GENCADE MODEL DEVELOPMENT AND APPLICATIONS

INLET ENGINEERING TOOLBOX

Yan Ding, Ph.D.

Mitchell Brown, Nicholas Cohn, Rusty Permenter, Scott Spurgeon, Peter Tereszkiewicz

District PDT members

Robert Hampson (NAP), Keith Watson (NAP), Harry Friebel (NAP), Rebecca Turpin(NAO) , Erik Rourke (NAP)

02 OCT 2024

COASTAL INLETS RESEARCH PROGRAM

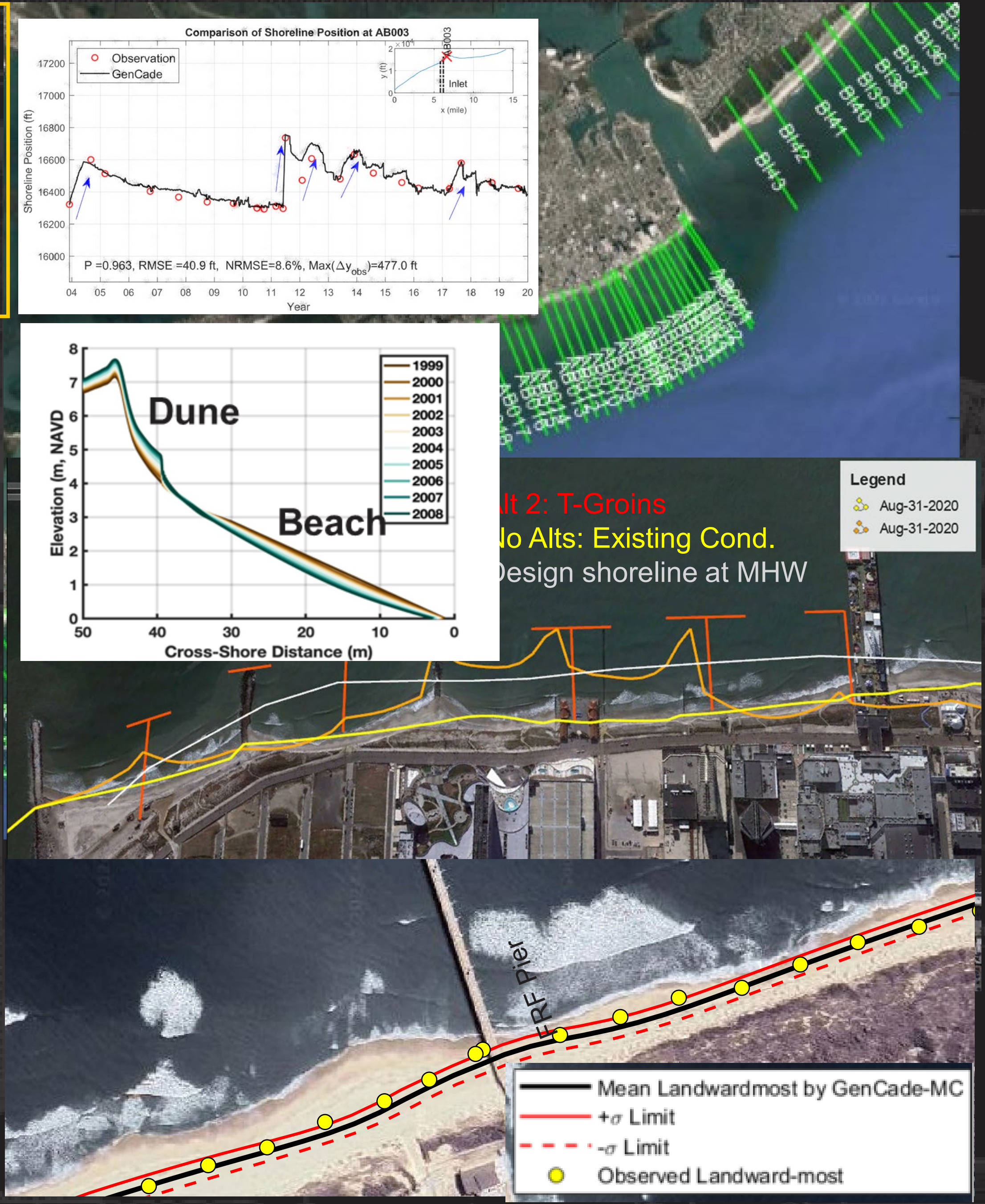
FY24 IN PROGRESS REVIEW

U.S. ARMY

US Army Corps of Engineers®

ERDC

CIRP



PROBLEM STATEMENT

- Most U.S. eroding shorelines are protected by various hard structures and periodically maintained by beach fill and nourishment.
- Prediction of long-term (decadal) and regional shoreline changes is a key task in coastal planning and management.
- Scientific research on **subaqueous sediment transport (longshore and cross-shore transport**) due to waves and currents has evolved considerably for decades. Accuracy and capability for long-term prediction are still needed to be improved.
- **Subaerial transport processes (aeolian, dune erosion) alter shoreline postions, are important to long-term shoreline evolution, but has not yet included in the GenCade shoreline evolution modeling.**
- Quantifying erosion risk and uncertainty in simulating long-term shoreline changes is essential for risk-based coastal management practice.

Strategic R&D: 80% Innovation in Sediment Management (I-SM); 20% Comprehensive Water Risk Management (CWRM)

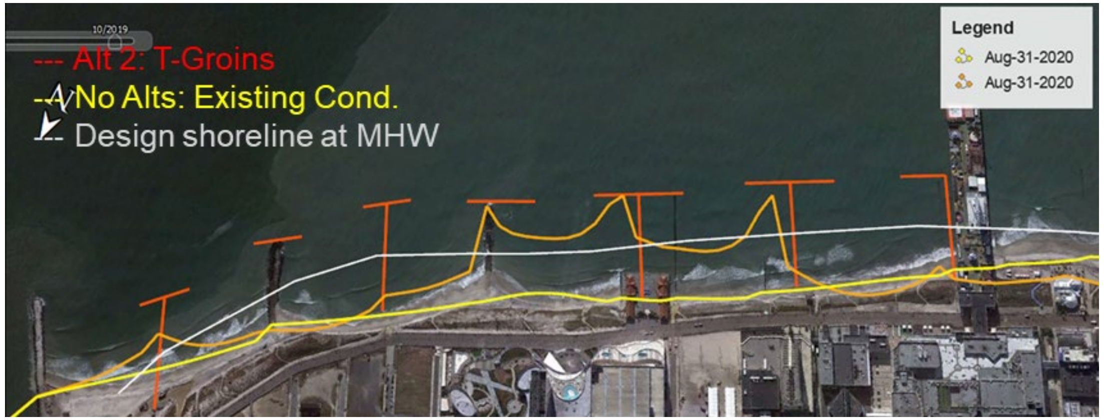
SoN #1846 - Development of Long-term Simulation Capabilities to Predict Risk-Based Shoreline Changes in Regional-Scale Coast
SoN-NAV-1726 Nearshore Nourishment Best Management Practices
2020-F-1539 Improved Capabilities for Quantifying Coastal Dune Evolution and Resilience
SoN-1386 Strategic Nearshore Placement of Dredged Material to Sustain Coastal Beach & Dune Resilience

CAPABILITY AND STRATEGIC IMPACT STATEMENT

ERDC

CAPABILITIES

- GenCade simulates **long-term** shoreline change, longshore and cross-shore sand transport, and inlet morphology on a local to **regional** scale.
- Provides long-term impact assessment of structure and non-structural protection measures for engineering planning.
- Operated in SMS, GenCade brings functionality of a georeferenced environment together with accessibility of other USACE numerical models (CMS, SBAS, etc).
- The GenCade team provides training workshops, technical services, and trouble shooting.



