New Modeling Capabilities of GenCade for Simulation of Shoreline Changes in Northern Atlantic Coast

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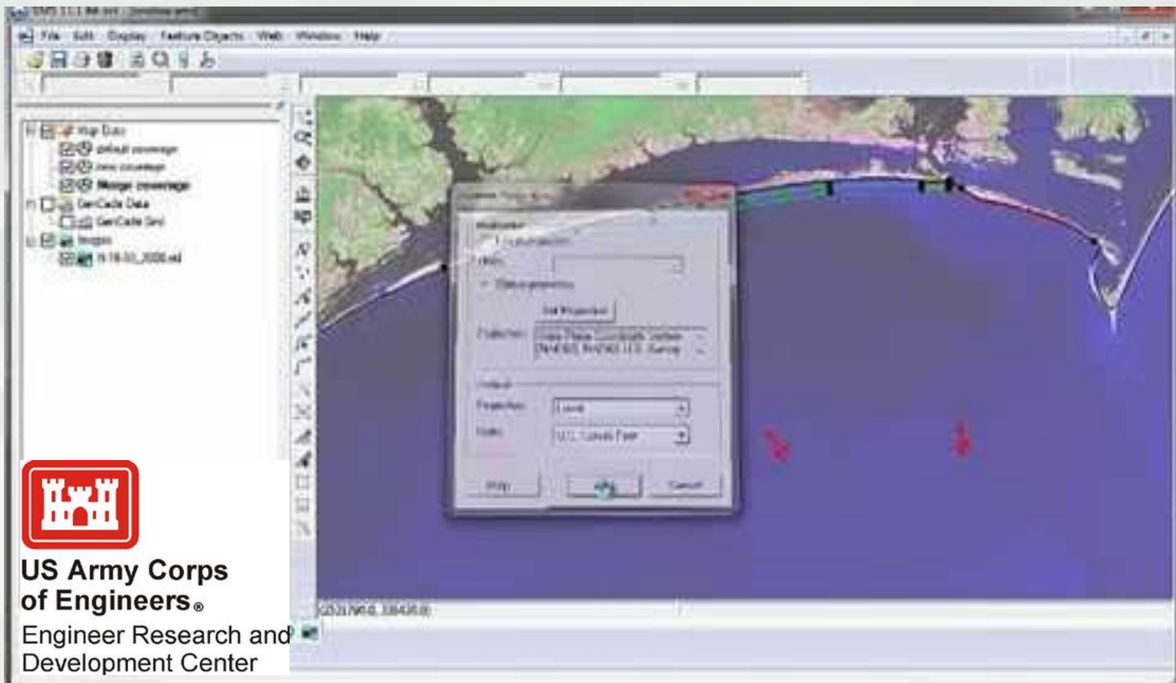
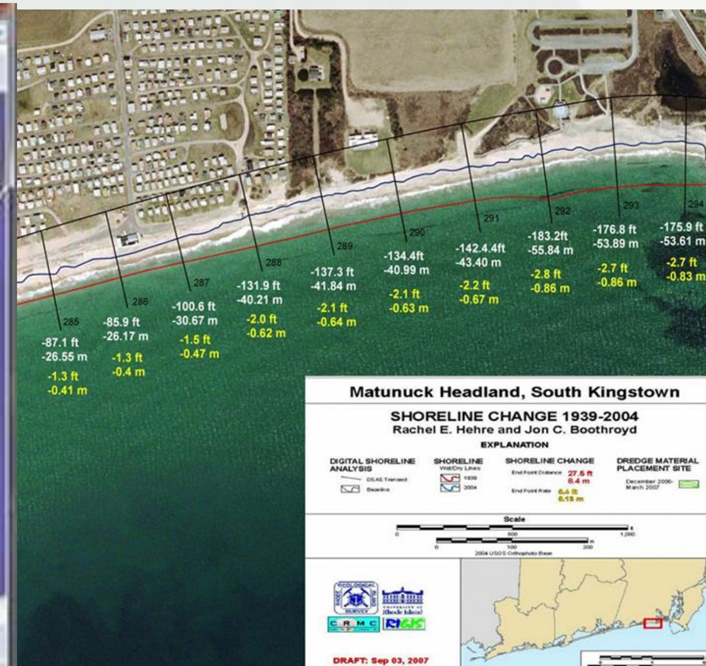
Outline

