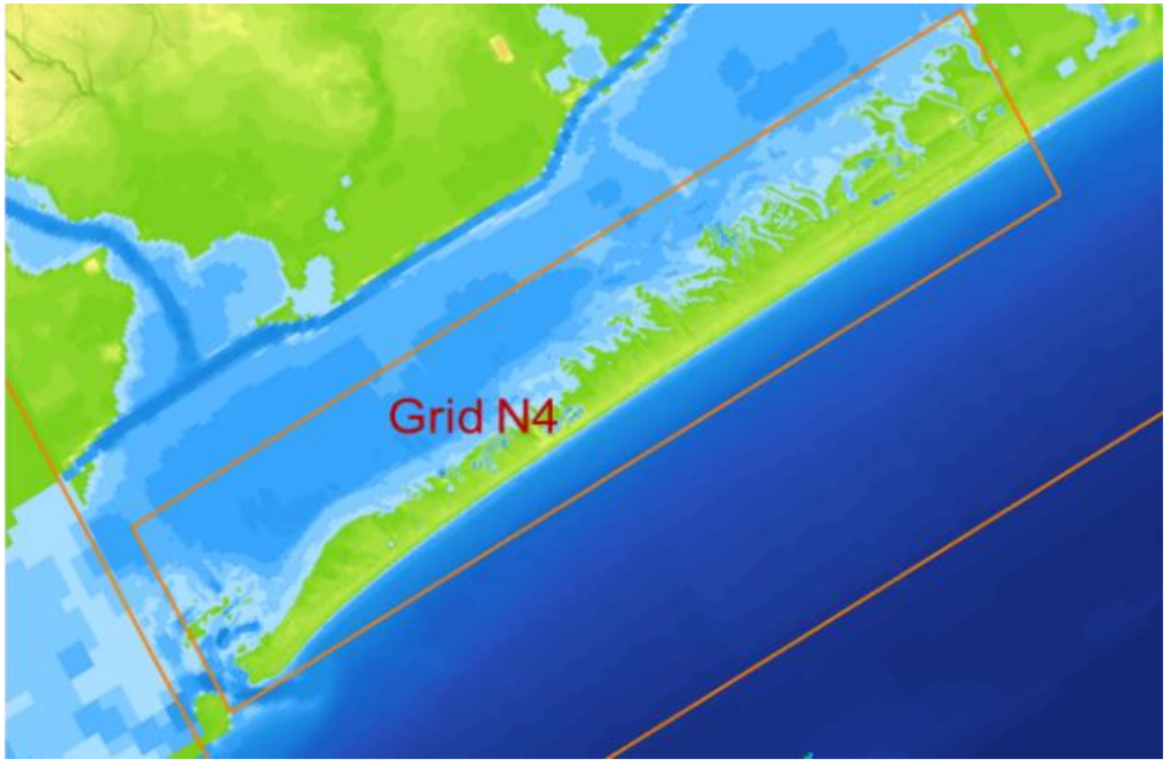
- Delft3D-FLOW ↔ SWAN (hourly coupling)
- Bathy/topo: GEBCO, CRM, CUDEM for bay detail