APPLICATIONS

- GenCade shoreline evolution model has been successfully applied to reproduce long-term shoreline changes with various erosion protection measures.
- Long-term shoreline simulations are essential to evaluate long-term (e.g. a life cycle) effect of erosion protection.
- GenCade Monte-Carlo simulation provides an effective tool to estimate uncertainties of shoreline changes and sediment transport driven by wave conditions and erosion protections.

BENEFITS

- Predictions of shoreline changes and sediment transport volumes facilitate optimization of regional sediment management, which can provide cost-effective solutions.
- Quantify erosion risks and uncertainty of protection measures for risk-based coast design.
- Continuous improvement of simulation capabilities, user training, and technical services broaden benefits of GenCade for CSRM practices.

GENCADE – SMS 13.4 INTERFACE

Approximately 95% complete.

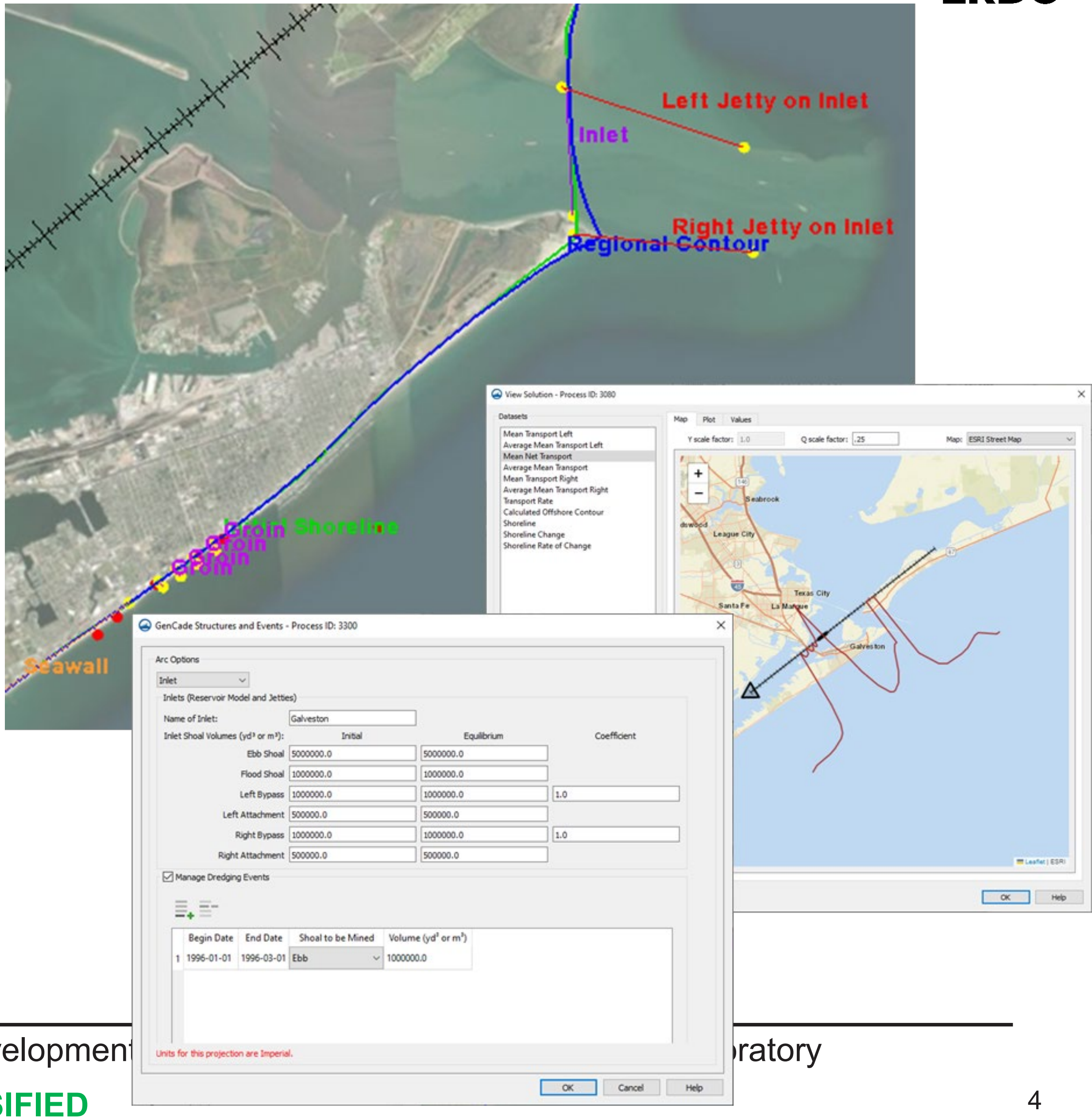
Completed:

- Creation of GenCade grid, Structures, Events, and Point attributes
- Model Control including new features
- Export for all needed files for running GenCade
- Visualize results from GenCade simulation

Full functionality being tested on several cases

Future add-ons:

