Simulation of Shoreline Evolution and Sediment Pathway around Absecon Inlet Using GenCade and CMS

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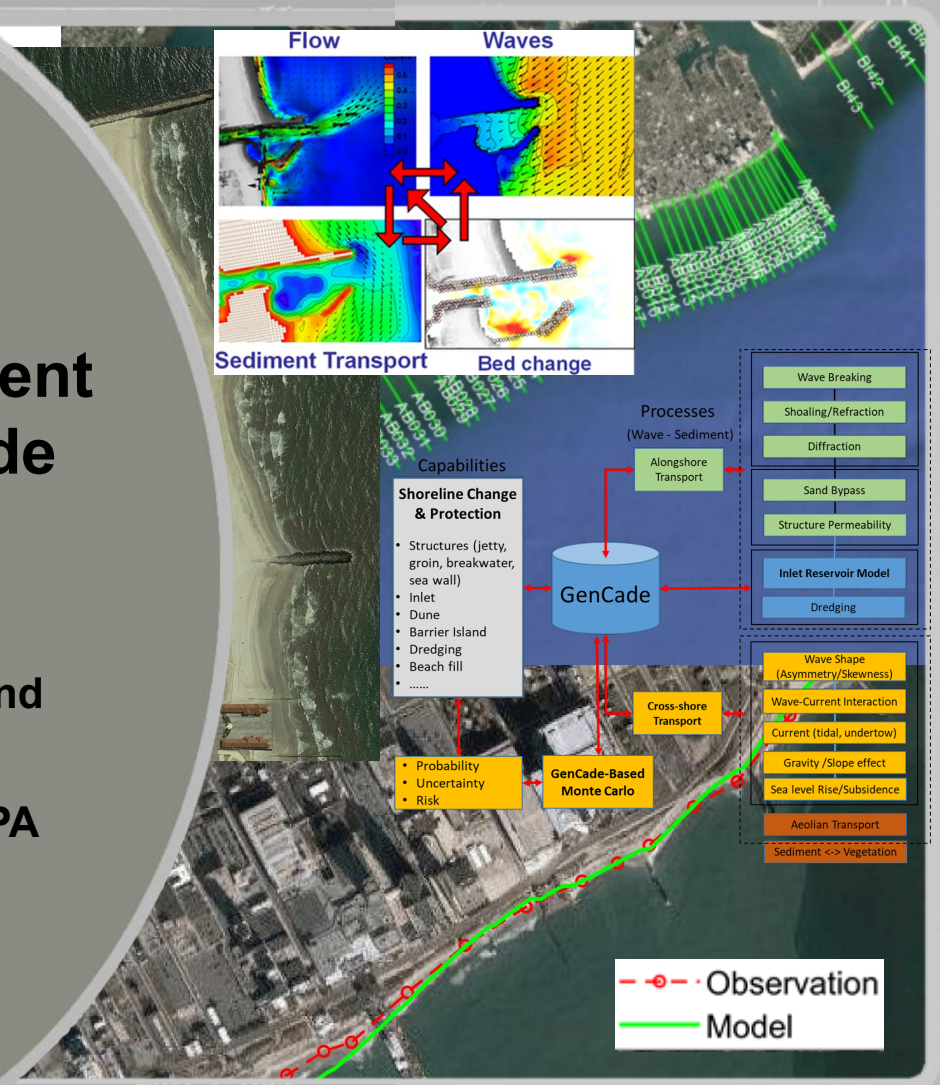

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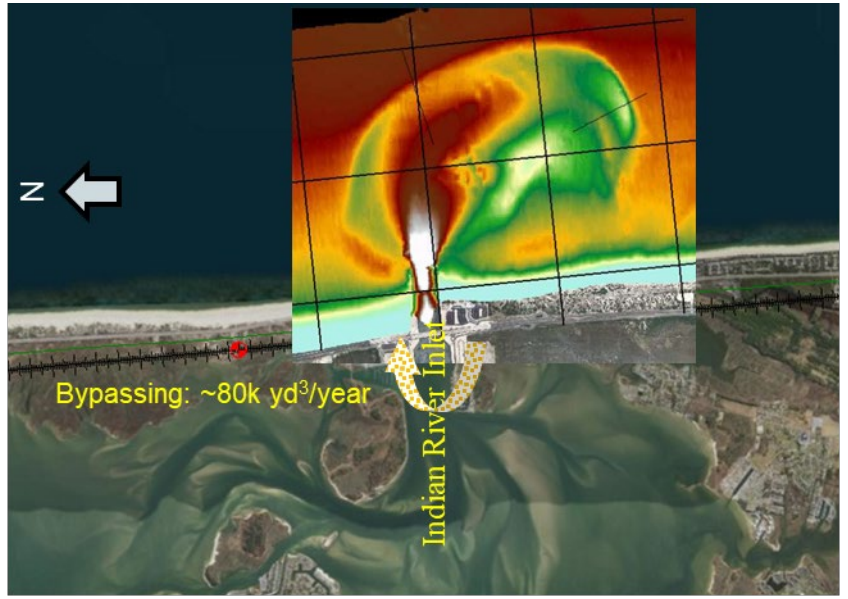
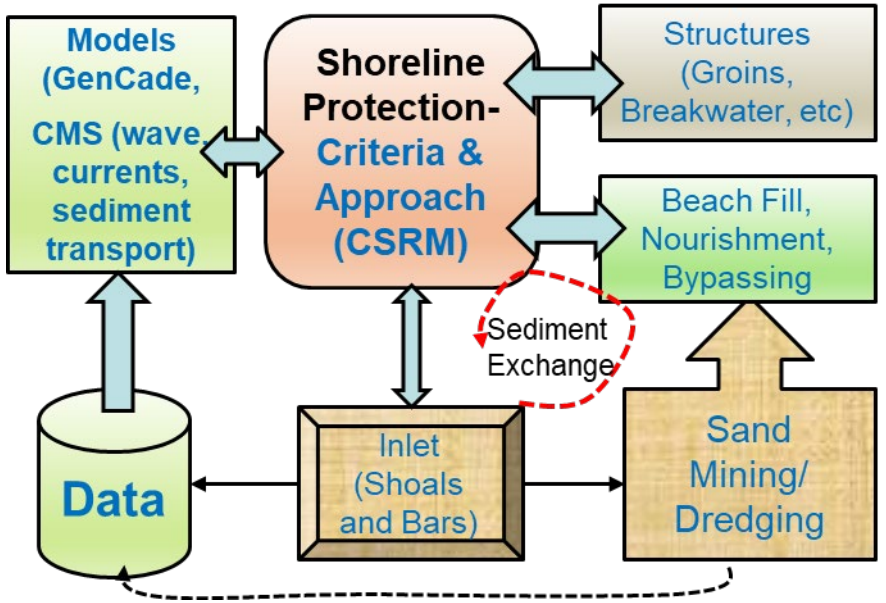
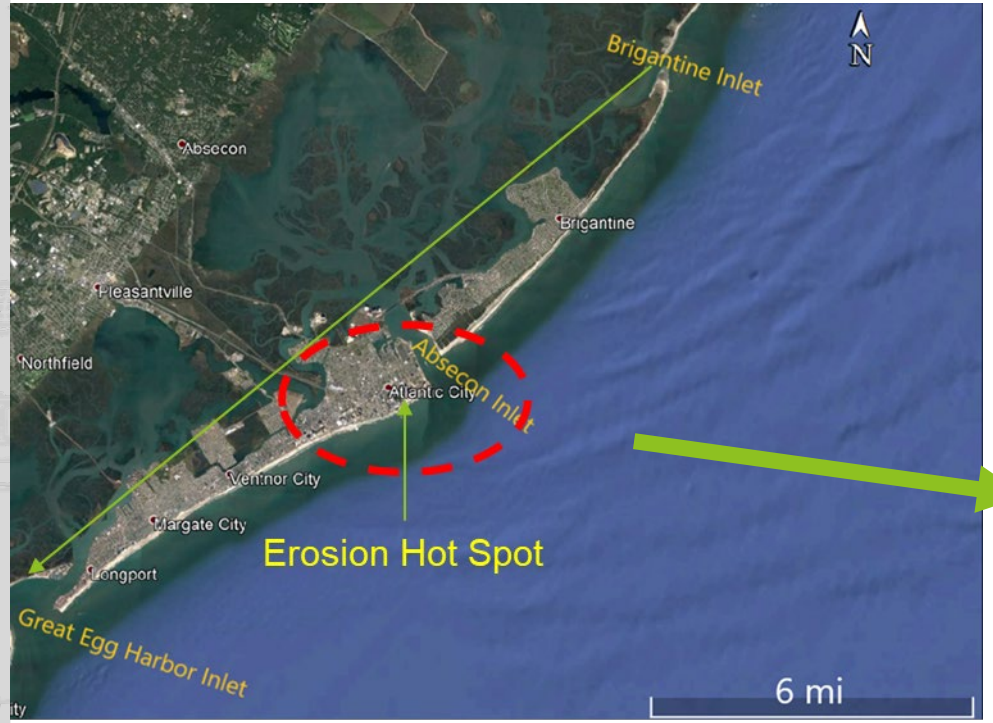
Introduction

- **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**
  - **Effct 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.**





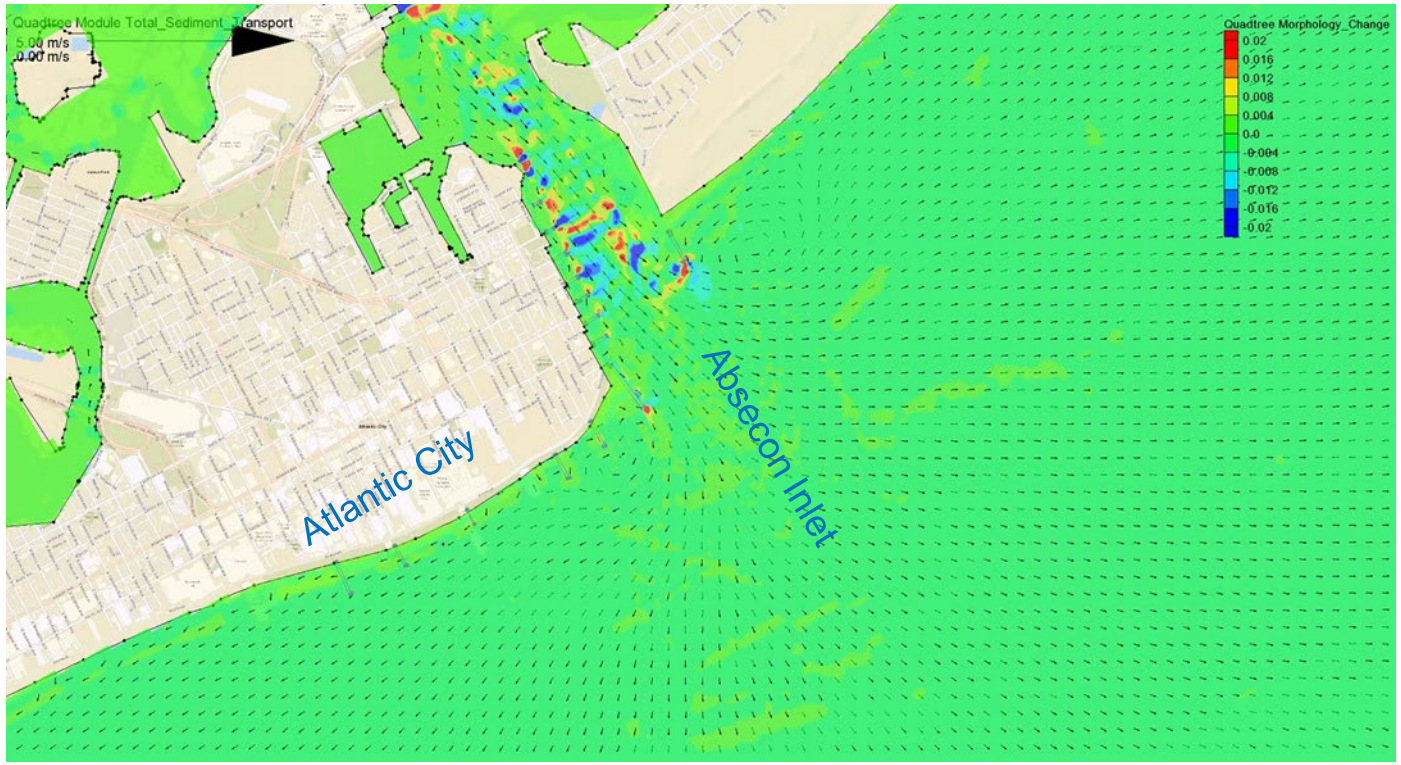
Examples of Shoreline Evolution Simulations by GenCade



Shorelines around Absecon Inlet, NJ

Shorelines (2011-2019) by observation and model (GenCade)

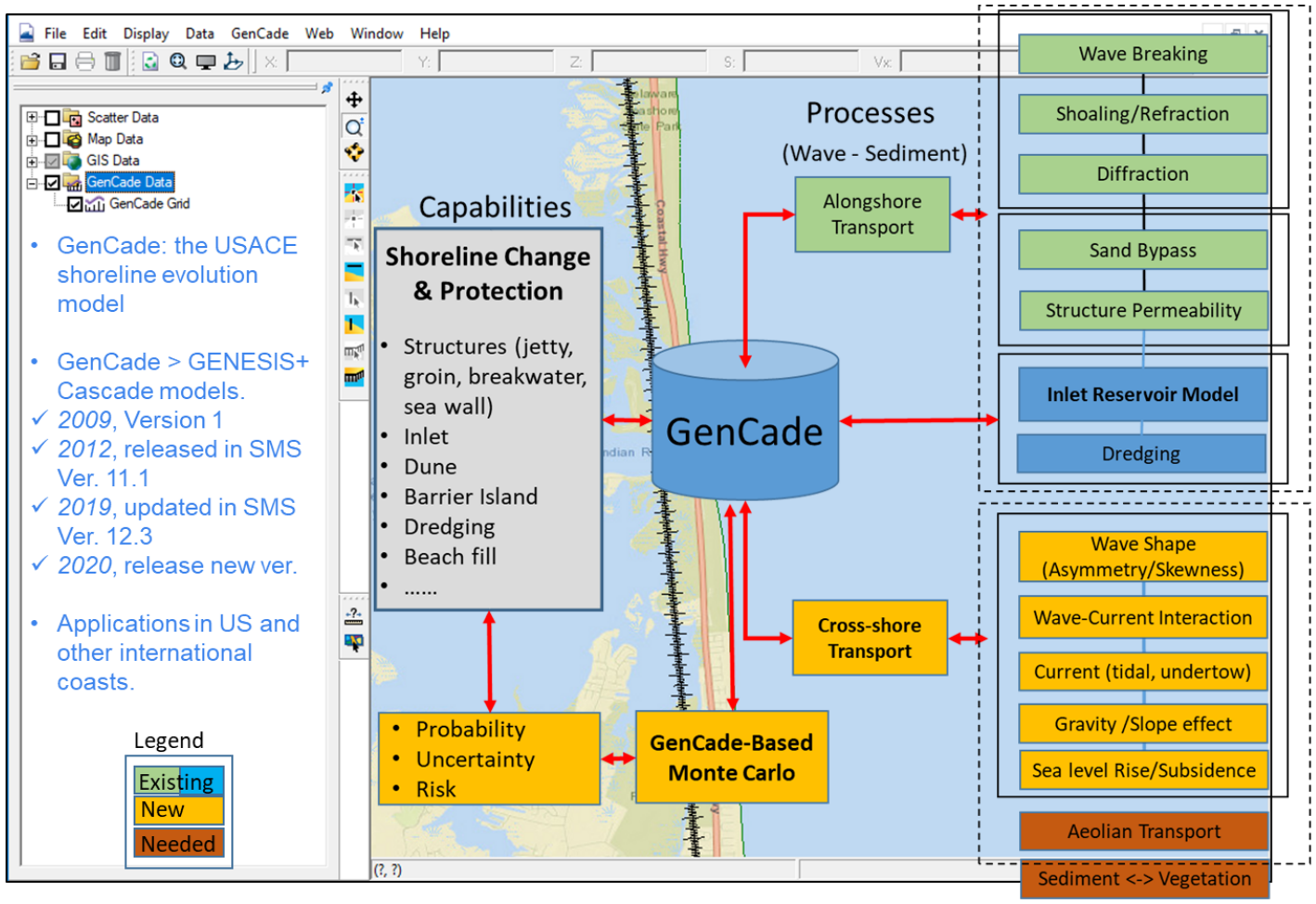
Example of Sediment Transport and Morphological Change around Absecon Inlet by CMS



Driving forcing:
wave and tide

Total sediment transport flux (kg/m/s) and bed change (m) in one week by waves and tidal currents