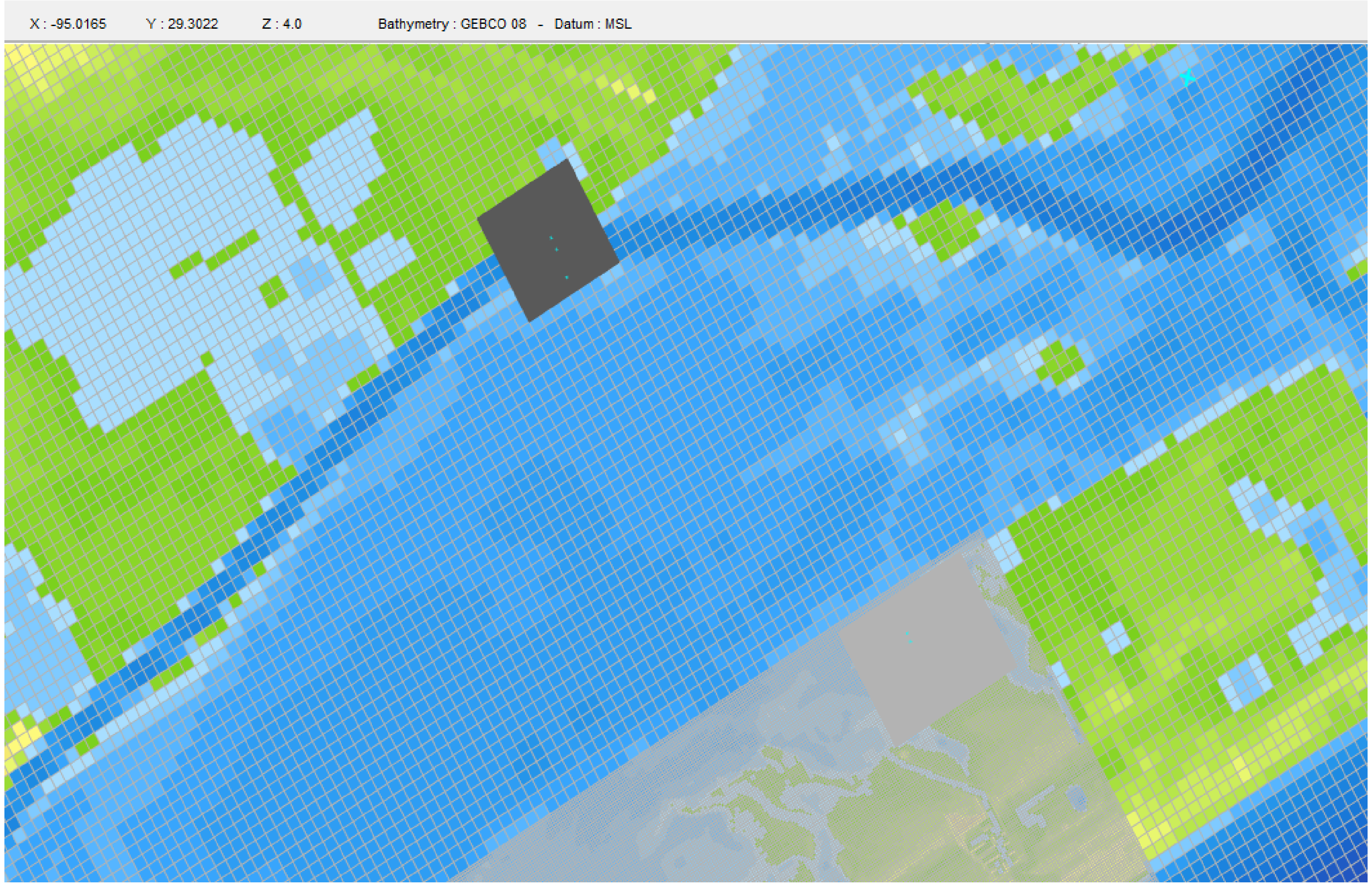
Model grid

- 9 nested/equidistant grids; tidal BCs from TPXO

