Shoreline Evolution Modeling Using GenCade and CMS for Coastal Erosion Protection Planning

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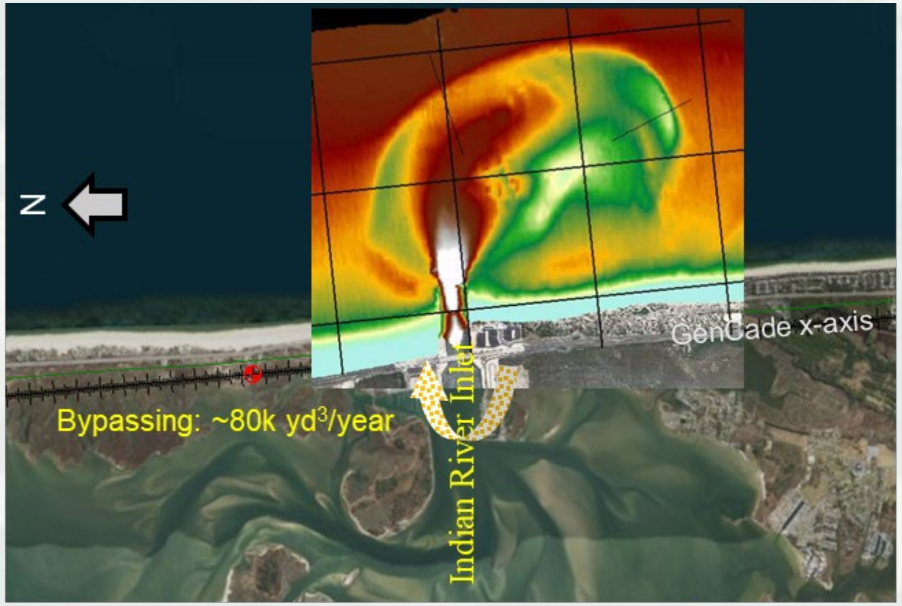
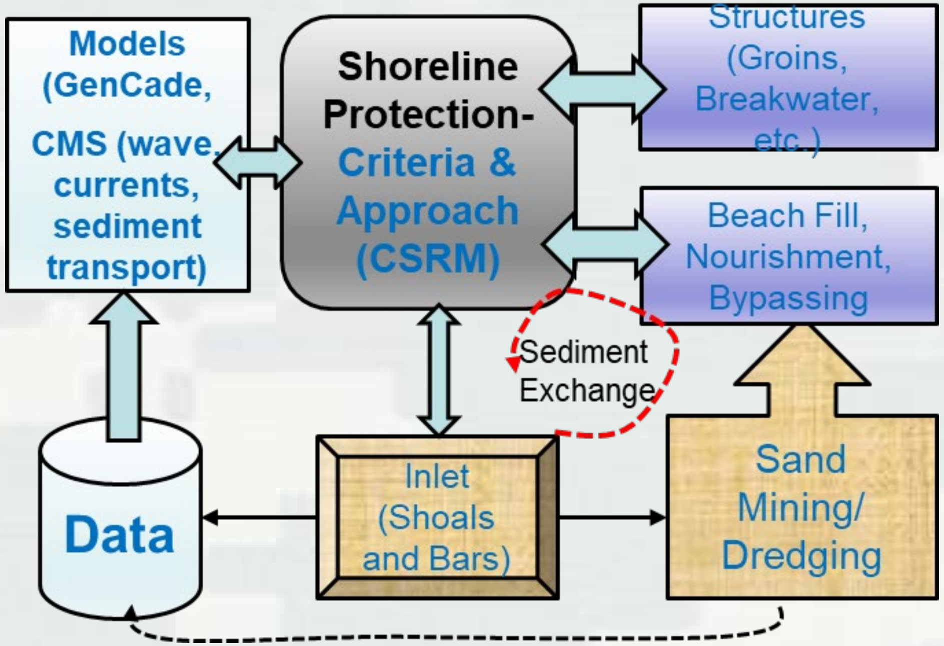
Outline

- Introduction
  - ➢ A Brief Review of GenCade and CMS Capabilities
  - ➢ Connections between CMS (Wave, Flow, and Sediment Transport) and GenCade
- Example on Shoreline Simulations using Three Wave Datasets (Duck, NC):
  - ➢ *How to select wave data which is good for regional shoreline simulation?*
- Example on Long-Term Shoreline Evolution Modeling and Feasibility Study of Erosion Protection Alternatives (Absecon Inlet, NJ):
  - ➢ *How to simulate shoreline evolution with complicated conditions of structures and beach fill, inlet bypassing, shoal dredging*
  - ➢ How different in morphological changes simulated by CMS and GenCade?
- Example on Long-Term Shoreline Changes after Beach fill/Nourishment Constructed
  - ➢ *Is it important to include tidal currents into longshore sediment transport*

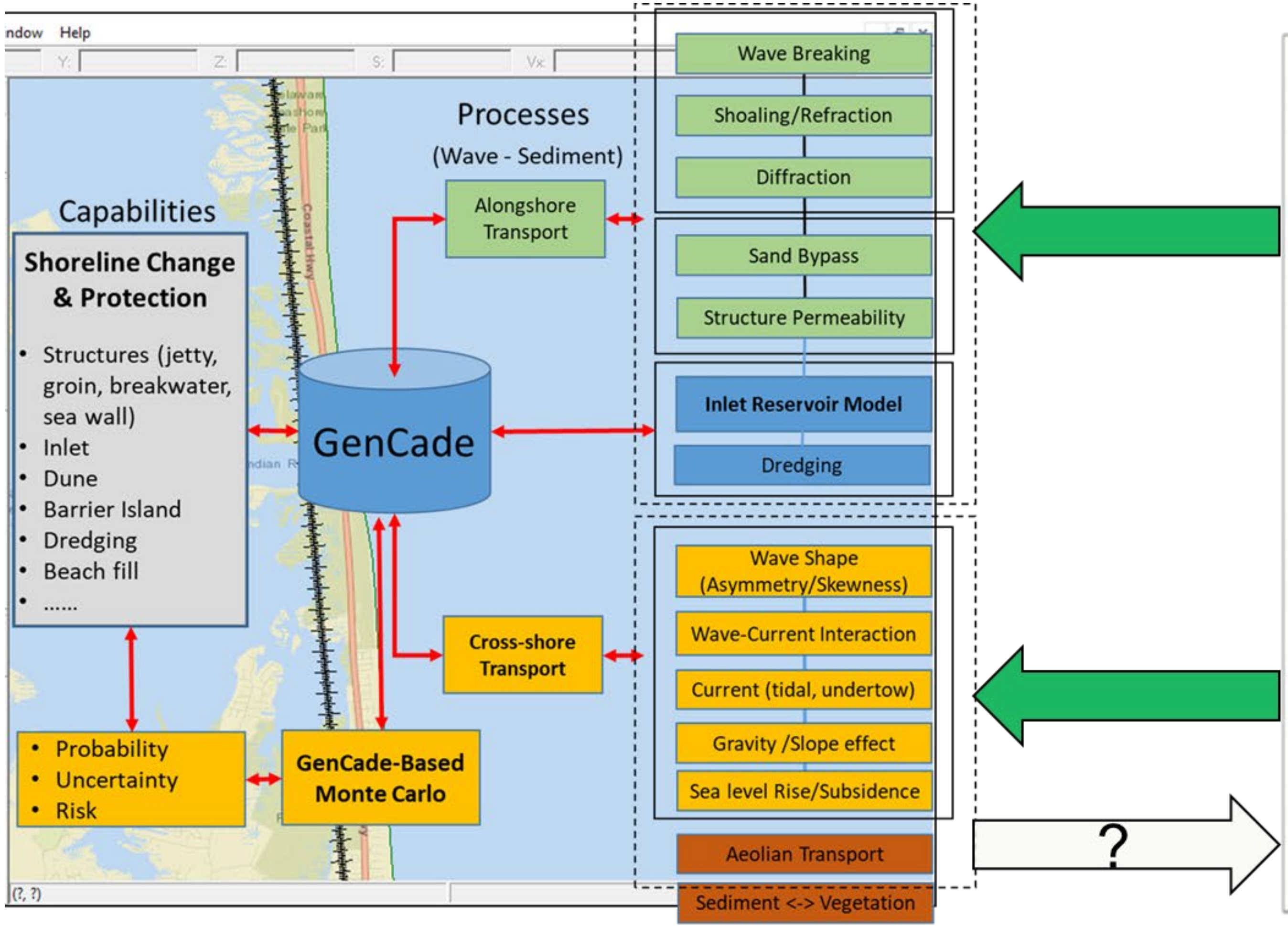
Introduction

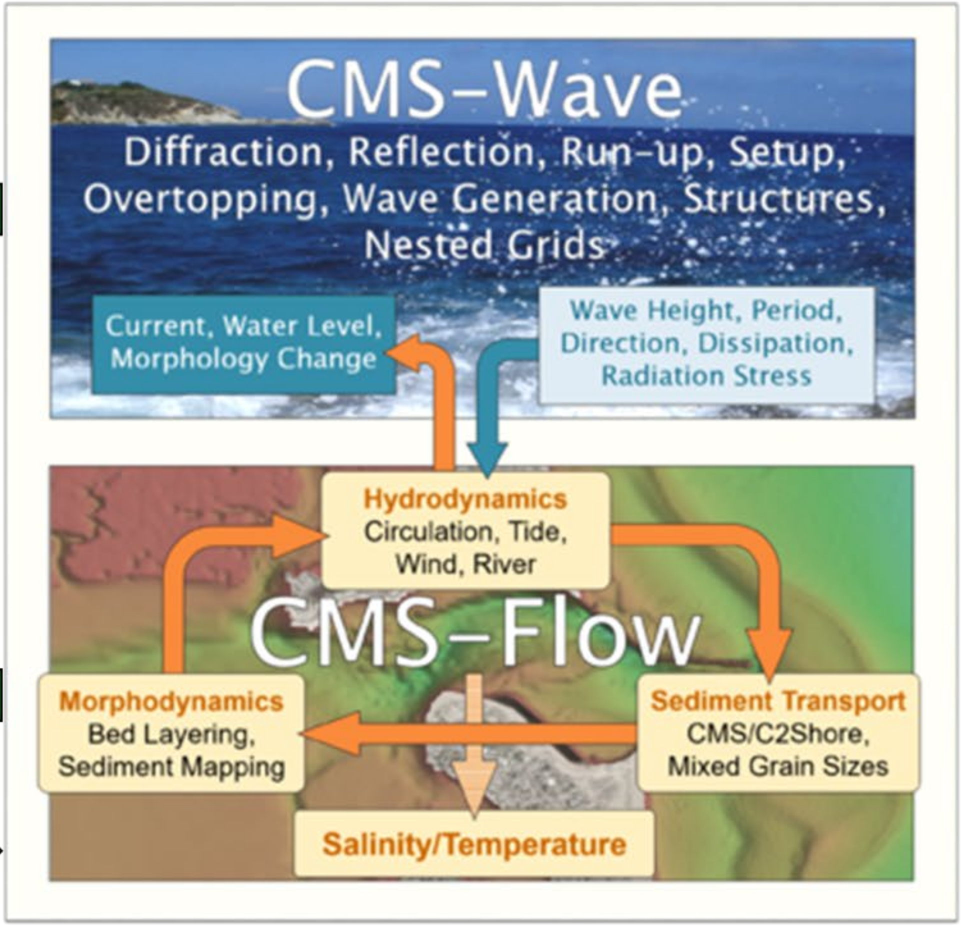
- Shoreline management requires information on long-term and regional shoreline evolution
  - Long-term: 1 ~ 10^2 years (≥ a life cycle)
  - Regional scale: 10~10^2 miles (~ a CSRM region)
- Inlets: Challenge for modeling long-term shoreline evolution in barrier islands to quantify
  - Sediment pathway between inlet and adjacent shorelines, sediment bypassing, evolution of inlet shoals/bars
  - Effect of jetties, bypassing operation, dredging/mining, etc.
- Quantification of performance of erosion protection measures in CSRM projects including:
  - Structures: groins, breakwaters (reefs), jetties, etc.
  - Non-structural measures: beach fill, nourishment, sand bypassing, dredged material placement, vegetation, etc.





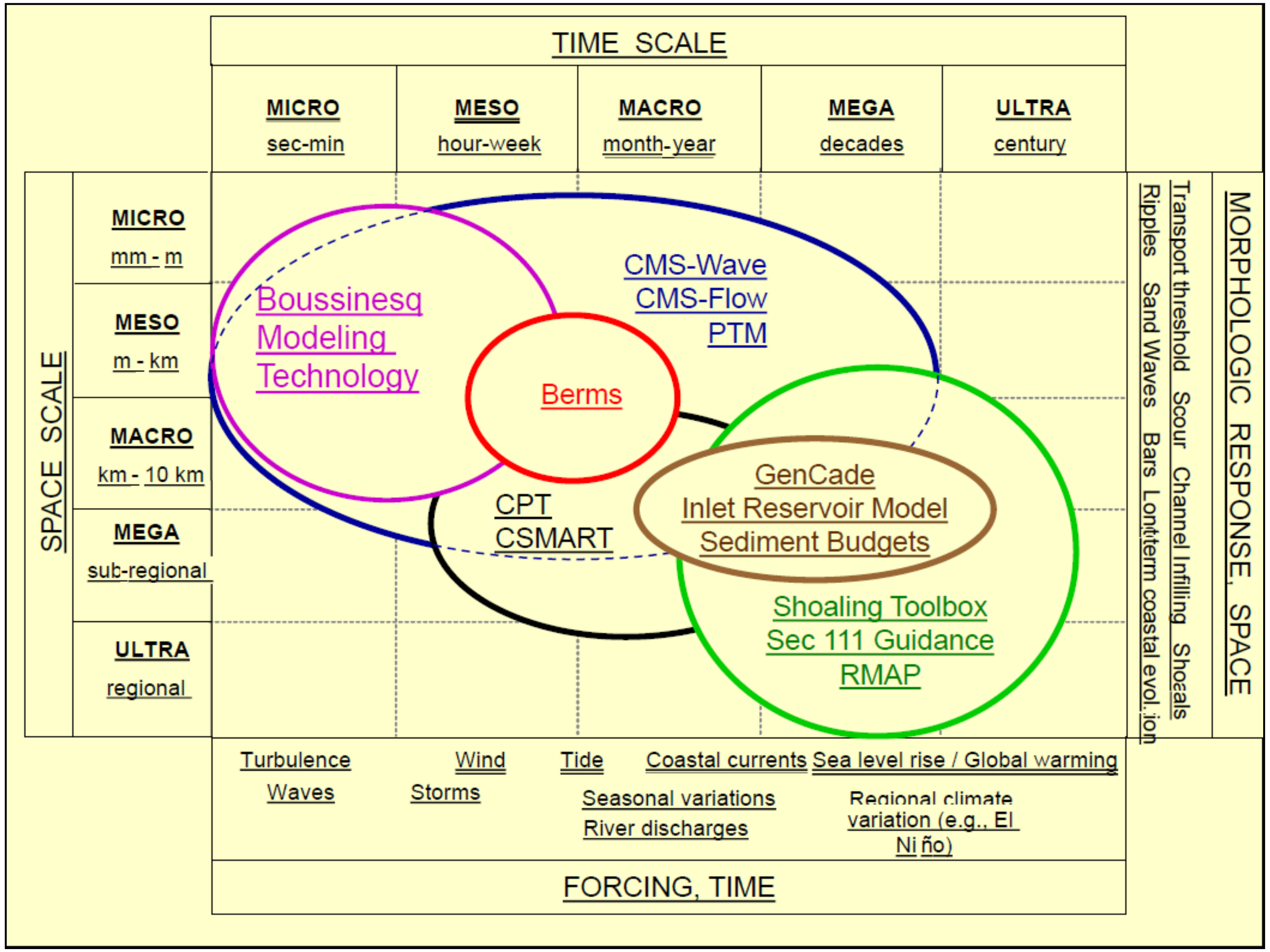
GenCade and CMS





- ❑ CMS provides waves and currents for better alongshore variation of sediment transport in GenCade.
- ❑ CMS identifies sediment transport patterns around inlet and pathway for bypassing.

Scales and Model Coverage



From Brown and Li (2019)

Principal features of one-line and 2-D morphological models

Simulation Input	GenCade	CMS
Wave	√	√
Current	√	√
Bed levels	–	√
Shoreline position	√	–
Shoal/bar	√	–

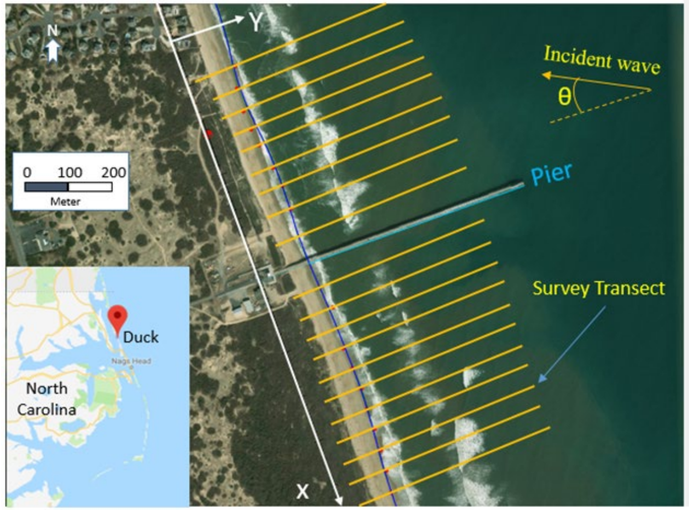
Simulation Output	GenCade	CMS
Wave	Breaking wave	√
Current	–	√
Sediment Flux	Total Longshore cross-shore rate	√ (2-D)
Bed change	–	√ (2-D)
Shoreline position	√	limited
Shoal/bar evolution	limited	√

Questions on CMS working for GenCade

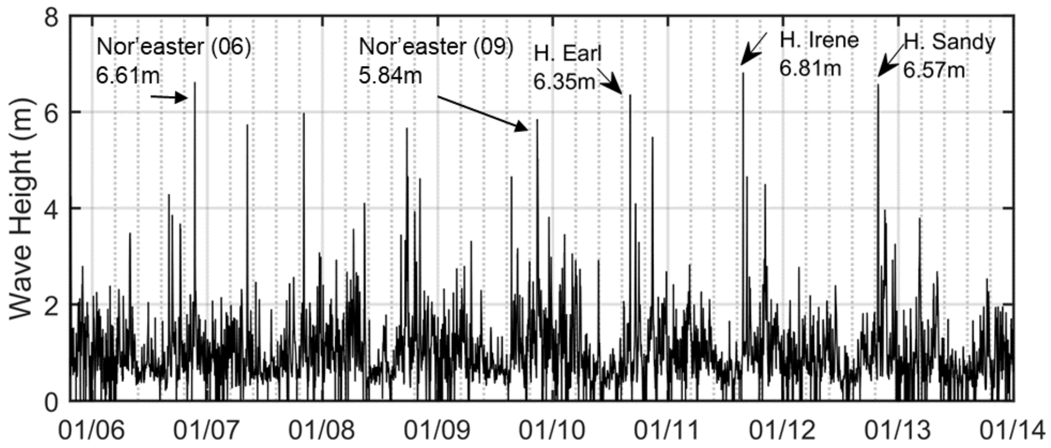
- How to determine if GenCade needs CMS-wave to generate wave conditions? or CMS-Flow to provide conditions of currents and water levels?
- How to use CMS (sediment transport results) to help GenCade IRM (Inlet Reservoir Model) simulating inlet bypassing?
- How good is the volumetric changes predicted by GenCade (based on the equilibrium beach profile assumption)? Or what is the difference in Vol. Changes between equilibrium profile assumption (GenCade) and non-equilibrium profile model (CMS)?
- It is time-consuming process to run CMS-Wave/Flow for generating long-term conditions of waves and currents. Any other efficient approach?