- Introduction of GenCade for Modeling Long-Term Shoreline Evolution
- New Features for Crossshore Sediment Transport and Sea Level Change
- Model Validation and Applications in Duck, NC
- Simulation of shoreline changes after beach fill in Delaware Coast (Ongoing Project)
- Remarks

GenCade

The GenCade (Frey et al. 2012) is a shoreline evolution model (a one-line model), using a alongshore sediment transport model to simulate shoreline changes driven by offshore wave climate. The SMS (Surfacewater Modeling System) provides a user-interface for GenCade, including data input and visualization





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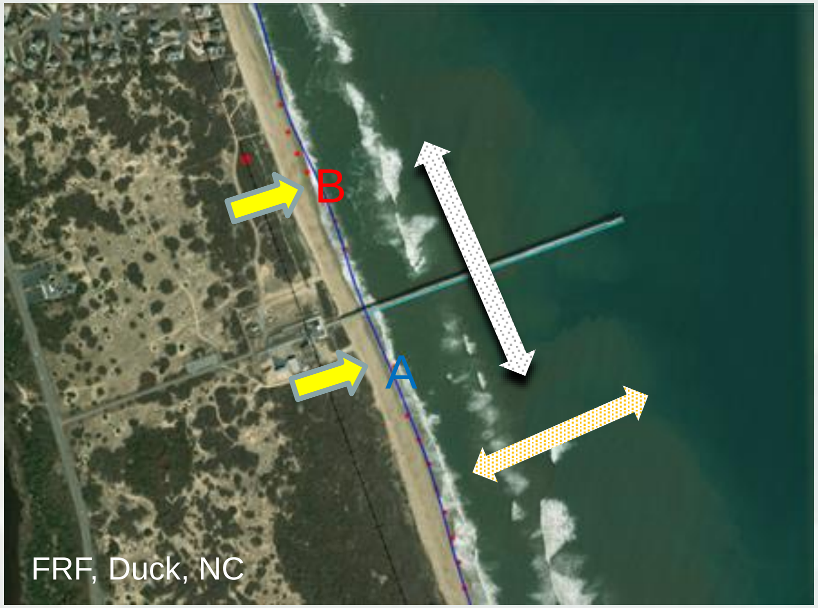
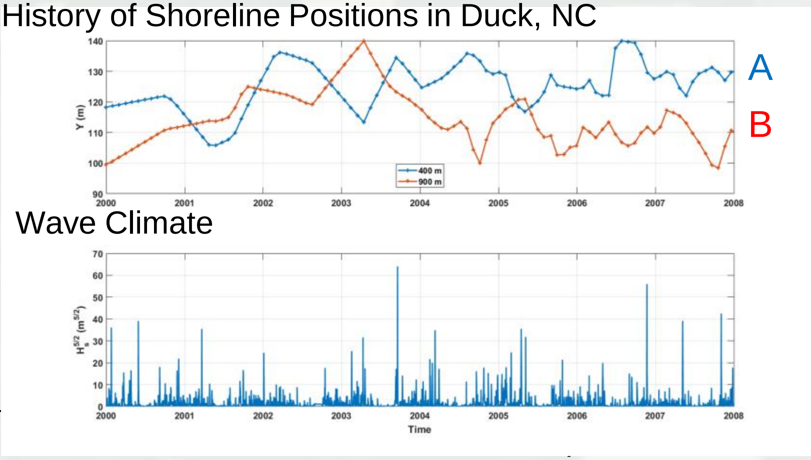
Long-Term Shoreline Changes

- Multiple physical processes drive shoreline changes: wave, wind, tide, storm, current, **sea level change**, sediment properties, **longshore/cross-shore sediment transport**, **human activities** (structure installation, beach refill, beach recreation),etc.
- Shoreline changes induced by natural physical processes in general are highly irregular.
- **Probabilistic shoreline change prediction** is needed for best shoreline management practice for long-term protection purpose.
- **Uncertainty estimation** of shoreline changes is required for best shoreline erosion control management.