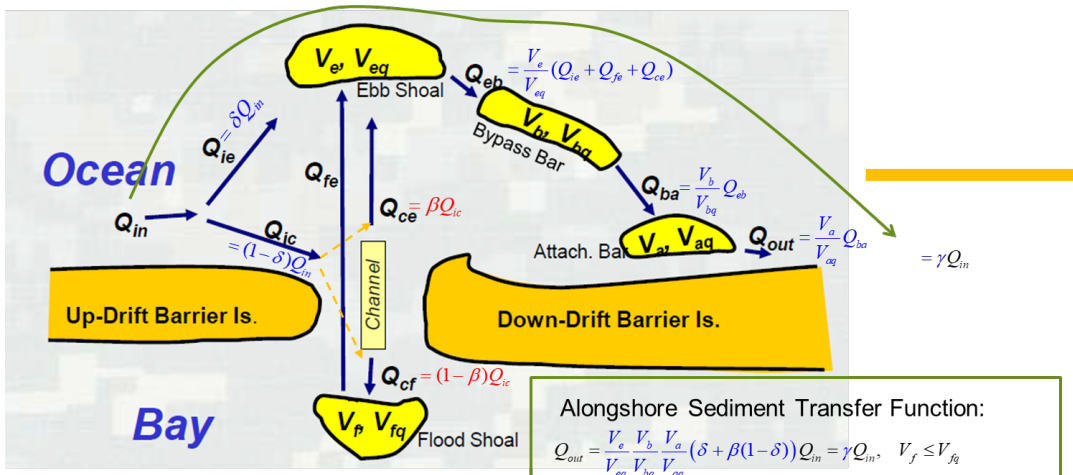
GenCade - USACE Shoreline Evolution Simulation Model



Principal Features of GenCade

- For modeling long-term and regional shoreline evolution driven by **longshore & cross-shore transport**
- Inlet Reservoir Model (IRM): Simulation of **inlet morphology element evolution**, including dredging/mining in shoals and bars.
- Simulation of hard structure effects on shoreline changes → groins, breakwaters, jetties, seawall
- Simulation of soft structure (**non-structural**) effects → beachfills, nourishment, sediment bypassing
- Latest release: GenCade Version 1r8 in SMS Ver. 13.1
- **User manual**, technical transfer, customer service

Inlet Reservoir Model for Simulating Sediment Bypassing through Inlet



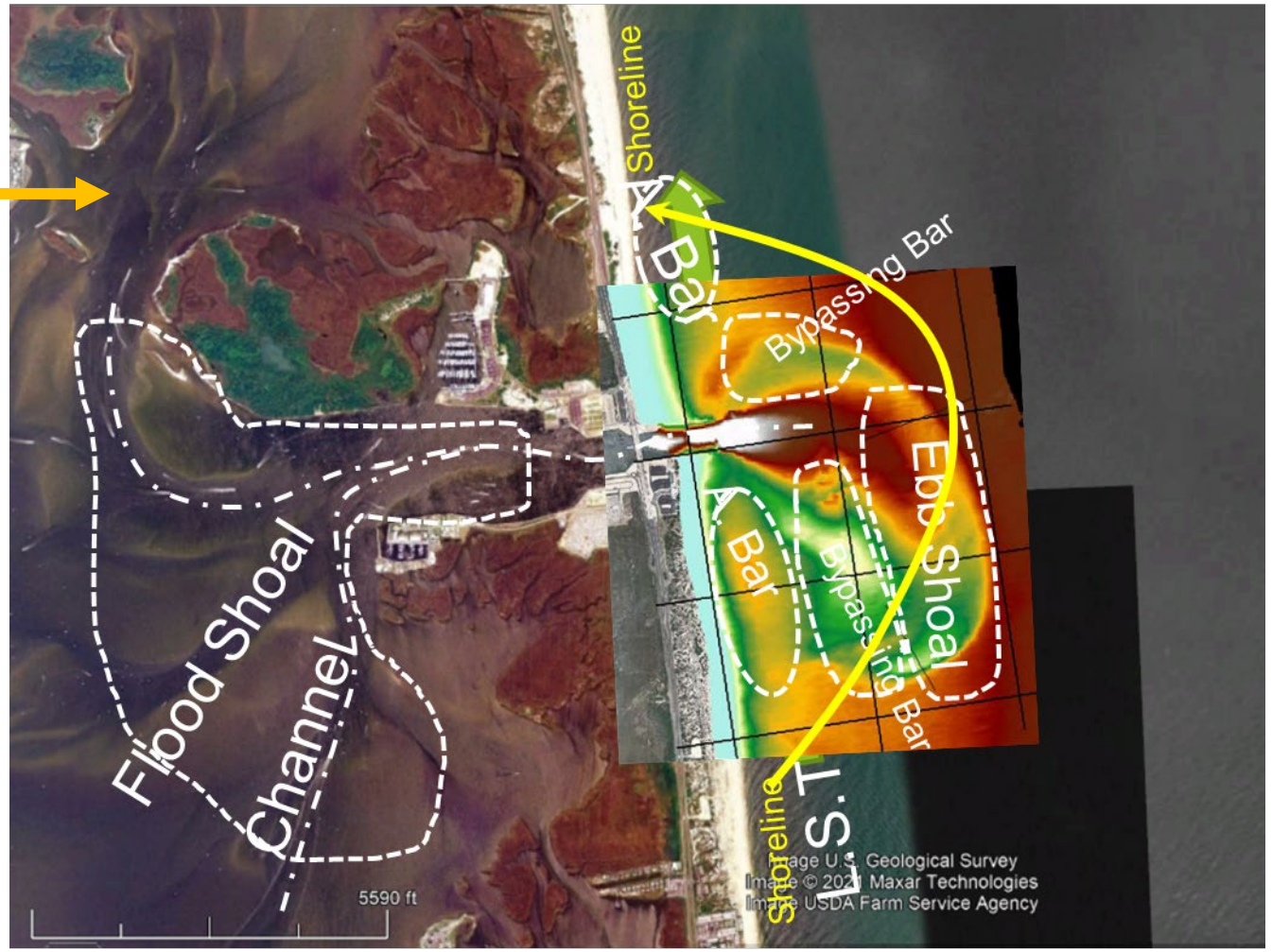
$$Q_{fe} = \begin{cases} (V_f - V_{fq})/dt & V_f > V_{fq} \\ 0 & V_f \le V_{fq} \end{cases}$$

Alongshore Sediment Transfer Function:

$$Q_{out} = \frac{V_e}{V_{eq}}\frac{V_b}{V_{bq}}\frac{V_a}{V_{aq}}(\delta + \beta(1-\delta))Q_{in} = \gamma Q_{in}, \quad V_f \le V_{fq}$$

$$Q_{out} = \frac{V_e}{V_{eq}}\frac{V_b}{V_{bq}}\frac{V_a}{V_{aq}}\left[(\delta + \beta(1-\delta)) + \frac{V_f - V_{fq}}{Q_{in}dt}\right]Q_{in} = \gamma' Q_{in}, \quad V_f > V_{fq}$$

- Two Transfer Factors exist: γ_{left}, and γ_{right}.



Indian River Inlet, DE

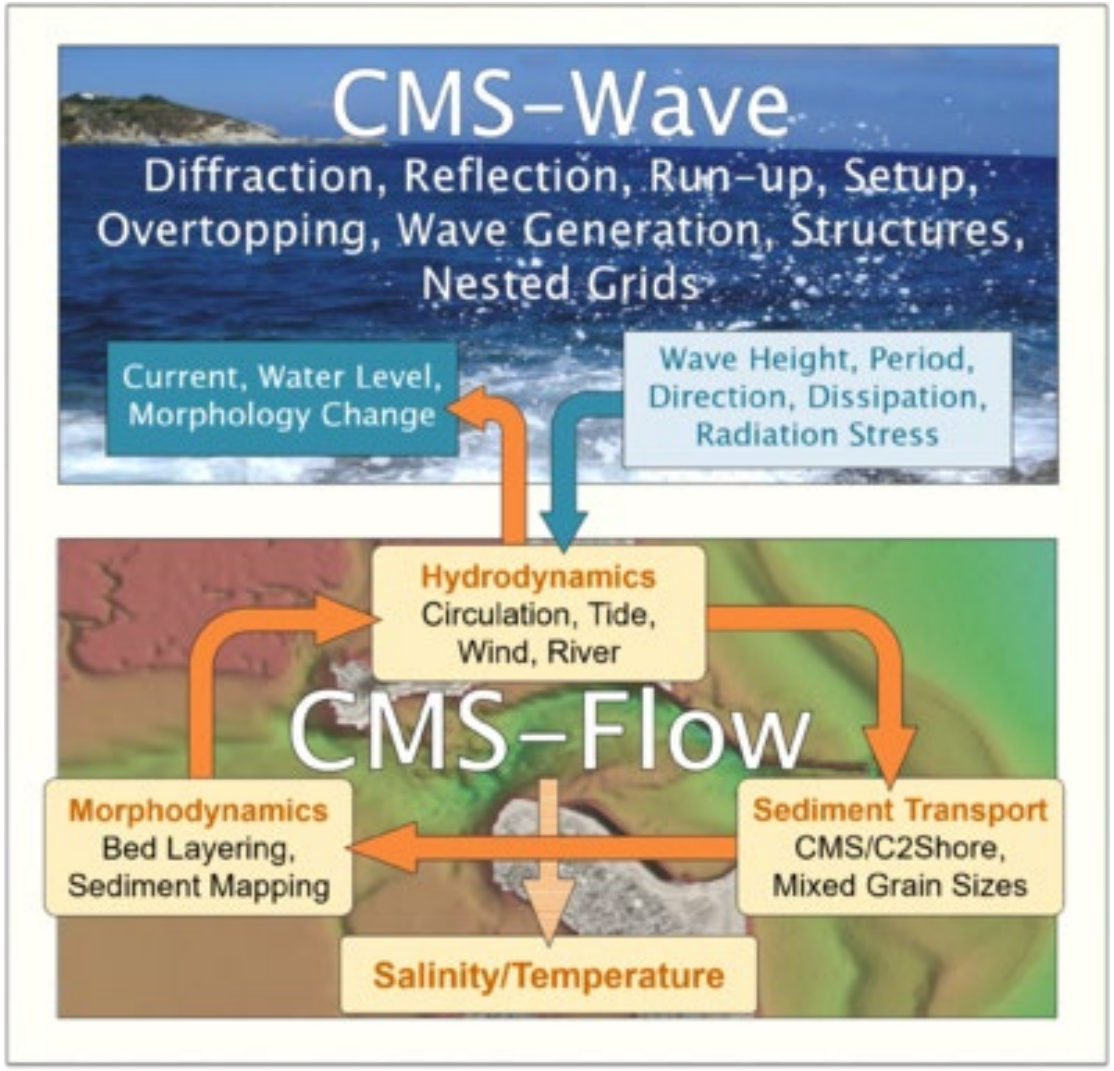
Inlet Reservoir Model (IRM)
for Simulation of Inlet Morphology Evolution

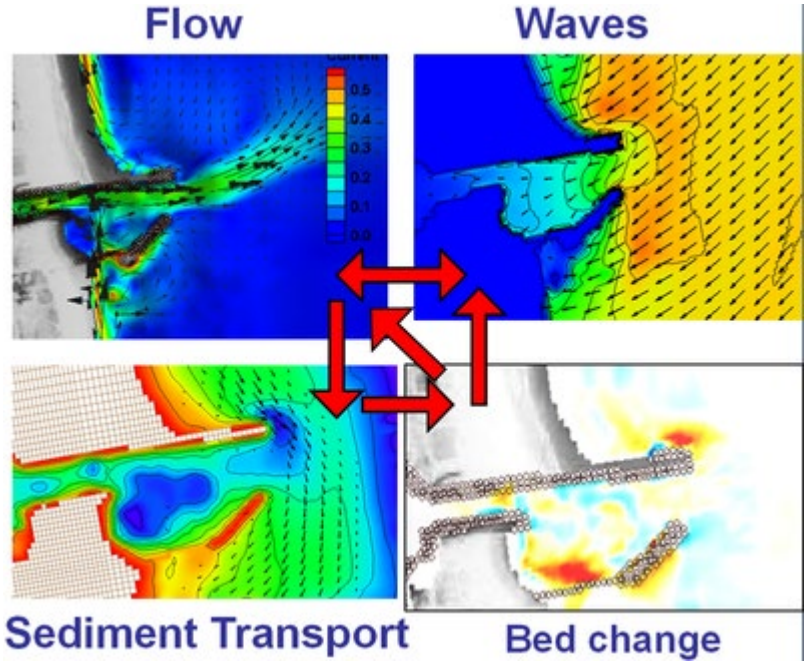
Parameters required: V_{x0} =initial volumes ?

V_{xq} =equilibrium volumes ?

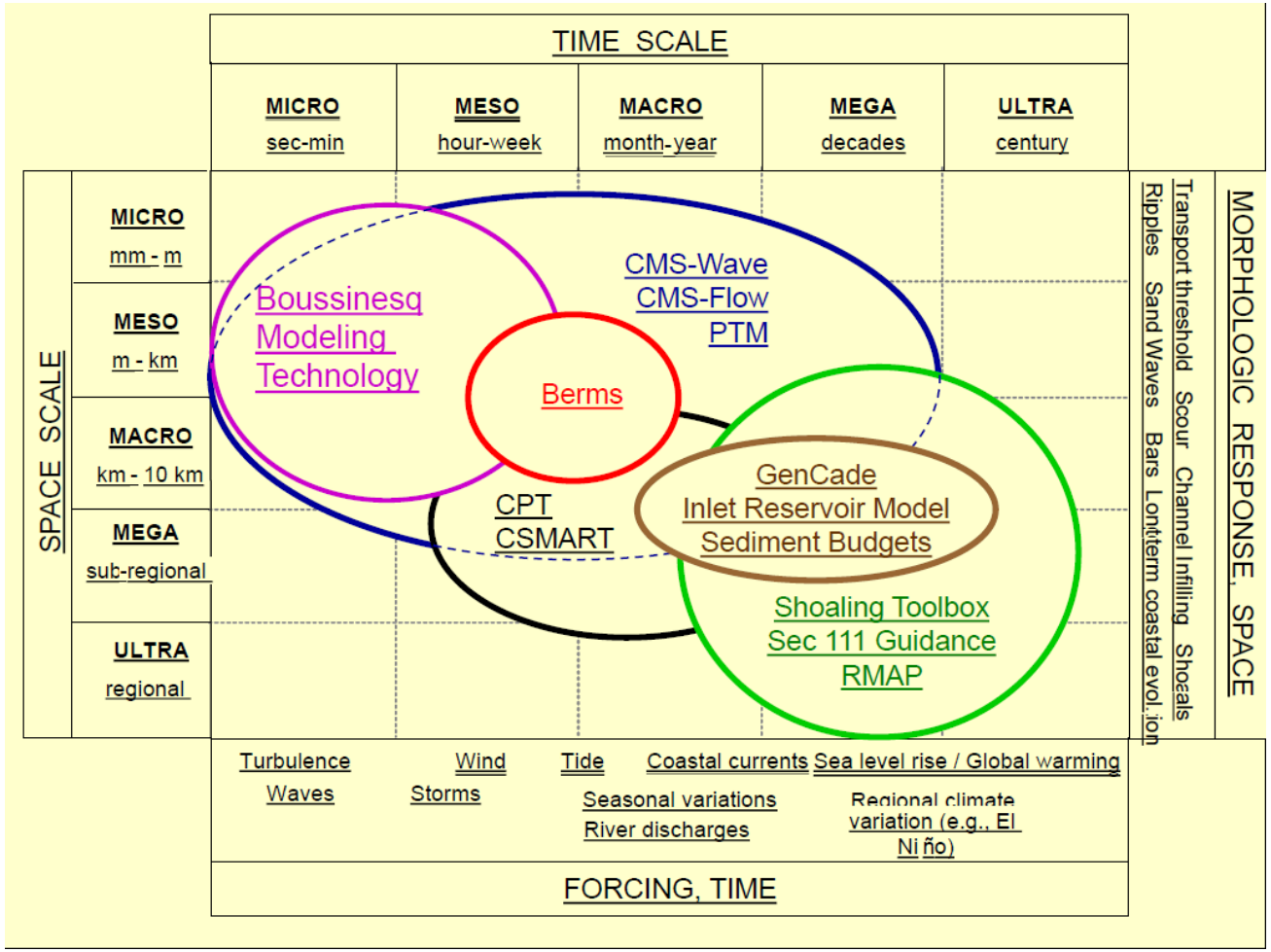
Locations of attachment bar for sediment bypassing ?