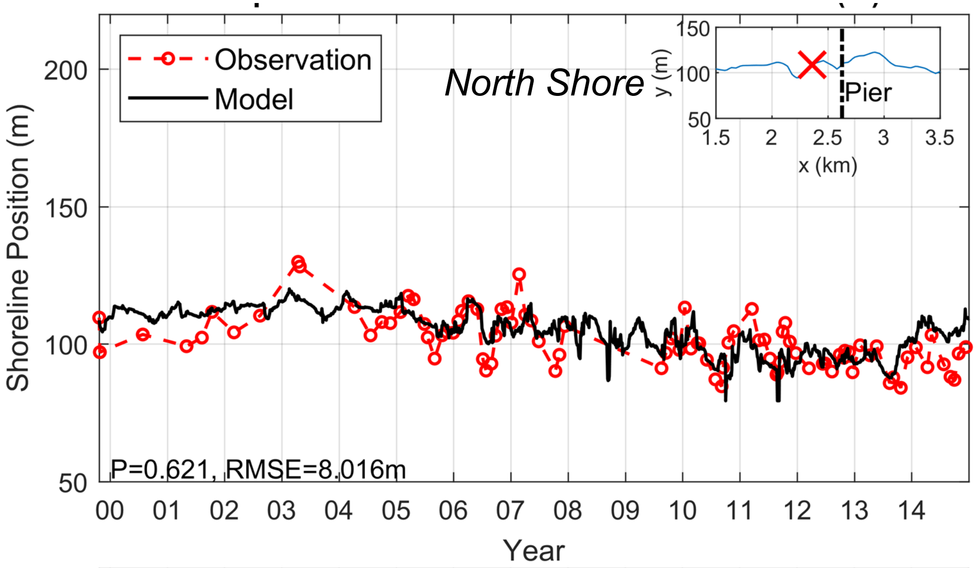
GenCade for Long-term and Regional Shoreline Evolution, Duck, NC

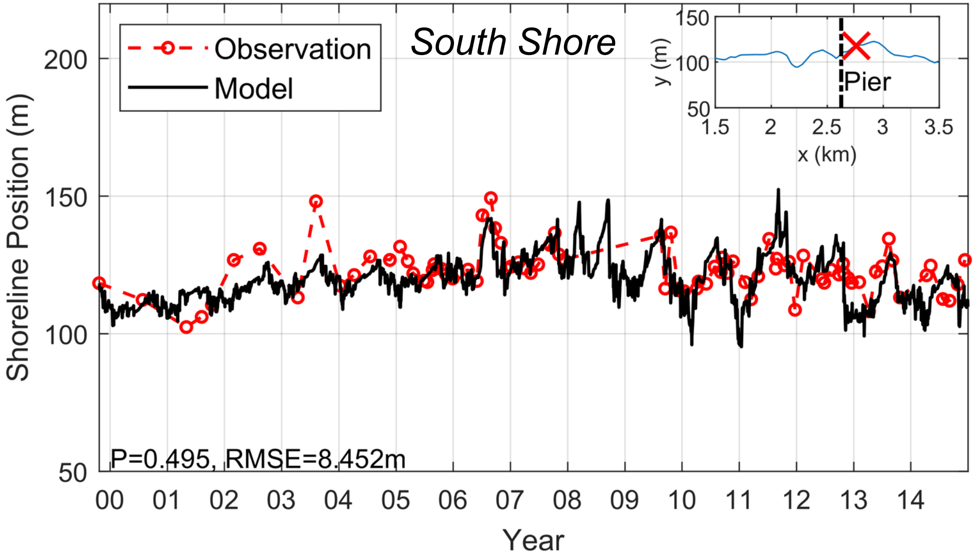
- Validated GenCade model using FRF 8-m Array data
- Simulation of effect of the FRF pier on sediment transport



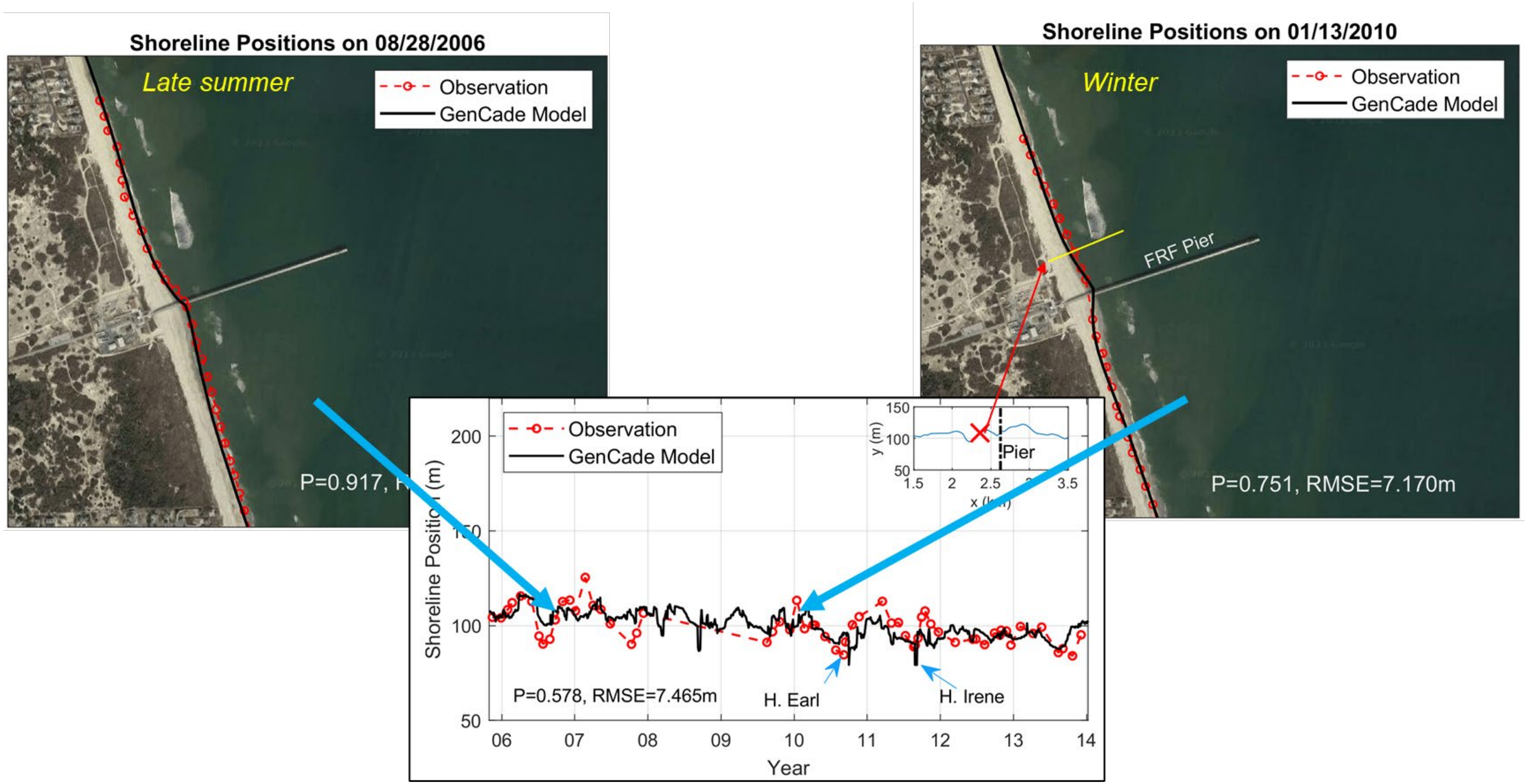
Wave: FRFSenso-Metric 8m Array
Δt = 3 minutes
K_1 = 0.40; K_2 = 0.25
Grain size = 0.20 mm
Berm Height = 1.0 m
Closure depth = 7.0
SLR Rate = 4.55 mm/year
Cross-shore Transport: $\alpha_D = 1.75$
Boundary Conditions: Pined
Permeability of Pier = 0.6





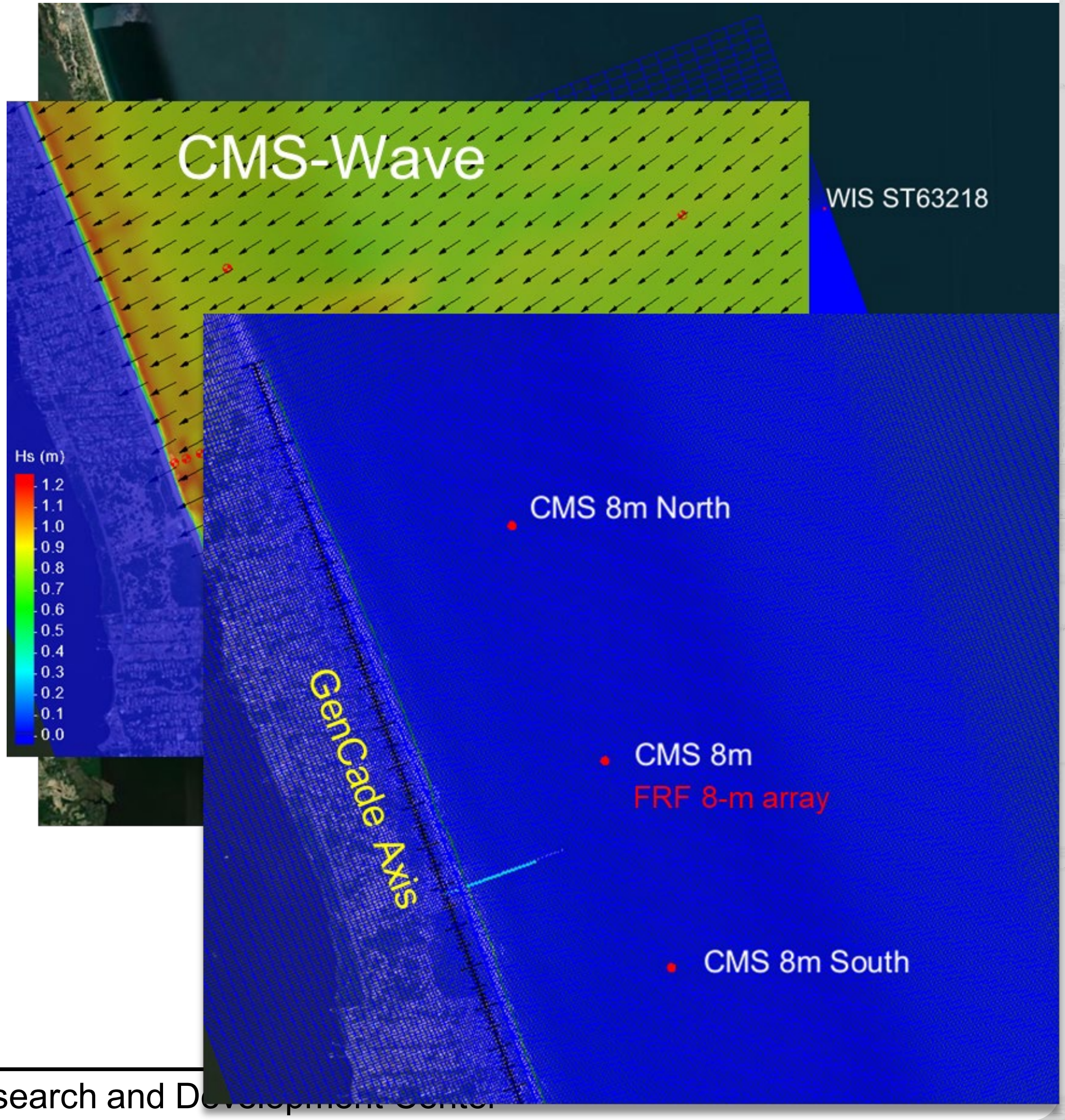


Model Validation: Seasonal Variation of Shoreline Profiles



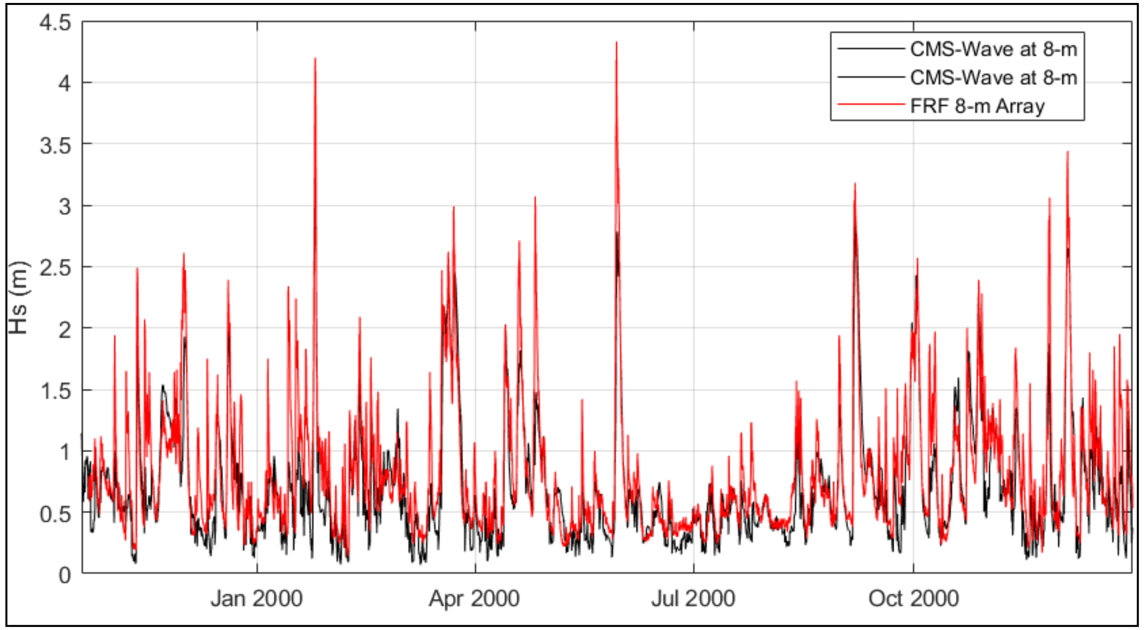
Wave Data Sources for Shoreline Simulations

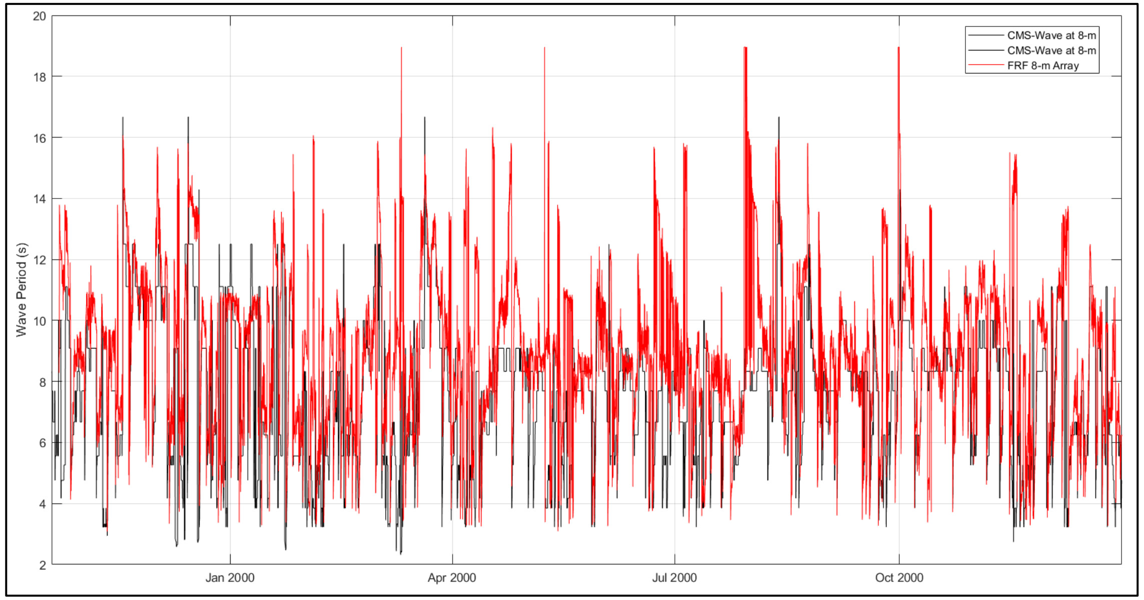
- Using wave samples at a single deepwater(e.g. WIS station) may not represent alongshore variations of waves (particularly direction) and shoreline changes.
- Using wave gage data nearshore such as FRF 8-m Array Wave data
- Using CMS-Wave to transform WIS deepwater waves to nearshore waves for better representing alongshore variations of waves (energy)
- We need to find which wave datasets are the best for shoreline simulation

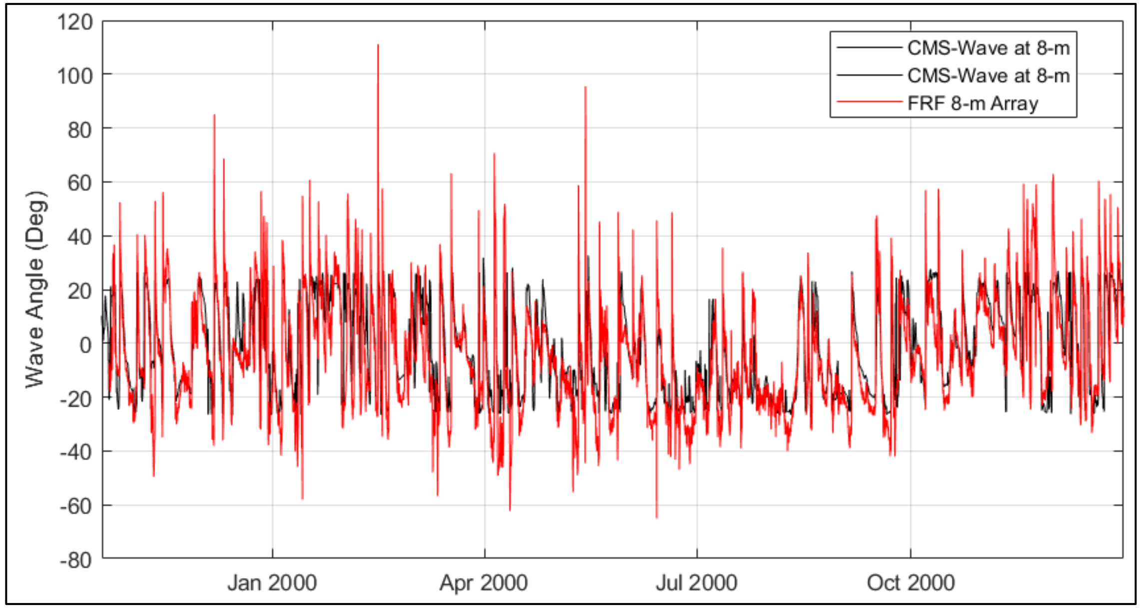


Station	Depth (m)	Wave Data for Training GPR model
WIS ST63218	25.0	WIS_waves_and_wind_ST63218.dat
FRF 8m Array	8.0	Wave_corr_nozero_8mFRF.dat
CMS 8m North	8.85	CMS_wave002_99_05_8mFRF_NORTH.dat
CMS 8m	8.90	CMS_wave005_99_05_8mFRF.dat
CMS 8m South	8.83	CMS_wave012_99_05_8mFRF_SOUTH.dat