- Import older model native files (*.gen) into SMS

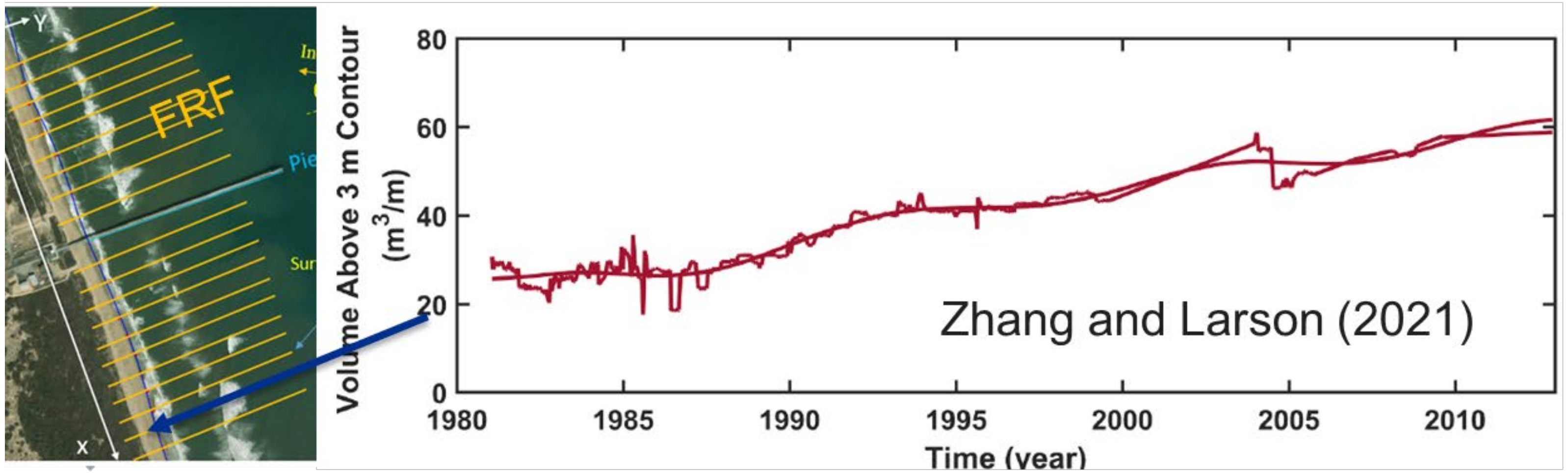


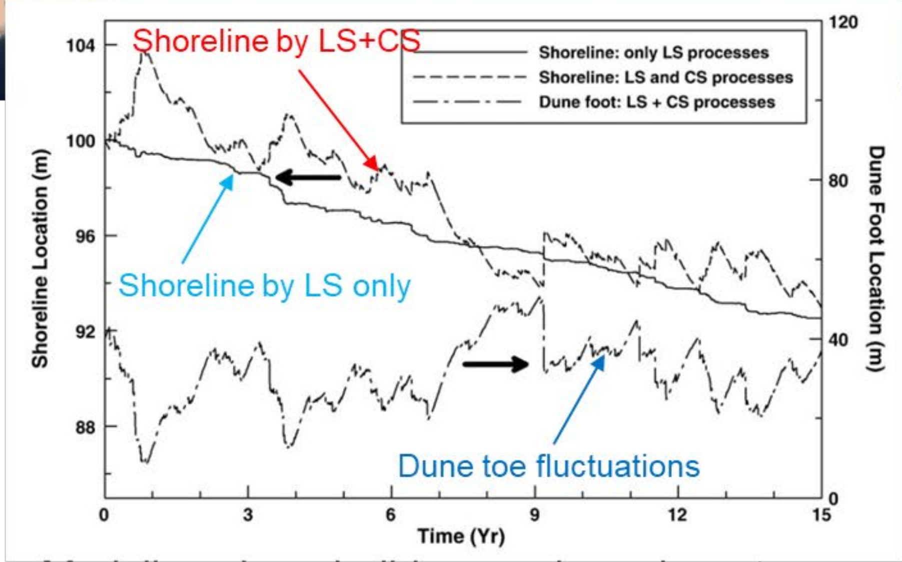
CROSS-SHORE TRANSPORT DUE TO WIND (FY24~)

- Subaerial transport processes (aeolian, dune erosion) alter shoreline postions, are important to long-term shoreline evolution.
- For evaluation of lifecycle performance of beach protection, long-term (LST and Aeolian Transport) and short-term processes (waves and surges in storms) must be combined in a modeling system.

Related to cross-shore transport, GenCade should simulate:

- dune erosion
- dune build-up from wind-blown sand
- overwash of dunes and barrier islands
- material exchange between berm and longshore bar(s)





Modeling dune build-up and erosion at Westhampton Beach (Hanson & Kraus 2010)

CROSS-SHORE TRANSPORT MODELS DUE TO WIND (FY24~)

Cross-Shore Profile Model for Dune Changes

CS Profile Model	Dune Erosion	Dune Built-up	Longshore Gradient Effect	References
CS model	√	√	N/A	Larson et al. (2016), Hanson et al. (2011)
CSHORE	√	?	√	Johnson et al. (2012)
XBEACH-Duna	√	√	√	Roelvink & Costa (2019)
SBEACH	√	No	No	Larson & Kraus (1989)

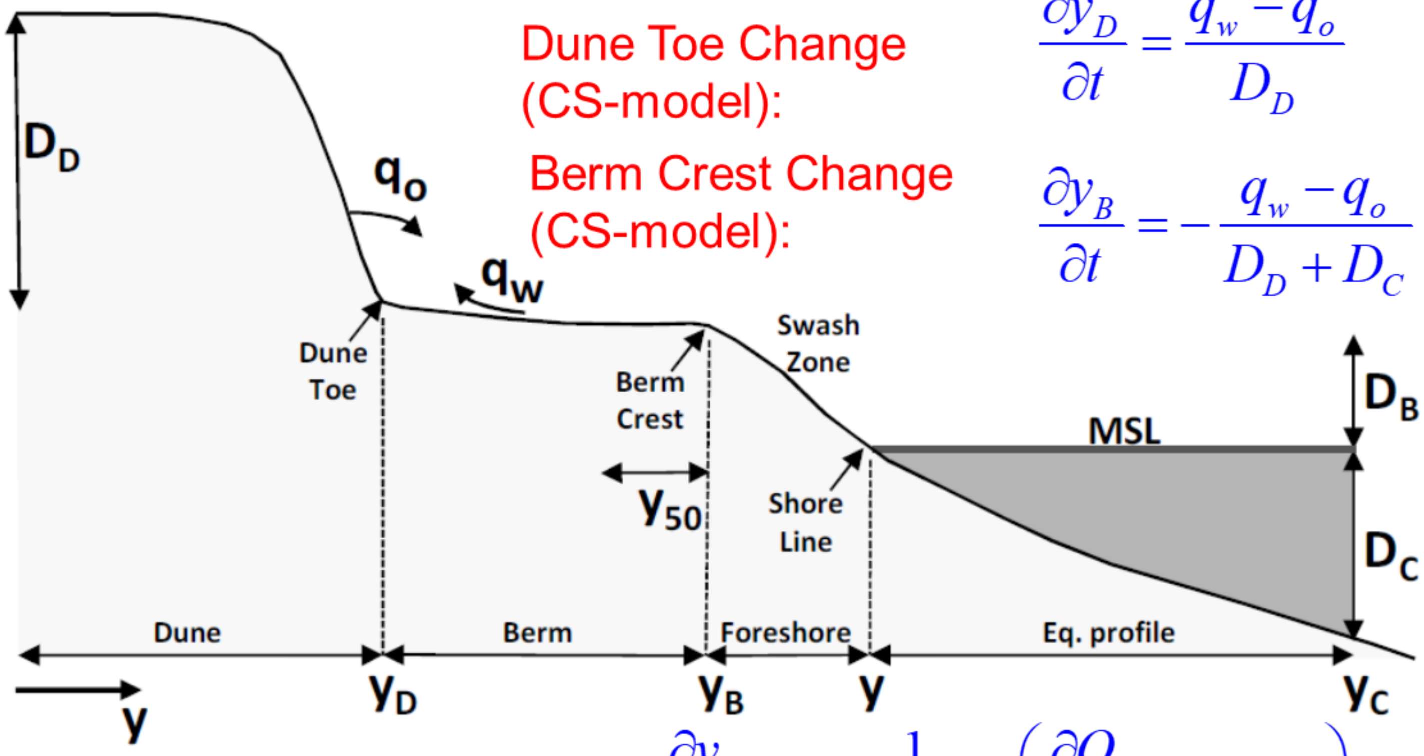
2-D Dune Evolution model

AEOLIS

q_w : Onshore sand transport by wind

q_o : Dune erosion rate by waves

Hanson's CS model of Dune Erosion and Simple Empirical Aeolian Transport Formulation