CMS: Coastal Modeling System





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	√	–

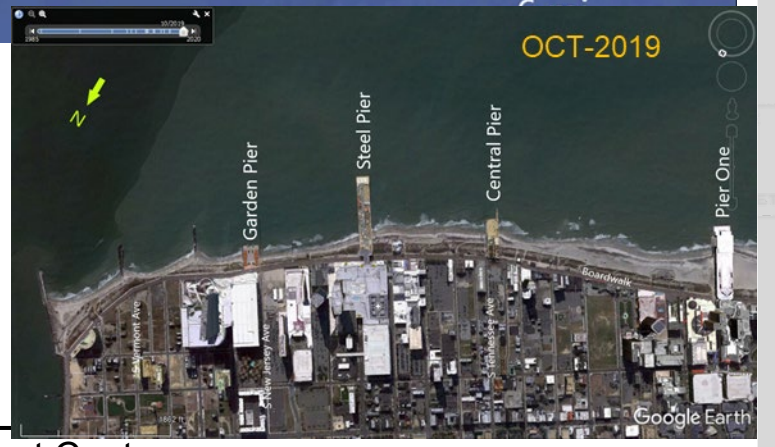
Simulation Output	GenCade	CMS
Wave	Breaking wave	√
Current	–	√
Sediment Flux	Total Longshore cross-shore rate	√ (2-D)
Bed change	–	√ (2-D)
Shoreline position	√	limited
Shoal/bar evolution	limited	√

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

Problems

- Persistent shoreline erosion occurs at the northeast end of Atlantic City, often called the erosion hot spot (EHS).
- For erosion protection, hard structures (groins, breakwater, jetties) have been constructed, periodical beach fills and post-storm nourishment have been performed along Absecon Island, focused on the EHS.
- Persistent erosion of dune, berm, and beach sands has significantly reduced storm damage reduction capabilities that the project should provide and has significantly impacted public access.

Study area and erosional hot spot (EHS)



Project Objectives

1. To identify principal factors that contribute to the EHS by learning from survey data and numerical model simulations by GenCade and CMS;
2. By using the validated numerical models to study feasibility of the design alternatives that can reduce and eliminate the EHS and maintain the authorized CSRM beach fill template between nourishment cycles.

Historical Shoreline Positions at MHW on NAP Monitoring Lines

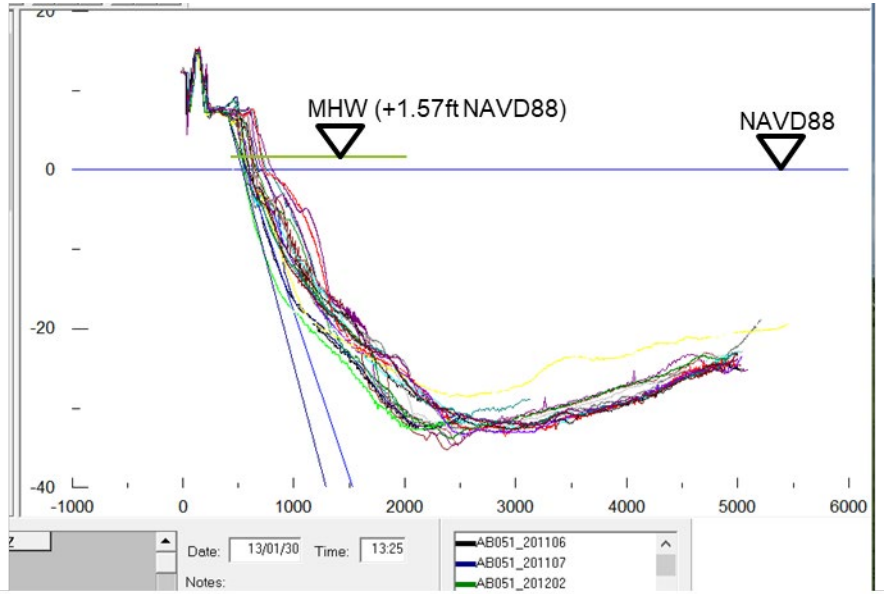
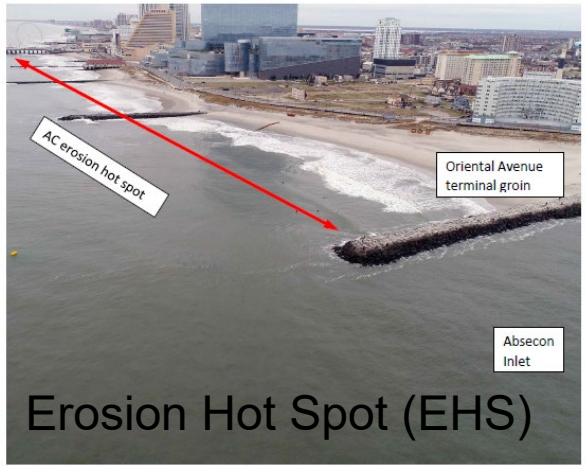
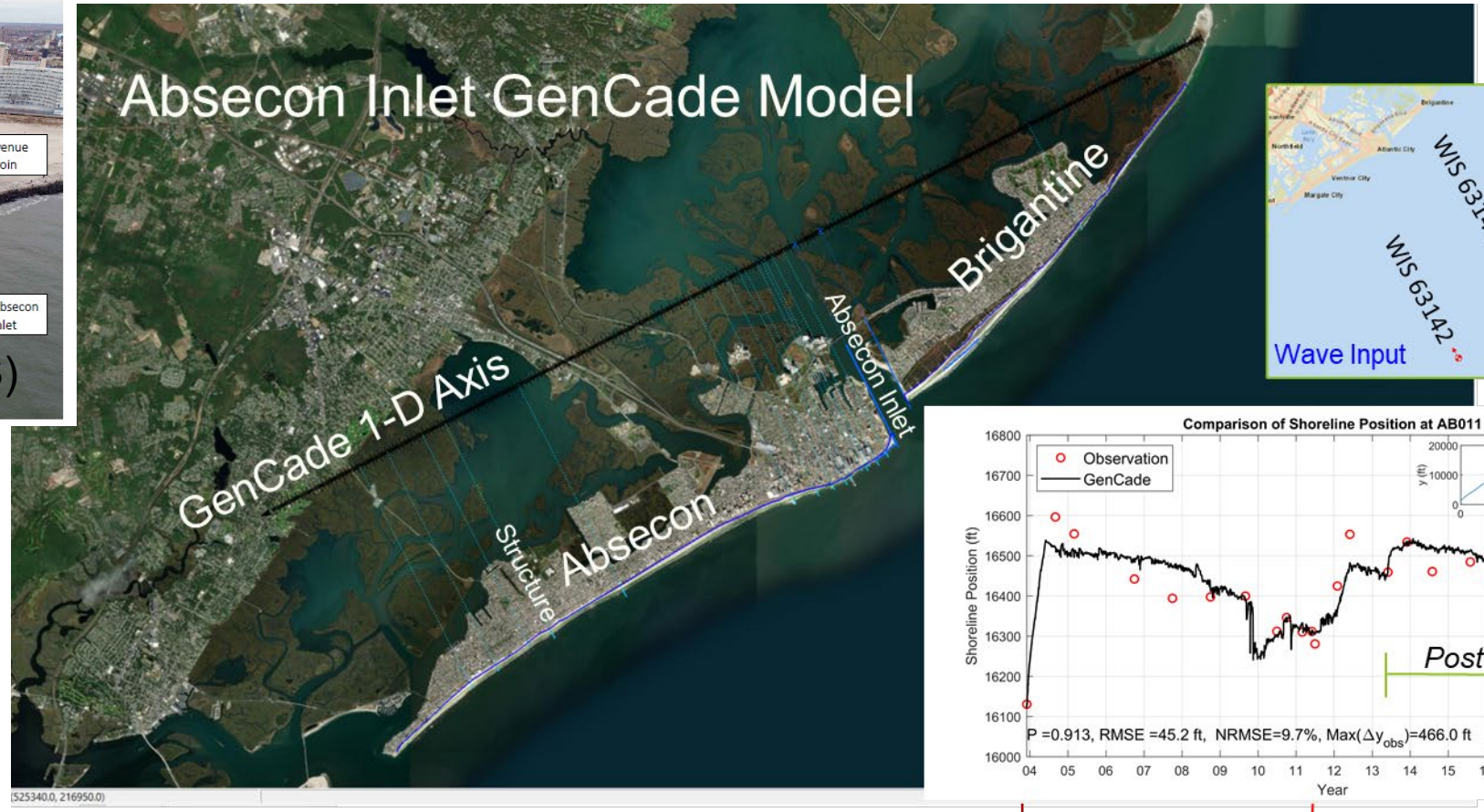


Table. Transect surveys (2003-2021)

Season	Absecon	Brigantine
Spring	1	1
Summer	6	2
Autumn	10	14
Winter	4	2
Total	21	19

GenCade Shoreline Model for Absecon Inlet



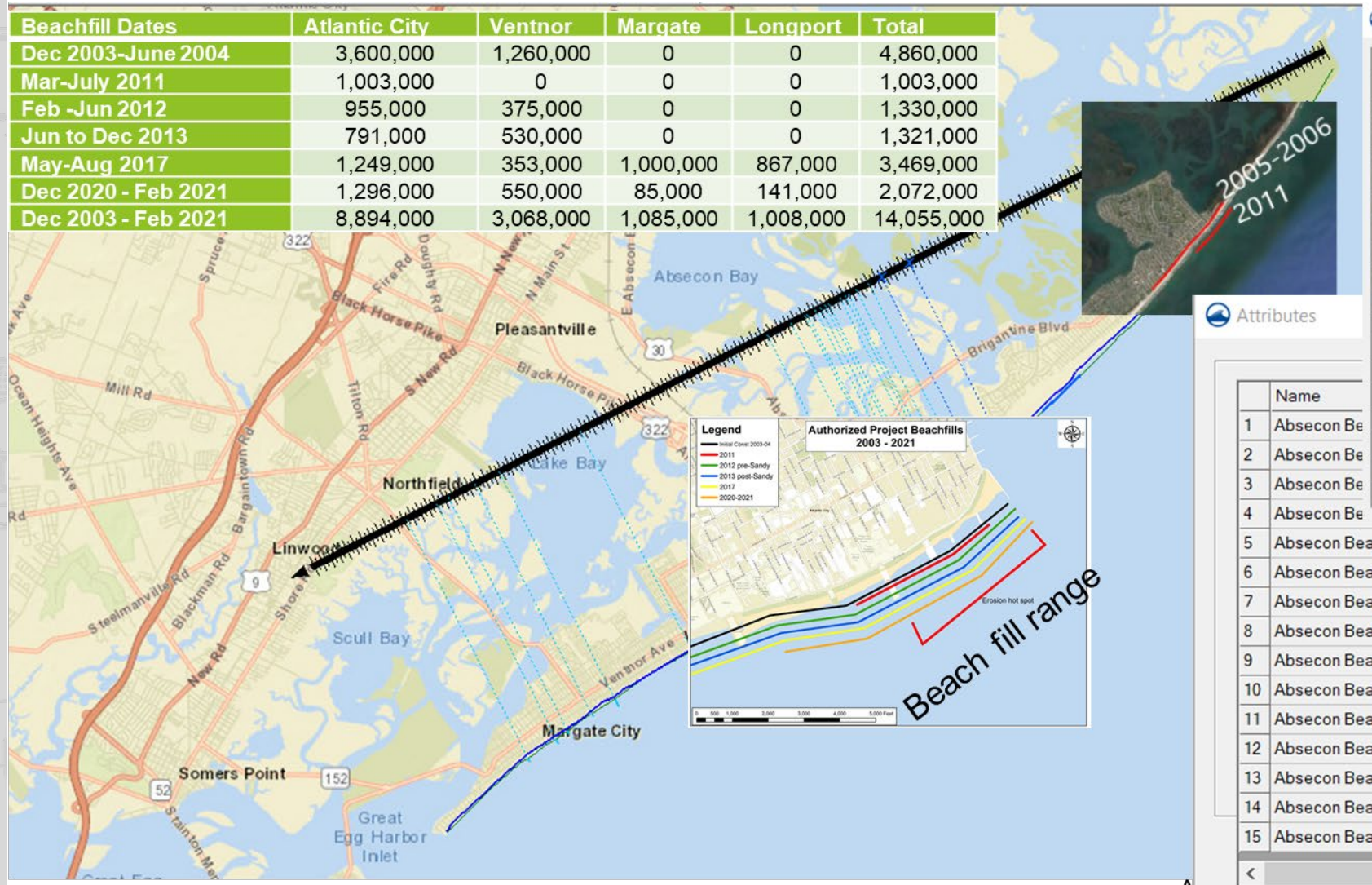


Calibration: 2003-2011
Validation: 2011-2019

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

Beach fills (2003-2021) Included in GenCade

Beachfill 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

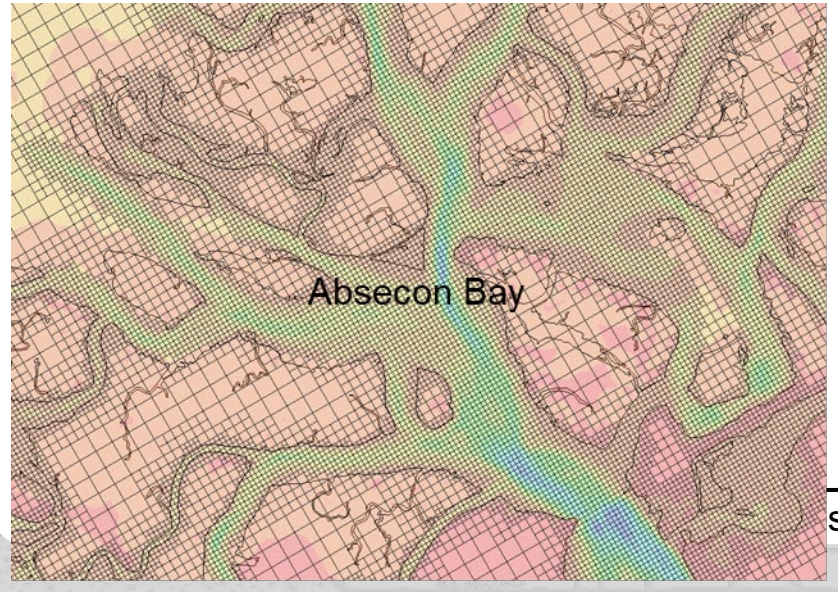
Attributes

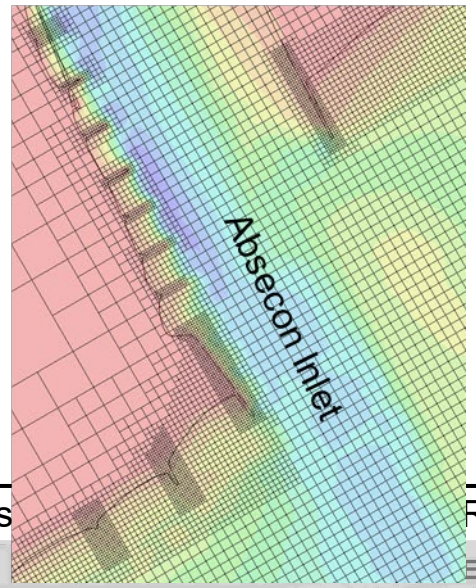
	Name					
1	Absecon Be					
2	Absecon Be					
3	Absecon Be					
4	Absecon Be					
5	Absecon Beach Fill Range	Feb-2012	Jun-2012	110.869133	AB025	AB033
6	Absecon Beach Fill Range	Jun-2013	Dec-2013	101.829072	AB051	AB012
7	Absecon Beach Fill Range	Jun-2013	Dec-2013	65.419285	AB014	AB033
8	Absecon Beach 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

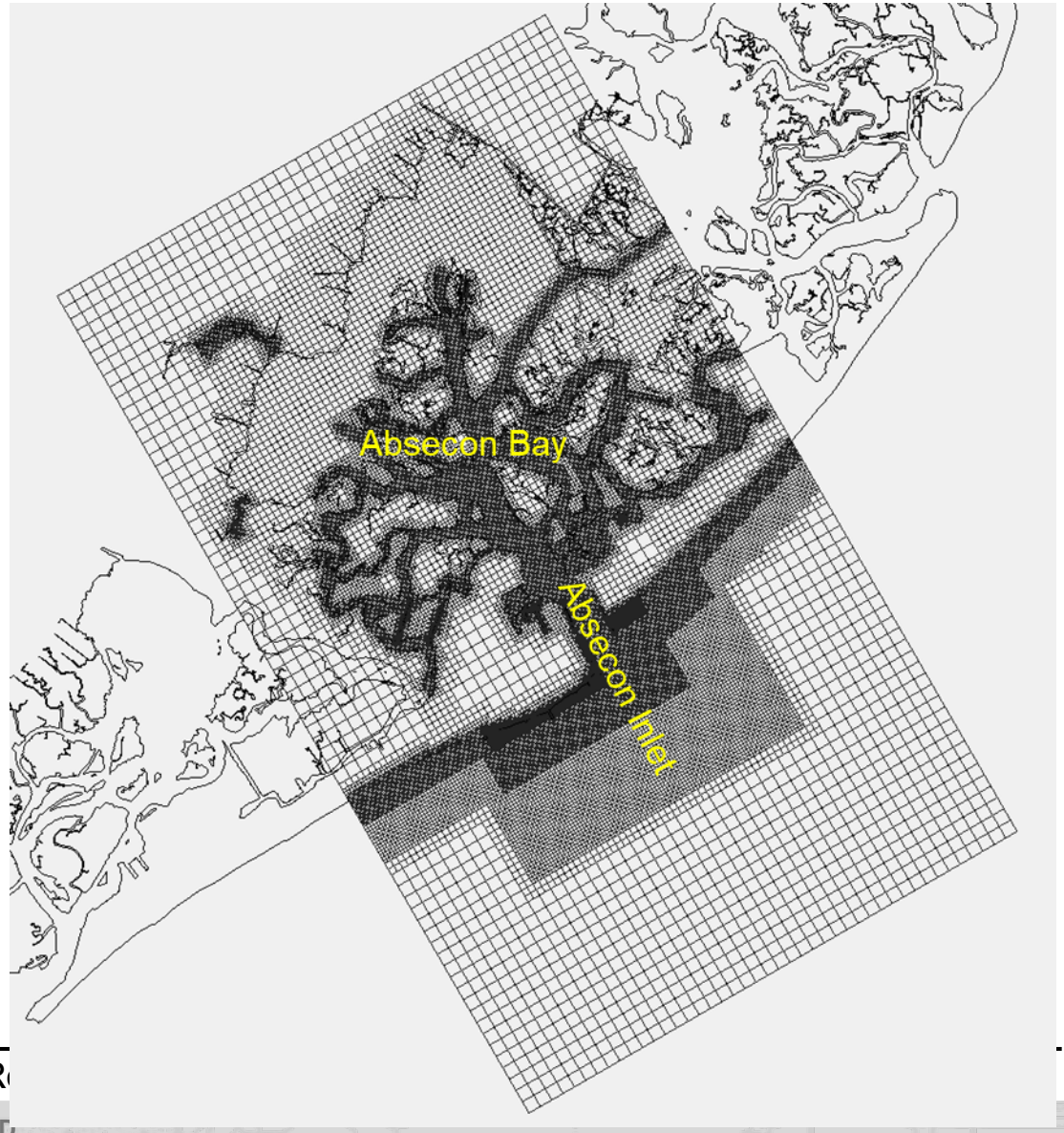
- Added berm width was estimated from the measured shoreline changes