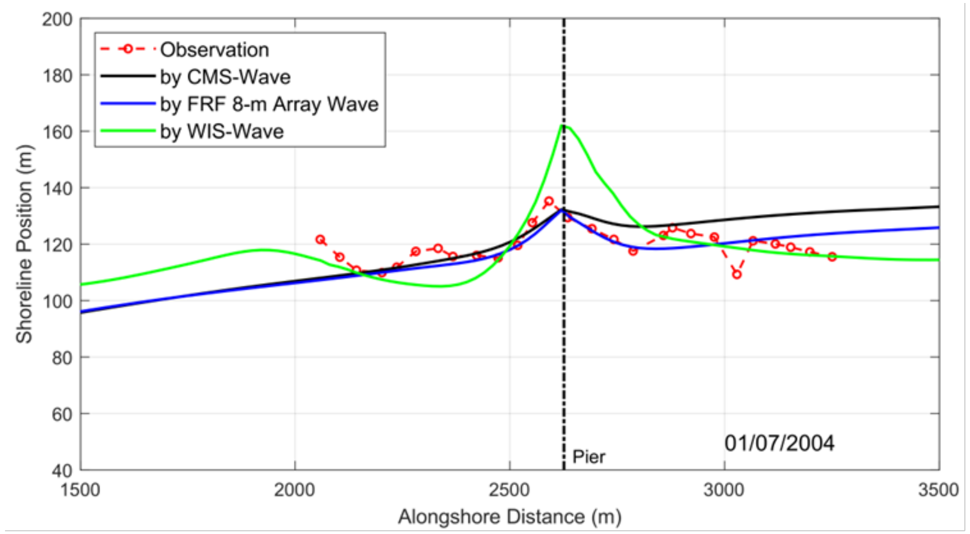
CMS-Wave vs FRF 8-m Array

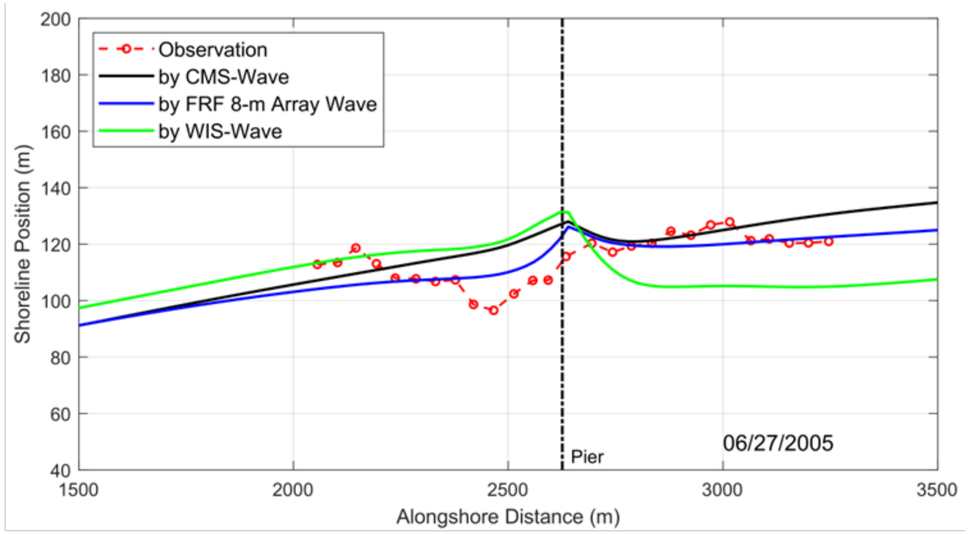


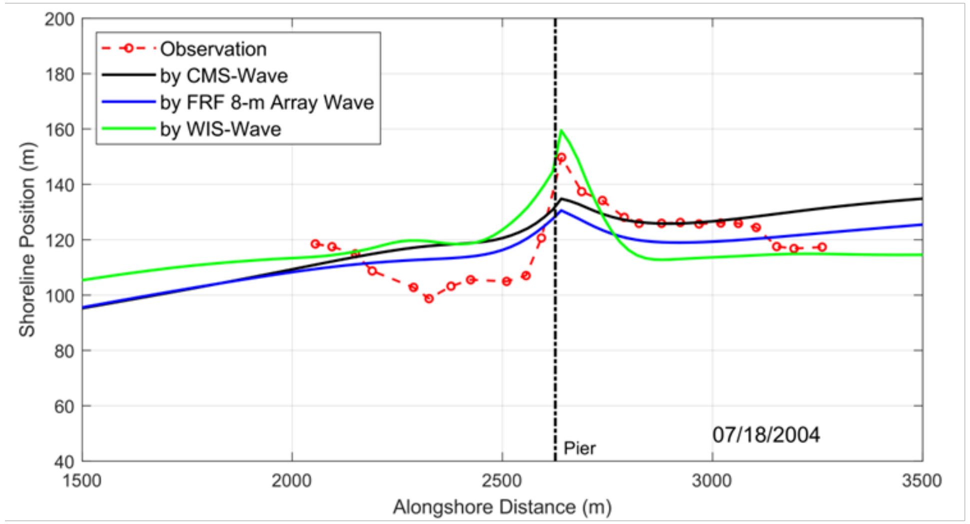


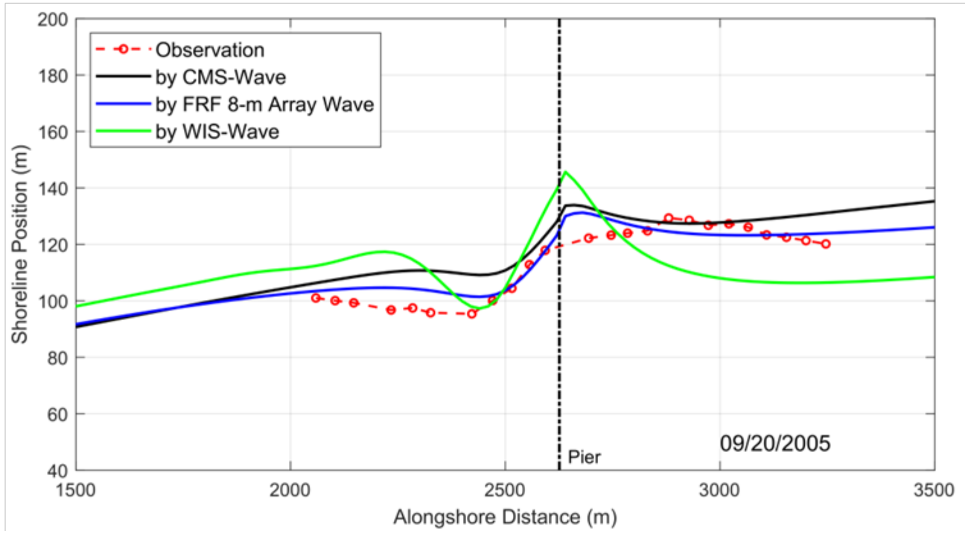


Comparisons of Shoreline Positions by 3 Wave Data

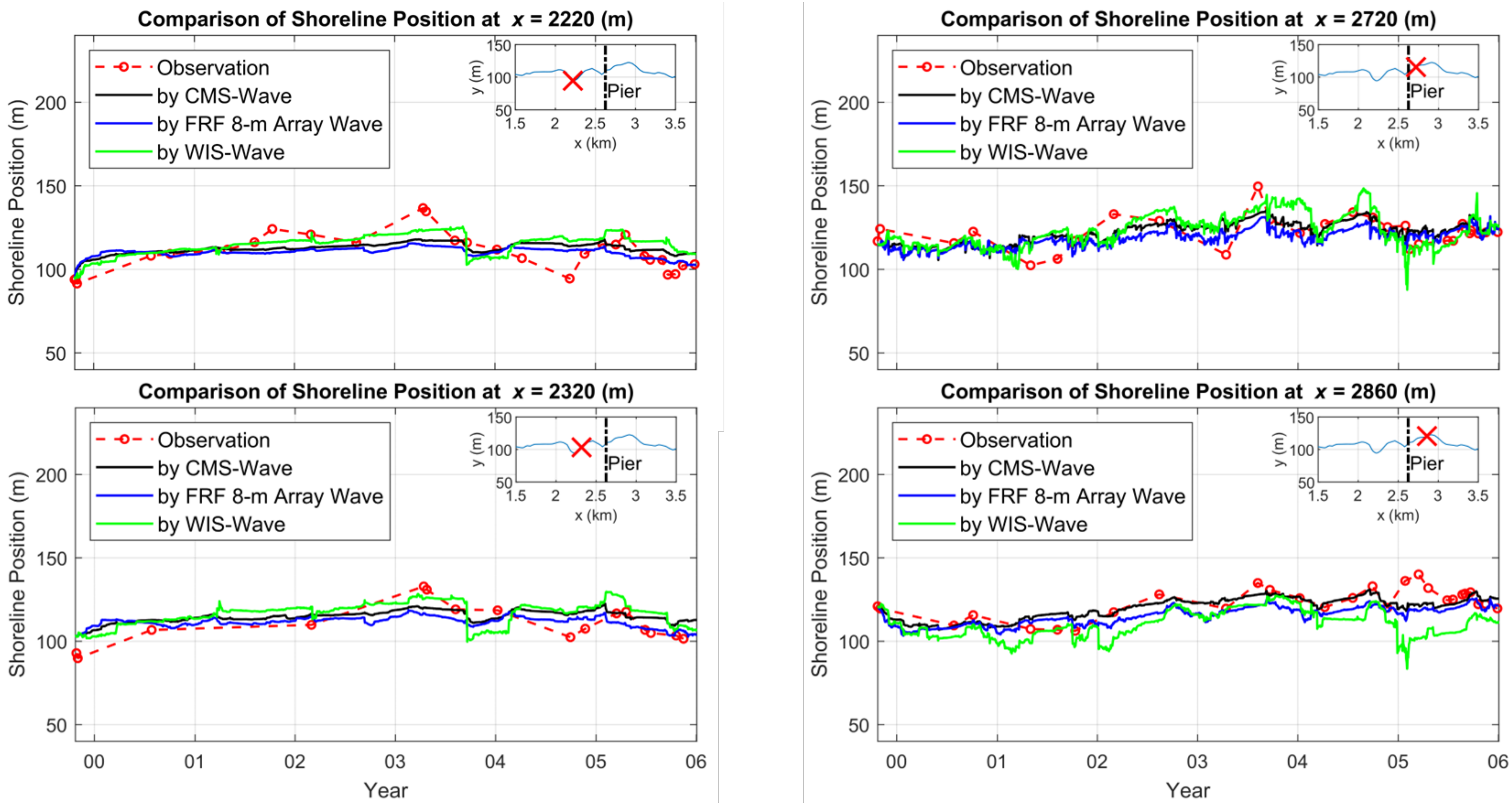




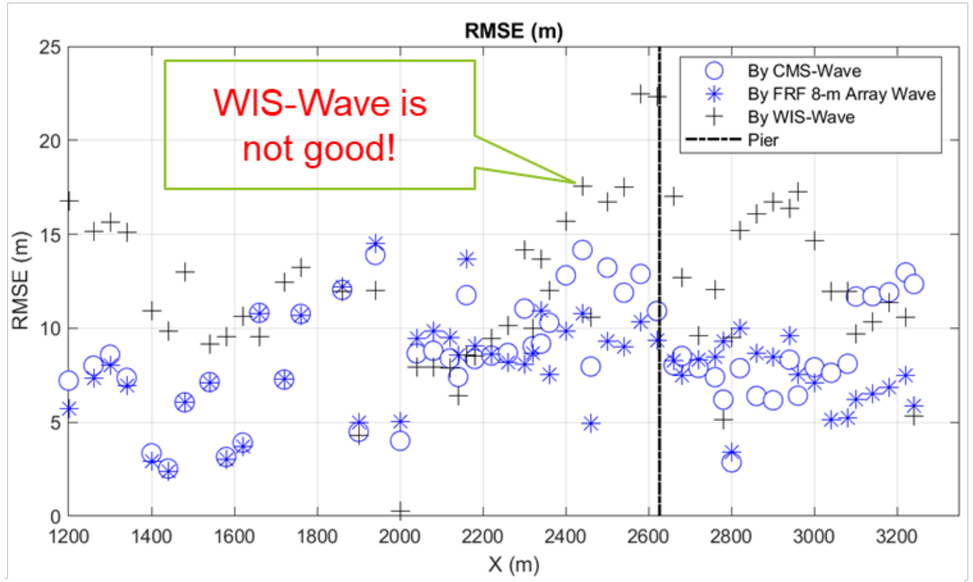


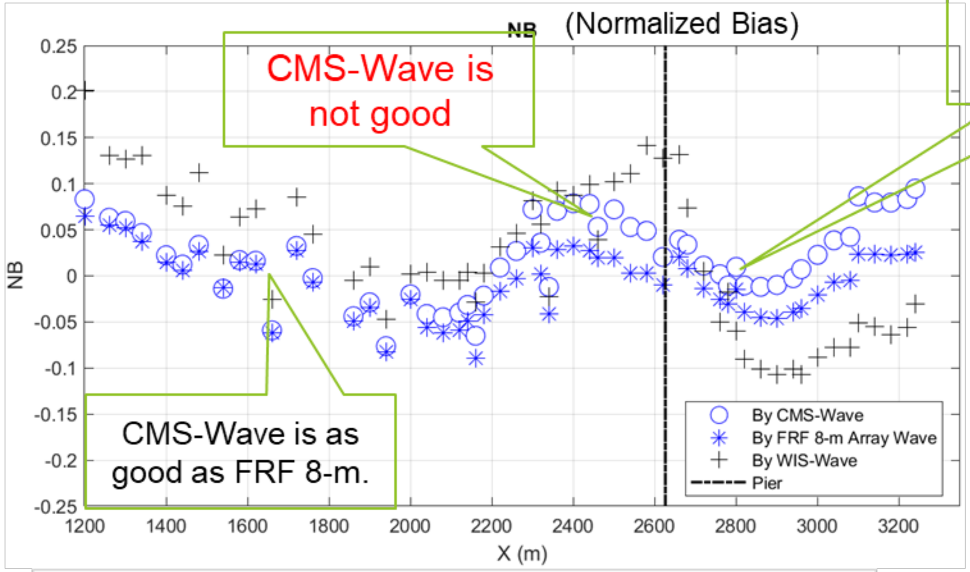


Comparisons of Shoreline Changes by Using 3 Wave Data

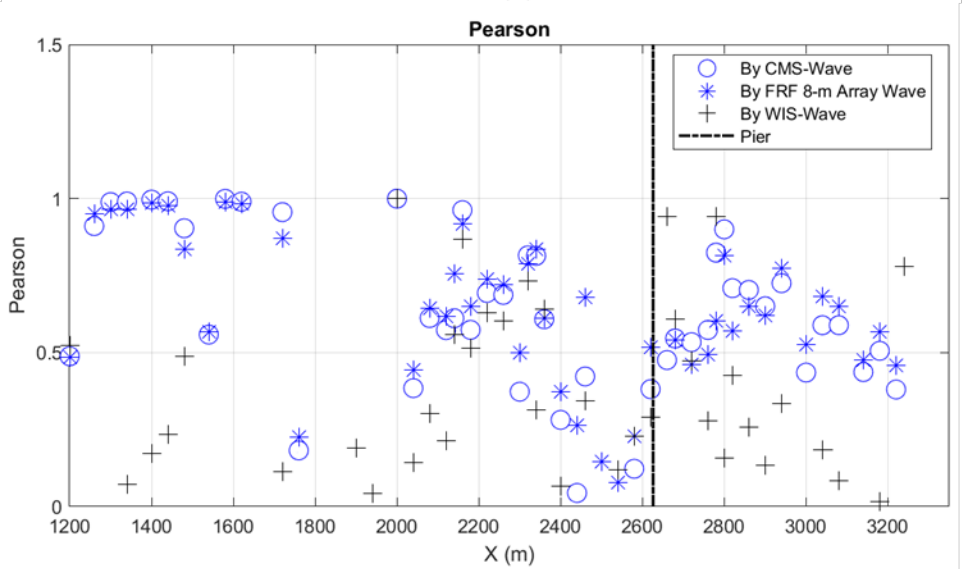


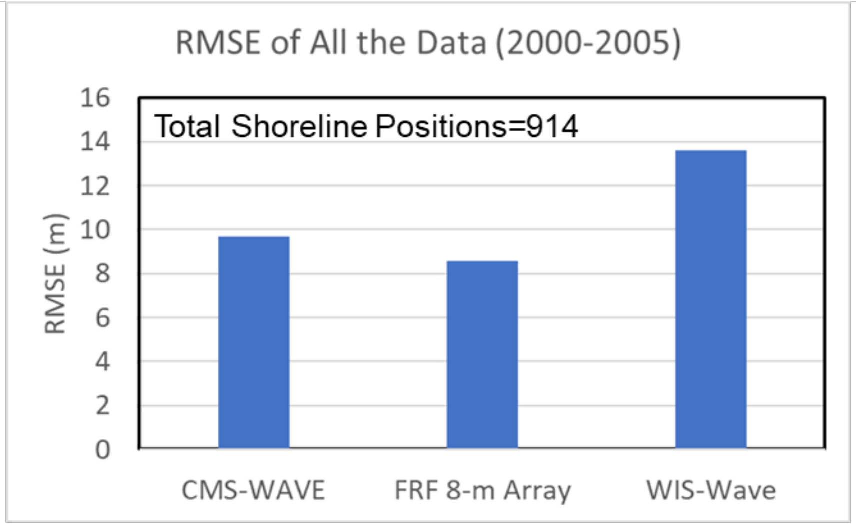
Error Distributions of Shoreline Positions by 3 Wave Datasets



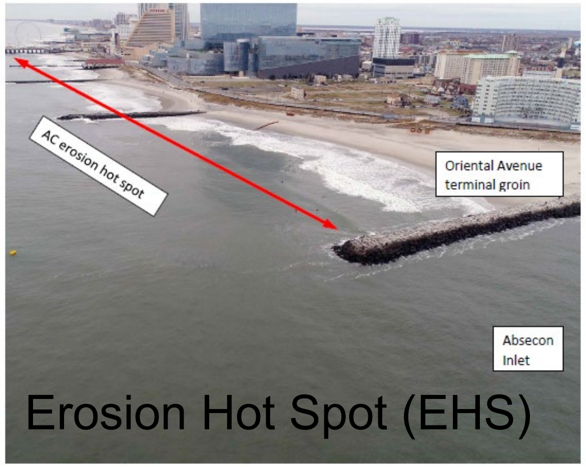


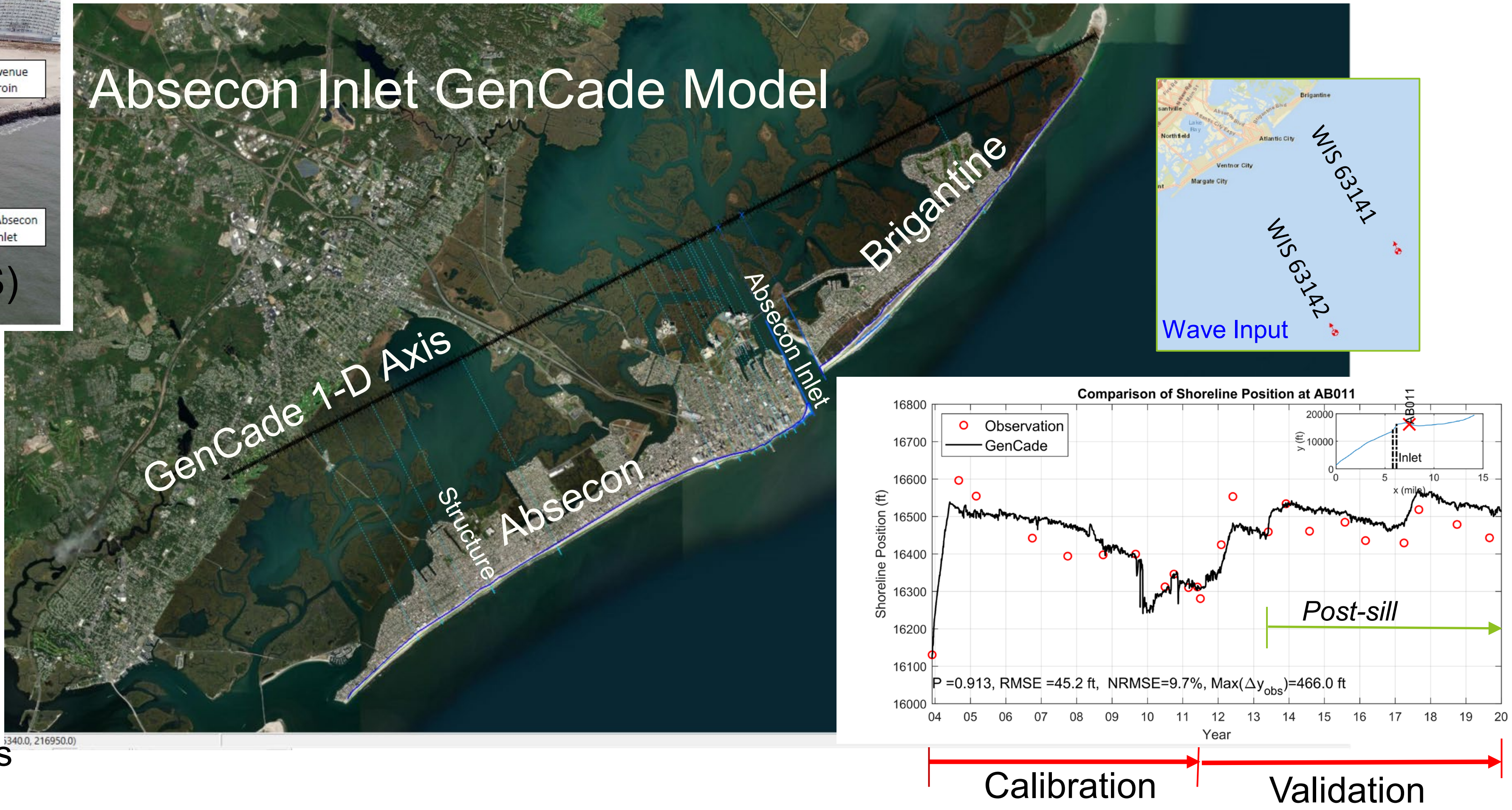
CMS-Wave is better than FRF 8-m Array data.





Simulation of Shoreline Evolution and Morphological Change around Absecon Inlet, NJ



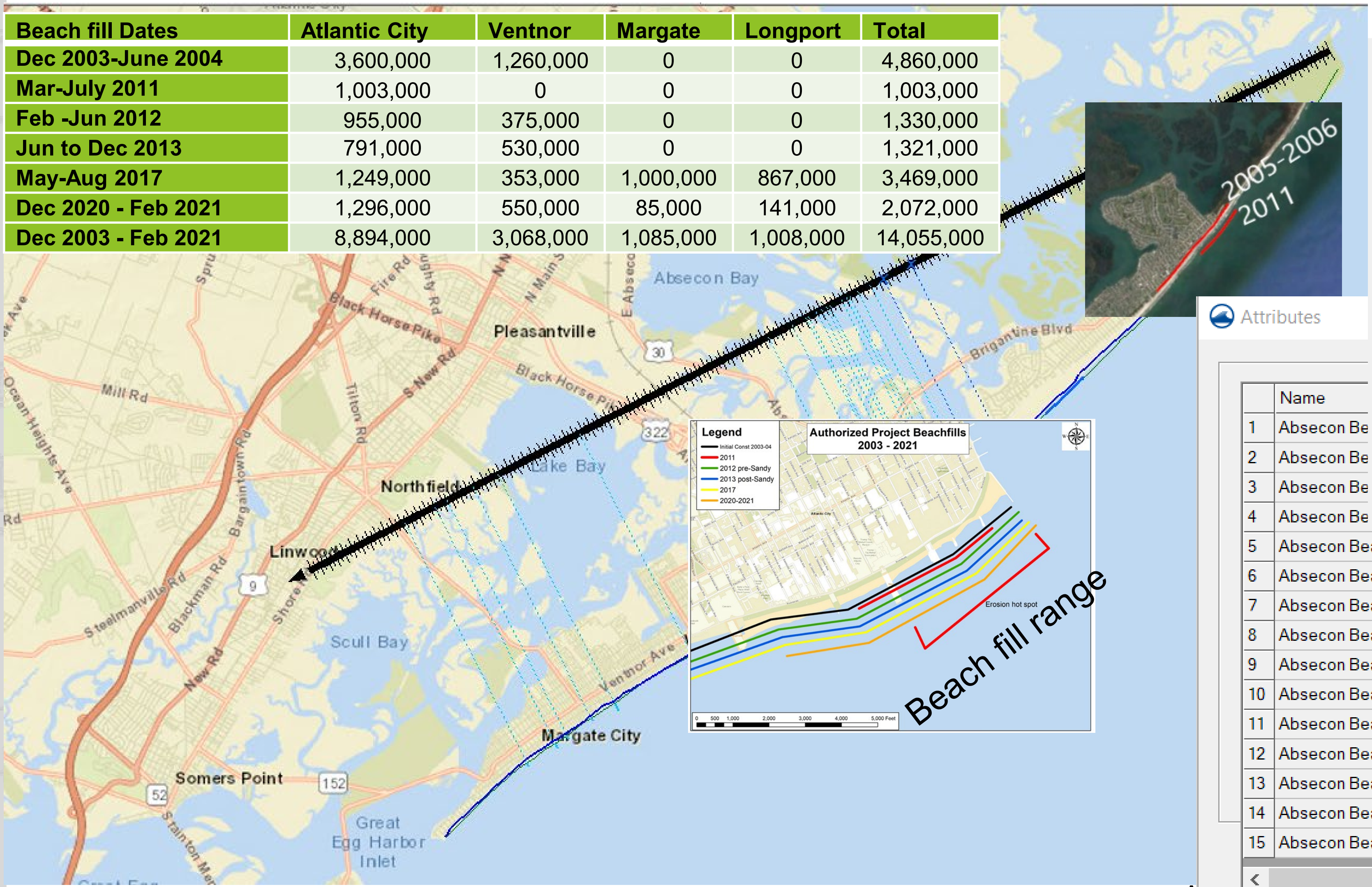


Calibration: 2003-2011
Validation: 2011-2019

Length (*L*)=14.1 miles
Grid space (*Δx*)=60 ft
Grid size (*N*) = 1243 transects

Beach fills (2003-2021) Included in GenCade

Beach fill Dates	Atlantic City	Ventnor	Margate	Longport	Total
Dec 2003-June 2004	3,600,000	1,260,000	0	0	4,860,000
Mar-July 2011	1,003,000	0	0	0	1,003,000
Feb -Jun 2012	955,000	375,000	0	0	1,330,000
Jun to Dec 2013	791,000	530,000	0	0	1,321,000
May-Aug 2017	1,249,000	353,000	1,000,000	867,000	3,469,000
Dec 2020 - Feb 2021	1,296,000	550,000	85,000	141,000	2,072,000
Dec 2003 - Feb 2021	8,894,000	3,068,000	1,085,000	1,008,000	14,055,000



Beach Fill

	Begin Date	End Date	Start Cell	End Cell	Added Berm Width (ft)
1	01-Nov-2005	01-Sep-2006	146	161	96.58
2	01-Nov-2005	01-Sep-2006	161	176	140.49
3	01-Oct-2011	01-Jan-2012	161	176	55.05
4	01-Dec-2017	01-Apr-2018	161	176	317.94
5	01-Nov-2012	01-Jun-2013	161	176	172.88
6	01-Nov-2005	01-Sep-2006	176	183	171.52
7	01-Oct-2011	01-Jan-2012	176	183	39.63
8	01-Nov-2012	01-Jun-2013	176	183	378.76
9	01-Dec-2017	01-Apr-2018	176	183	479.81
10	01-Nov-2005	01-Sep-2006	183	191	177.92
11	01-Dec-2017	01-Apr-2018	183	191	360.48
12	01-Oct-2011	01-Jan-2012	183	191	50.47
13	01-Nov-2012	01-Jun-2013	183	191	439.11
14	01-Nov-2005	01-Sep-2006	191	198	179.97
15	01-Nov-2012	01-Jun-2013	191	198	408.78
16	01-Dec-2017	01-Apr-2018	191	198	279.78
17	01-Oct-2011	01-Jan-2012	191	198	73.93
18	01-Nov-2005	01-Sep-2006	198	206	163.32