Dune Toe Change (CS-model):

$$\frac{\partial y_D}{\partial t} = \frac{q_w - q_o}{D_D}$$

Berm Crest Change (CS-model):

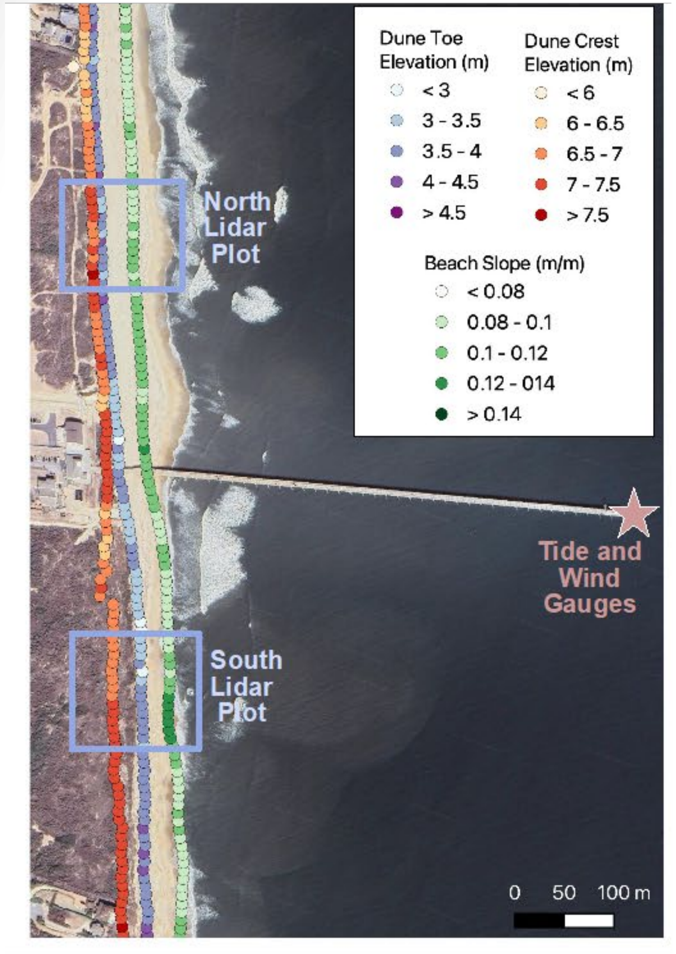
$$\frac{\partial y_B}{\partial t} = -\frac{q_w - q_o}{D_D + D_C}$$

Shoreline Change: (GenCade)

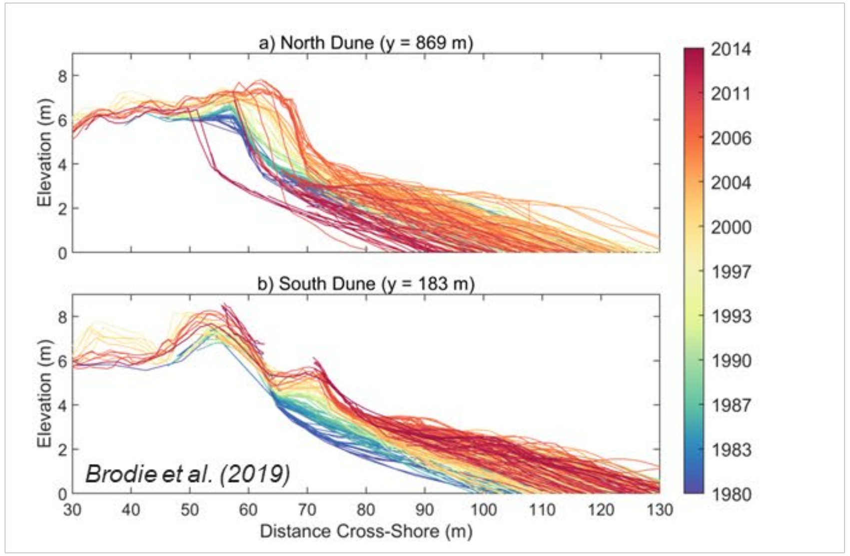
$$\frac{\partial y}{\partial t} = -\frac{1}{D_C + D_B}\left(\frac{\partial Q}{\partial x} - q_0 + q_w\right)$$

AEOLIAN SEDIMENT TRANSPORT CONTRIBUTIONS TO BEACH AND SHORELINE EVOLUTION (FY24~)

USACE Field Research Facility



Insights from Topographic Field Data

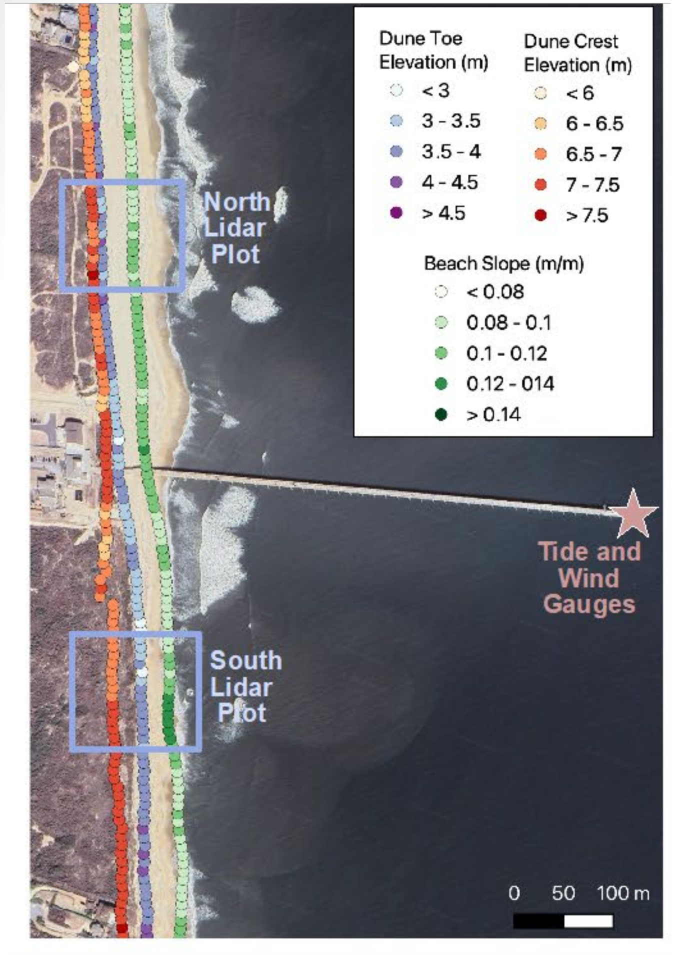


- Dunes intermittently grow and erode
- In the absence of major storms, typical dune growth rates ~1-2 $m^3/m/yr$
- Over long time scales these fluxes account for a substantial loss of sediment from the subaerial beach

Can we incorporate aeolian sediment transport processes into predictive shoreline modeling frameworks?

AEOLIAN SEDIMENT TRANSPORT CONTRIBUTIONS TO BEACH AND SHORELINE EVOLUTION (FY24~), CONT.