CMS-Flow Grid around Absecon Inlet

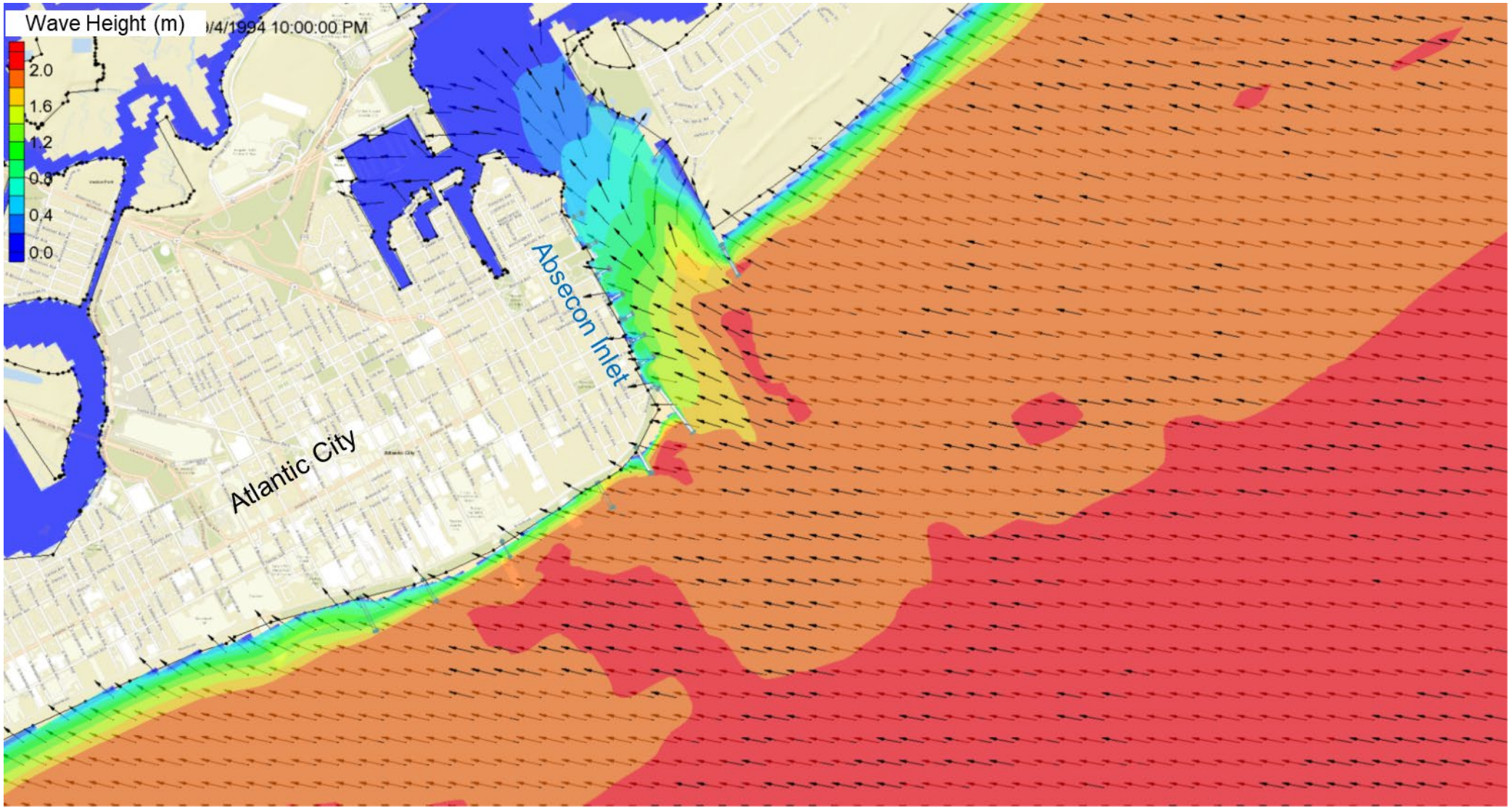
- Horizontal Coordinate System: UTM 18N (Meters)
- Vertical Coordinate System: m, MSL
- Telescoping Grid
  - Minimum resolution: 4 to 8 m @ structures
  - Maximum resolution: 256 m @ offshore
  - Square cells: 4, 8, 16, 32, 64, 128, 256
- Structures
- Variable Manning's Roughness
- Boundary Conditions: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