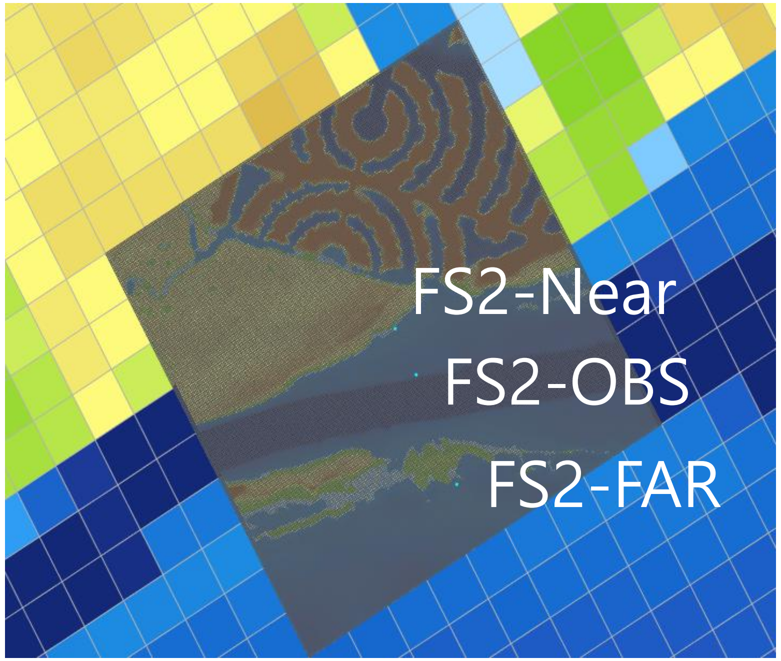




Site of Interest



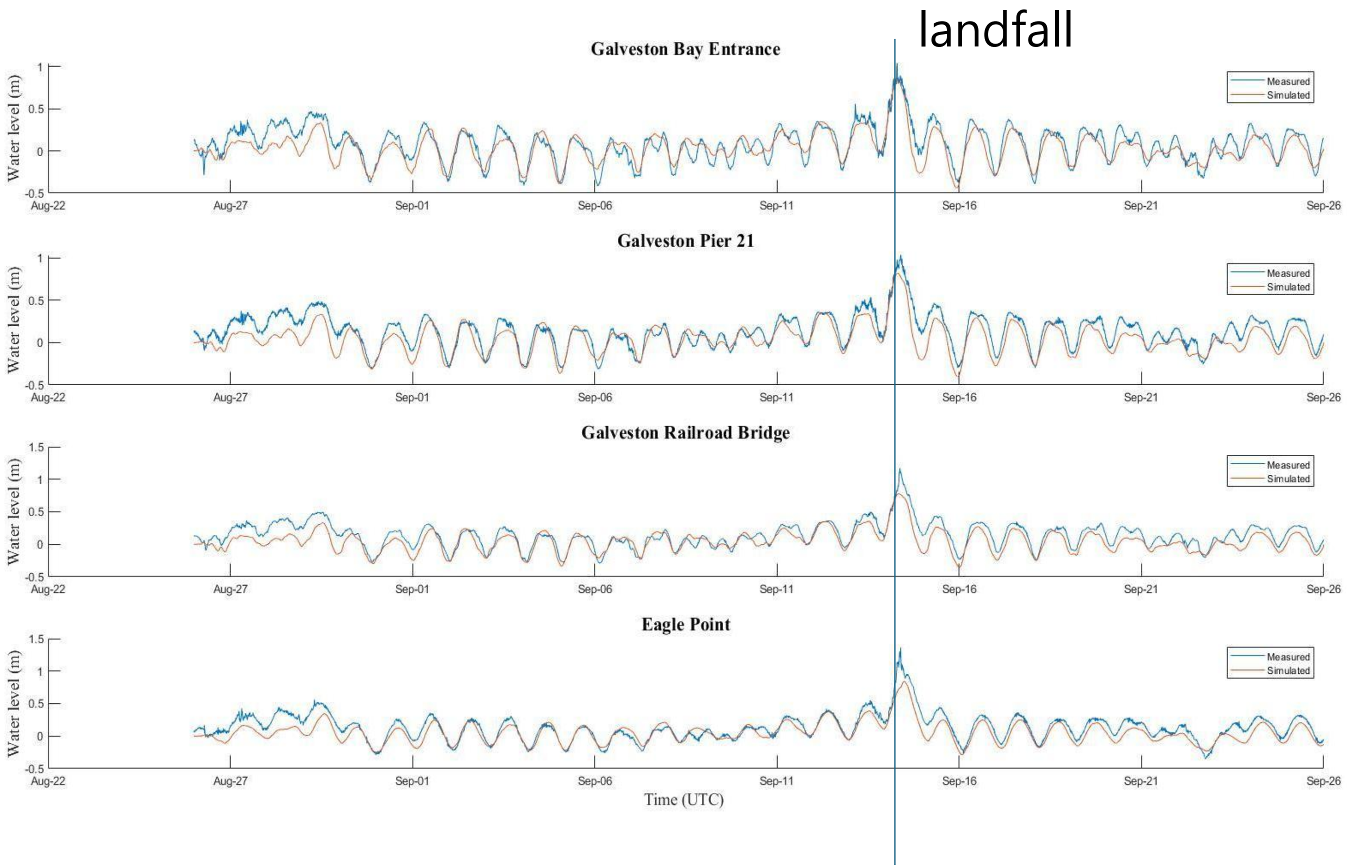
Site of Interest (FS2)