USACE Field Research Facility

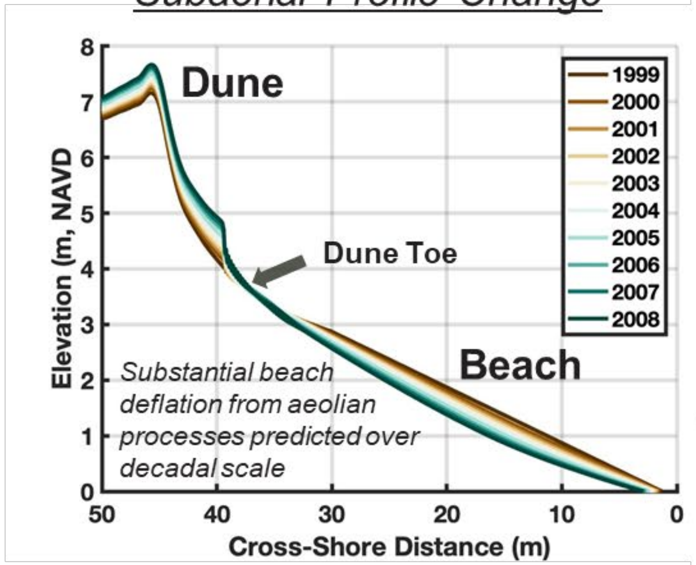


Site-Specific AeoLiS Model Inputs

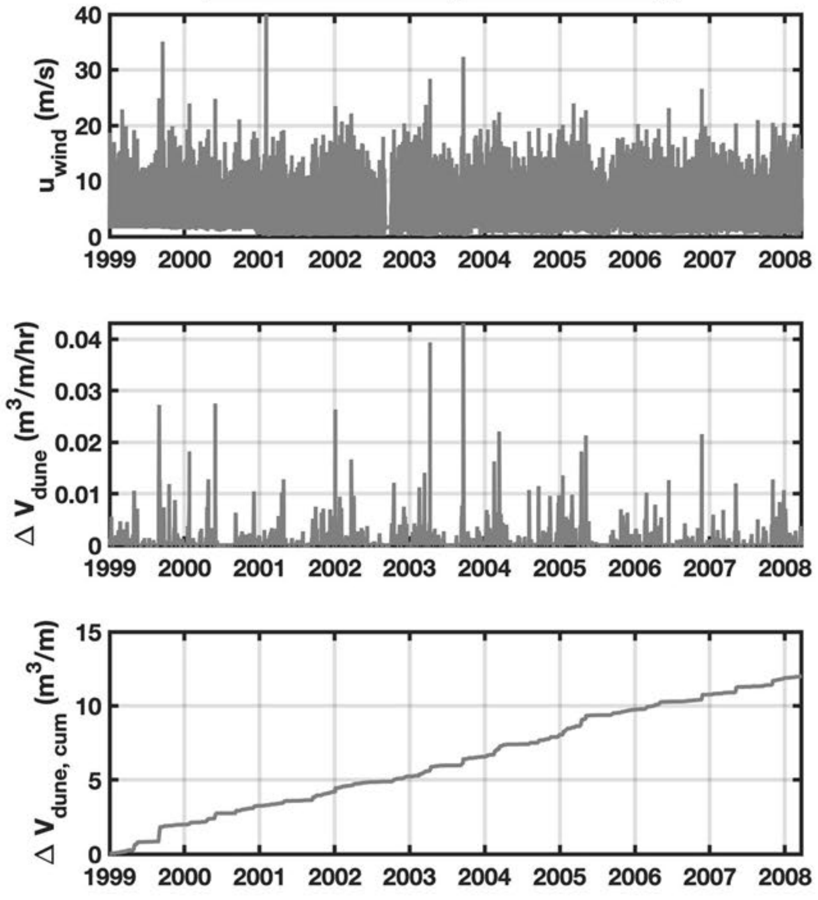
Grain Size
Topography
Winds
Waves
Tides
Vegetation
Morphometrics

AEOLIS

Subaerial Profile Change

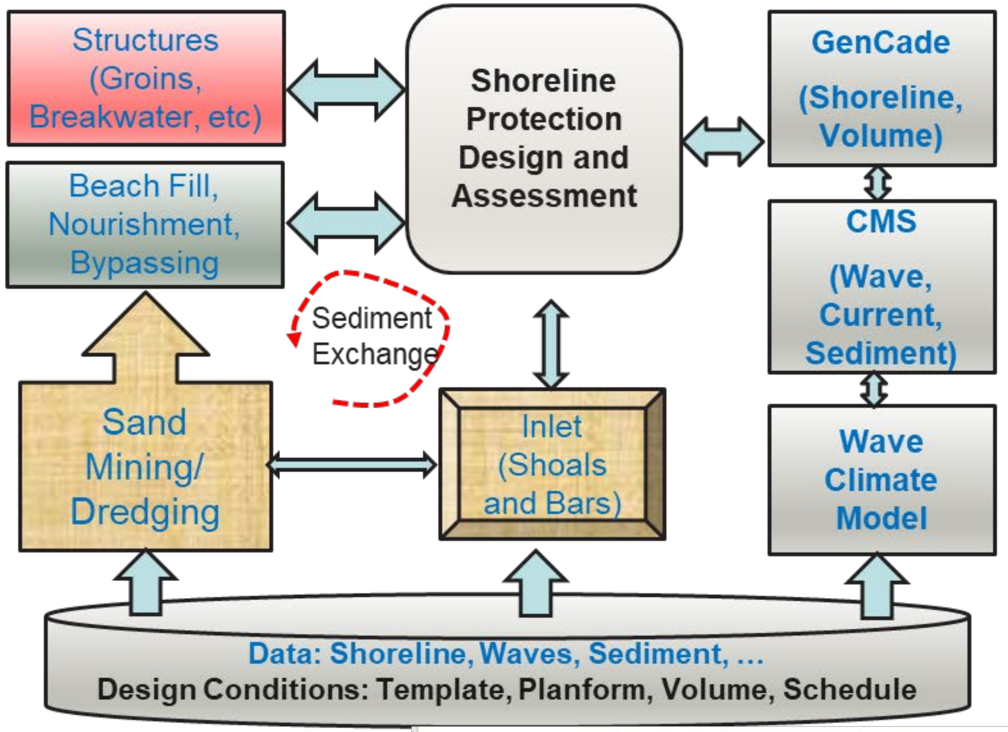


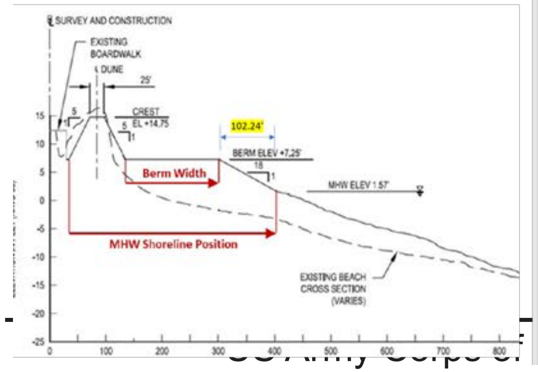
Time Series (1999-2008)

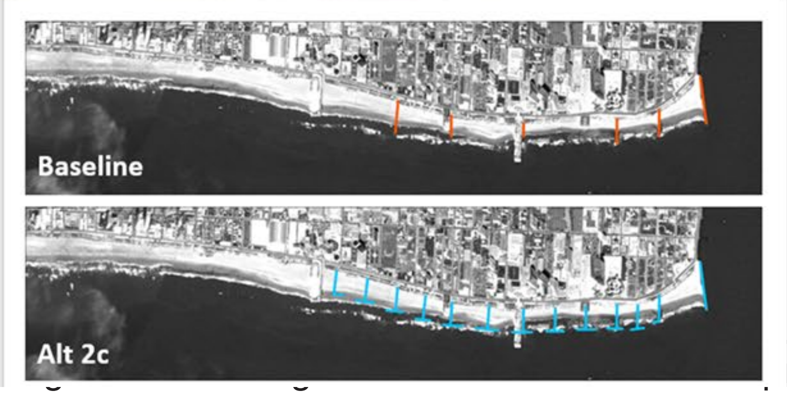


AeoLiS can provide all inputs GENCADE needs to account for sediment losses/gains to dune from aeolian and marine processes.
Closely matches rates found from field.