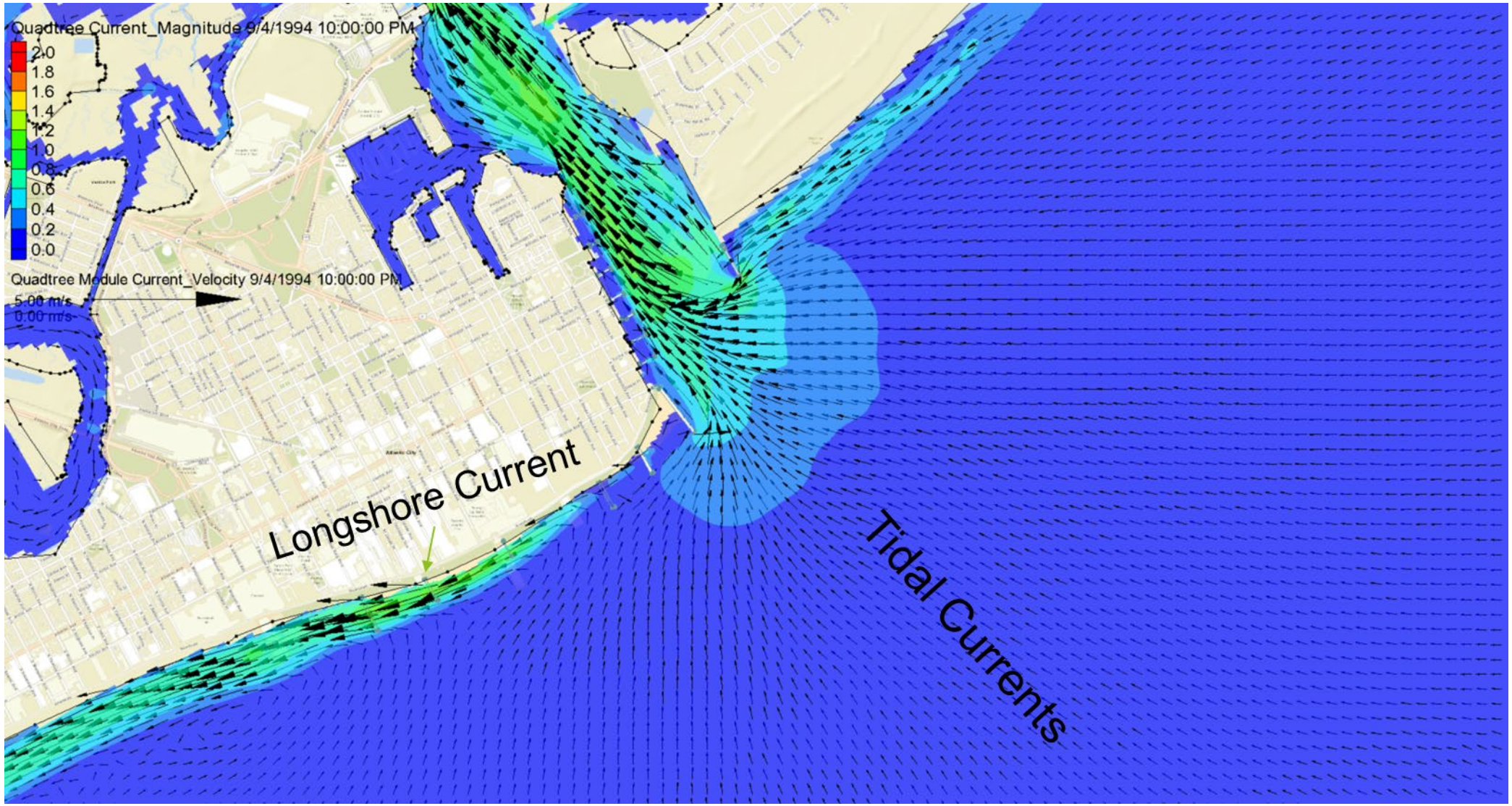




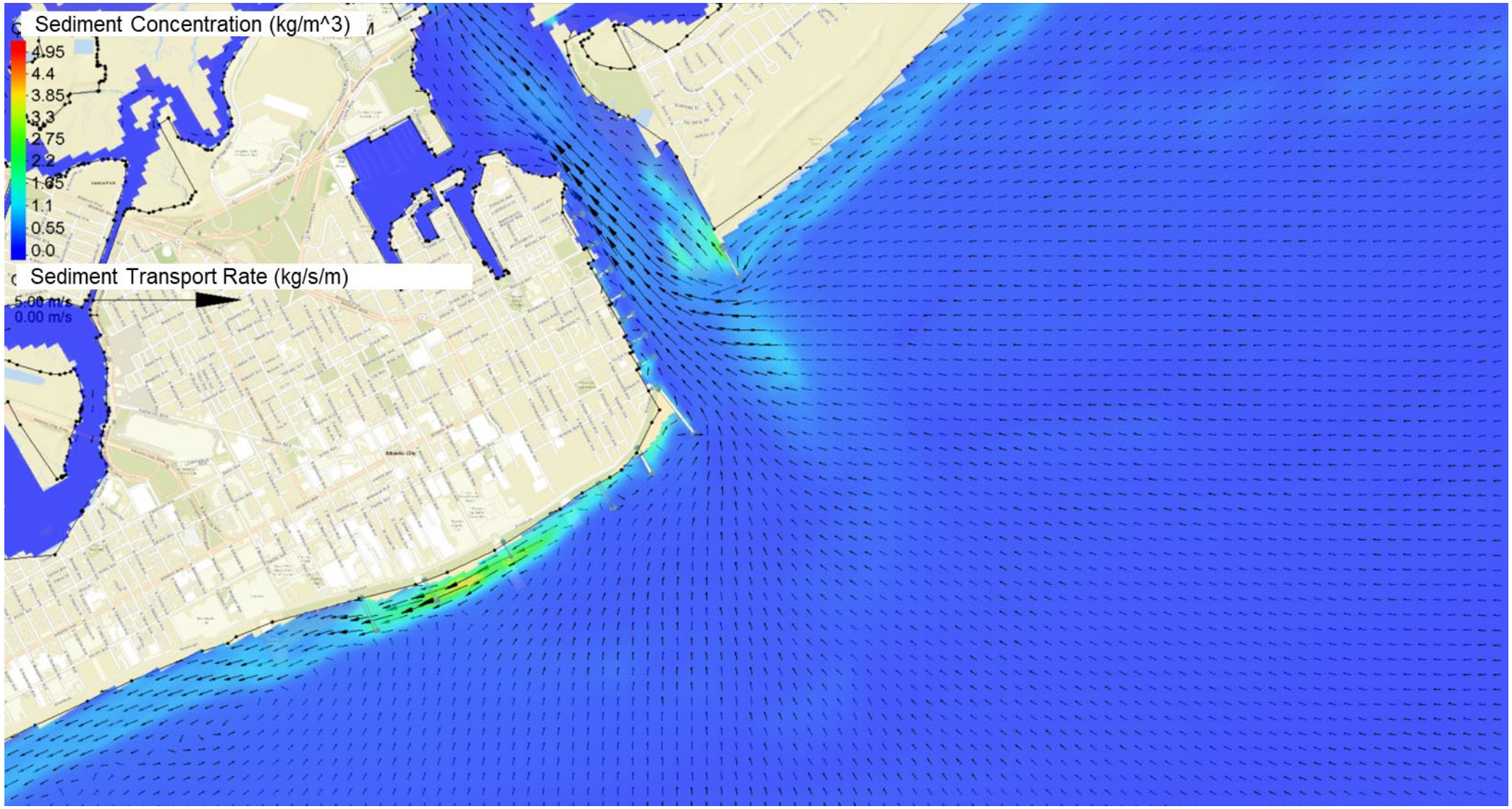
Wave Heights and Mean Directions



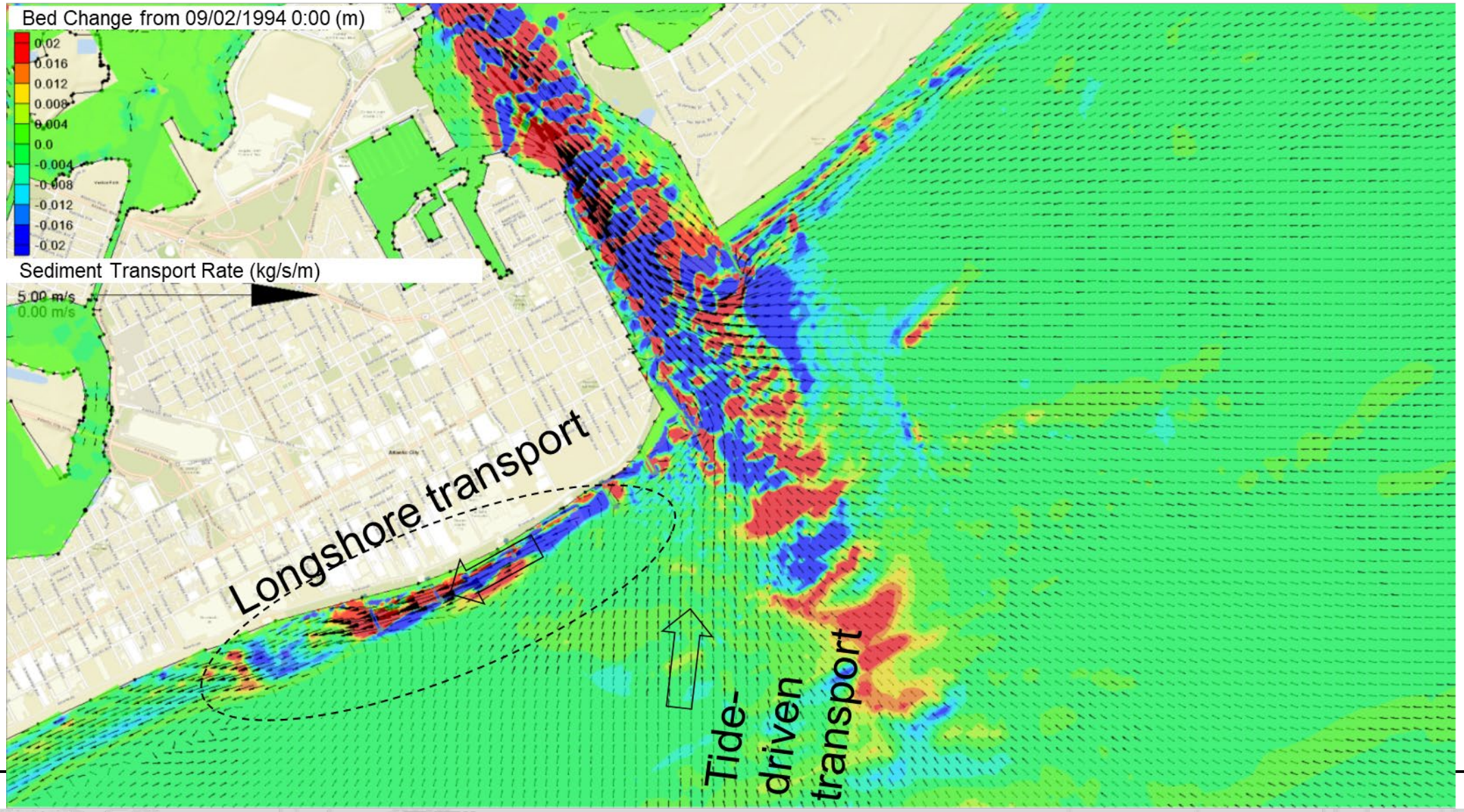
Mean Currents in a Flood Tide



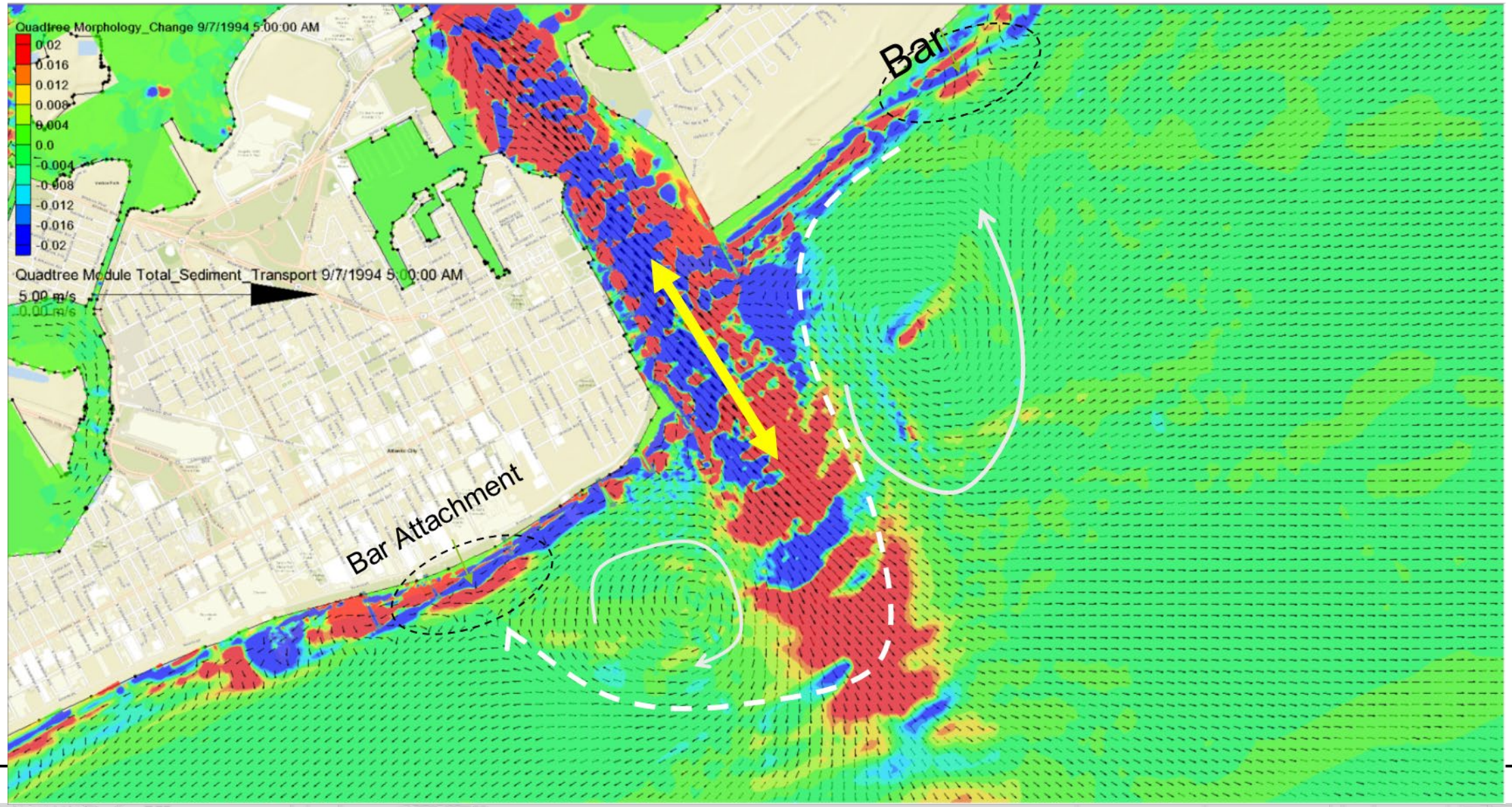
Sediment Concentration and Flux



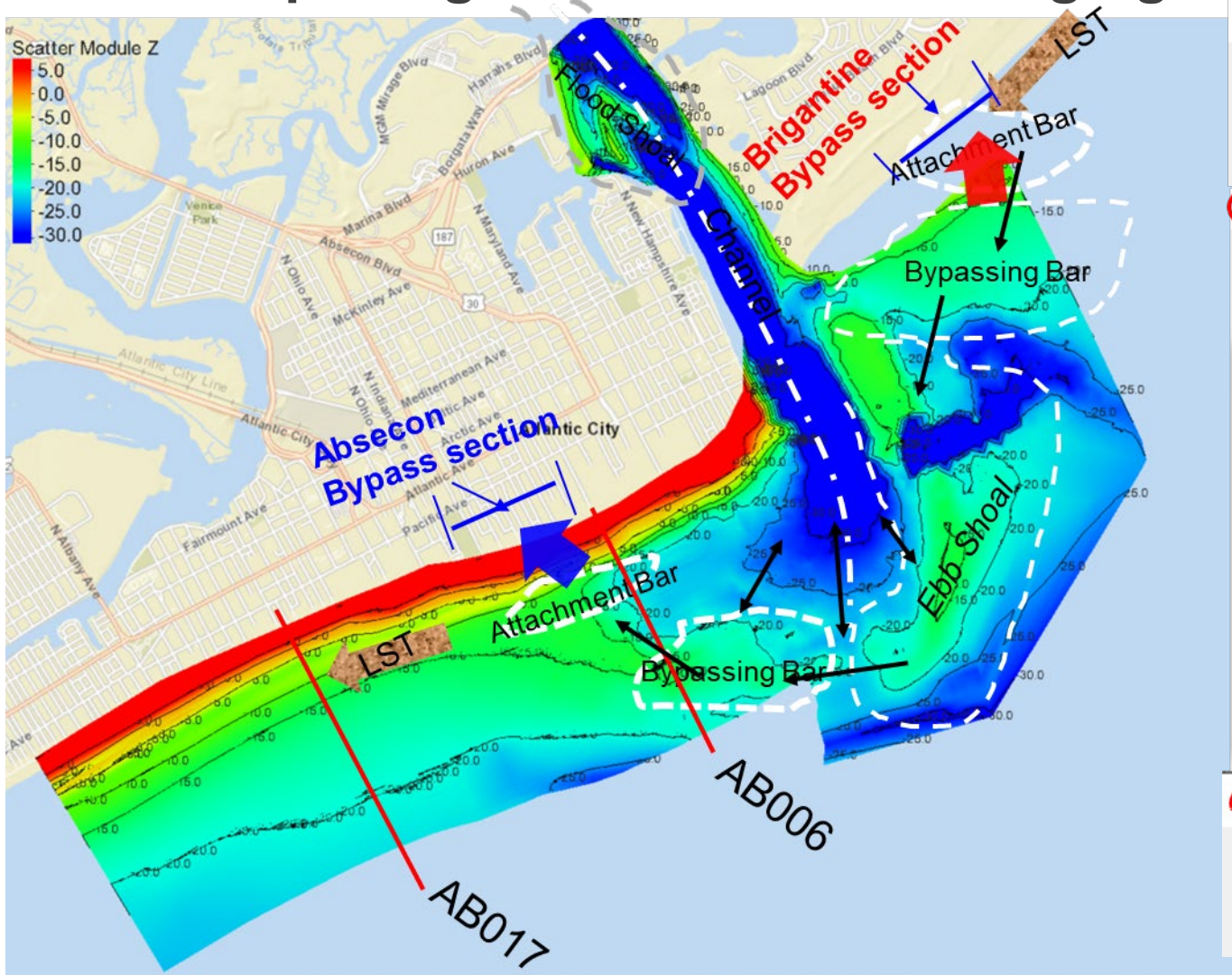
Longshore Transport and Tide-driven Transport at a flood tide



Sediment Transport Pattern and Sediment Pathway



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

Model Calibration (2003-2011)

Objectives:

(1) to calibrate the empirical parameters:
- two longshore sediment transport rate (CERC formula) parameters (K_1 and K_2),
- permeability parameters of structures,

(2) to determine diffracting feature of each structure,

(3) to find a longer time step to optimize simulation efficiency, and

(4) to verify the IRM model parameters (volumes of shoals & bars)

Table 1. Absecon Island Beachfill Placement since Initial Construction in 2003 (NAP Report)

Beachfill Dates	Atlantic City	Ventnor	Margate	Longport	Total	Notes
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	Vermont to North Carolina Aves. in AC
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	

Table 2. Brigantine Island Beachfill Placement since Initial Construction in 2006 (NAP Report)

Construction	Date Completed	Pay Quantity, cy
Initial (including 1st periodic renourishment)	Feb 2006	671,000
FCCE emergency rehab	Dec 2011	94,000
2nd periodic renourishment	Dec 2012	500,000
FCCE restoration ("repair/restore" project Hurricane Sandy)	Jul 2013	427,000
3rd periodic renourishment and FCCE restoration	Apr 2018	755,000

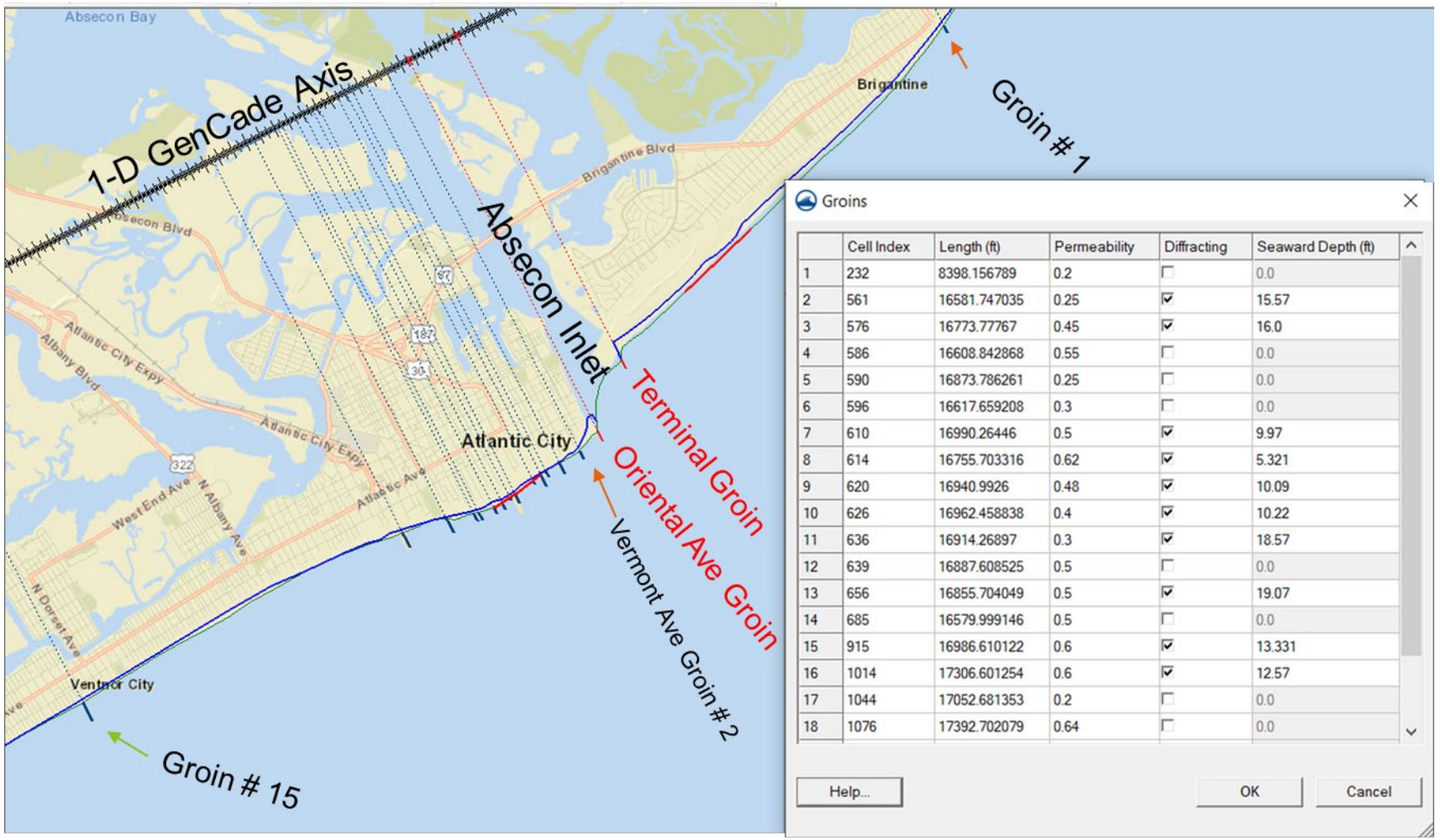
Conditions and Values:

Computational Period: 8 years
2003/12/01 0:00 - 2011/12/01 0:00
Including beach construction projects (2003-2011):
Absecon: Initial Construction (Dec 2003-June 2004), Mar - July 2011
Brigantine: Initial construction (Nov. 2005 ~Feb 2006), Oct. 2011~Dec. 2011)
- GenCade requires added berm width as input parameter for each beach fill construction. The actual berm width extensions were determined by survey data at NAP monitoring lines. The berm width increases at those model transects between two lines were linearly interpolated from the survey data at two lines.

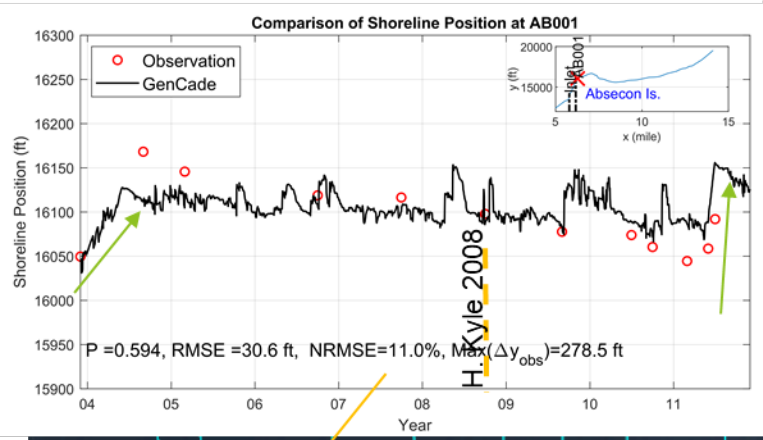
Offshore Waves: WIS 62141 (BI07-AB017) WIS 63142 (AB018-049)
Time step (Δt) = 90 seconds
Grid Size (Δx) = 60 ft
Calibrated Model Parameters:
K_1 = 0.25; K_2 = 0.16
No cross-shore transport included.
Dredging: Actual volumes were included in the IRM model

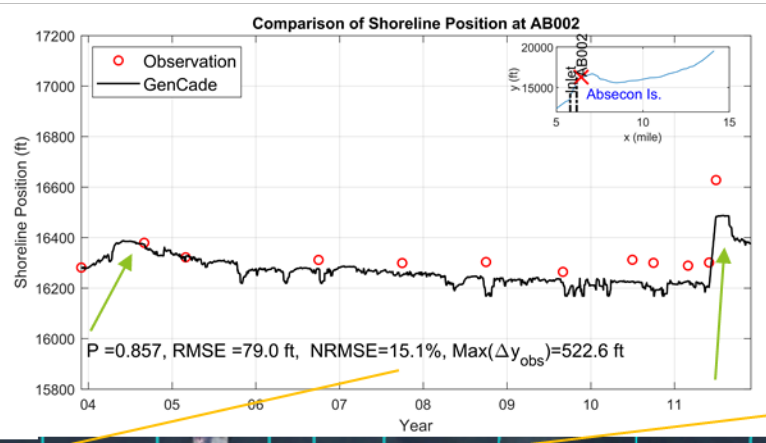
Calibrated Parameters for Estimating Bypassing Effect of Groins on LST

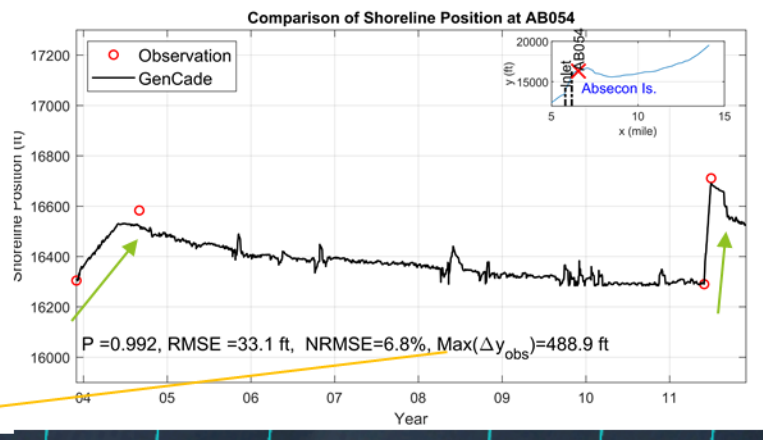
- **Diffracting Structures**: Groins, Piers
- Non-Diffracting Structures: Short groins, outfalls
- **Seaward depth** at the tip of groin is given from transect profile near the structure
- **Length:**the distance from the seaward tip to the GenCade 1-D Axis.
- **Permeability** (sand transmission capability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