Grid resolution : 10 m

Hydrodynamic response & Validation

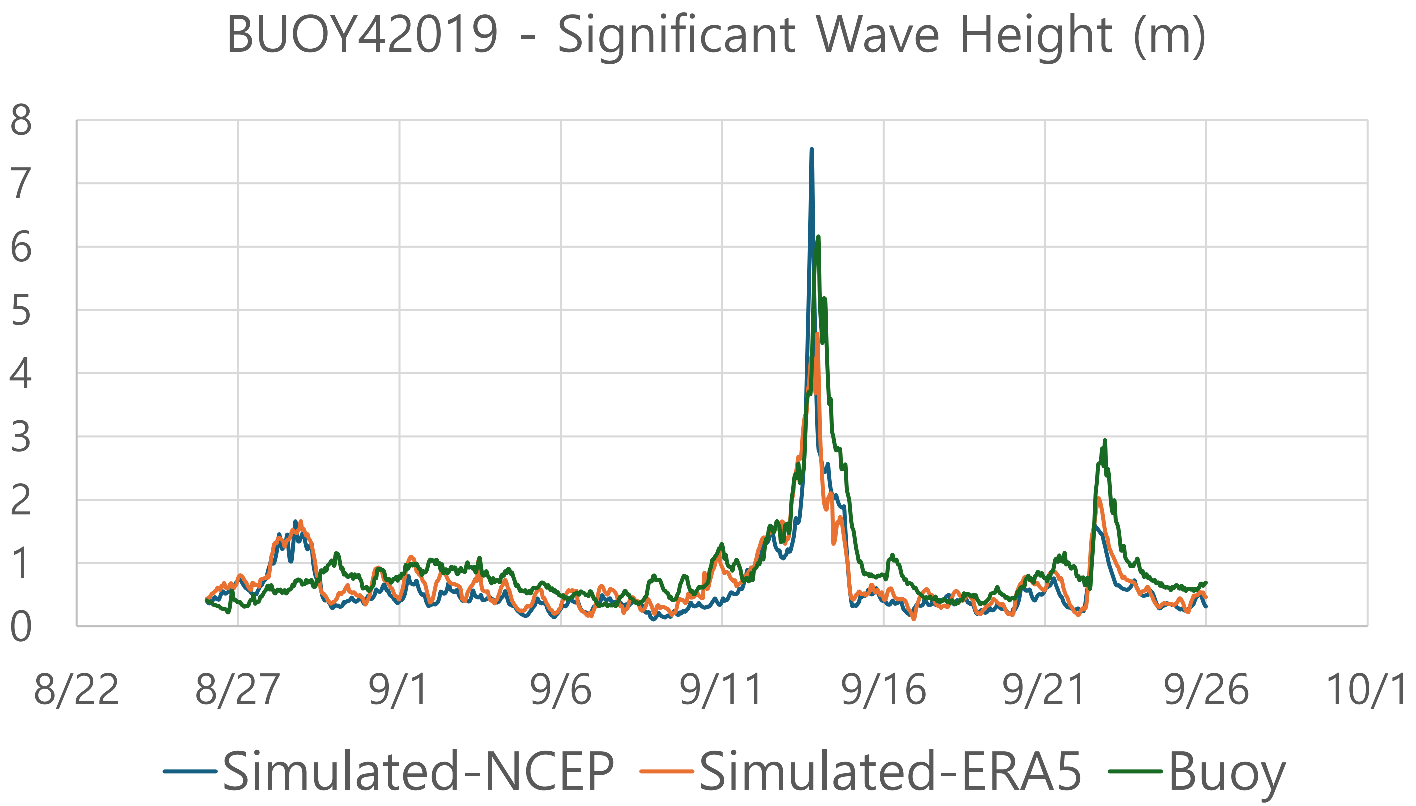
- Water level at 4 tide gauges
  : RMSE 0.07–0.09 m, r^2 0.73–0.81
- Bay-wide setup 0.5–1.0 m during peak



Geographic location	RMSE (m)	r^2	SI	E_NORM
Galveston Bay Entrance	0.09	0.73	0.0059	0.53
Galveston Pier 21	0.09	0.76	0.0004	0.56
Galveston Railroad Bridge	0.08	0.77	0.002	0.55
Eagle Point	0.07	0.81	0.0002	0.50

Wave response & Validation

- Hurricane Nicholas simulation results comparison
  - Hs timing captured; peaks slightly underestimate



→ Hourly records (1 h)