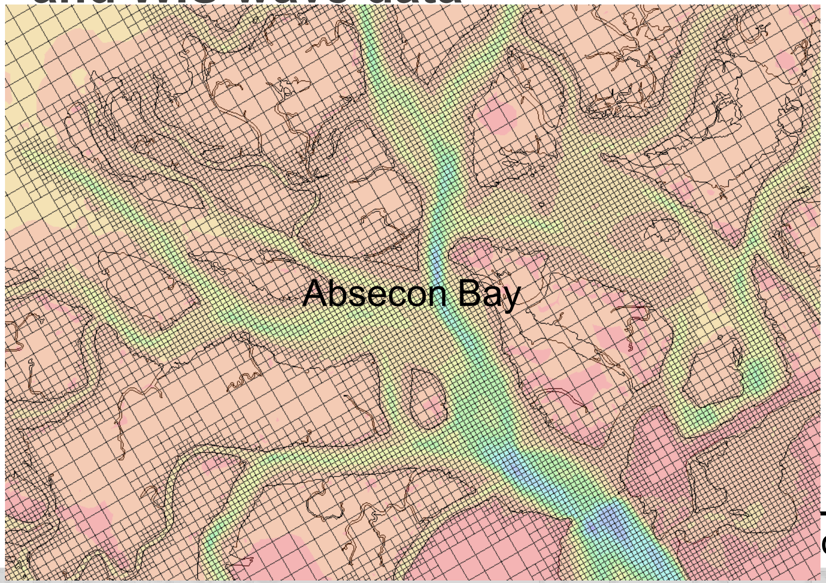
Attributes

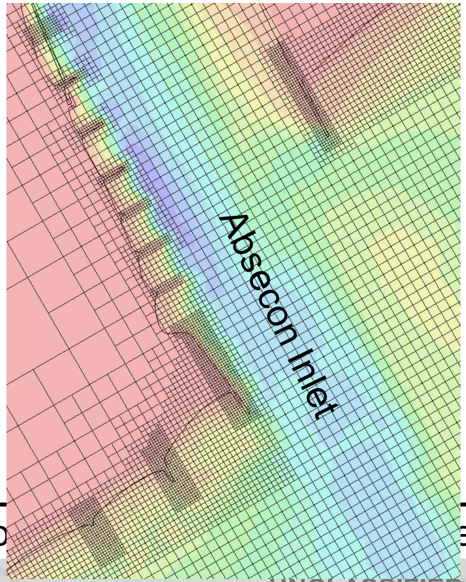
	Name					
1	Absecon Be					
2	Absecon Be					
3	Absecon Be					
4	Absecon Be					
5	Absecon Beach Fill Range	Feb-2012	Jun-2012	110.869133	AB025	AB033
6	Absecon Beach Fill Range	Jun-2013	Dec-2013	101.829072	AB051	AB012
7	Absecon Beach Fill Range	Jun-2013	Dec-2013	65.419285	AB014	AB033
8	Absecon Beach Fill Range	Apr-2017	Sep-2017	89.402910	AB051	AB024
9	Absecon Beach Fill Range	May-2017	Sep-2017	49.782800	AB025	AB032
10	Absecon Beach Fill Range	Jun-2017	Jan-2018	174.625111	AB033	AB041
11	Absecon Beach Fill Range	Oct-2017	May-2018	158.458487	AB042	AB049
12	Absecon Beach Fill Range	Sep-2020	Jan-2021	174.537400	AB029	AB032
13	Absecon Beach Fill Range	Sep-2020	Dec-2020	81.448550	AB033	AB034
14	Absecon Beach Fill Range	Nov-2020	Dec-2020	41.856267	AB047	AB049
15	Absecon Beach Fill Range	Nov-2020	Feb-2021	228.729285	AB051	AB014

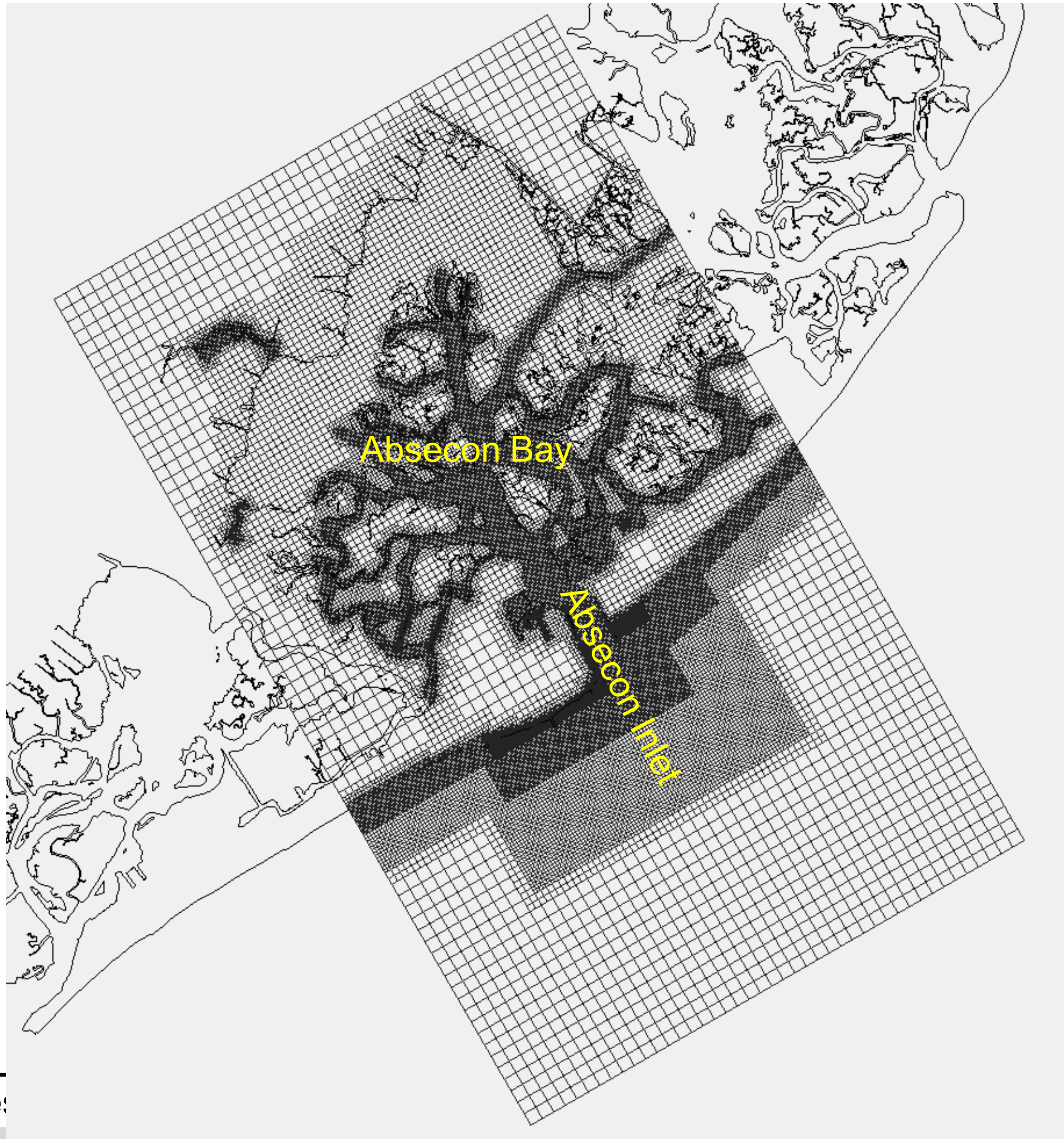
- Added berm width was estimated from the measured shoreline changes

CMS-Flow Grid around Absecon Inlet

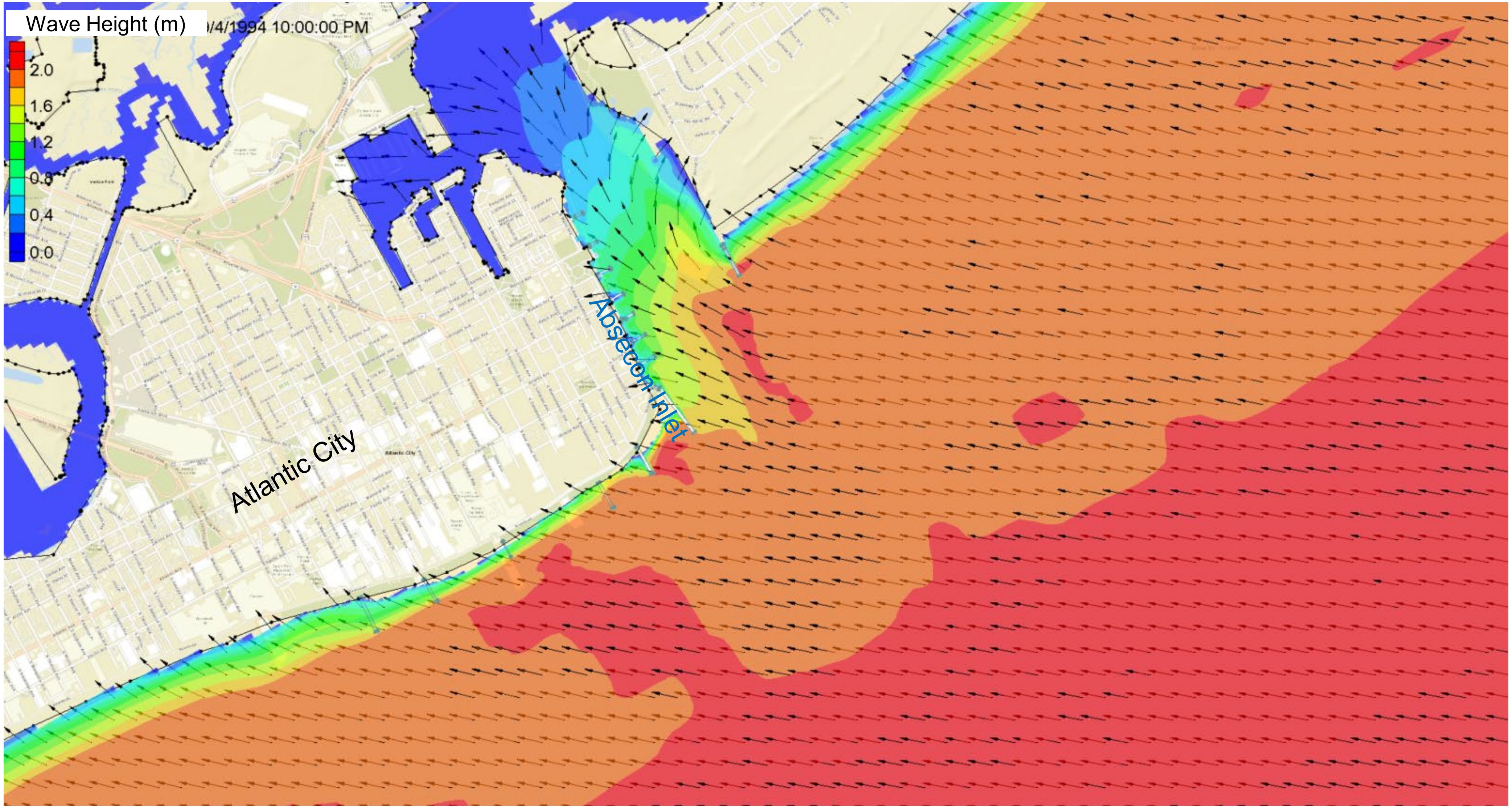
- Horizontal Coordinate System: UTM 18N (Meters)
- Vertical Coordinate System: m, MSL
- Telescoping Grid
  - Minimum resolution: 4 to 8 m @ structures
  - Maximum resolution: 256 m @ offshore
  - Square cells: 4, 8, 16, 32, 64, 128, 256
- Structures
- Variable Manning's Roughness
- Boundary Conditions: NOAA tide gage at Steel Pier and WIS wave data



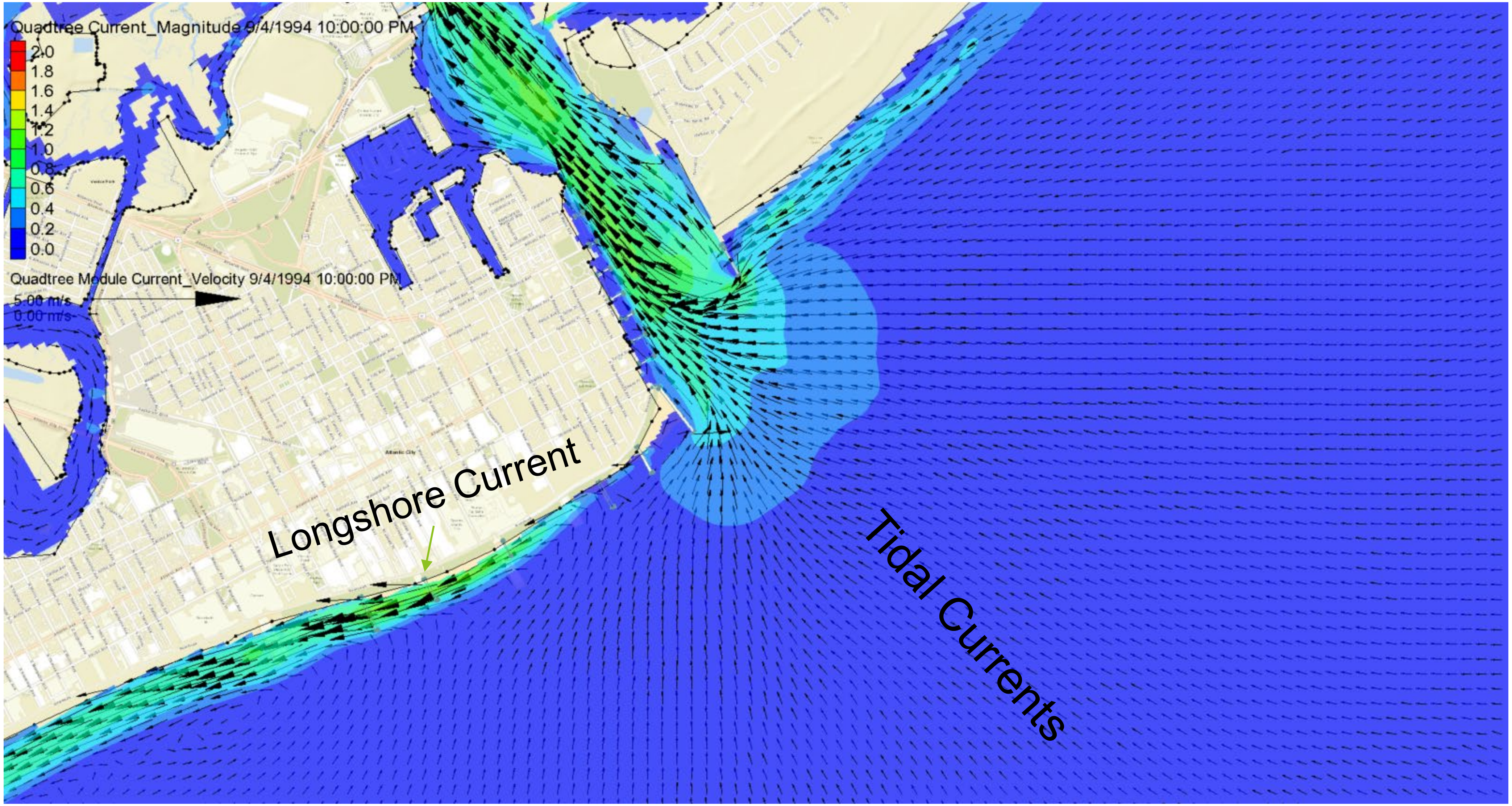




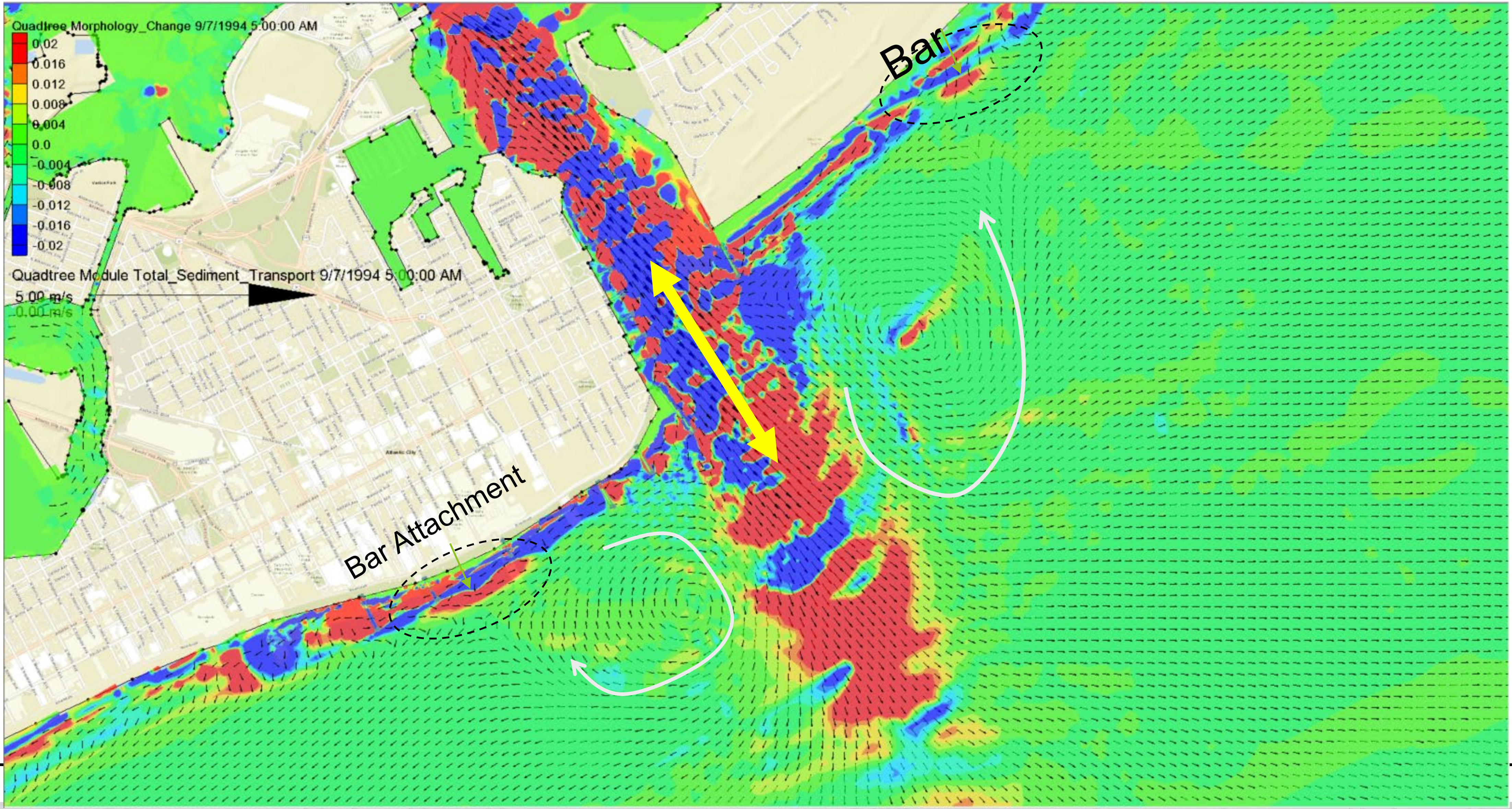
Wave Heights and Mean Directions



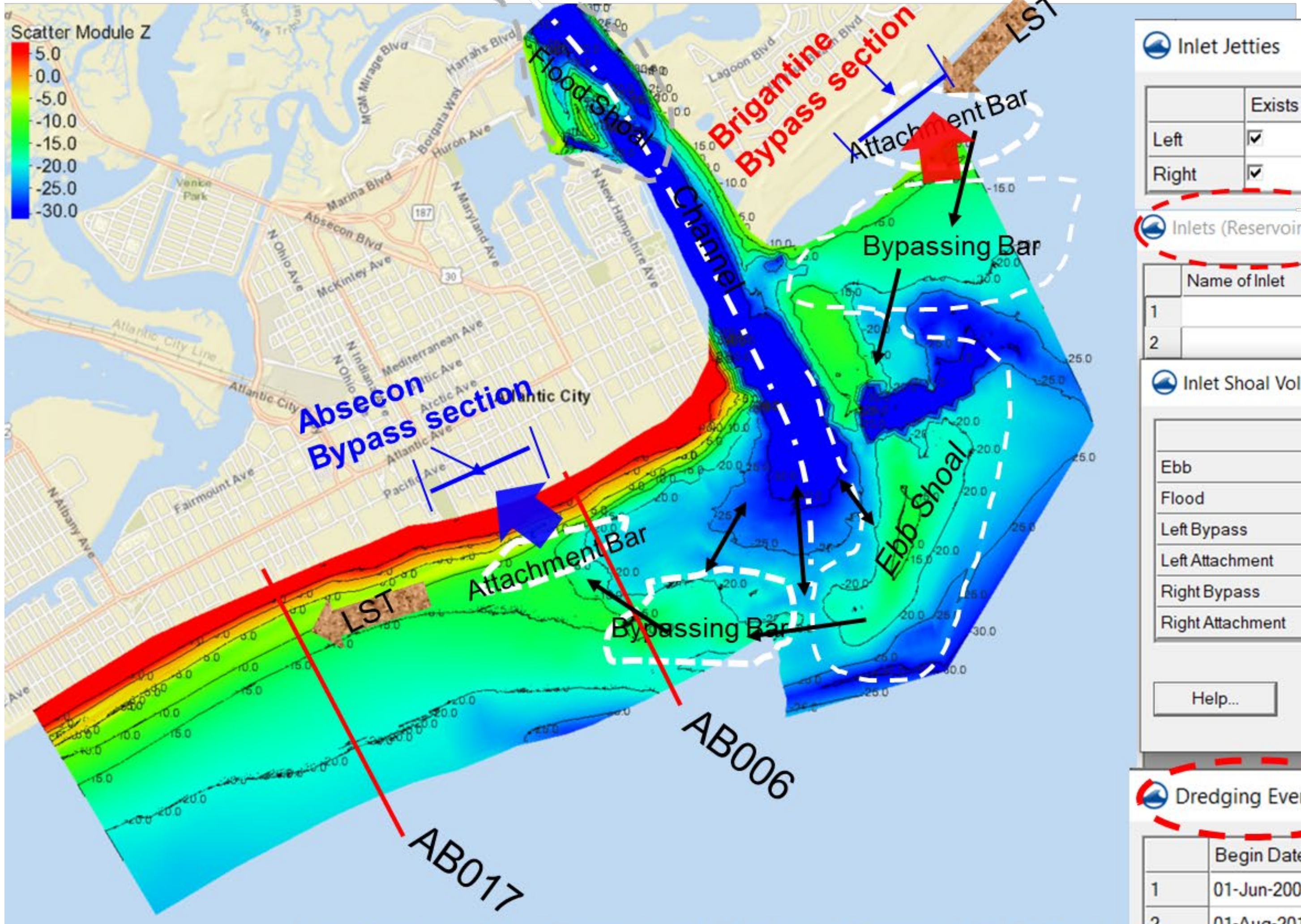
Mean Currents in a Flood Tide



Sediment Transport Pattern and Sediment Pathways



Absecon Inlet Reservoir Model (Absecon-IRM) for Inlet Morphologic Features and Dredging



Map: Combined Inlet Survey (2021-Mar) with Transects (2021-Feb)

Inlet Jetties

	Exists	Length (ft)	Permeability	Diffracting	Seaward Depth (ft)
Left	☑	14267.550616	0.0	☑	14.57
Right	☑	16321.459853	0.2	☑	17.37

Inlets (Reservoir Model and Jetties)

	Name of Inlet	Cell	(yd³)	Control	Manage	Left Bypass Coef	Right Bypass Coef
1		Position...	Volume...	Jetties...	Dredging...	1.0	1.1
2		Position...	Volume...	Jetties...	Dredging...		