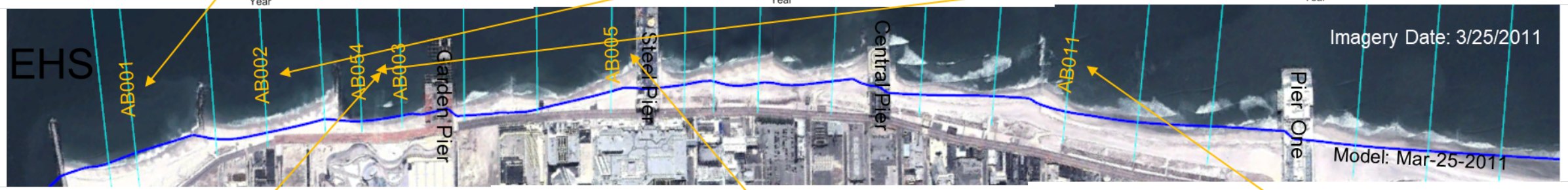


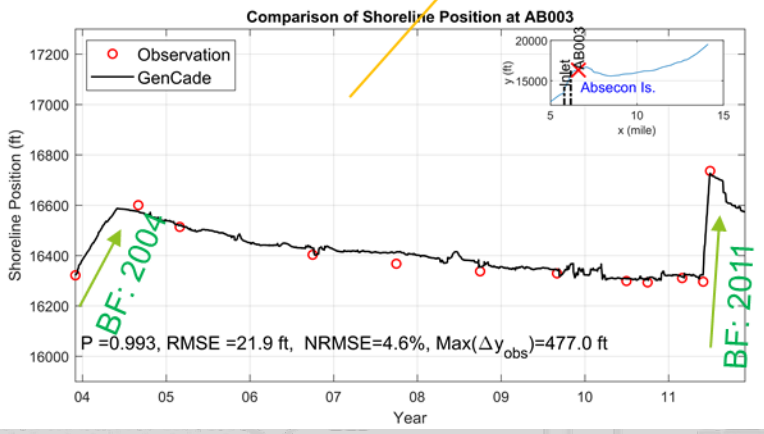
Calibrated Model Results: Shoreline Evolution (2003-2011)

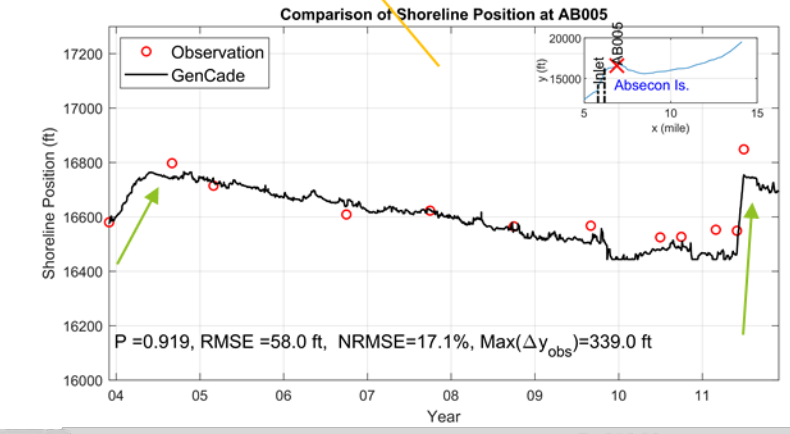


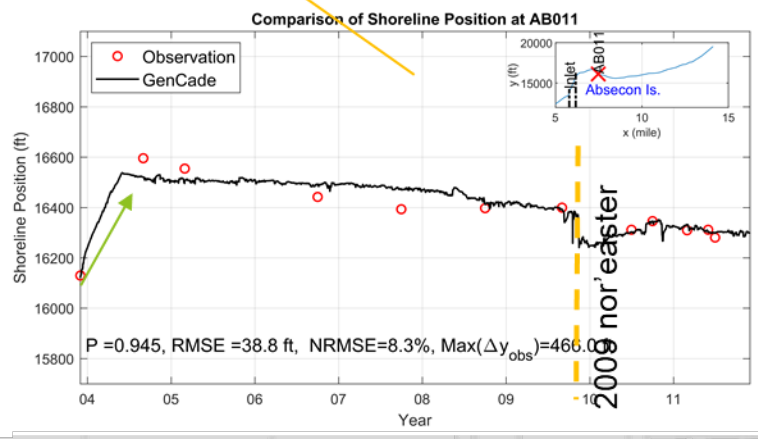












Model Validation (2011-2013-2019)

Objectives:

(1) to validate the GenCade Absecon Inlet model using the calibrated parameters

(2) to examine the effect of Revel Sill (detached breakwater),

(3) to adjust permeability of groins due to structure rehab/extension) , and

(3) to validate the IRM model for simulation of shoal evolution and sediment bypassing by the inlet.

Table 1. Absecon Island Beachfill Placement since Initial Construction in 2003 (NAP Report)

Beachfill Dates	Atlantic City	Ventnor	Margate	Longport	Total	Notes
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	Vermont to North Carolina Aves. in AC
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	

Table 2. Brigantine Island Beachfill Placement since Initial Construction in 2006 (NAP Report)

Construction	Date Completed	Pay Quantity, cy
Initial (including 1st periodic renourishment)	Feb 2006	671,000
FCCE emergency rehab	Dec 2011	94,000
2nd periodic renourishment	Dec 2012	500,000
FCCE restoration ("repair/restore" project Hurricane Sandy)	Jul 2013	427,000
3rd periodic renourishment and FCCE restoration	Apr 2018	755,000

Conditions and Values:

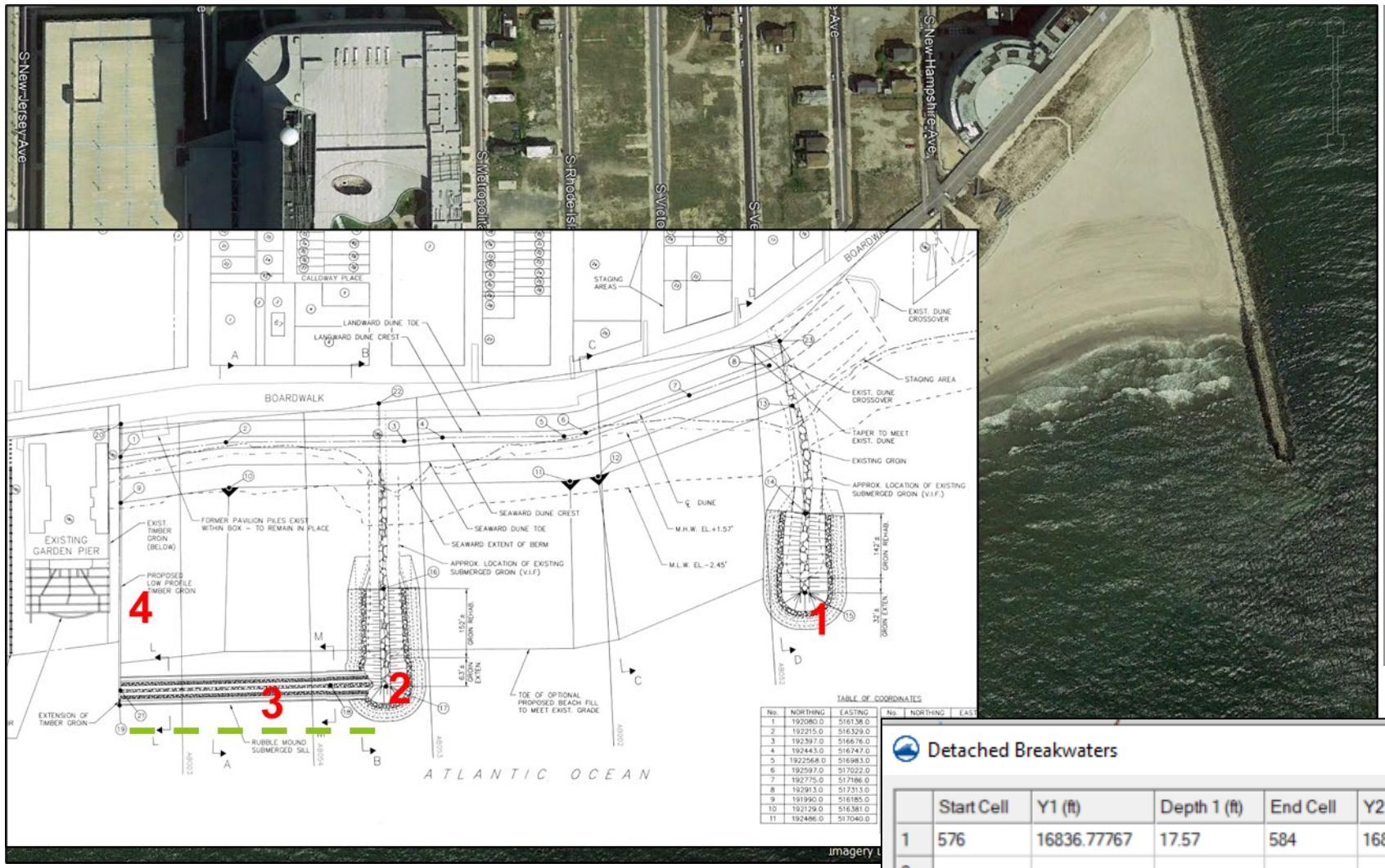
Computational Period:
pre-sill: 2 years, 2011/06/01 0:00 - 2013/06/01 0:00
post-sill: 6.5 years, 2013/06/01 0:00-2020/01/01 0:00
Measured Initial Shorelines: 2011-Jun for pre-sill, 2013-Jun for post-sill

Including beach construction projects (2003-2011):
Absecon: 2011~ 2017
Brigantine: 2011 ~ 2018

Offshore Waves: WIS 62141 (BI07-AB017) WIS 63142 (AB018-049)
Time step (Δt) = 90 seconds
Grid Size (Δx) = 60 ft
Grain size (d_{50}) = 0.25 mm
Berm Height (D_b) = 5.68 ft (above MHW, or 7.25 ft + NAVD88)
(*Based on beachfill template)
Closure depth (D_c) = 20.1 ft on Brigantine, 26.51 ft on Absecon
(*based on estimates by (Brutsche et al. CHETN-VI-45, 2016) and using wave data at WIS 63141 & 63142)
Smooth parameter = 11
No regional contour
Boundary Conditions: Moving bc at the north end of Brigantine; no moving bc at the south end of Absecon Island)
Calibrated Model Parameters:
K_1 = 0.25; K_2 = 0.16
No cross-shore transport included.

Permeability of Structures: Only those with extension were adjusted
Revel Sill: Wave transmission calibrated: k_t=0.92; dimension and depth were based on design layout
Dredging: Actual volumes were included in the IRM model.

Structure Installation and Rehab: Project Conditions



Project Included:

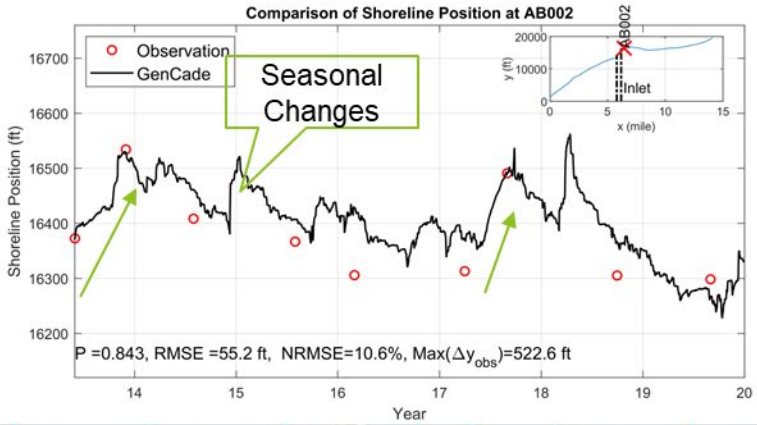
1. Vermont Ave Groin Rehab/Extension
2. Massachusetts Ave Groin Rehab/Extension
3. Submerged Sill
4. Low Profile Timber Groin
5. Garden Pier Shortened (not part of project)

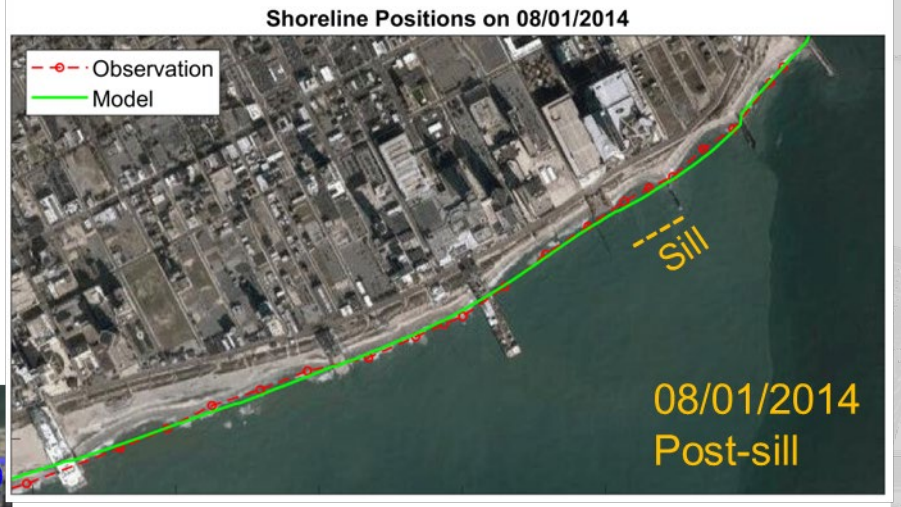
Project Constructed after Hurricane Sandy in 2013

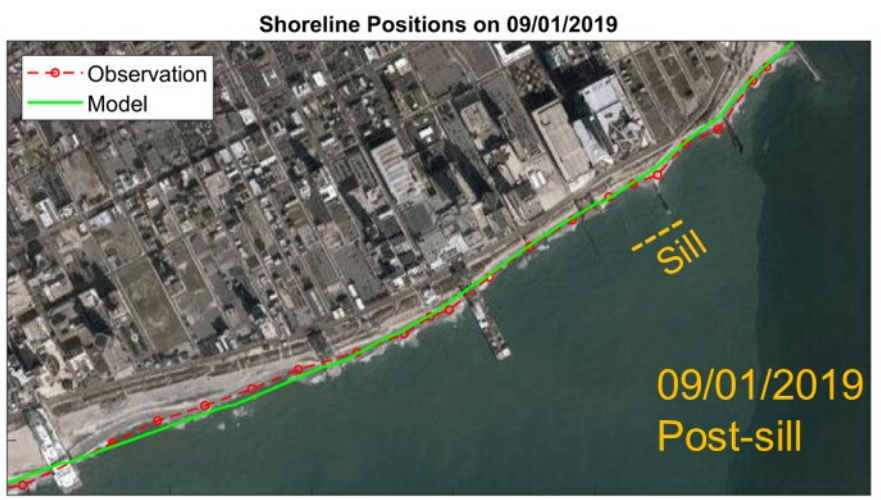
Detached Breakwaters

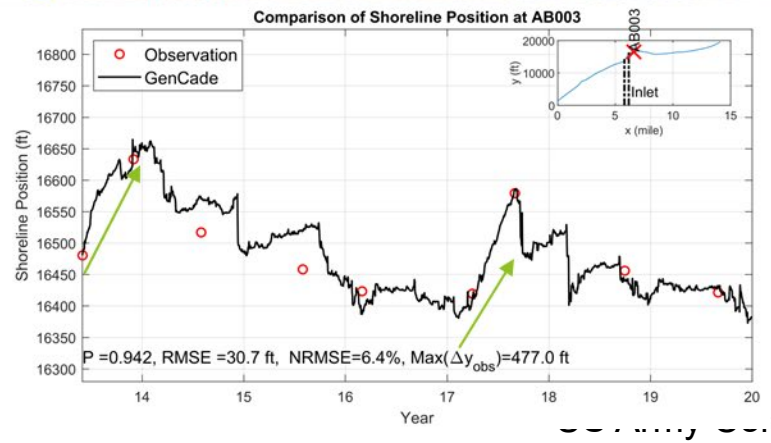
	Start Cell	Y1 (ft)	Depth 1 (ft)	End Cell	Y2 (ft)	Depth 2 (ft)	Transmission	Coeff/Perm/Atts
1	576	16836.77767	17.57	584	16836.77767	17.57	Constant	0.92
2								