Root Mean Square Error (m)

- NCEP : 0.56
- ERA5 : 0.48

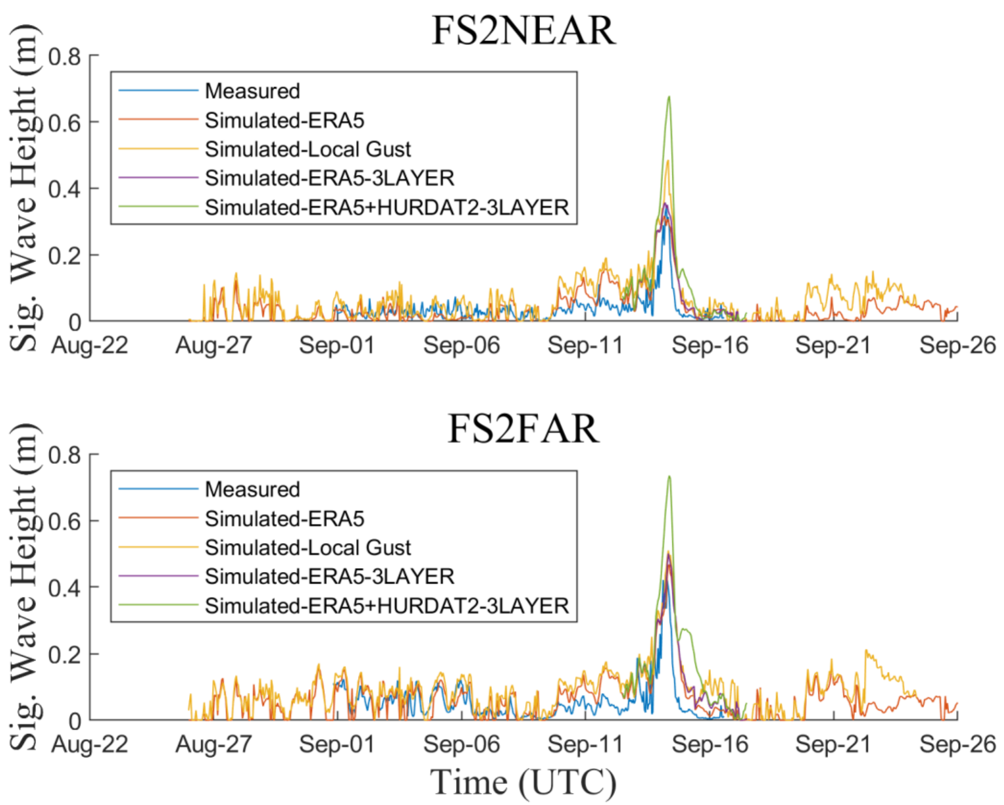
ERA5 slightly better

Note: Buoy measurements may be less reliable during the hurricane peak

Wave response & Validation

- Across-bay Hs increases with effective fetch and rotates with wind direction—largest on the windward shore, smallest on the downwind side
- Wave-current interaction enhances near-edge shear

<H_s>



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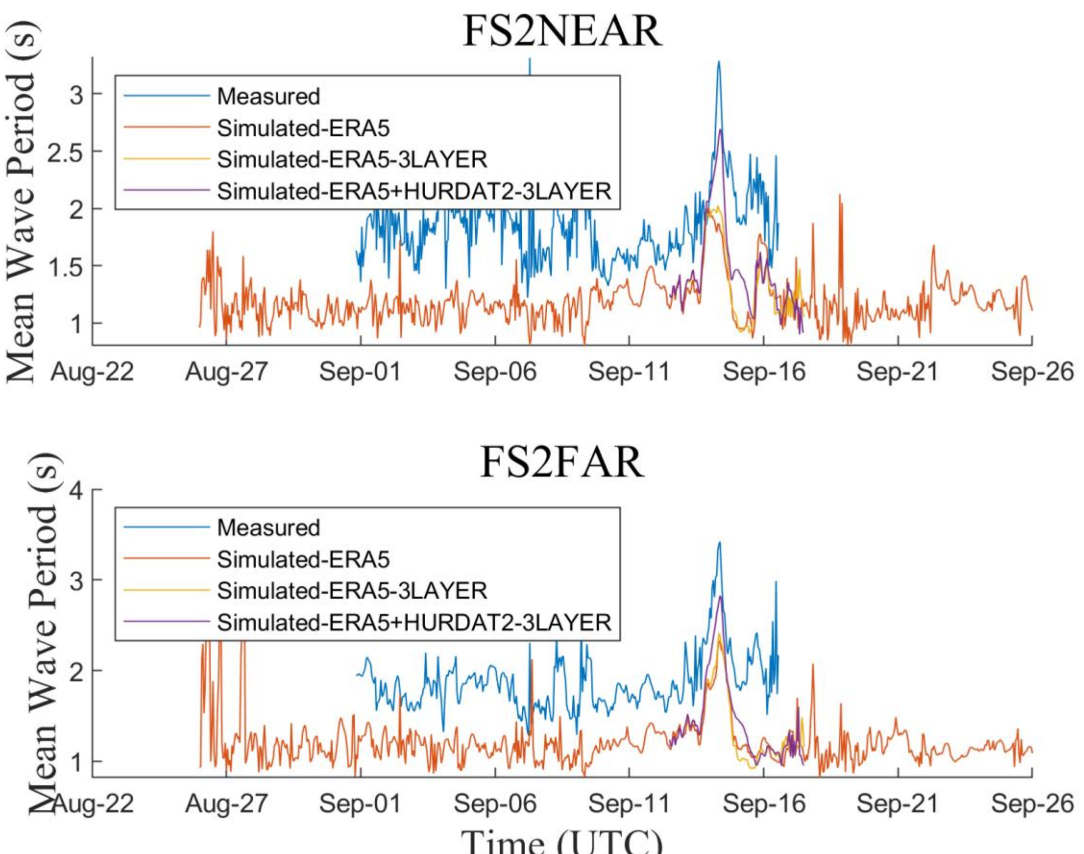