GenCade Shoreline Evolution Model with Cross-Shore Transport and SLR

- Shoreline Change Equation with Sea Level Rise (SLR)

$$\frac{\partial y}{\partial t}+\frac{1}{D_s}\left(\frac{\partial Q}{\partial x}-q-\phi\right)+\left((\frac{\Delta Z}{\Delta t})_{SLR}-(\frac{\Delta Z}{\Delta t})_{subsidence}\right)\frac{1}{\tan\beta}=0$$

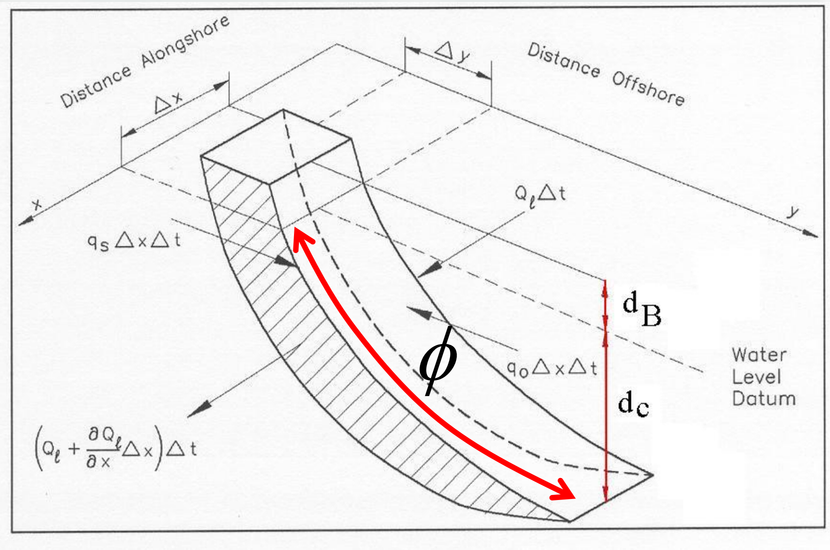
ϕ : Cross-shore sediment transport rate

$(\frac{\Delta Z}{\Delta t})_{SLR}$: Sea Level Change Rate

$(\frac{\Delta Z}{\Delta t})_{subsidence}$: Sea Level Change Rate

$tan\beta$: beach slope

$$D_S = d_c + d_b(t)$$



- Berm height varies with sea level change

$$d_b(t) = d_{b0} - ((\frac{\Delta Z}{\Delta t})_{SLR} - (\frac{\Delta Z}{\Delta t})_{subsidence})t$$

Longshore Sediment Transport
- *Energy Flux Method (CERC formula)*

$$Q = H_b^2 C_{gb}\left(a_1 \sin 2\alpha_b - a_2 \cos\alpha_b \frac{\partial H_b}{\partial x} \right)$$