Inlet Shoal Volumes

	Initial	Equilibrium
Ebb	10233118.0	15000000.0
Flood	2505170.0	3500000.0
Left Bypass	337410.0	1000000.0
Left Attachment	124380.0	350000.0
Right Bypass	84734.0	1750000.0
Right Attachment	130000.0	700000.0

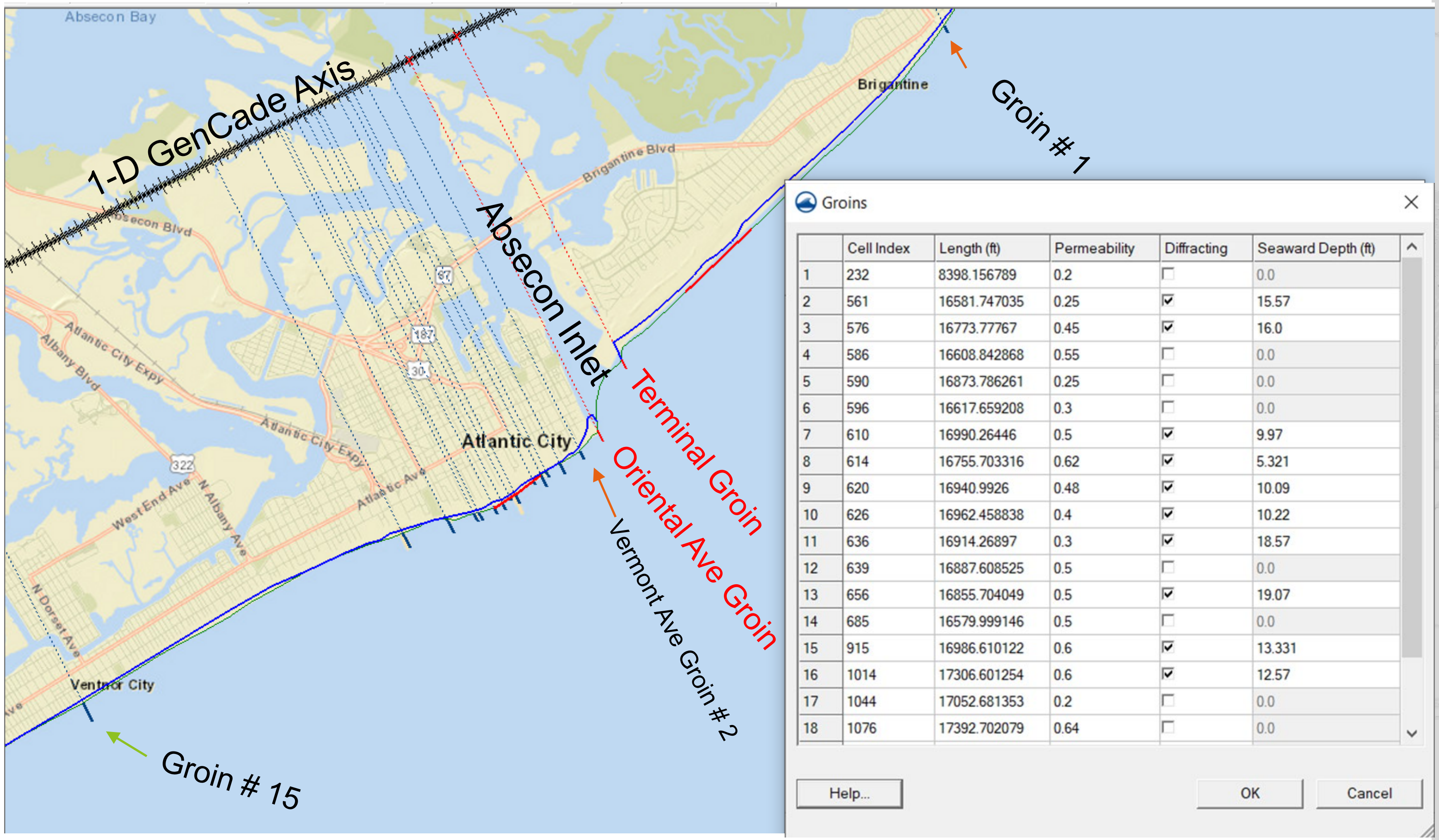
Help... OK Cancel

Dredging Events

	Begin Date	End Date	Shoal to Be Mined	Volume (yd³)
1	01-Jun-2004	30-Jun-2004	Ebb	4849844.0
2	01-Aug-2011	30-Aug-2011	Ebb	1165641.0

Calibrated Parameters for Estimating Bypassing Effect of Groins on LST

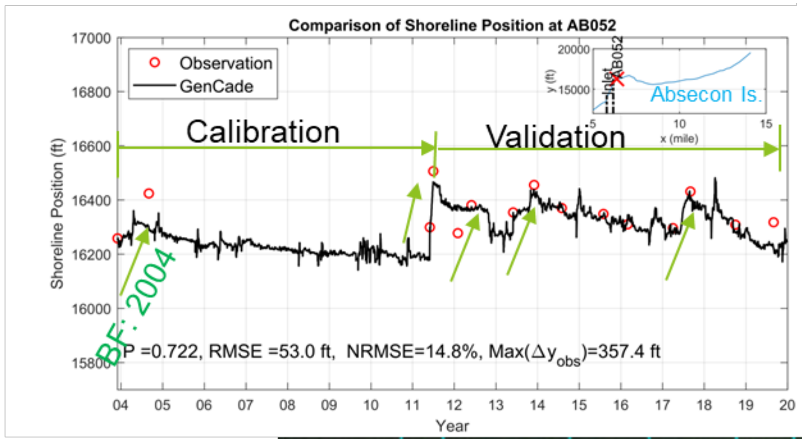
- **Diffracting Structures**: Groins, Piers
- Non-Diffracting Structures: Short groins, outfalls
- **Seaward depth** at the tip of groin is given from transect profile near the structure
- **Length: the** distance from the seaward tip to the GenCade 1-D Axis.
- **Permeability** (sand transmission capability through the structure): **calibrated**

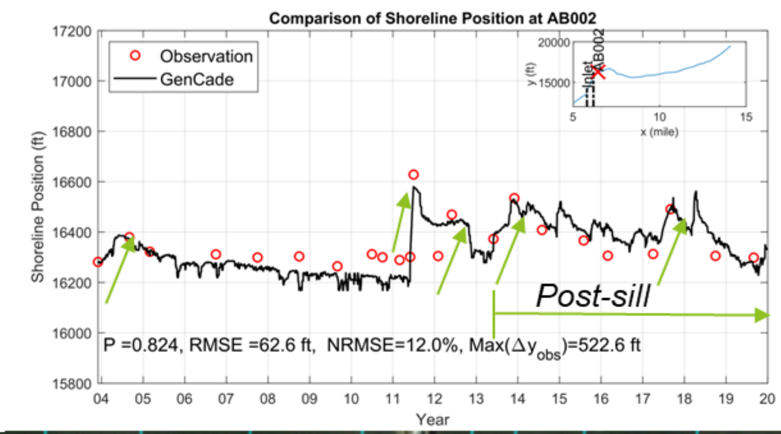


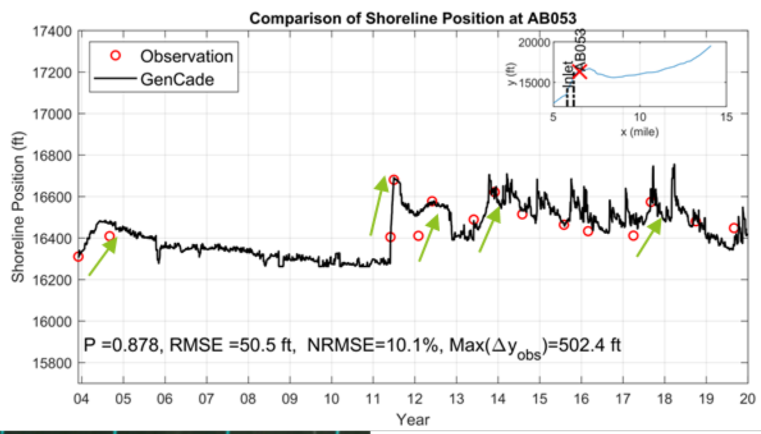
	Cell Index	Length (ft)	Permeability	Diffracting	Seaward Depth (ft)
1	232	8398.156789	0.2	☐	0.0
2	561	16581.747035	0.25	☑	15.57
3	576	16773.77767	0.45	☑	16.0
4	586	16608.842868	0.55	☐	0.0
5	590	16873.786261	0.25	☐	0.0
6	596	16617.659208	0.3	☐	0.0
7	610	16990.26446	0.5	☑	9.97
8	614	16755.703316	0.62	☑	5.321
9	620	16940.9926	0.48	☑	10.09
10	626	16962.458838	0.4	☑	10.22
11	636	16914.26897	0.3	☑	18.57
12	639	16887.608525	0.5	☐	0.0
13	656	16855.704049	0.5	☑	19.07
14	685	16579.999146	0.5	☐	0.0
15	915	16986.610122	0.6	☑	13.331
16	1014	17306.601254	0.6	☑	12.57
17	1044	17052.681353	0.2	☐	0.0
18	1076	17392.702079	0.64	☐	0.0

Help... OK Cancel

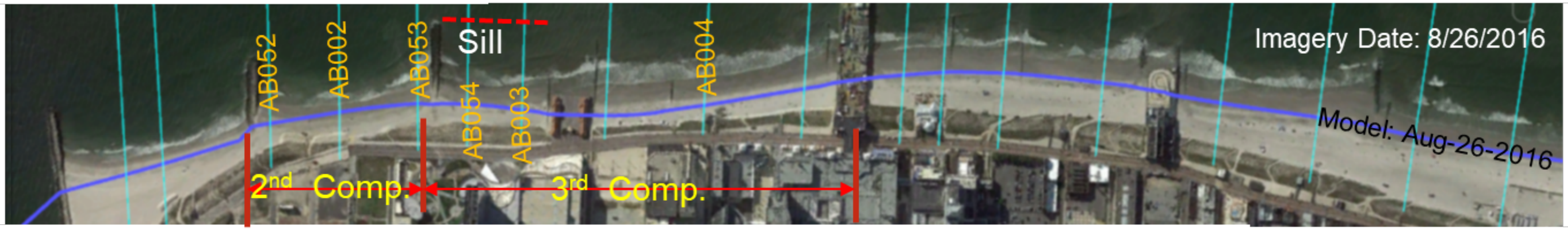
All Simulation Results (2003-2020) in Second and Third Compartments of EHS

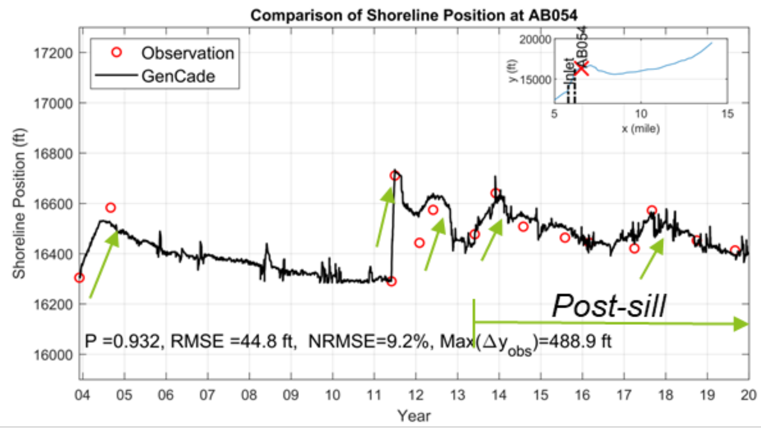


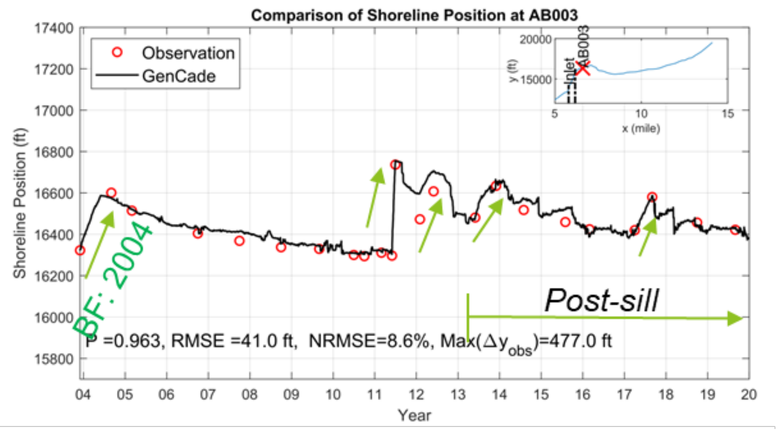


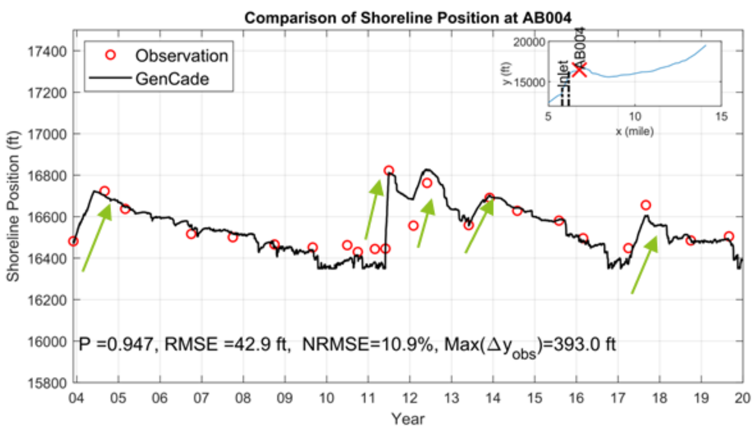


EHS

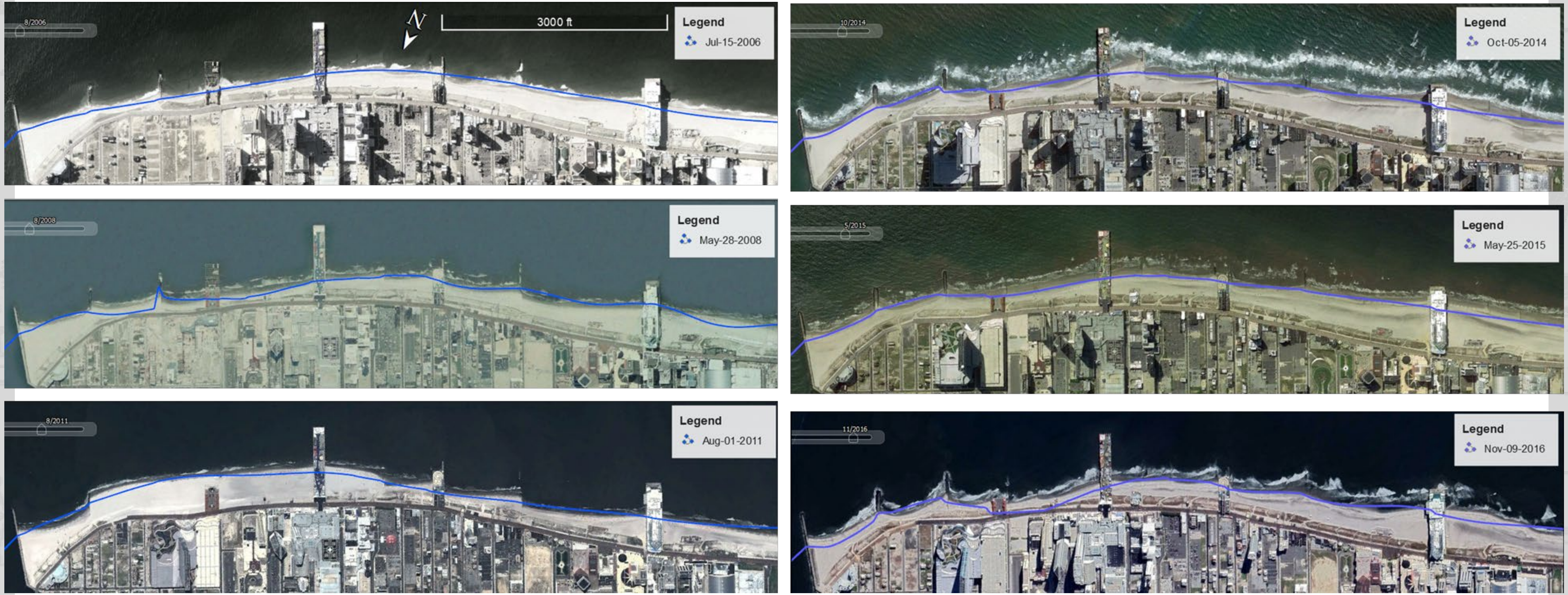




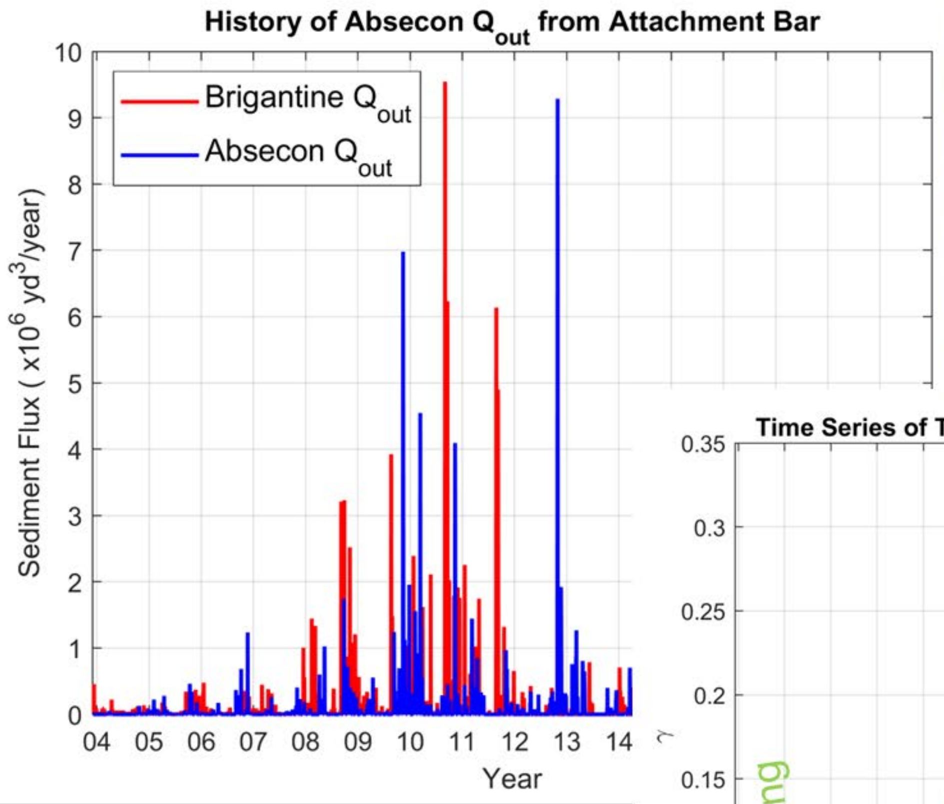


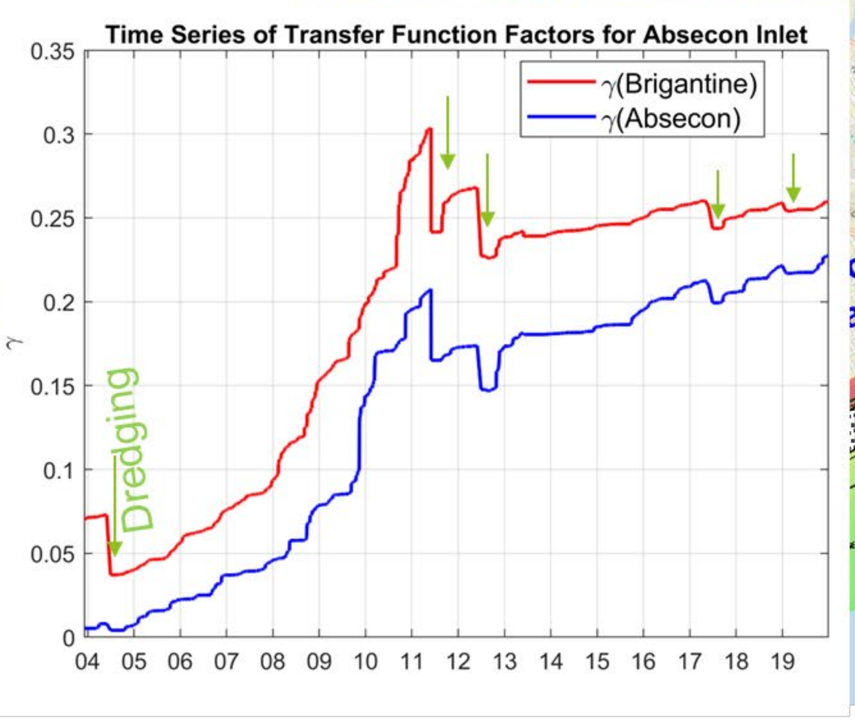


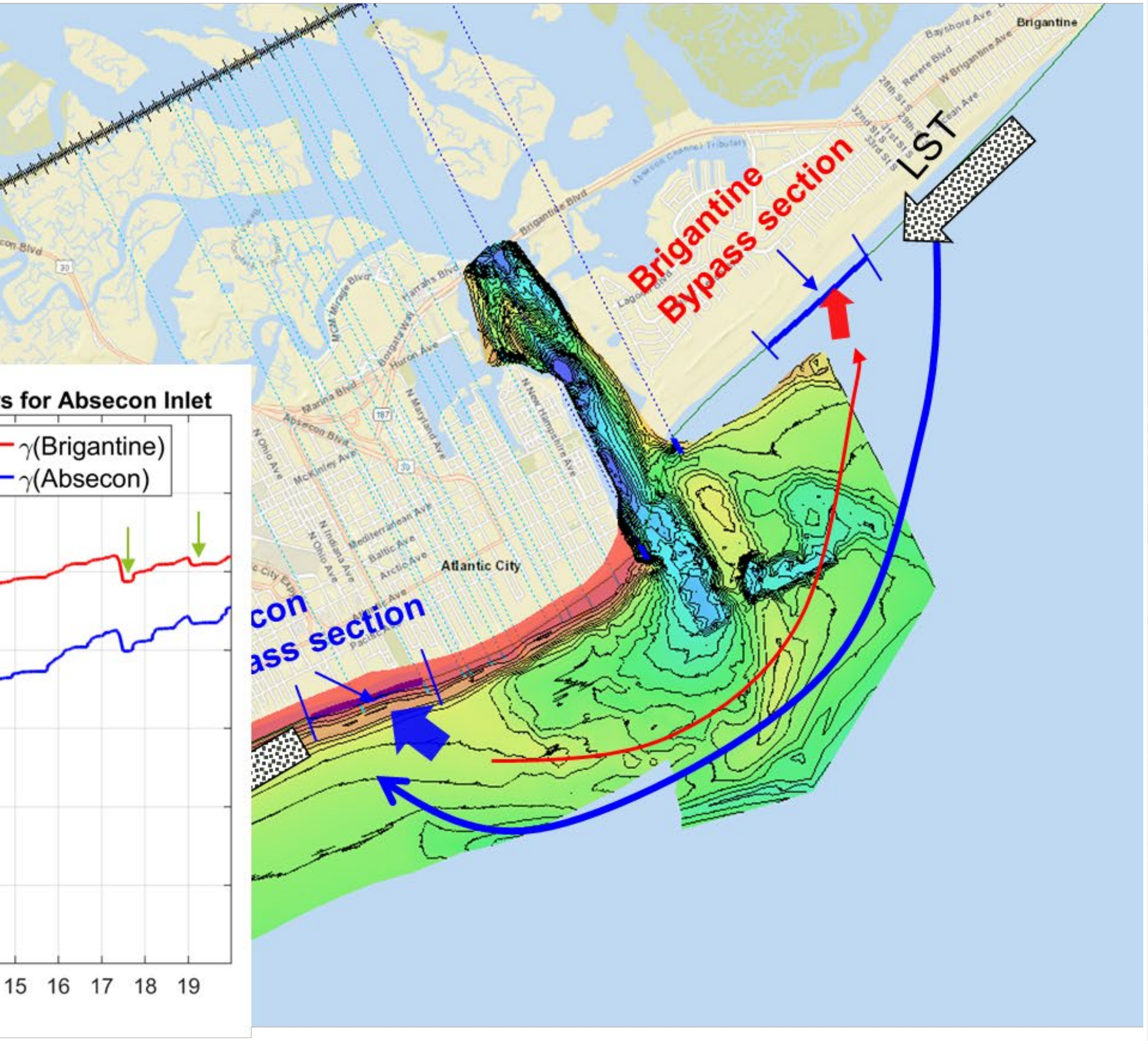
Simulated shoreline profiles on the satellite imagery with the same date