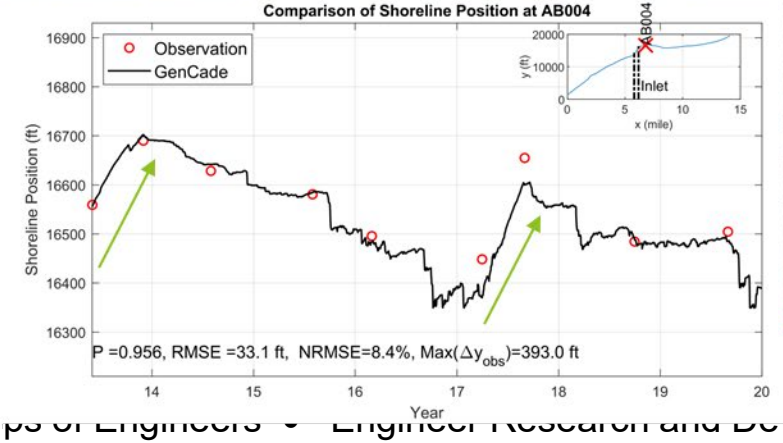
Validation Results: Shoreline Changes on EHS (2013-2019)



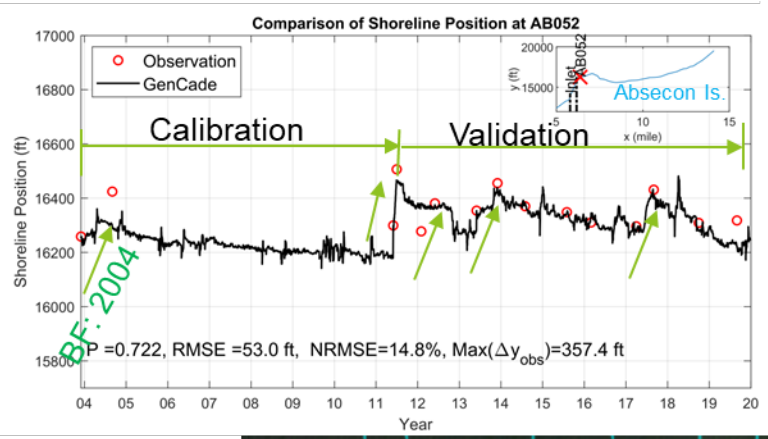


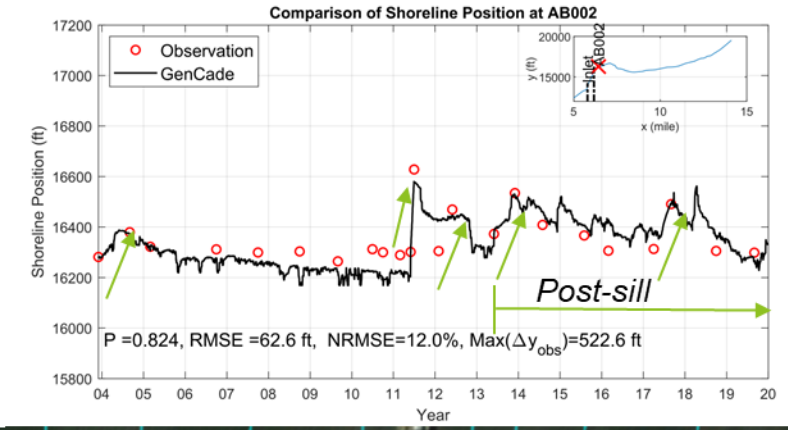


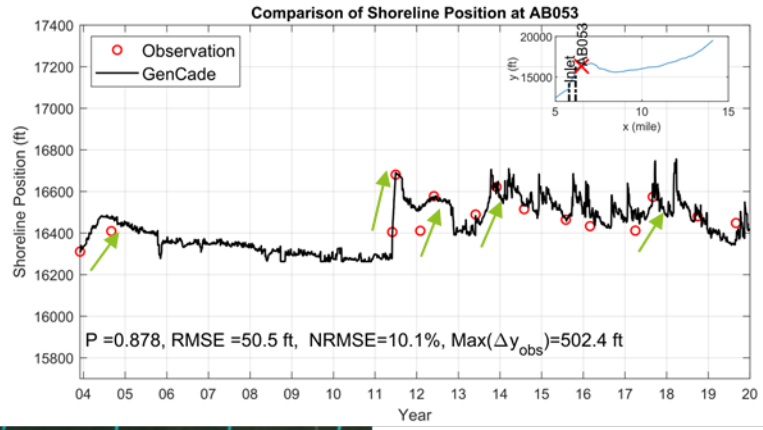




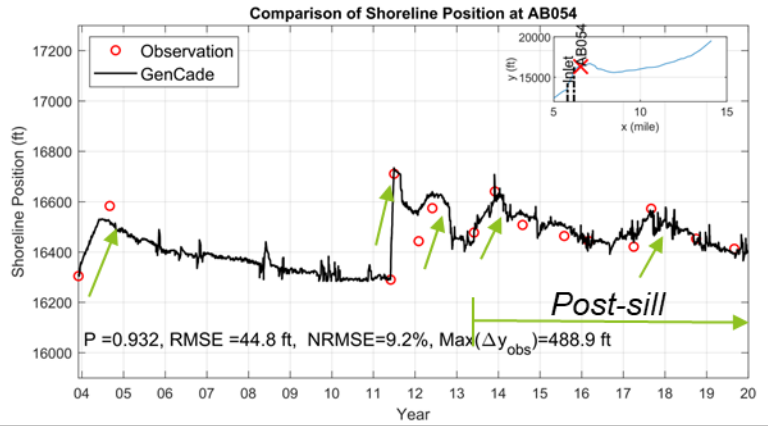
All Simulation Results (2003-2020) in Second and Third Compartments of EHS

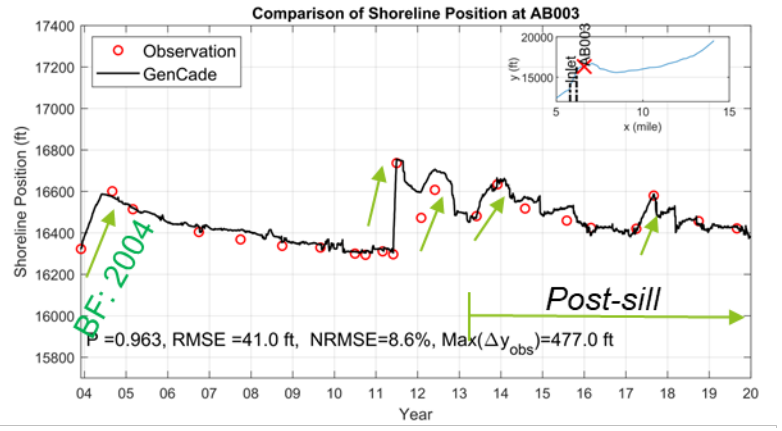


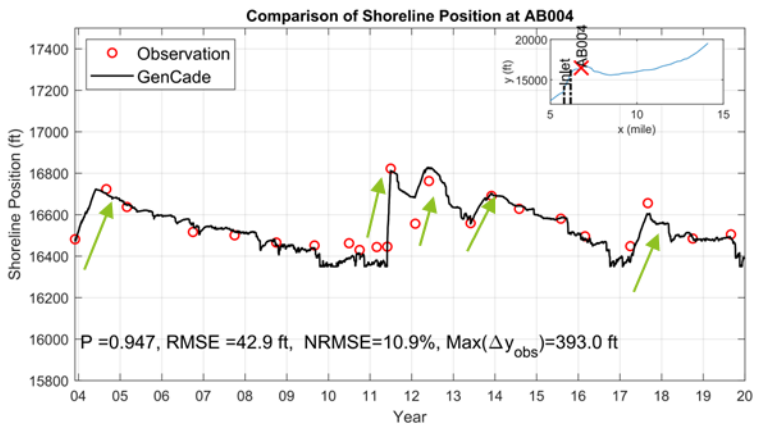




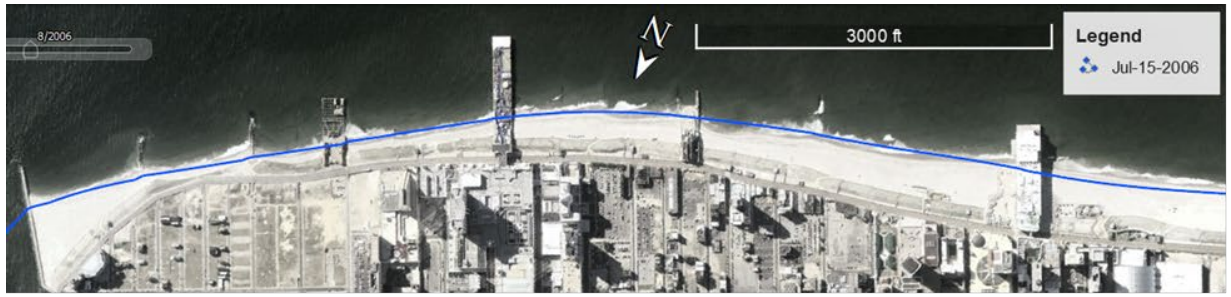
EHS





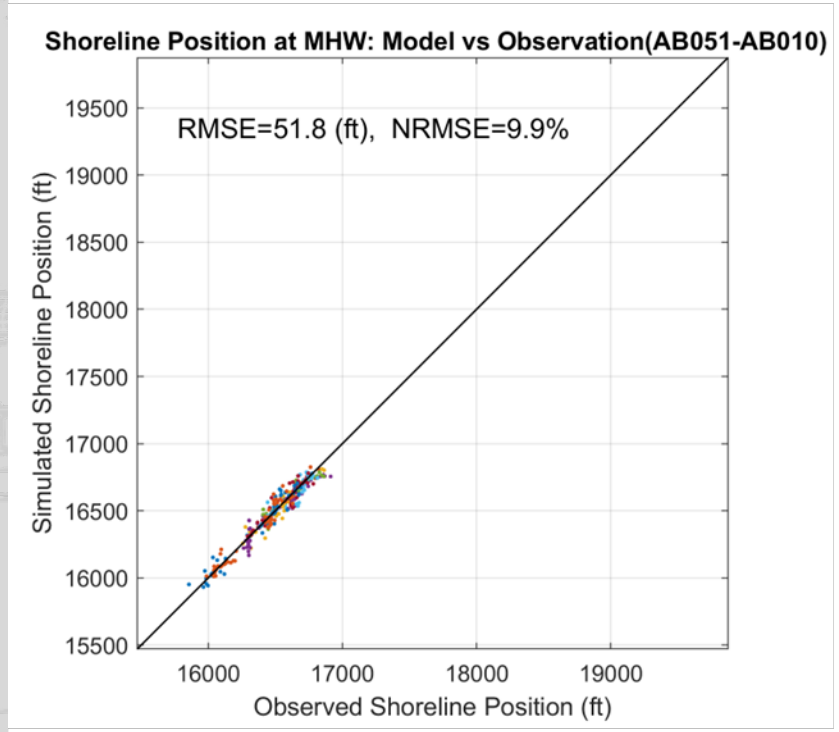


Simulated shoreline profiles on the satellite imagery with the same date



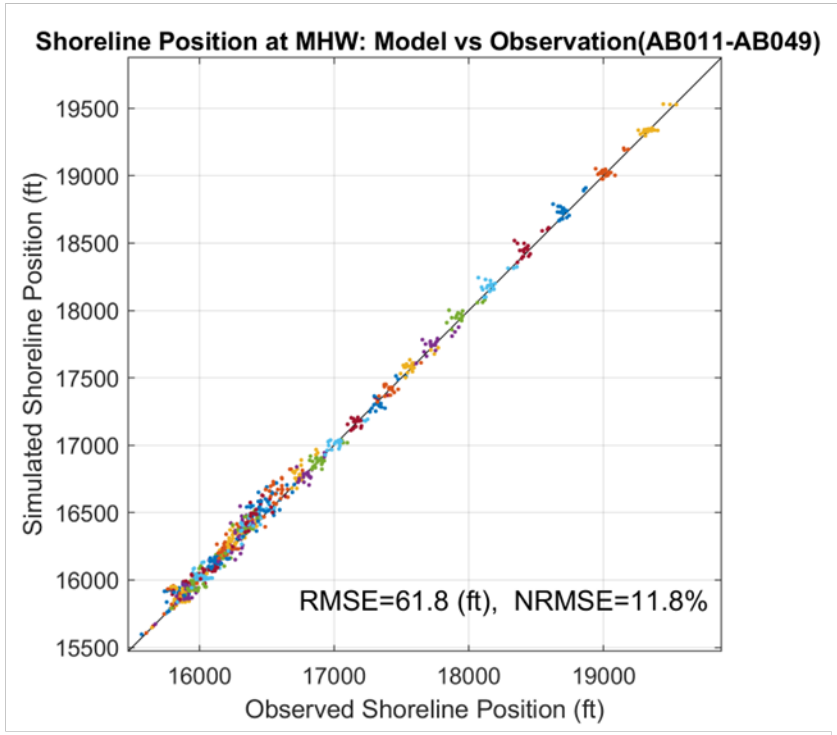
Q-Q Plots of Shoreline Positions (2003-2020)