Wave Power (Wave energy flux)

- Schwimmer (2001) found that the marsh lateral retreat rate is correlated to the averaged wave power

- $P_w = \left(\frac{\rho g H_s^2}{8}\right) C_g$

- $C_g = \frac{1}{2}\sqrt{\frac{g}{k}\tanh kh}\left(1 + \frac{2kh}{\sinh(2kh)}\right)$

- $\boldsymbol{P_i} = P_w \cos\alpha$

where H_s is significant wave height, ρ is the water density, C_g is the wave group velocity, k is wave number (k=2πλ, λ being the wavelength), and α is the mean wave direction relative to the shore-normal direction of the marsh edge

P_w : Bulk wave power, $\boldsymbol{P_i}$: Effective wave power

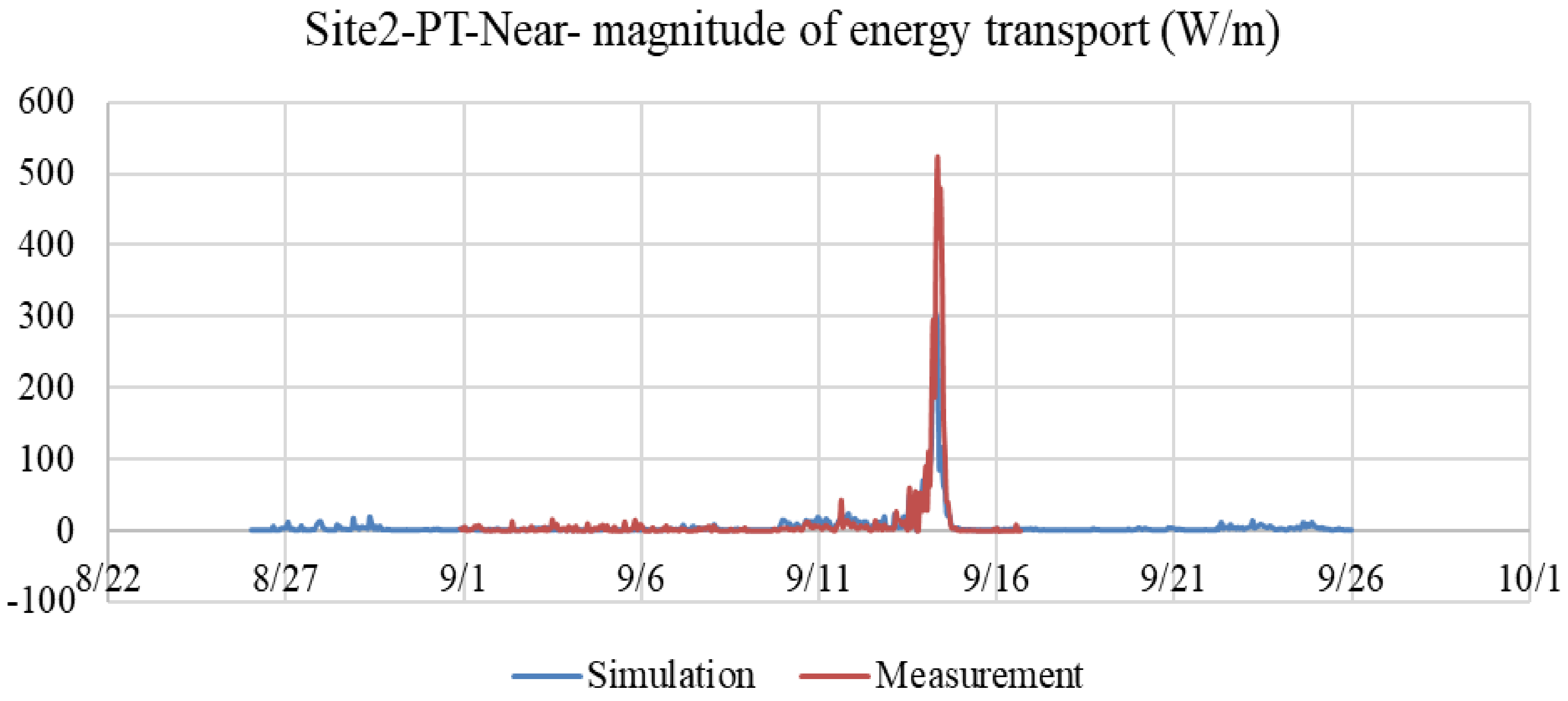
Erosion Rate

It is reported that the marsh erosion rate E is correlated to the averaged wave power, here we can define E as