GENCADE + CMS FOR SHORELINE EVOLUTION MODELING



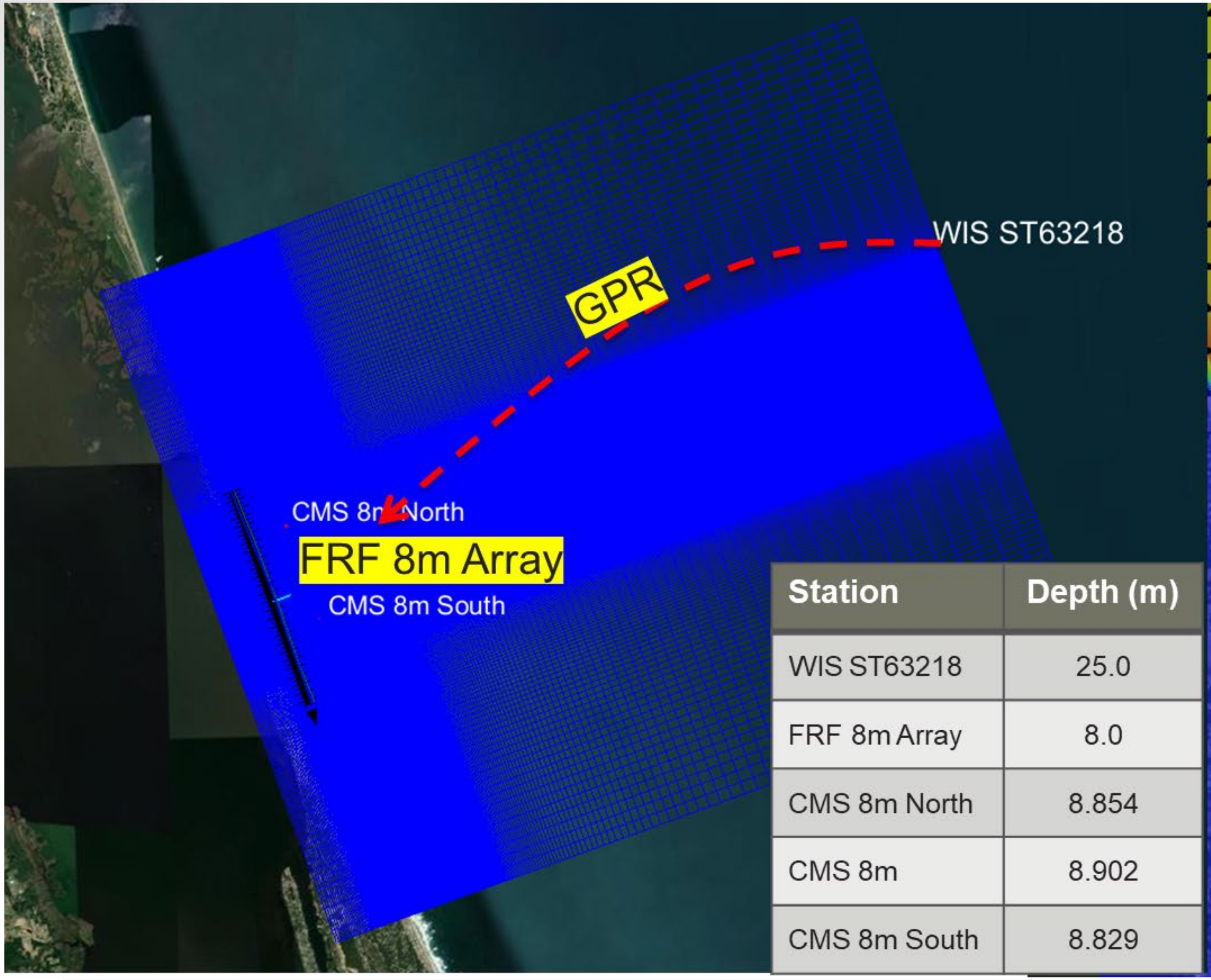




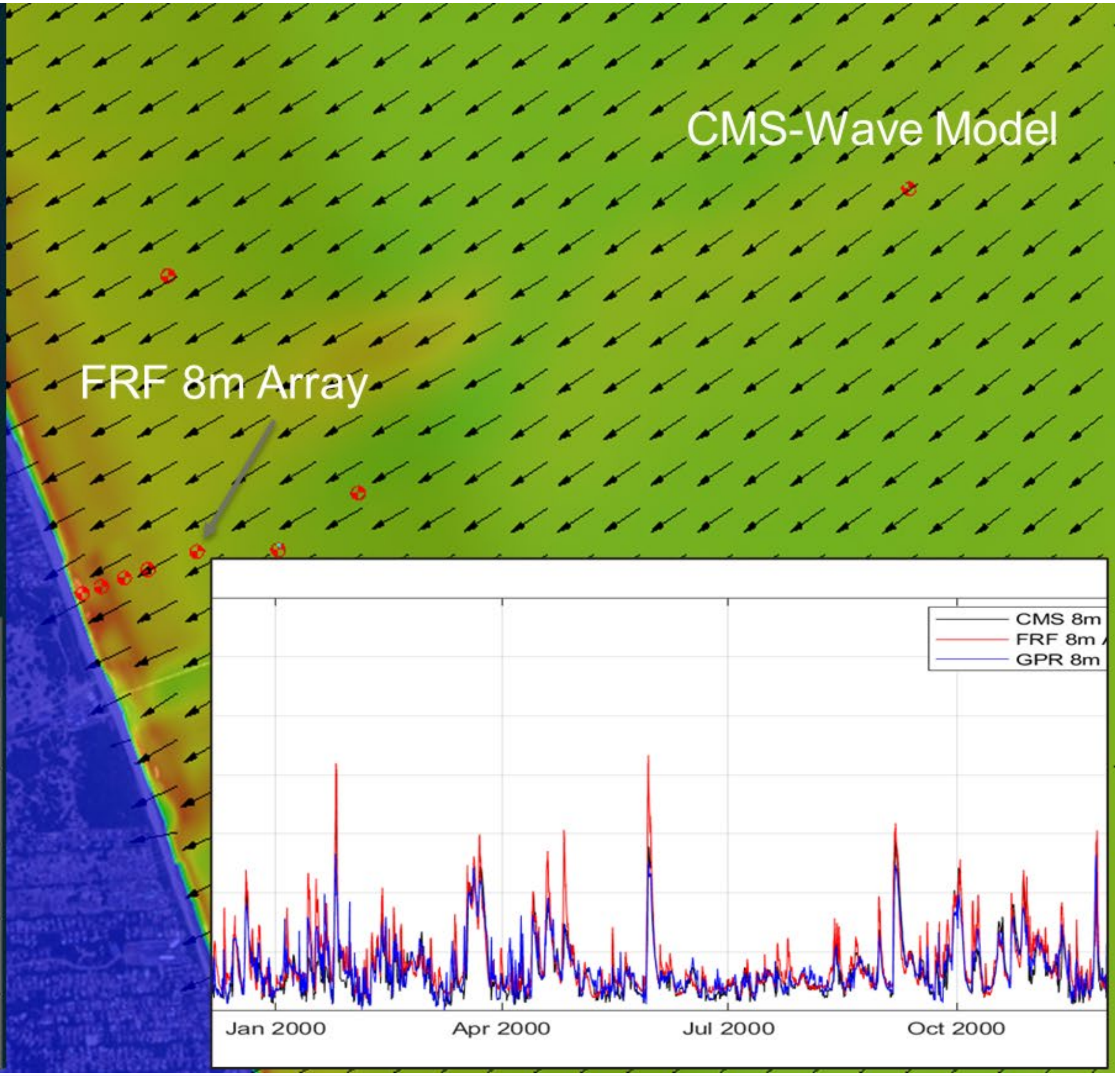
Problem Solving Capabilities

Relevant Processes	CMS	GenCade
Changes in Shoreline Position	Limited	✓
• Long-term Evolution	Limited	✓
• Long-term Beach Fill Impacts	Limited	✓
Bathymetry Change	✓	—
• Shoal/Bar Behavior	✓	Limited
• Channel Infilling	✓	—
• Nearshore Placement	✓	—
• Sediment Pathways	✓	Limited
Cross-shore Transport	✓	Limited
• Non-equilibrium Profiles	✓	—

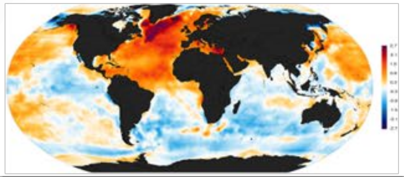