(1) EHS



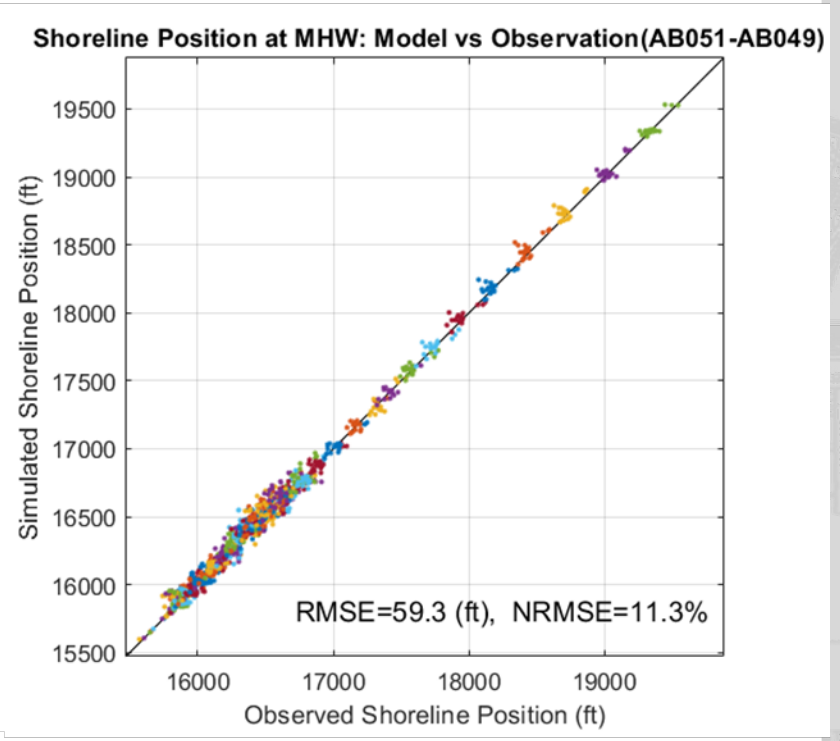
Number of Data (N)=319

(2) Beyond EHS



Number of Data (N)=841

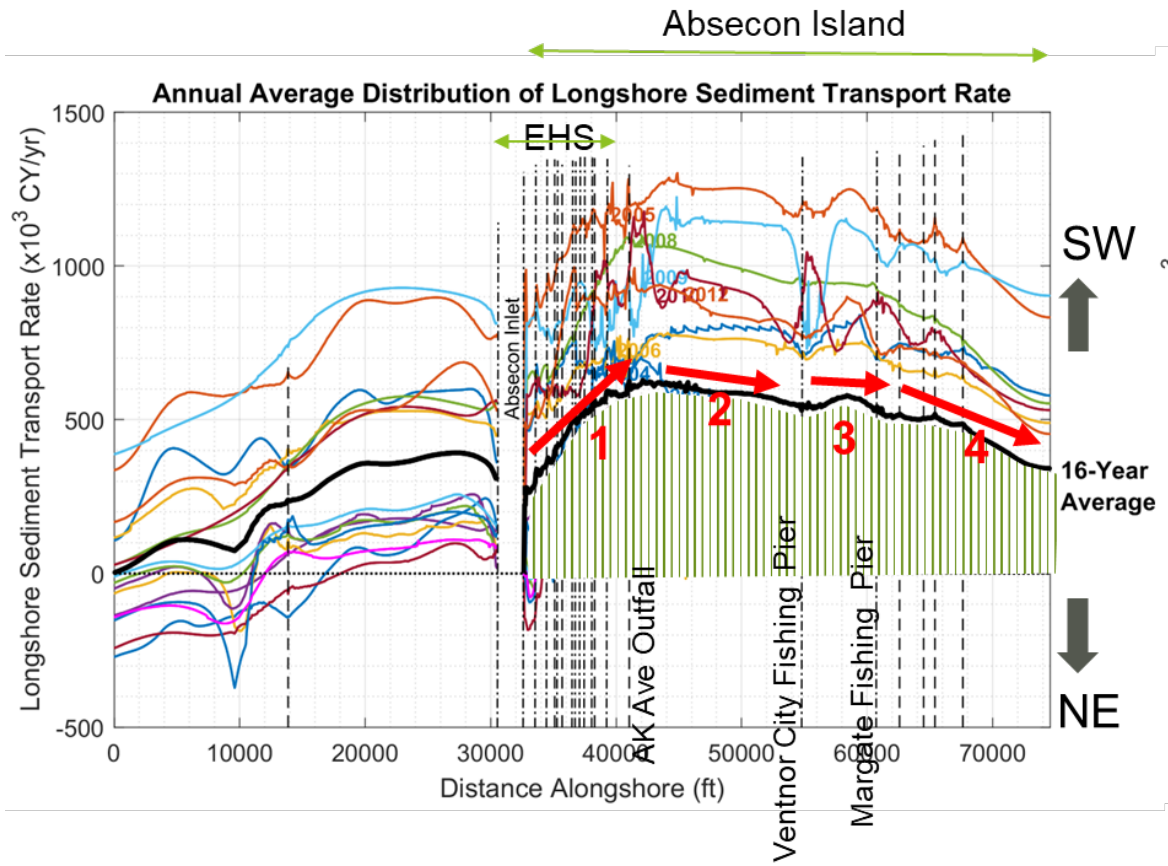
(3) All Lines in Absecon Island

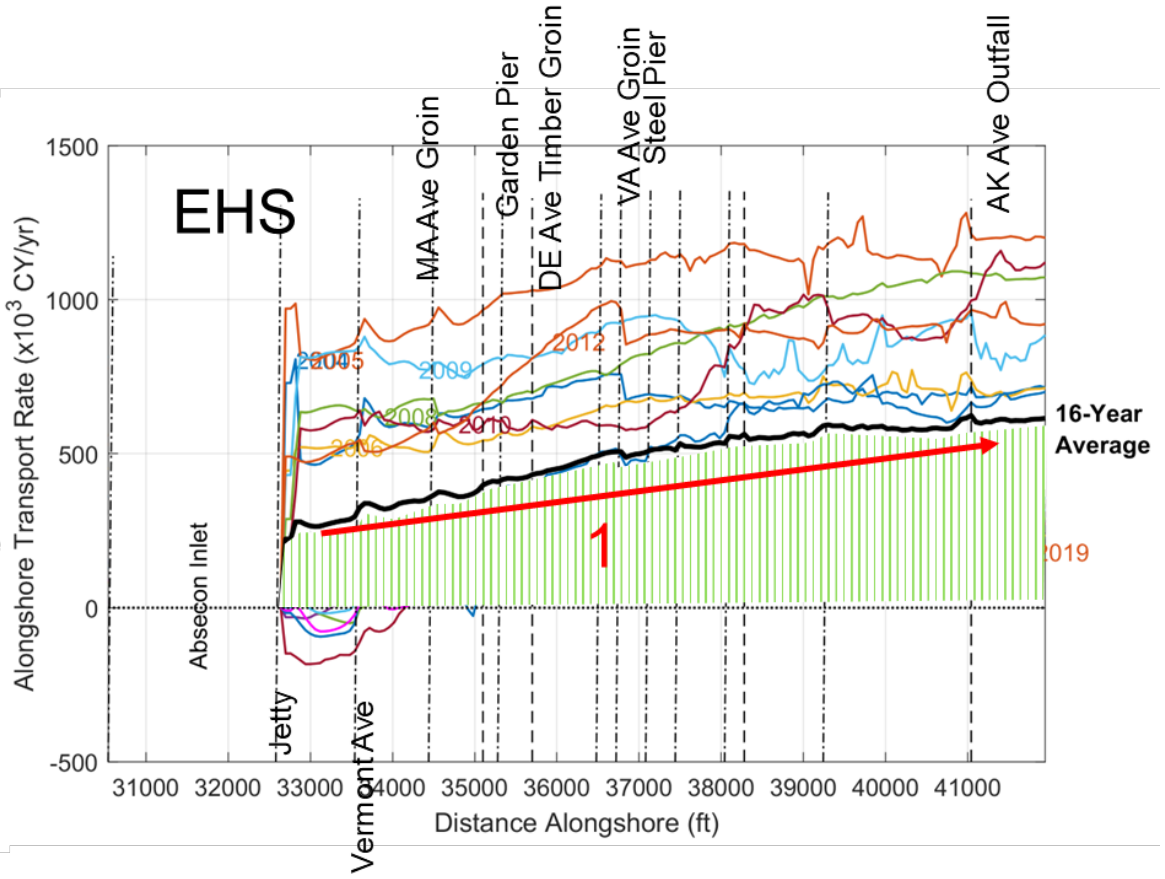


Number of Data (N)=1160

UNCLASSIFIED

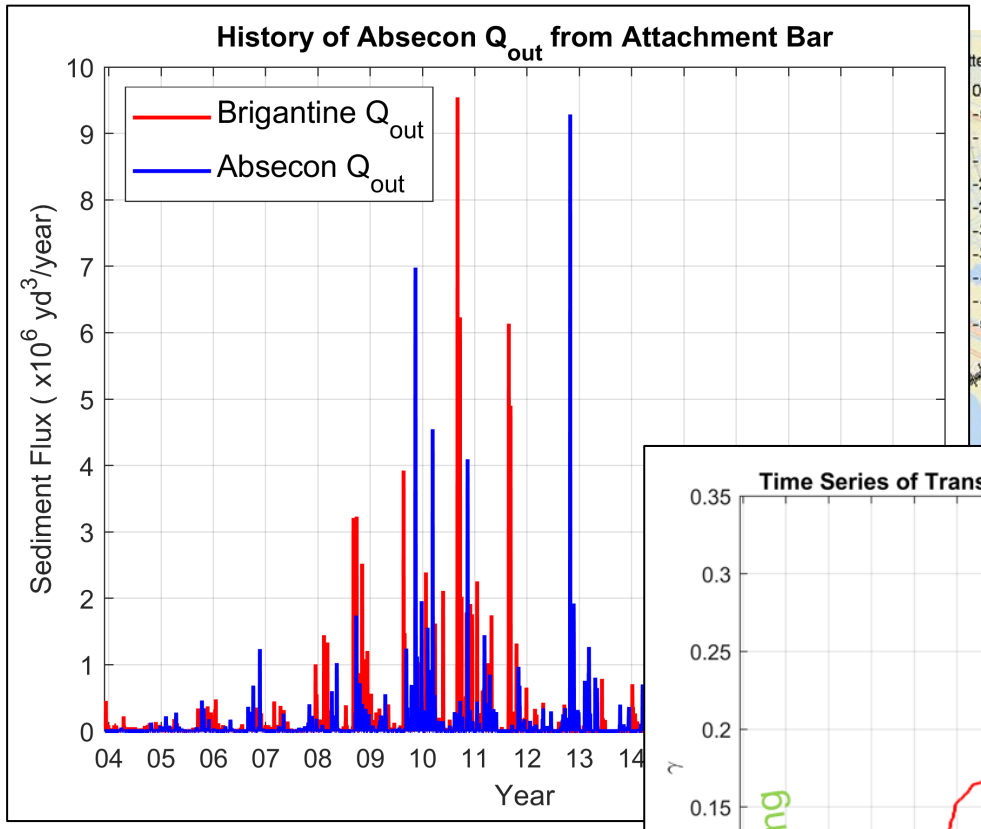
Validated GenCade for Understanding Long-Term Trend of Annual Average LSTR Profiles

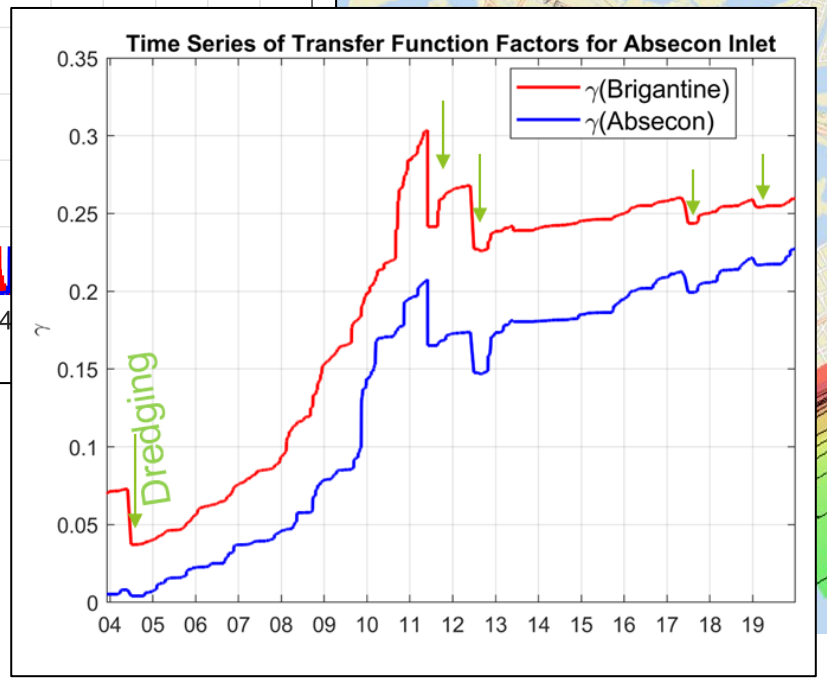




- Trend of Shoreline Change on Absecon Island: 1 (EHS) – erosive; 2- accretive; 3 – erosive/accretive; 4 - accretive (erosive)
- Ranks of Annual LSTR on EHS:
  2005, 2012, 2009, 2008, 2004, 2010, 2006 < 16-year average < 2011, 2007, 2014, 2016, 2013, 2018, 2015, 2017, 2019

Inlet Bypass Estimated by IRM model (2003-2020)



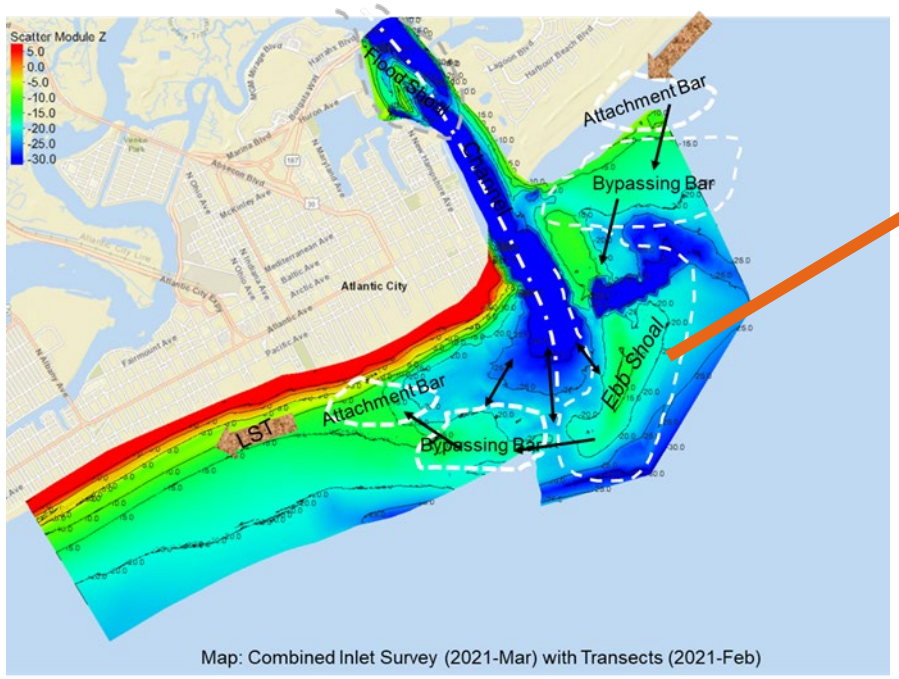


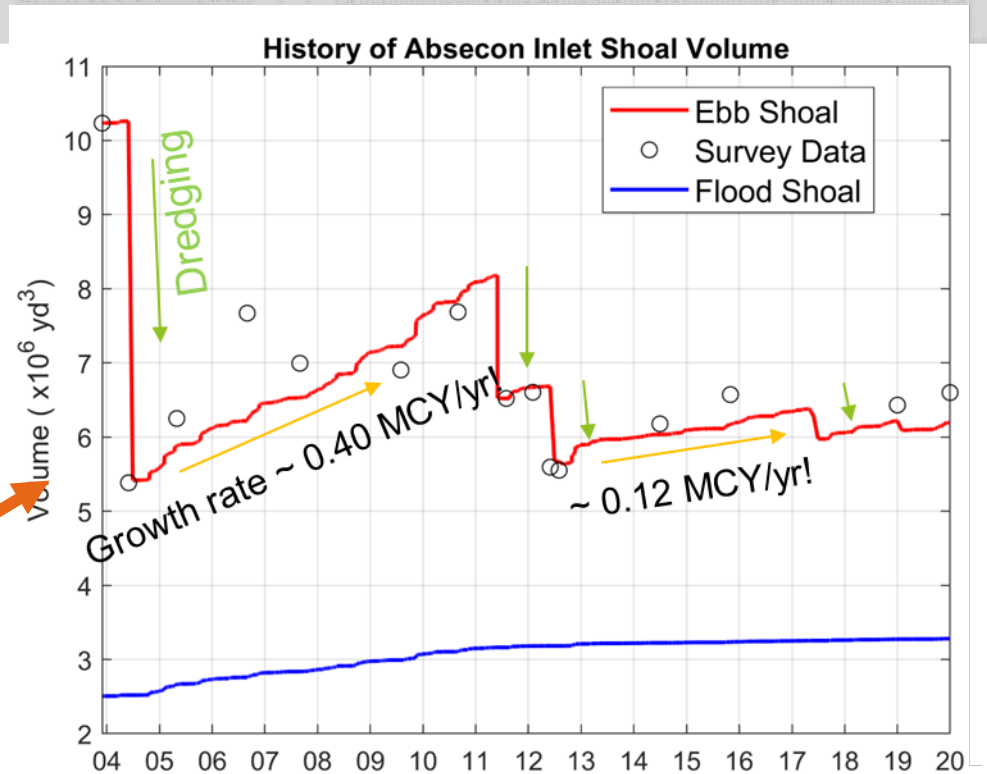
Longshore Sediment Transfer Factor:

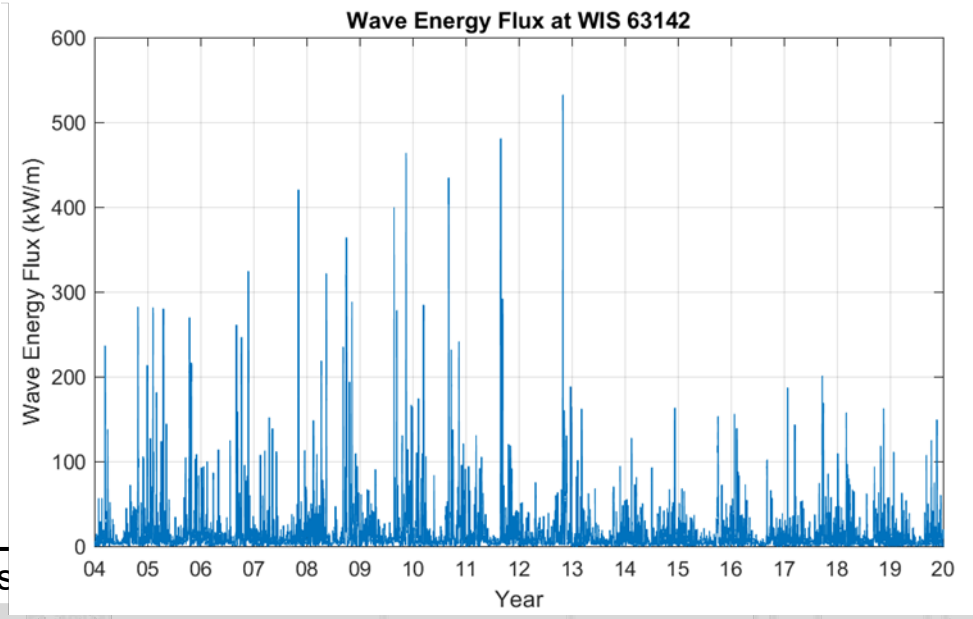
$$\gamma = \frac{Q_{downdrift}}{Q_{updrift}}$$

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

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







Remarks

- **Long-term and regional-scale shoreline evolution can be simulated by GenCade shoreline model.**
- **CMS provides spatiotemporal sediment pathway across inlet and locations of attachment bars. Those morphology features and patterns of changes are basic information for configuring inlet reservoir models (IRM). More capabilities by CMS can be used for driving IRM and GenCade.**
- **The empirical parametric Inlet Reservoir Model provides a reasonable volumetric evolution of ebb shoal. Impacts of dredging/mining and bypassing operation can be simulated quite well.**
- **GenCade simulate the effects of (hard) structures and non-structural measures on longshore sediment transport and shoreline change.**

Future Topics:

- Morphological changes of shoals and bars by CMS can further help setup of IRM models.
- 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

- The simulation of shoreline evolution and CMS around Absecon Inlet was sponsored by USACE Philadelphia District. Questions about this project can be addressed to Yan Ding (Yan.Ding@usace.army.mil), Robert Hampson (Robert.W.Hampson@usace.army.mil), Harry Friebel (Harry.C.Friebel@usace.army.mil), and Keith Watson (Keith.D.Watson@usace.army.mil)

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