$$\boldsymbol{E} = \boldsymbol{C}\boldsymbol{P_i}$$

where C is the marsh erosion coefficient

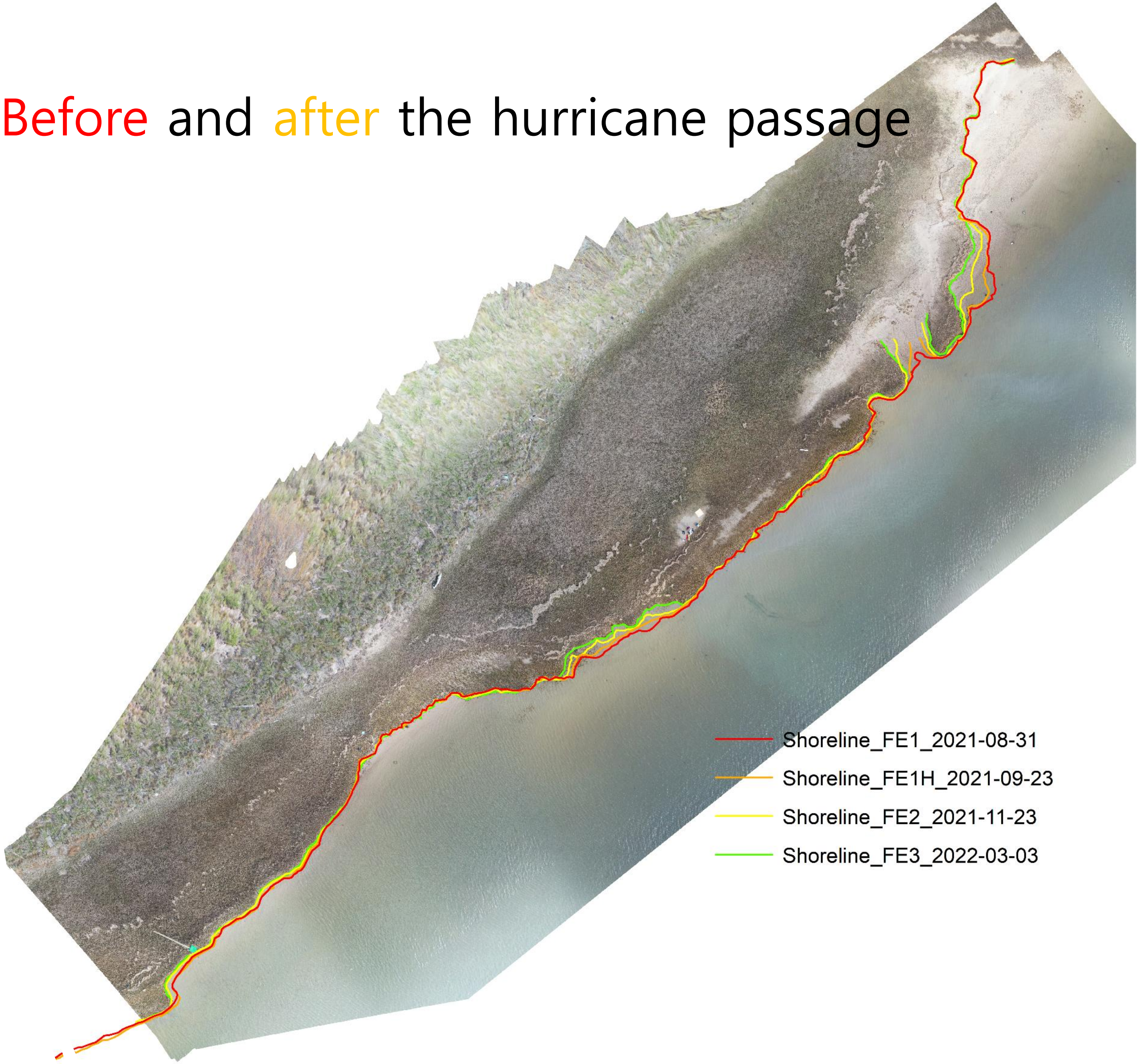
Wave power comparison



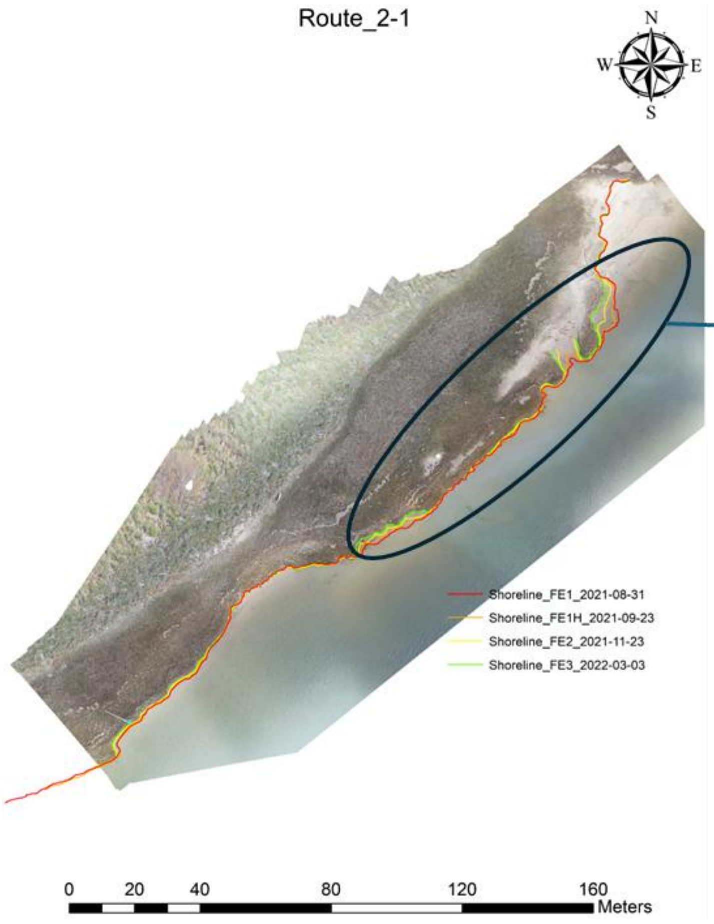
Before and after the hurricane passage

Morphodynamics

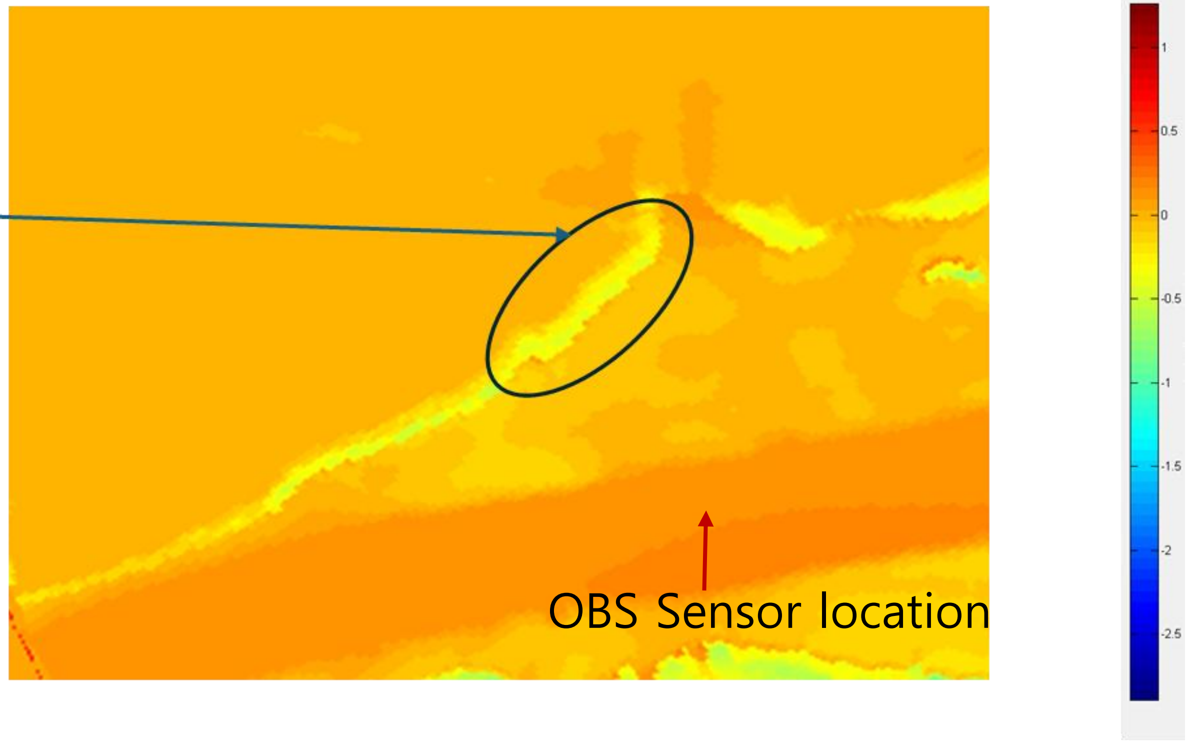
- DSAS quantifies retreat vectors and EPR