WAVE TRANSFORMATION TO NEARSHORE: CMS-WAVE VS GPR



Station	Depth (m)
WIS ST63218	25.0
FRF 8m Array	8.0
CMS 8m North	8.854
CMS 8m	8.902
CMS 8m South	8.829



GENCADE MONTE-CARLO WITH WAVE CLIMATE MODEL: UPDATE



Create “daily weather type” using SLP fields from ERA5

↓

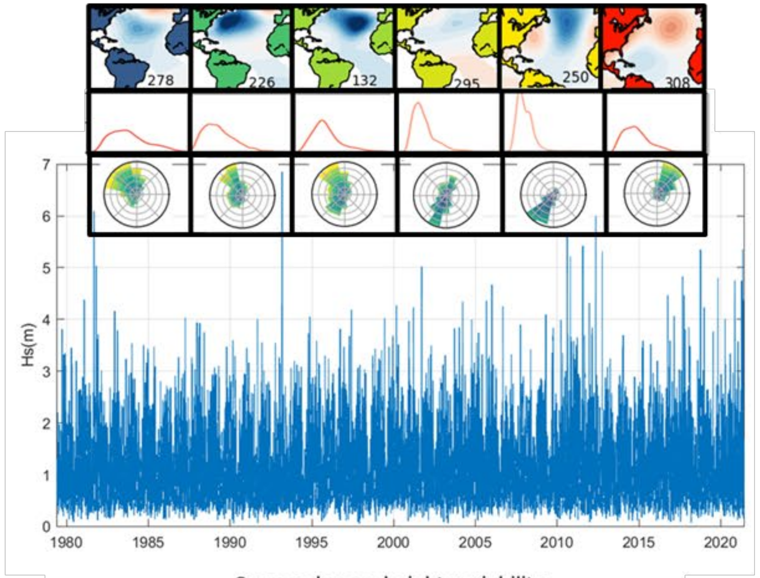
Auto-logistic model →Markov Chain of historical weather types

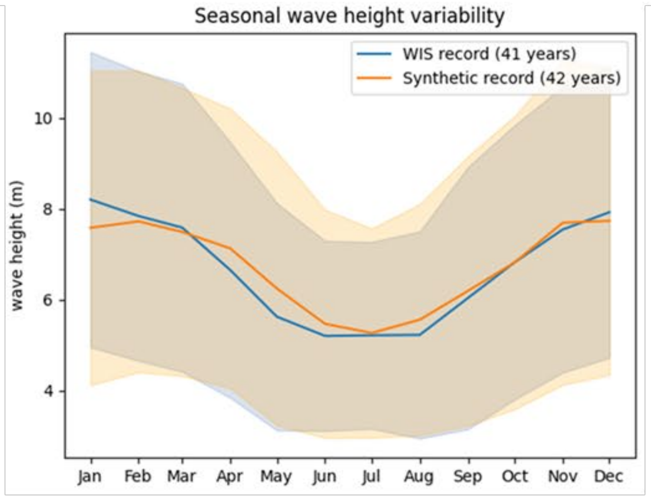
↓

Gaussian copula for unique conditional probabilities of waves and WLs within each weather type