Inlet Bypass Estimated by IRM model (2003-2020)





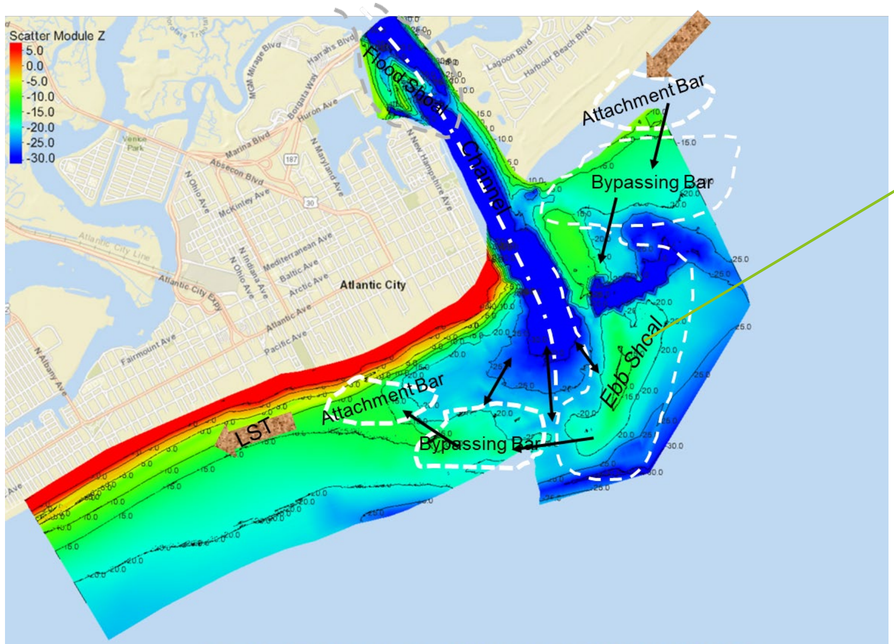


Longshore Sediment Transfer Factor:

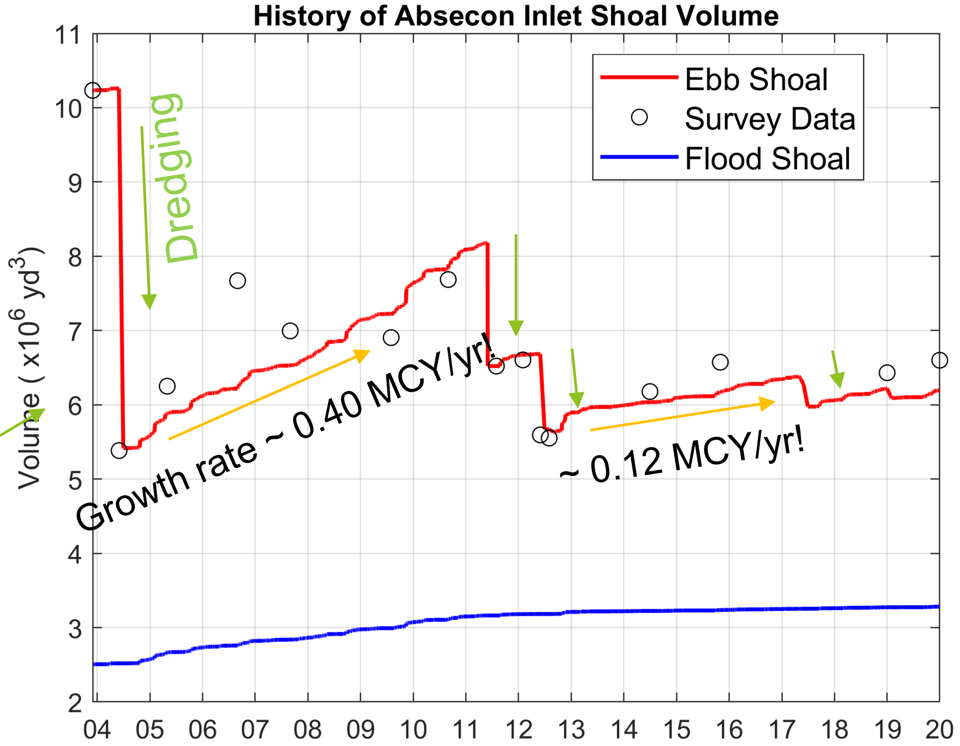
$$\gamma = \frac{Q_{downdrift}}{Q_{updrift}}$$

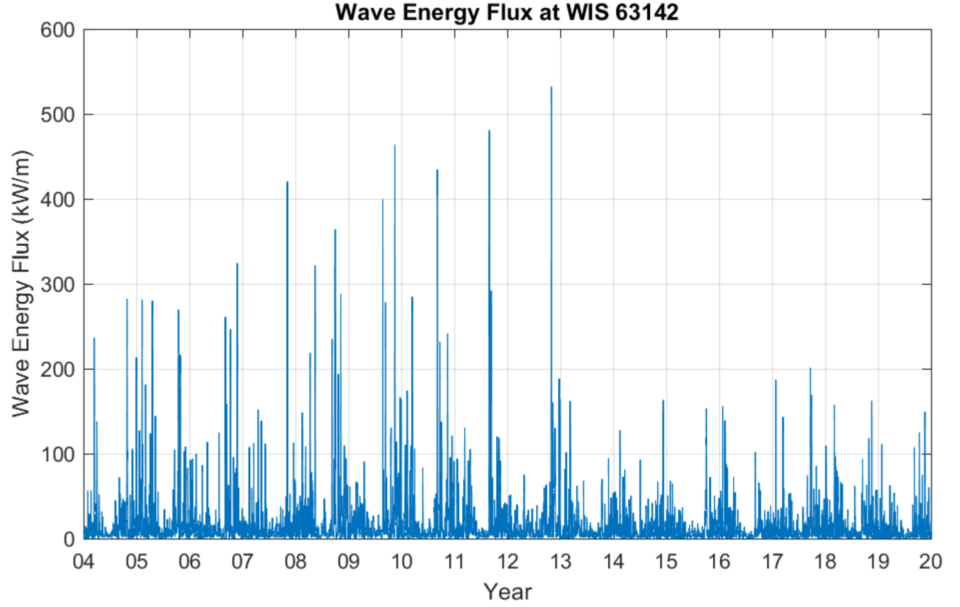
Bypassing impacted by:
Wave, current, dredging/mining, etc.

Volume Changes of Ebb Shoals and Effect of Dredging (2003-2020) by GenCade-IRM model

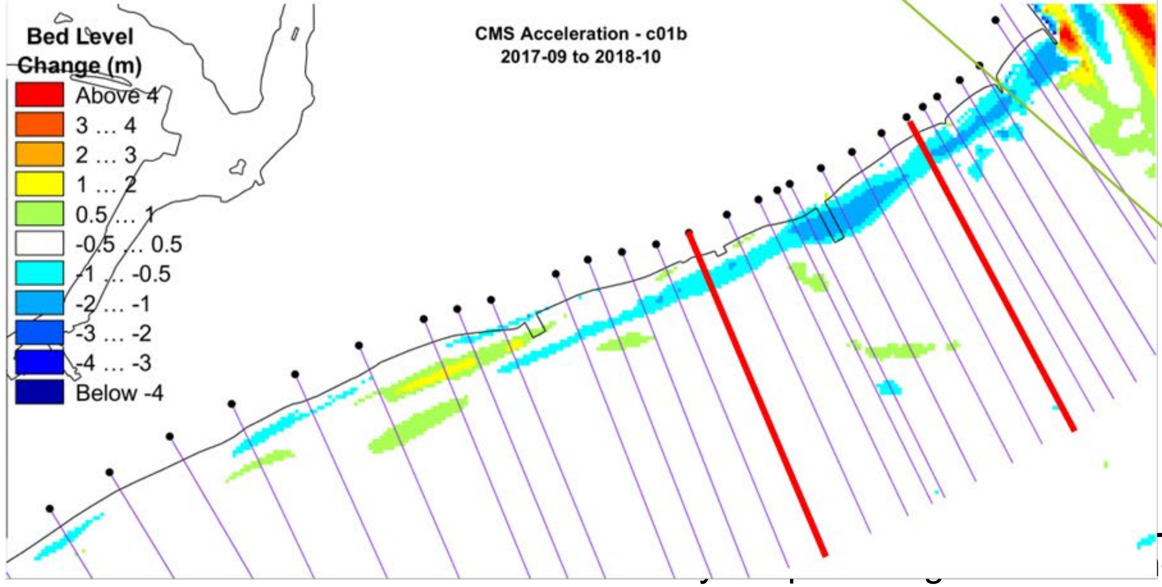


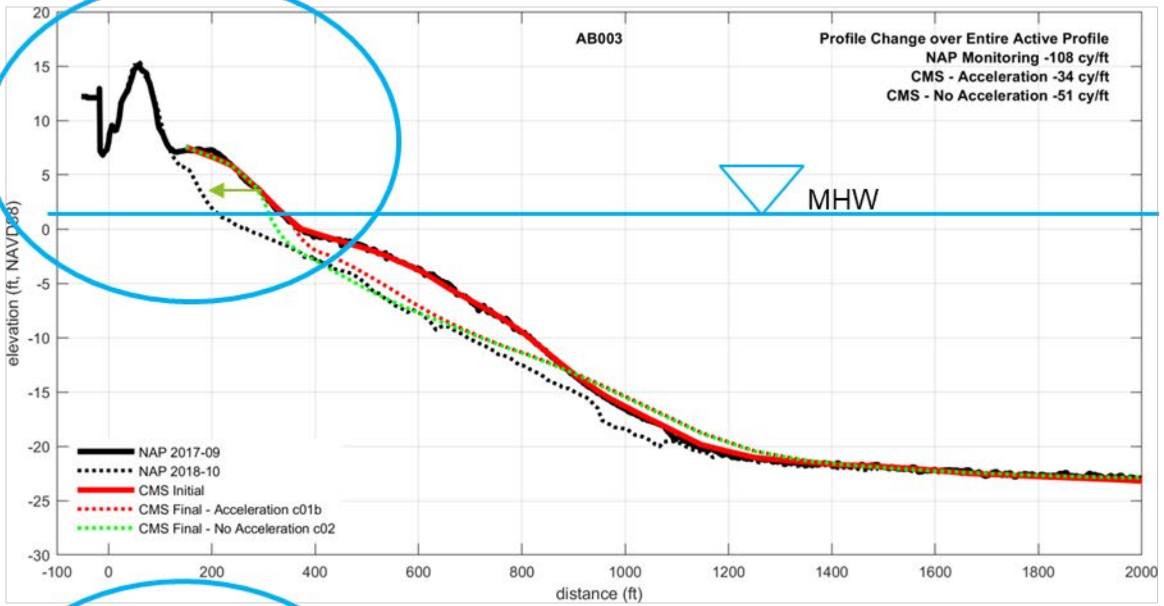
Map: Combined Inlet Survey (2021-Mar) with Transects (2021-Feb)

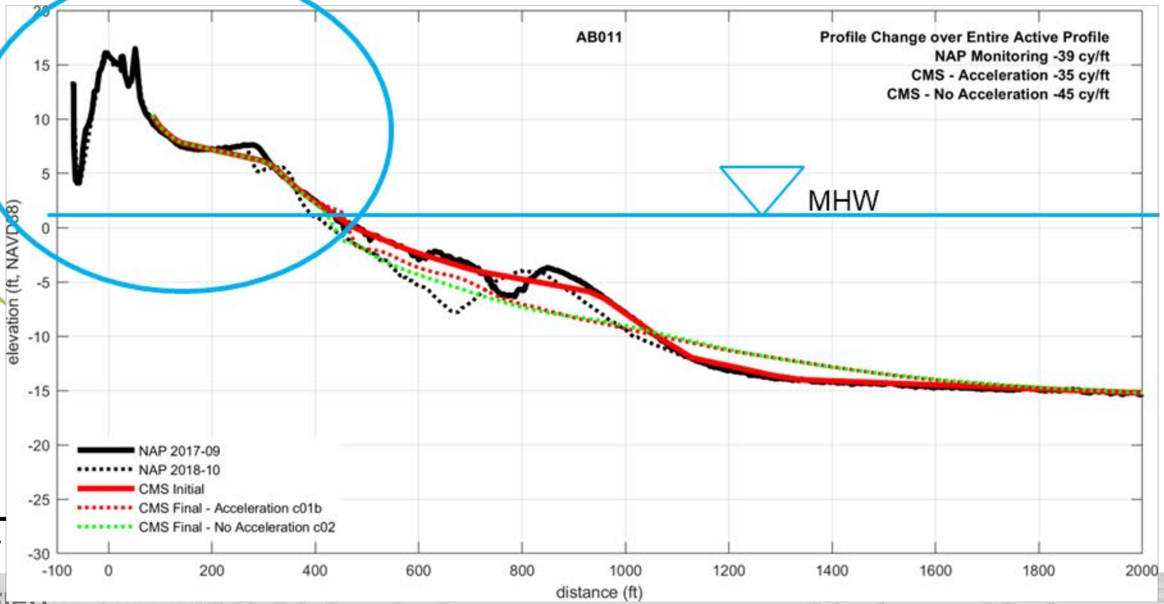




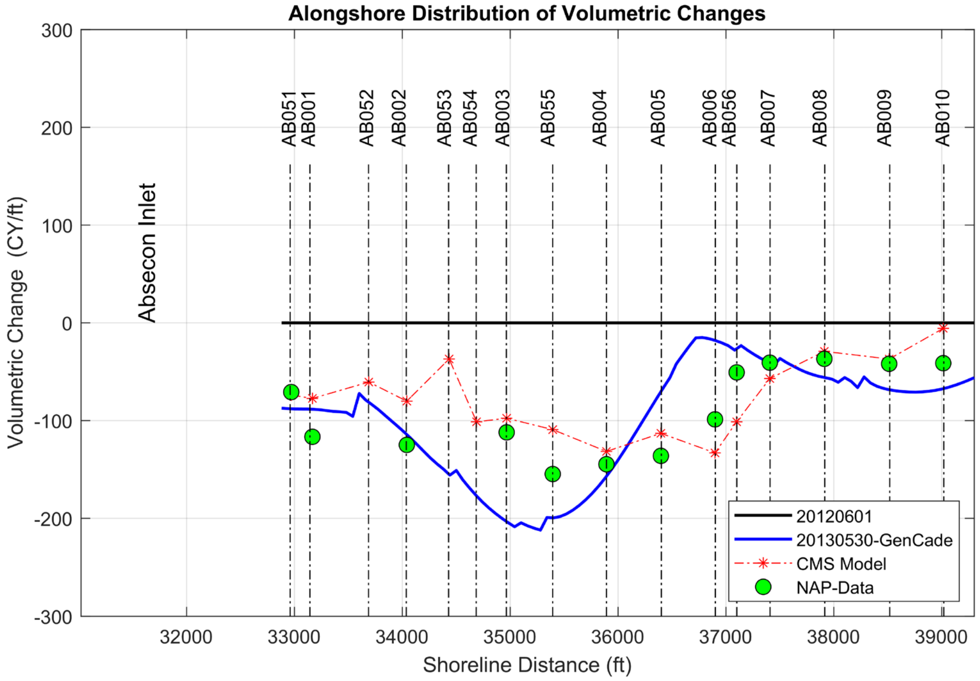
2017-2018 Morphology Results by CMS (Low Energy Year)

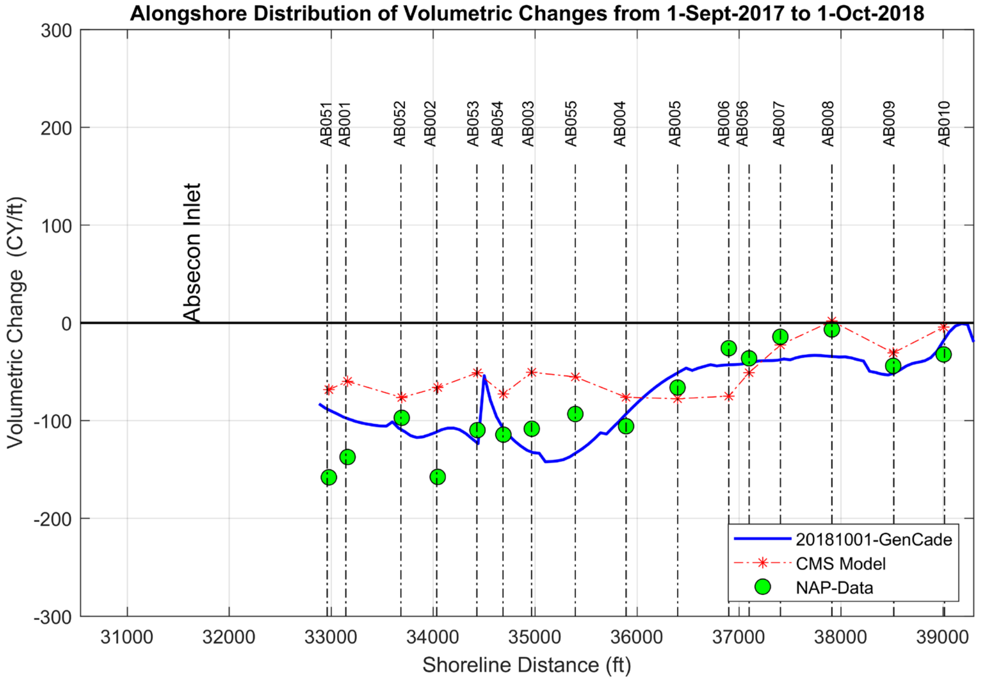






Volumetric Changes of the Entire Active Profiles: GenCade & CMS vs NAP-DATA





From 01-Jun-2012 to 01-Jun-2013

Model	Pearson Coeff.	RMS (CY/ft)	NRMSE* (%)
CMS	0.752	30.212	25.66
GenCade	0.664	43.711	37.12

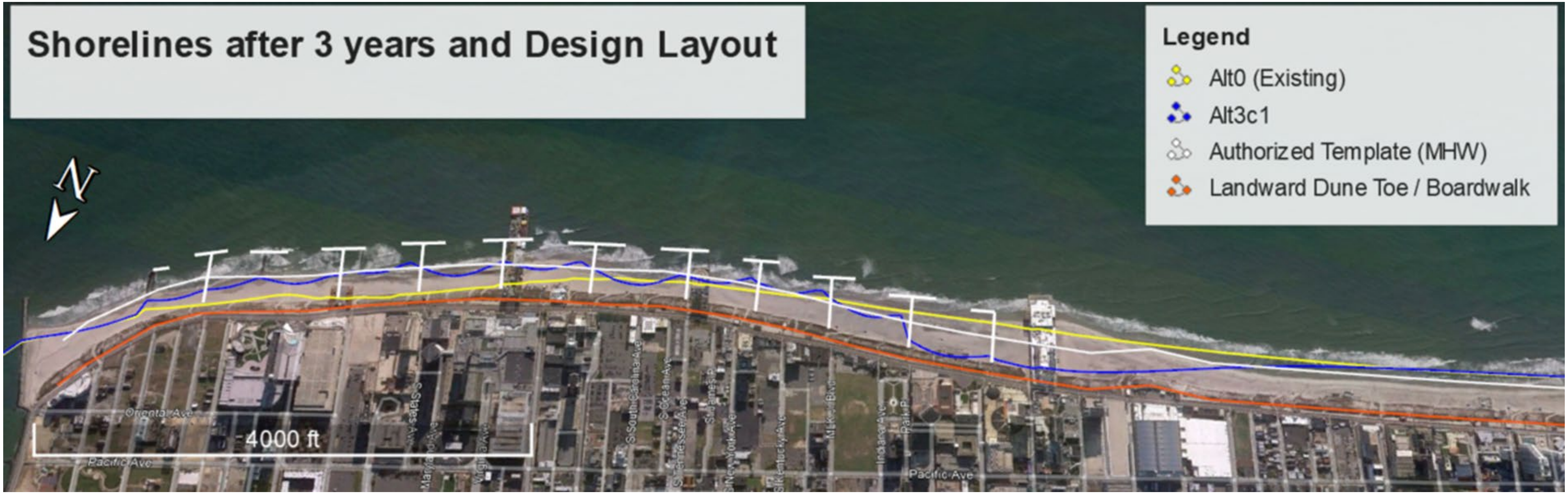
* Relative to Observed max. volume change, 117.76 CY/ft