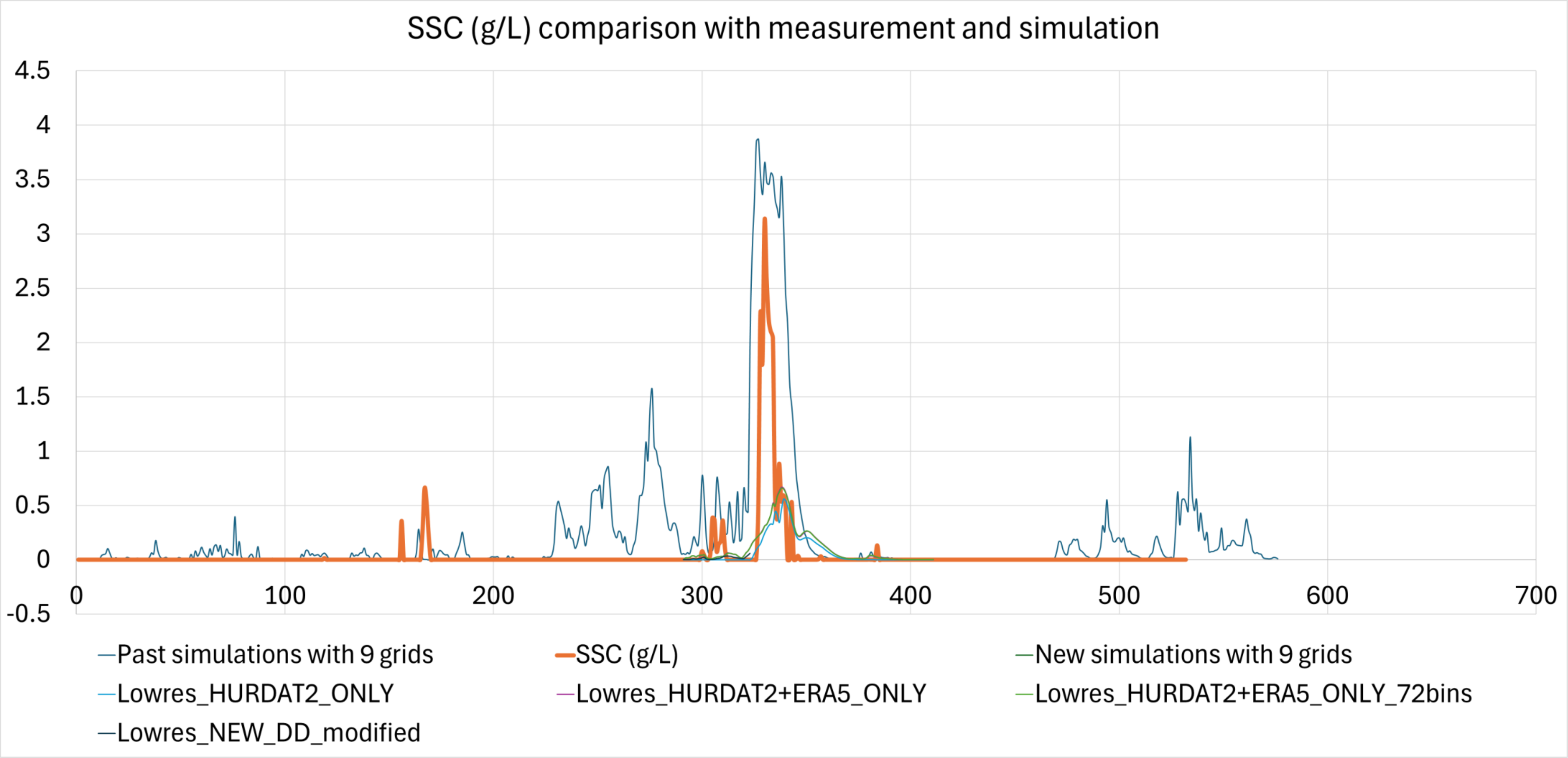
Morphodynamics comparisons



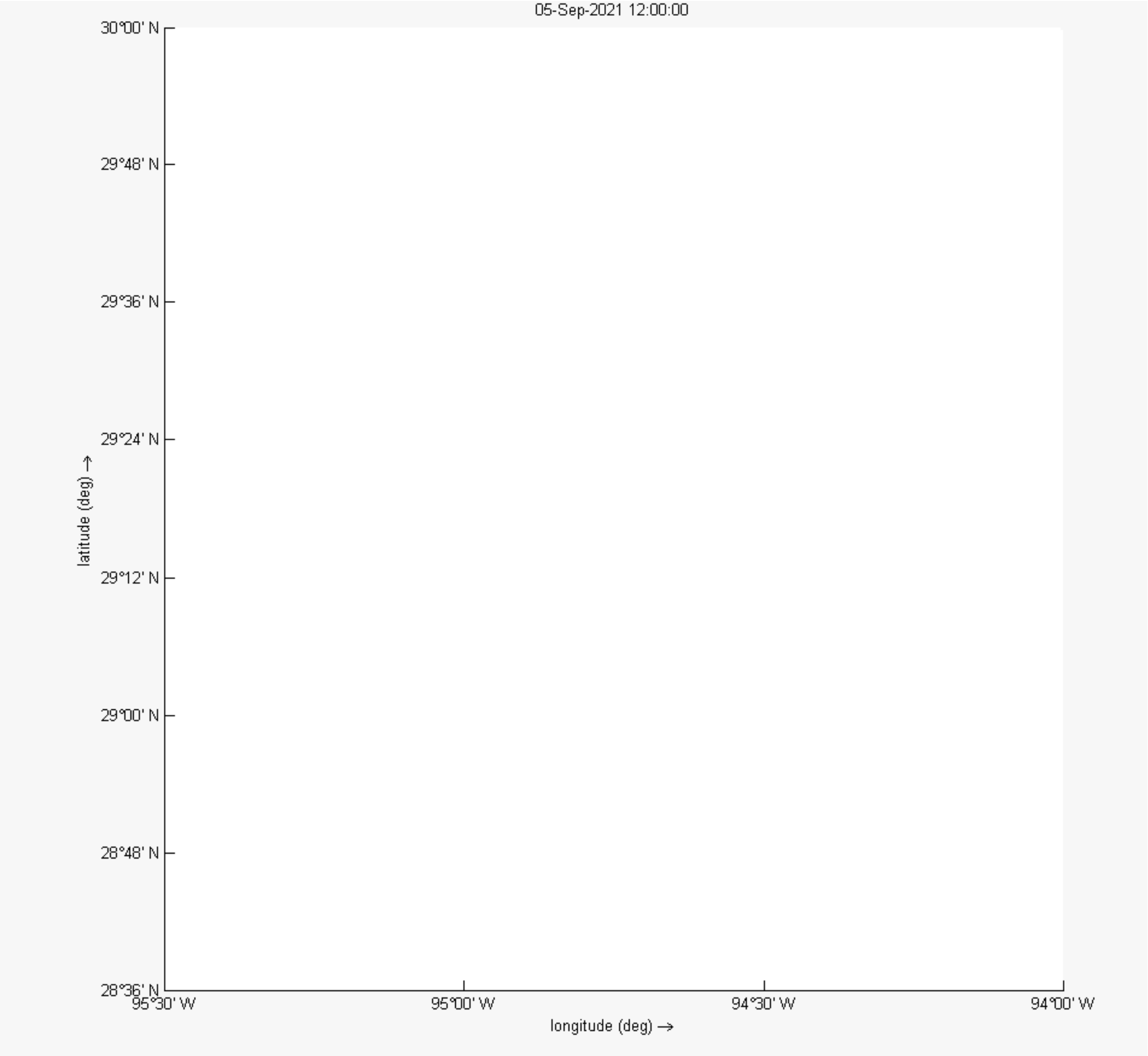
Cumulative Sedimentation (+) / Erosion (–)



Suspended Sediment Concentration (SSC) comparison



Suspended Sediment Transport during Hurricane Passages



Sensitivity & uncertainties

Wind	Wind forcing choice dominates peak Hs/setup timing
Assume	Thresholds: Assume τ_{crit}(mud) = 0.1 Pa and τ_{crit}(veg) = 1.0 Pa; these thresholds govern the onset of edge erosion.
Modeling	Modeling assumption: Bathymetry compiled from GEBCO/CRM/CUDEM; fine-scale morphology may be unresolved.

Takeaways

Hurricane waves are first-order controls on marsh edge change

Coupled Hydrodynamic/Wave modeling + UAV mapping provides actionable, event-scale insight

Refine in-bay wind fields and vegetation layers to improve forecast skill

Thank you

Q&A

Santander, Spain