↓

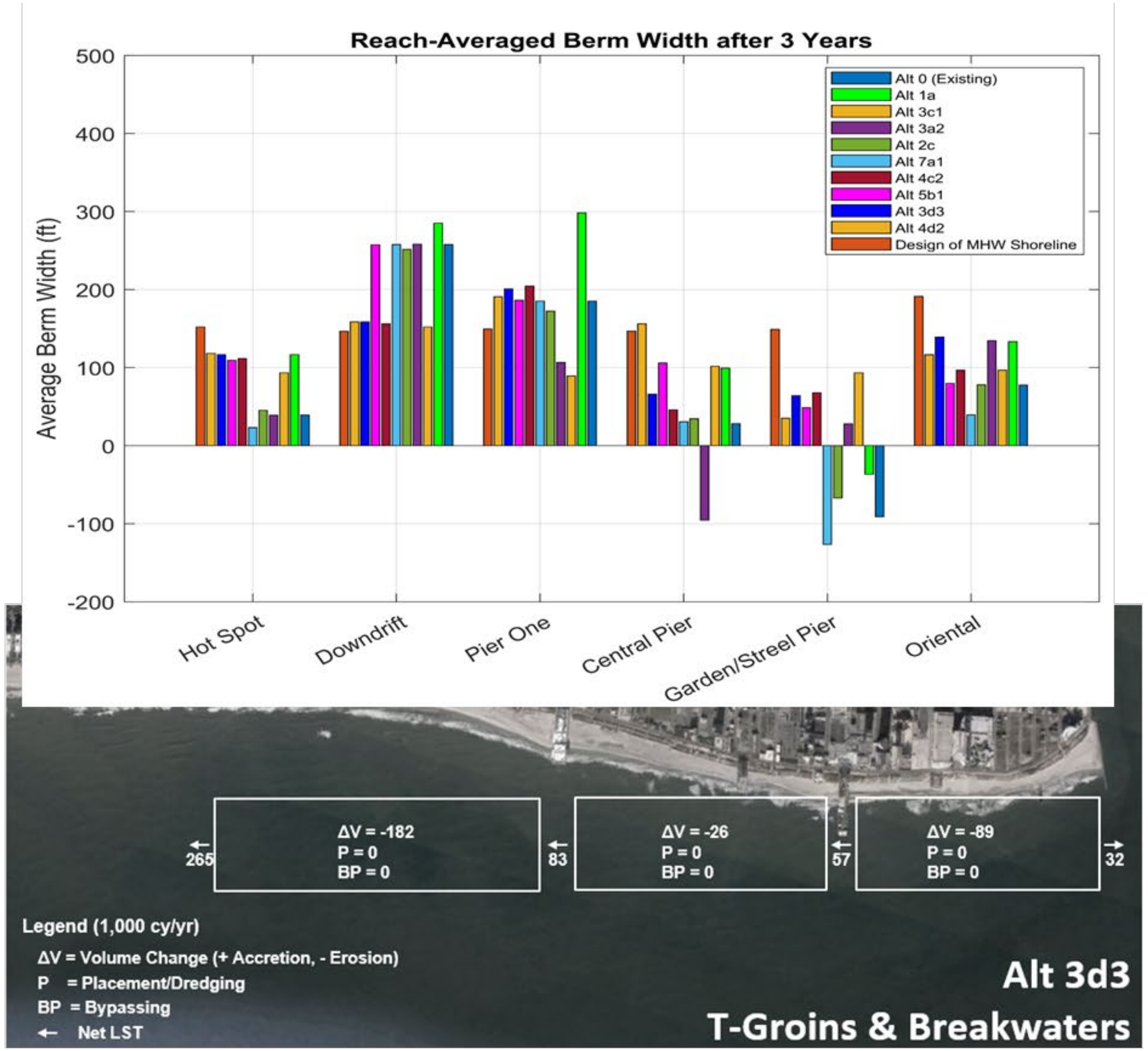
Create new time series of waves and water levels from the auto-logistic model





Extreme Shoreline Position with Uncertainty Estimation

SEDIMENT BUDGET BY GENCADE FOR DESIGN AND PLANNING: EXAMPLE



SUMMARY

FY24 Major Advances in Capability

- Develop DMI GenCade Interface
- ORISE Contract
- GenCade Monte-Carlo using Wave Climate Model
- Debug and optimize codes
- Reimbursable projects (NAP, NAO/NASA, EWN/SAS, LRC)
- Updated GenCade online information: (1) tutorial documentation, (2) GenCade wiki, (3) website for GenCade 2.0
- GenCade Training Webinar, 7/8/2024 (20 attendees)
- Publications and technical transfer

FY24 Major Products & Collaborations

ERDC

- **1 TR under review:** Jekyll Island Sand Motor,**1 LR under review:** Lynnhaven Inlet,
- **1 Training Webinar:** *7/8/2024, 2hrs*
- **5 Oral Presentations:** CIRP-TD, CE-PROSPECT, AGU OSM, ICCE 24, NASA-NAO Wallops
- **1 Poster:** AGU Fall
- **4 Reimbursable Projects:** NAP-Absecon, NAO-Wallops, SAS-Jekyll Island, LRC-Crescent Beach
- **Leveraging to other Programs**: CODS- Genade MC, EWN – Deer Island Restoration, CMS (wave/flow/sediment)
- **FY23 CW Value to Nation Book**

FY25 Products & Advancements

- GenCade with subaerial sediment transport (Aeolian process, interacting berm with dune) (**FY25**)
- Test SMS-GenCade DMI Interface and release new GenCade (**FY25**)
- CMS/GenCade training workshop, Buffalo District, Buffalo, NY 14207, 18-21 Nov. 2024 (**FY25**)
- Work with ORISE Interns for implementation of Dune erosion into GenCade (**FY25**)
- Release GenCade V.2.0 (Cross-shore + Monte-Carlo), publish TR (**FY25**)
- Stochastic Wave Climate model (SWCM) under CODS will leverage the capability of GenCade-MC (FY25)
- CoastSat or SSM for GenCade (FY24-25)
- Applications for reimbursable projects: NAP, NAO/NAD, LRC

RECENT PUBLICATIONS ON GENCADE

- USACE Reports
  - Ding, Y., Earl Hayter, and Lihwa Lin (2024). GENCADE Modeling of Ocean Park Beach and Cape Henry Beach, submitted to USACE Norfolk District (PI-Earl Hayter), April 2024.
  - Lin, Lihwa, Ding, Yan, Krafft, Douglas, McFall, Brian C., Woodson, C. Brock , Edwards, Catherine R. (2024). Numerical Modeling of Coastal Processes with Beneficial Use of Dredged Sediment in the Nearshore at Jekyll Island, Georgia, ERDC/CHL TR-24-xx, 97pp, under internal review.
  - Ding, Y., Hampson, R., Friebel, H., Watson, K., and Kim, S.-K. (2022). Calibration and Validation of Shoreline Evolution Model on the Erosion Hot Spot near Absecon Inlet, Atlantic City, New Jersey, ERDC-CHL LR-23-1.
  - Ding, Y., S. C. Kim, R. Permenter, R. Styles, and Gebert, J. A. (2021). Simulations of Shoreline Changes along the Delaware Coast, ERDC/CHL TR-21-1, Vicksburg, MS: US Army Engineer Research and Development Center, http://dx.doi.org/10.21079/11681/39559, January 2021
- Journal Publications
  - Ding, Y., Styles, R., Kim, S.-C., Permenter, R.L., and Frey A.E. (2021). Cross-shore sediment transport for modeling long-term shoreline evolution, J. Waterway, Port, Coastal, Ocean Eng., 2021, 147(4): 04021014, 25pp., DOI: 10.1061/(ASCE)WW.1943-5460.0000644
  - Whitley, A. E., Figlus, J., Valsamidis, A., and Reeve, D. E. (2021). One-line modeling of mega-nourishment evolution. Journal of Coastal Research, 37(6), 1224–1234. https://doi.org/10.2112/JCOASTRES-D-20-00157.1
- Conference Papers and Posters
  - Ding, Y. and Anderson, D. (2024). Probabilistic Long-Term and Regional Shoreline Evolution Modeling Using Wave Climate Emulator, to be published in proceedings of ICCE24, under preparation.
  - Ding, Y., et al. (2023). Modeling of Long-Term Shoreline Evolution along Barrier Islands for Coastal Erosion Assessment, AGU Fall Meeting, San Francisco, CA, Dec. 11-15, 2023.
  - Ding, Y., Hampson, R., Friebel, H., and Watson, K. (2023). Long-term and regional shoreline evolution along Ab second Island, New Jersey, In: Proceeding of Coastal Sediments 2023, pp1466-1476. World Scientific, https://doi.org/10.1142/9789811275135_0136

- Training Materials
  - GenCade Webinar, GenCade Workshop (Hands-on example, ppts, etc.)