From 01-Sept-2017 to 01-OCT-2018

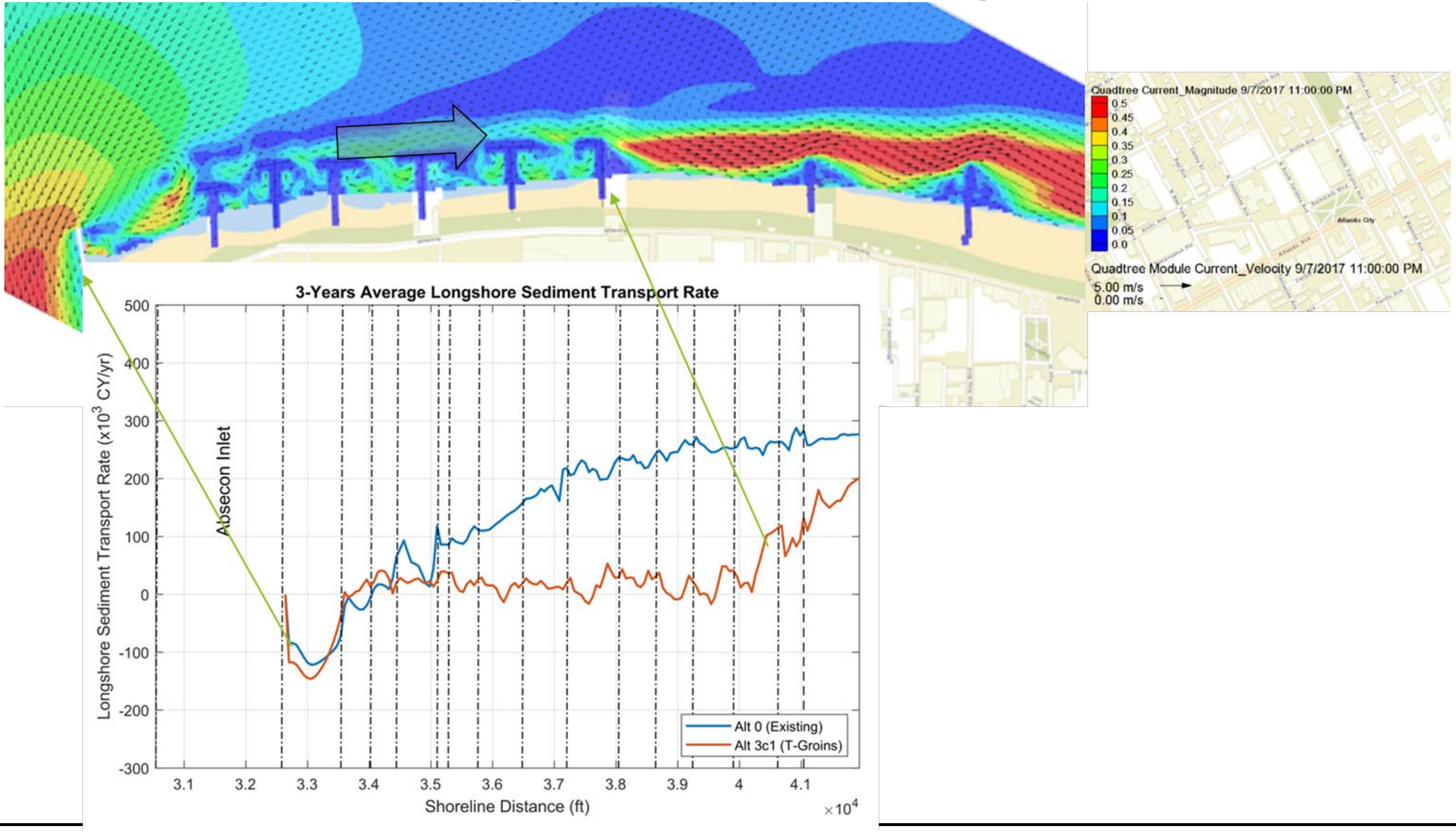
Model	Pearson Coeff.	RMS (CY/ft)	NRMSE* (%)
CMS	0.619	48.409	32.01
GenCade	0.806	28.805	19.05

* Relative to Observed max. volume change, 151.21 CY/ft

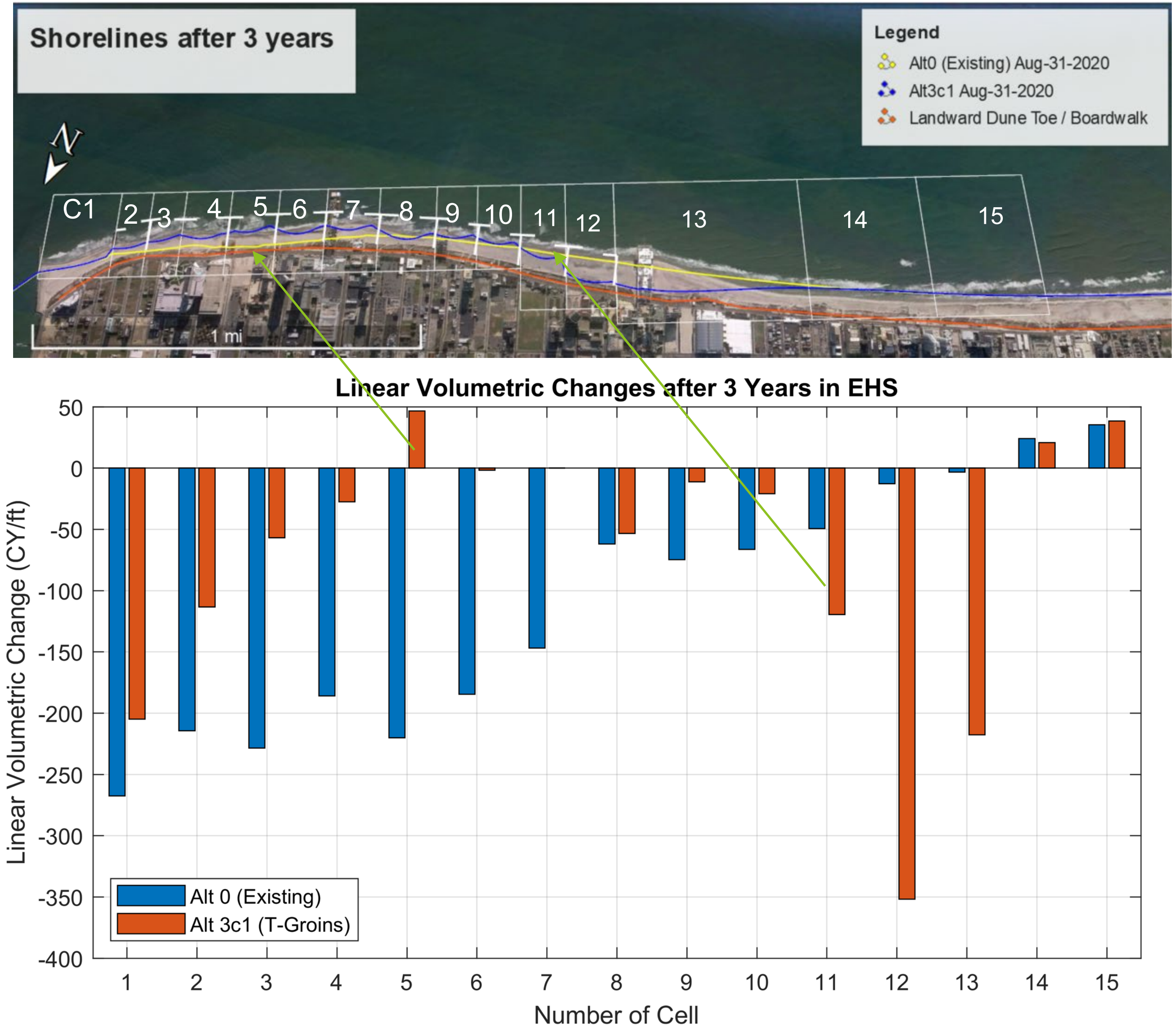
Assessment of Structure Parameters Using Validated GenCade model: *An example of T-Groin Group*



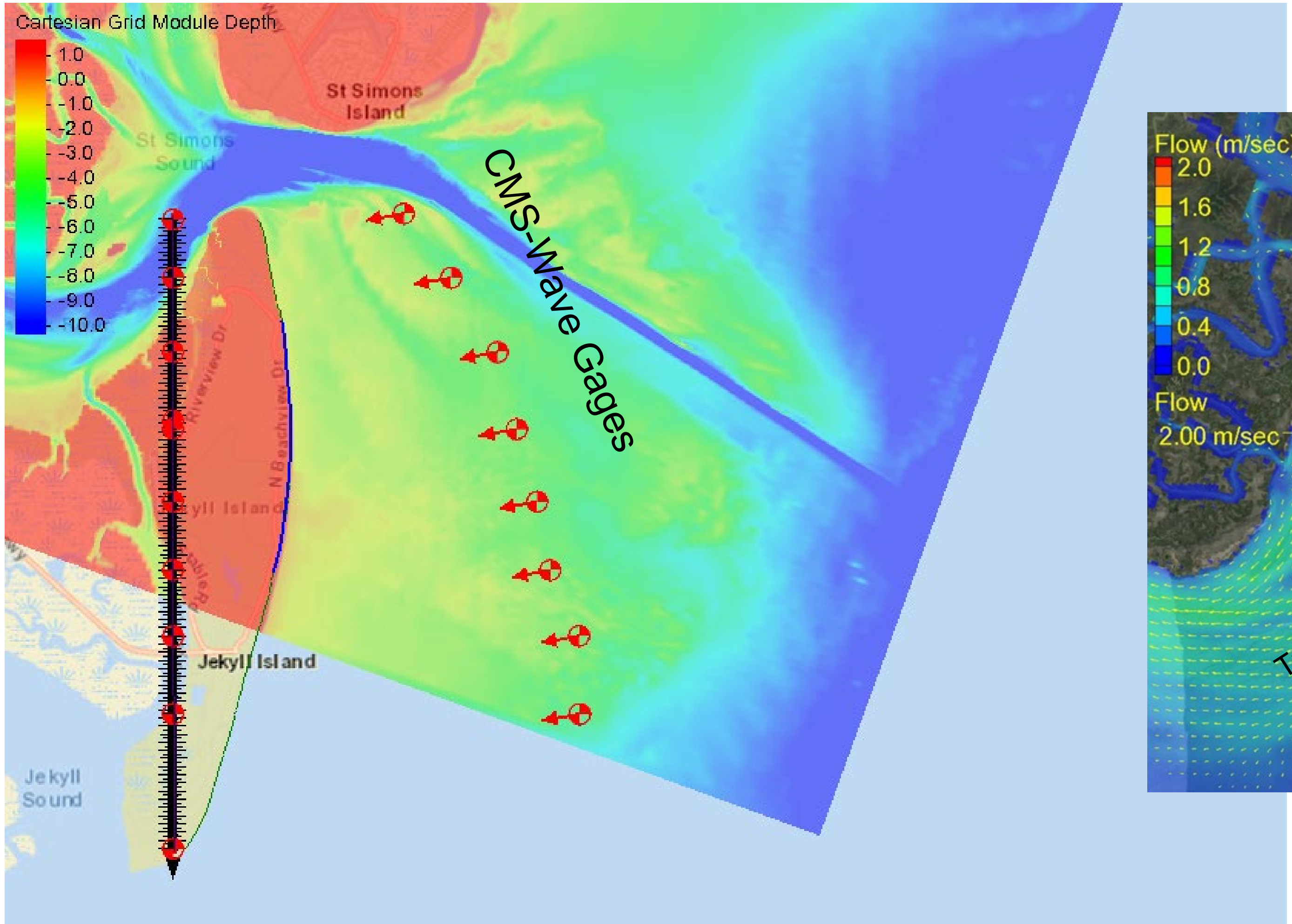
Nearshore Currents by CMS vs LST by GenCade

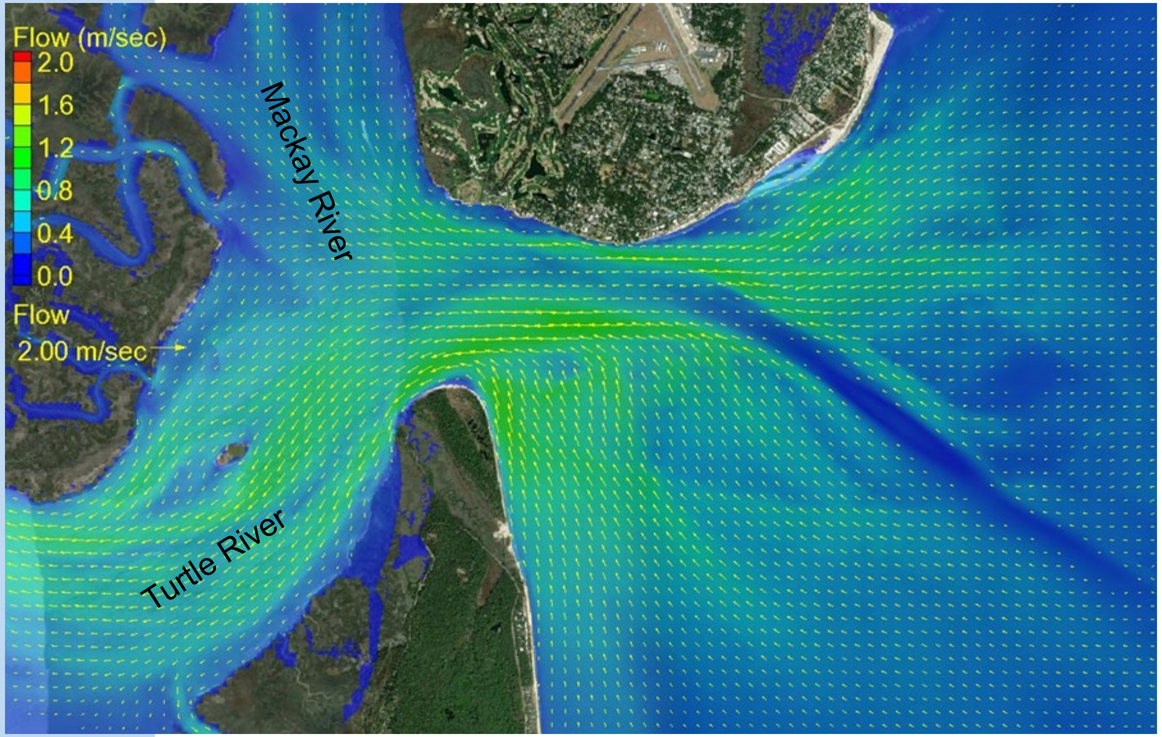


Linear Volumetric Changes: Project Conditions vs No Action



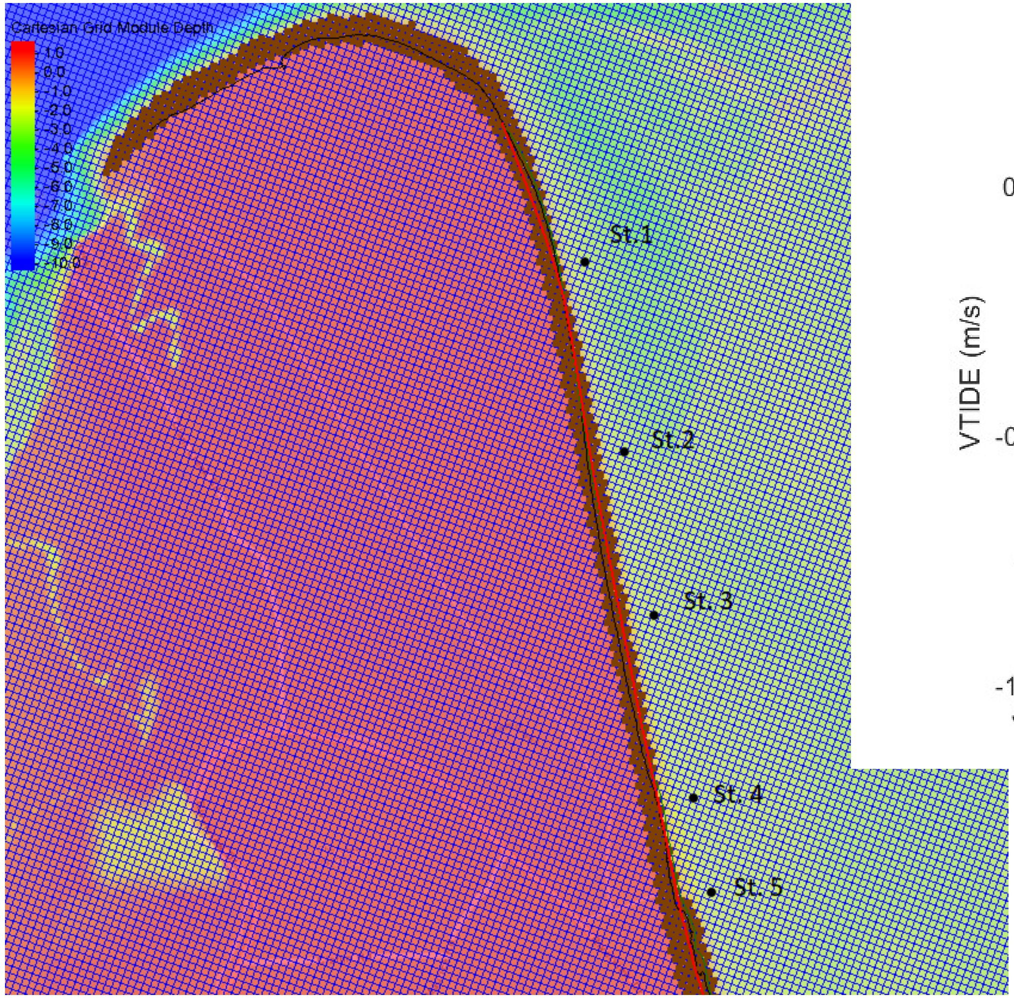
GenCade Model for Jekyll Island Using CMS-Wave and -Flow Results

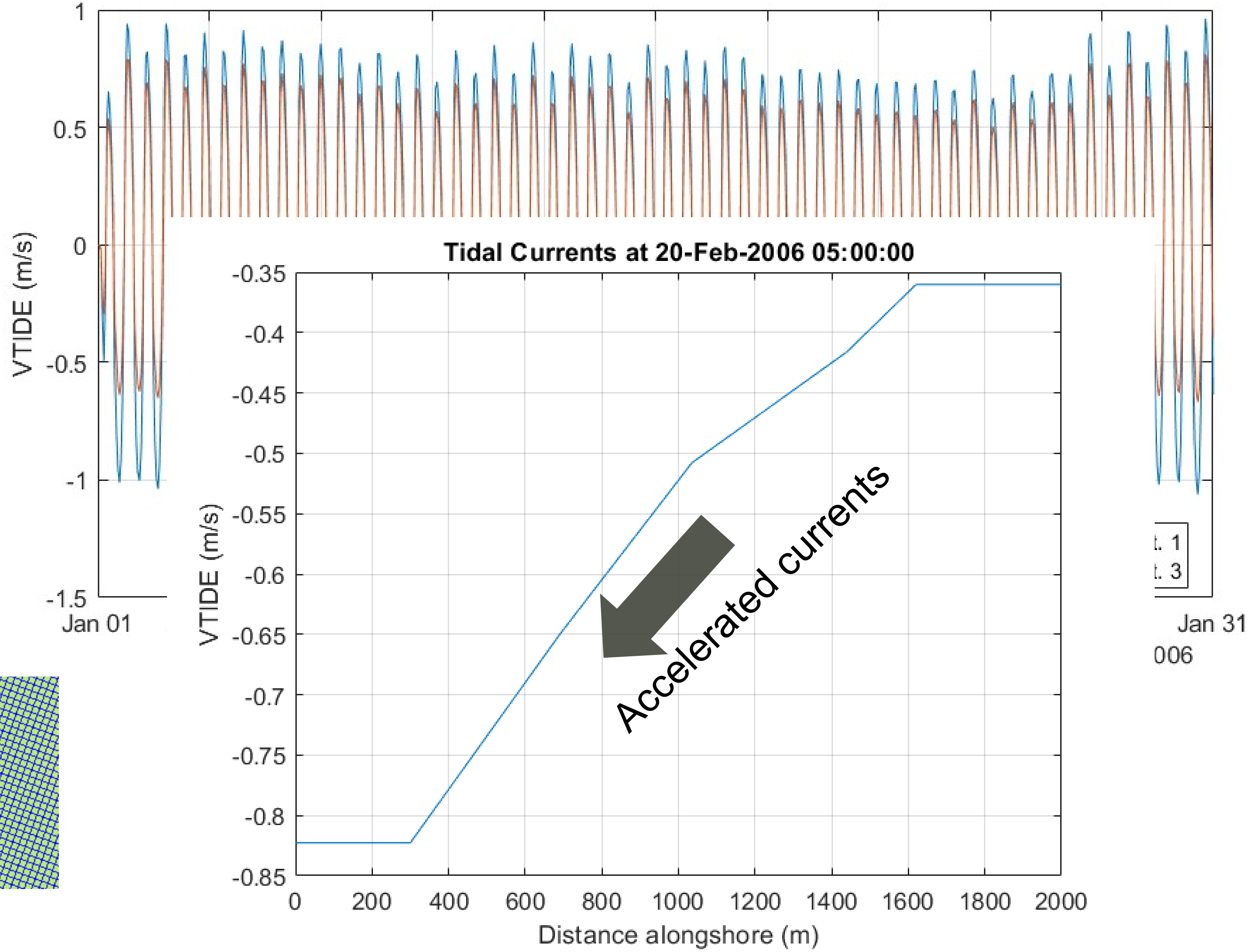




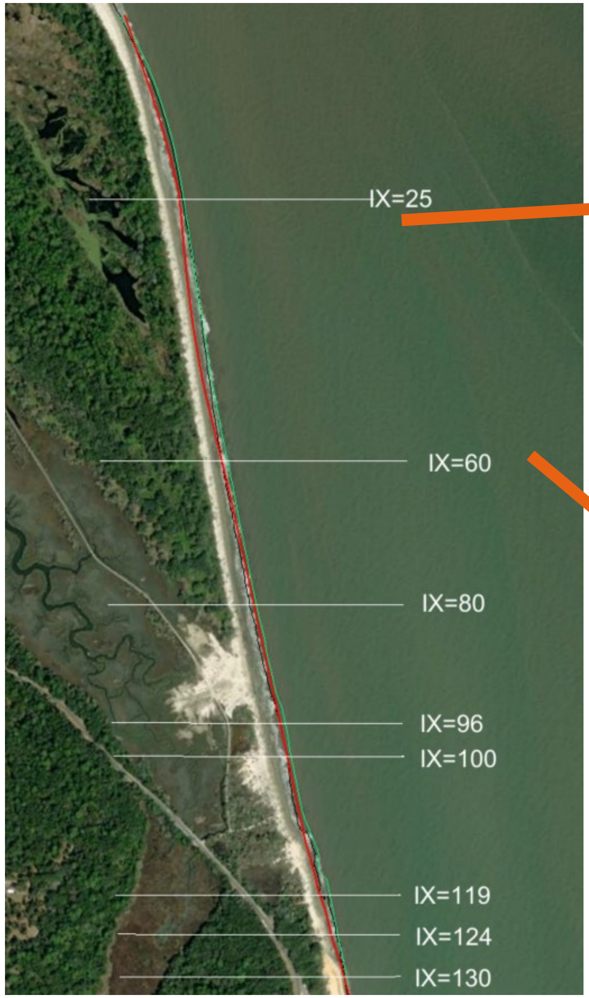
CMS-Wave Gages at 4.0m depth

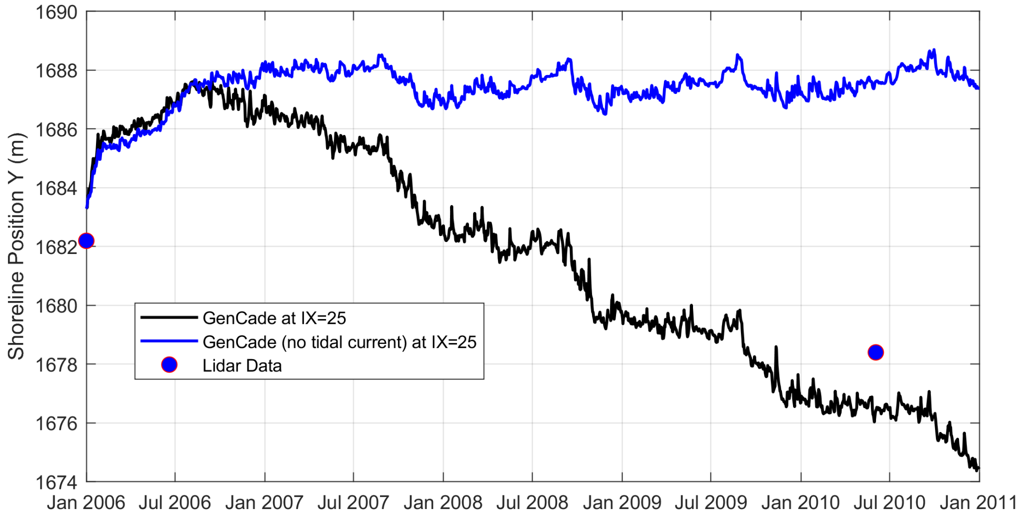
Tidal currents by CMS-Flow at selected gages are included in GenCade

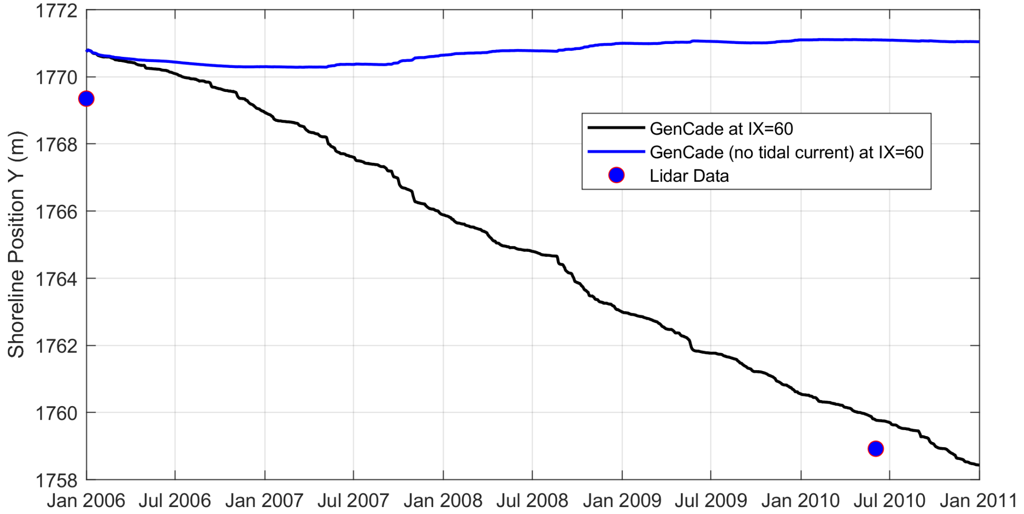




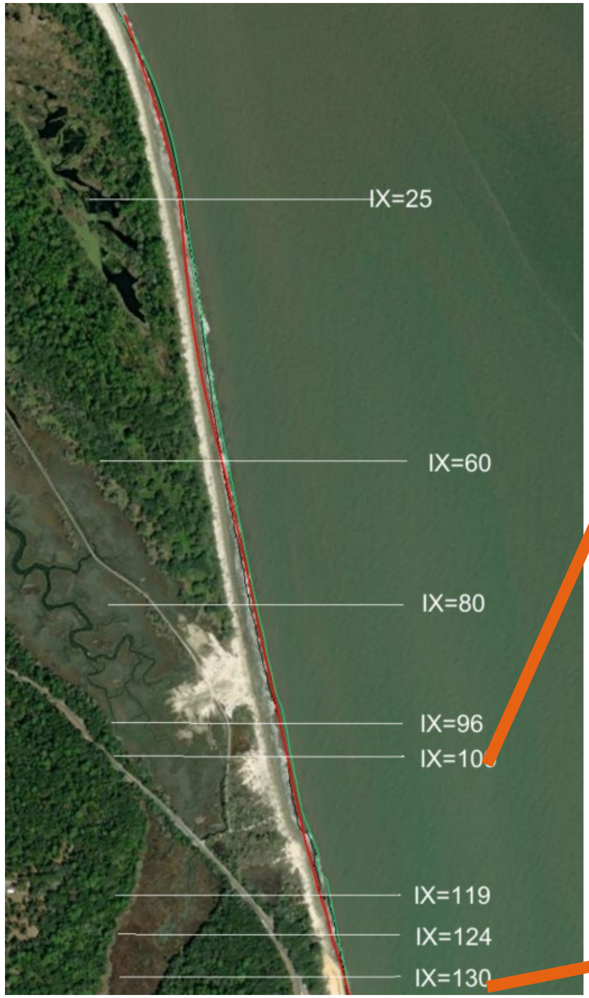
Histories of shoreline positions (with and without tidal currents)

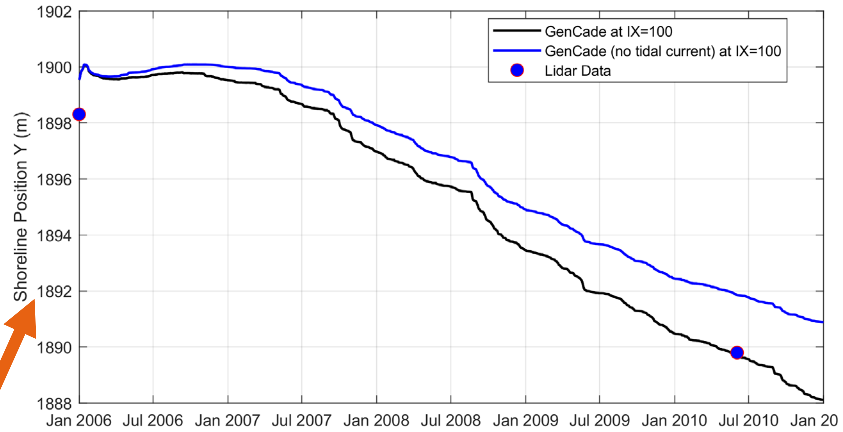


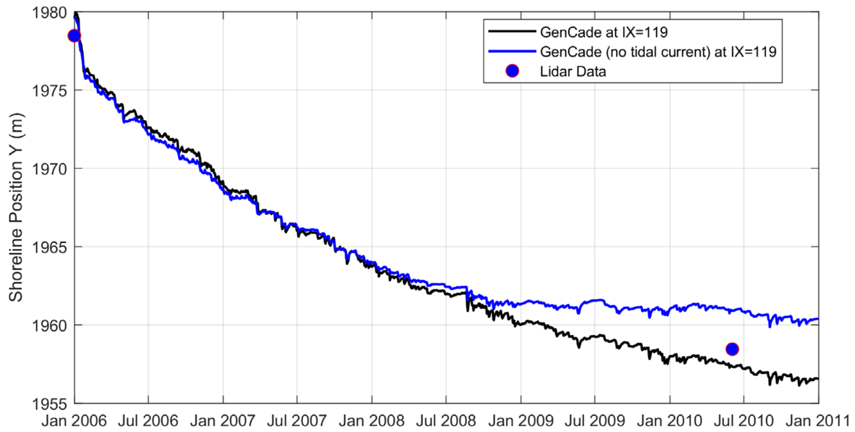


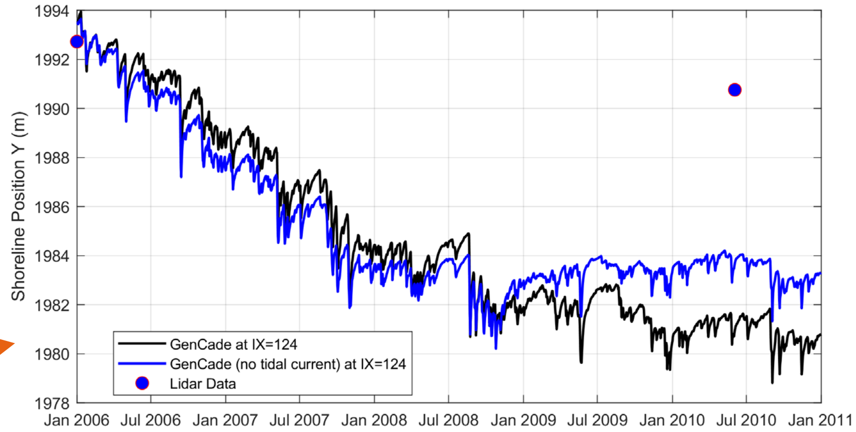


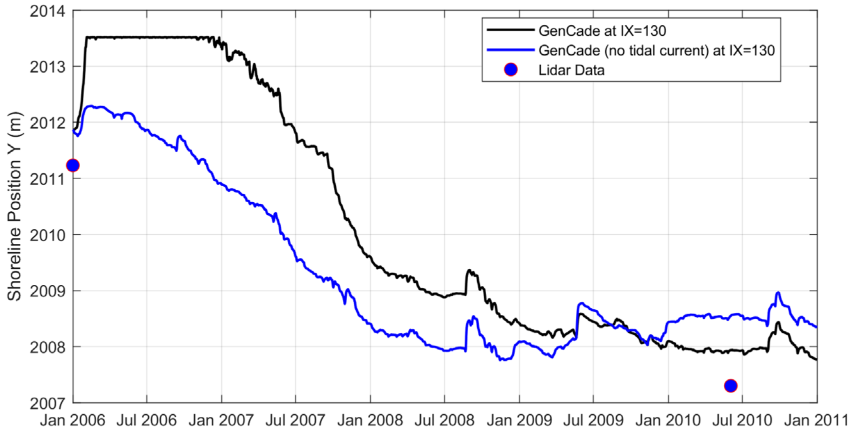
Histories of shoreline positions



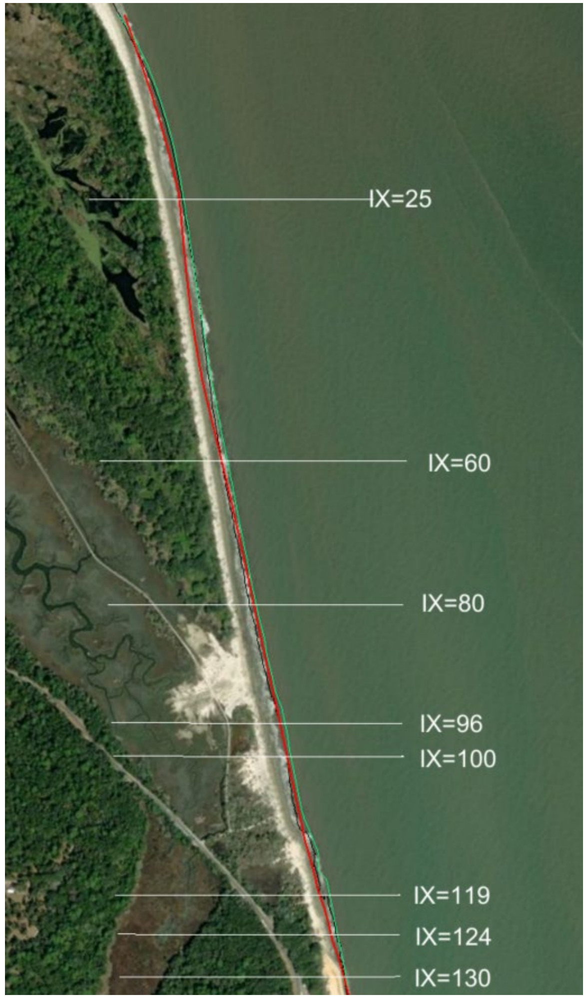


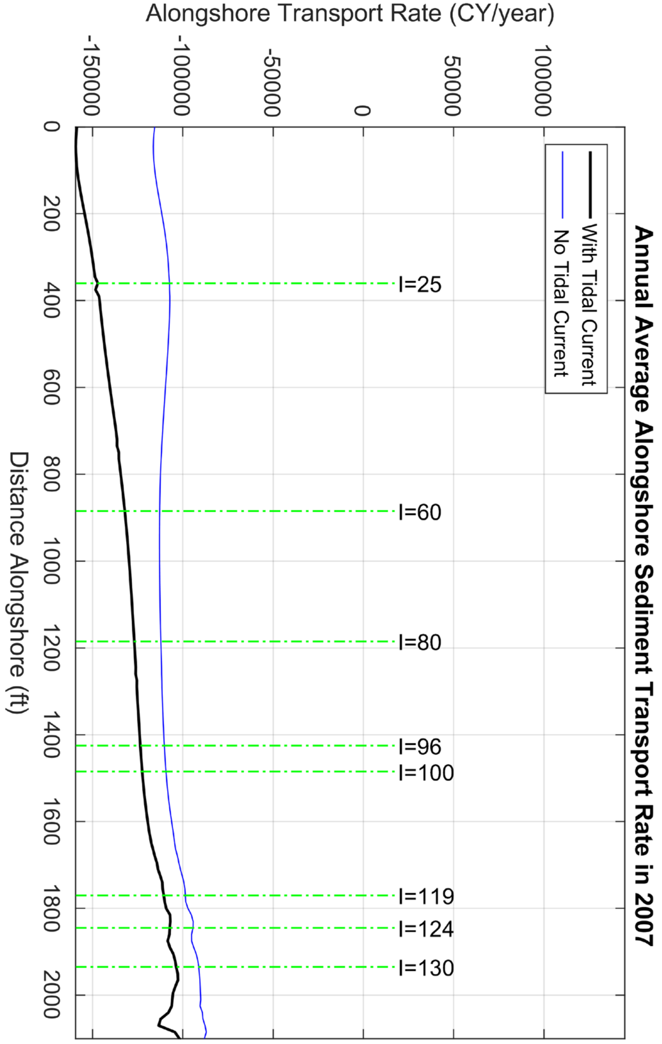


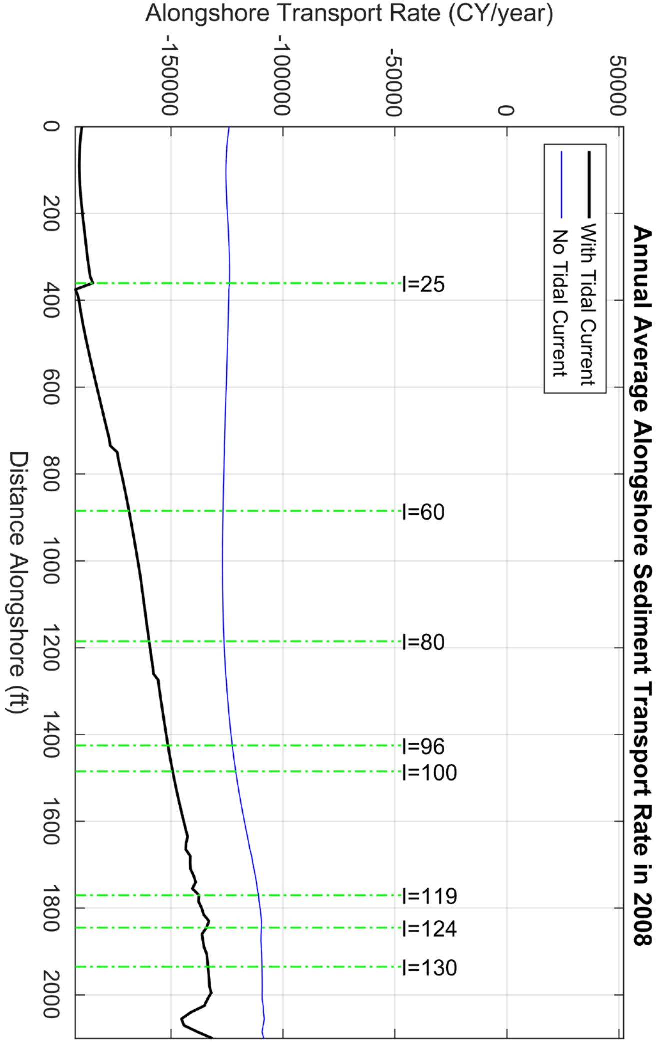




Annual Averages of Longshore Sediment Transport Rates with and without Tidal Currents





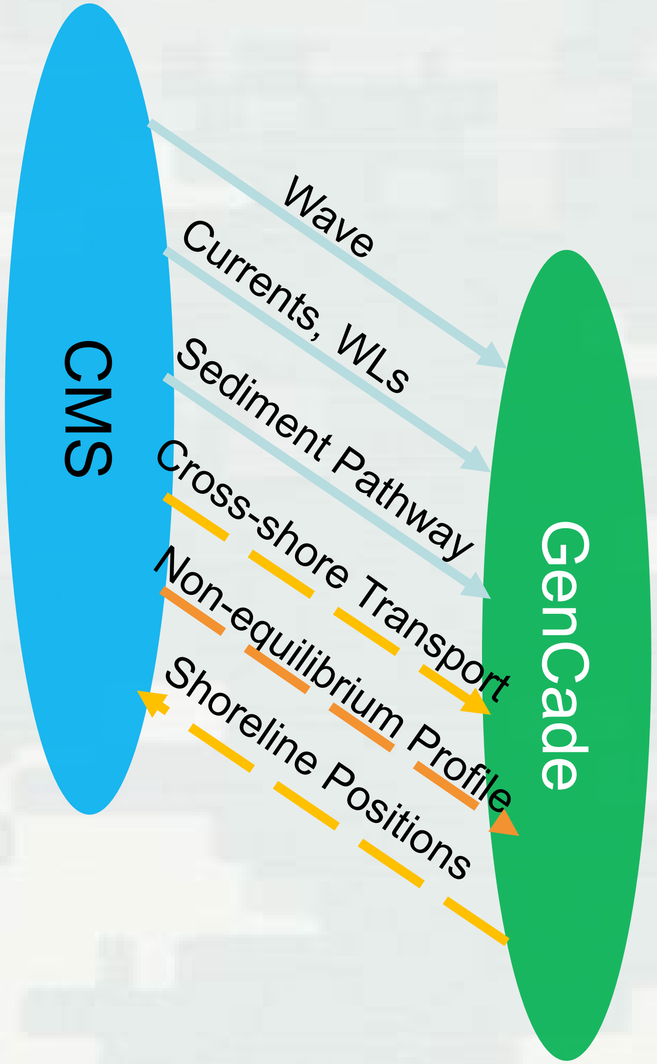


Remarks

1D and 2D: Mutually Beneficial?

Capabilities for Problem Solving

Coastal Erosion Protection Sediment Management Problems	**CMS**	**GenCade**
Long-term shoreline evolution	Limited	√
Nearshore Placement	√	—
Structures for Sediment Control	√	√
Navigation Sedimentation	√	—
Long-term Effect of Beach fill	Limited	√
Sand Bypassing on Shoreline Change	—	√
Sand Back passing	—	√



Topics of CMS and GenCade for Shoreline Modeling

- CMS provides waves for better alongshore variation of sediment transport in GenCade
- CMS identifies sediment transport patterns around inlet and pathway for bypassing
- How to use CMS inlet morphology simulation results for GenCade IRM?

- How to evaluate the effects of long-term shoreline changes on CMS modeling?

- Morphological changes of shoals and bars by CMS can further help setup of IRM models. How to use CMS morphological simulation results to estimate inlet bypassing?
- Shoreline evolution can support refinement of CMS grids in wet and dry areas. Then it may enhance CMS's capability to simulate large-scale beach changes during long-term periods (>5~10 years).

Acknowledgements

- Funding supporting presentation of this study was provided by the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, the Coastal Inlets Research Program (CIRP), the USACE Regional Sediment Management (RSM) program, and USACE-ERDC's CHL CODS program
- The simulation of shoreline evolution and CMS around Absecon Inlet was sponsored by USACE Philadelphia District.

Thank you for your attention!

For GenCade model, Training Materials

http://cirp.usace.army.mil/products/gencade.php

For GenCade Wiki:

https://cirpwiki.info/wiki/GenCade

User manual, technical reports, etc.:

http://cirp.usace.army.mil/pubs/