H_b : *Wave Height at breaker line*

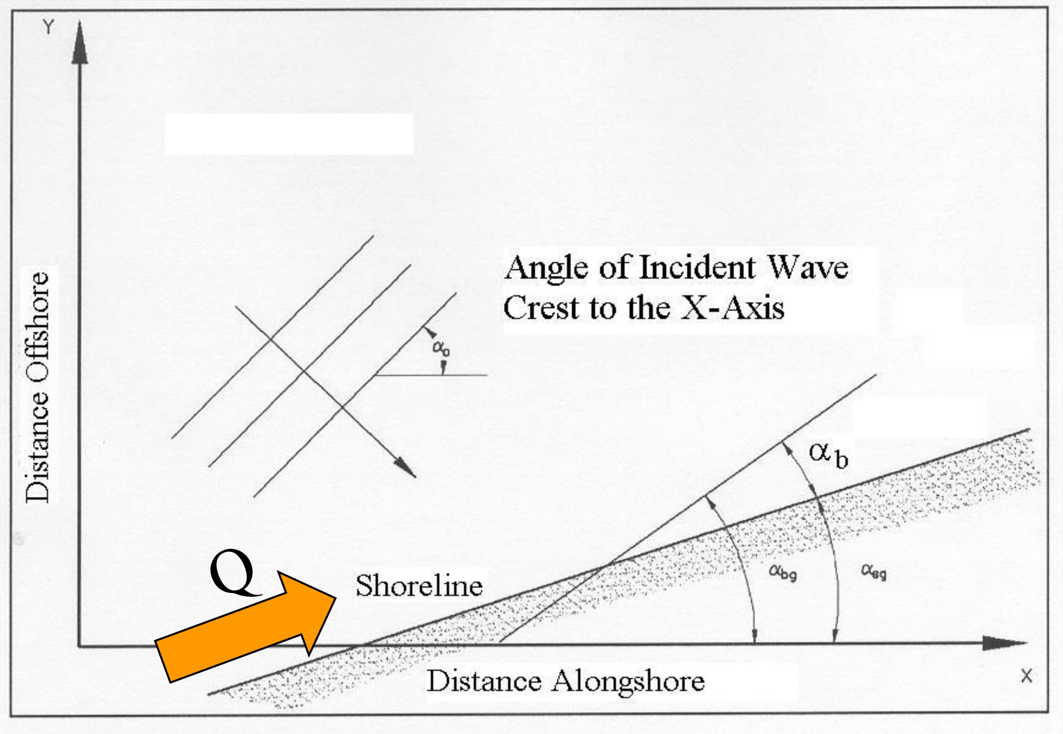
C_{gb} : *Group speed at breaker line*

$$a_1 = \frac{K_1}{16(s-1)(1-p)1.416^{2.5}}$$

$$a_2 = \frac{K_2}{8(s-1)(1-p)\tan\beta 1.416^{2.5}}$$

K_1,K_2=*empirical coefficients*

Typically, $0.5K_1 < K_2 < 1.5K_1$



New Feature of GenCade (1) - Cross-shore Sediment Transport due to Wave Asymmetry and Nonlinearity

Transport Rate due to Velocity Skewness (Hsu et al. 2006)

$$\phi = \frac{\alpha_D}{1-p}(Q_V + Q_C + Q_D)$$

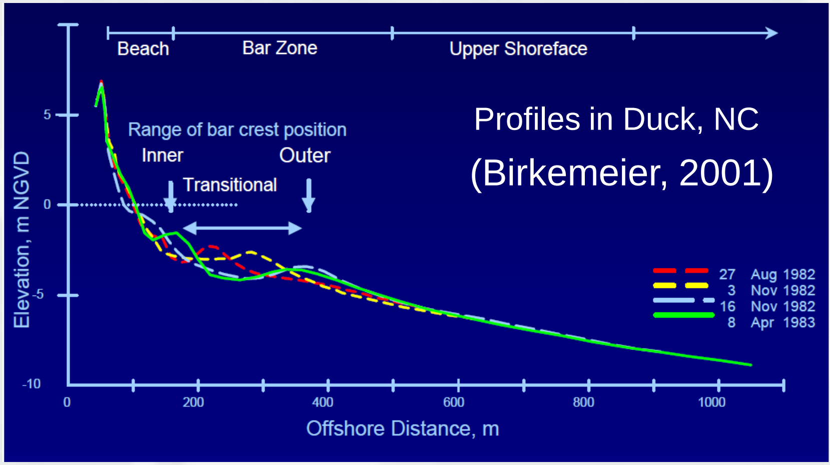
α_D=empirical parameters, p=porosity of sediment

Q_v and Q_C are the net sediment transport due to waves and currents

$$Q_V = \frac{C_W}{(s-1)g}\left(\frac{\varepsilon_B}{\tan\varphi} < \left|\vec{U}_0\right|^2 U_{0,x} > + \frac{\varepsilon_S}{W_0} < \left|\vec{U}_0\right|^3 U_{0,x} >\right)$$

$$Q_C = \frac{C_C}{(s-1)g}\left(\frac{\varepsilon_B}{\tan\varphi} < \left|\vec{U}_t\right|^2 U_x > + \frac{\varepsilon_S}{W_0} < \left|\vec{U}_t\right|^3 U_x >\right)$$

U_0 = the wave orbital velocity vector,
U_t = the total velocity vector (waves plus currents), and
U = the current velocity vector, related to longshore current and undertow current.
φ = the friction angle
W_0 = the sediment fall velocity
C_w, C_C, ε_B, ε_S = empirical parameters



Q_D represents a diffusive transport due to downslope move of sand:

$$Q_D = \frac{\lambda_d v \tan\beta}{\tan\varphi(\tan\varphi - \tan\beta)}$$

λ_D, v=empirical parameters

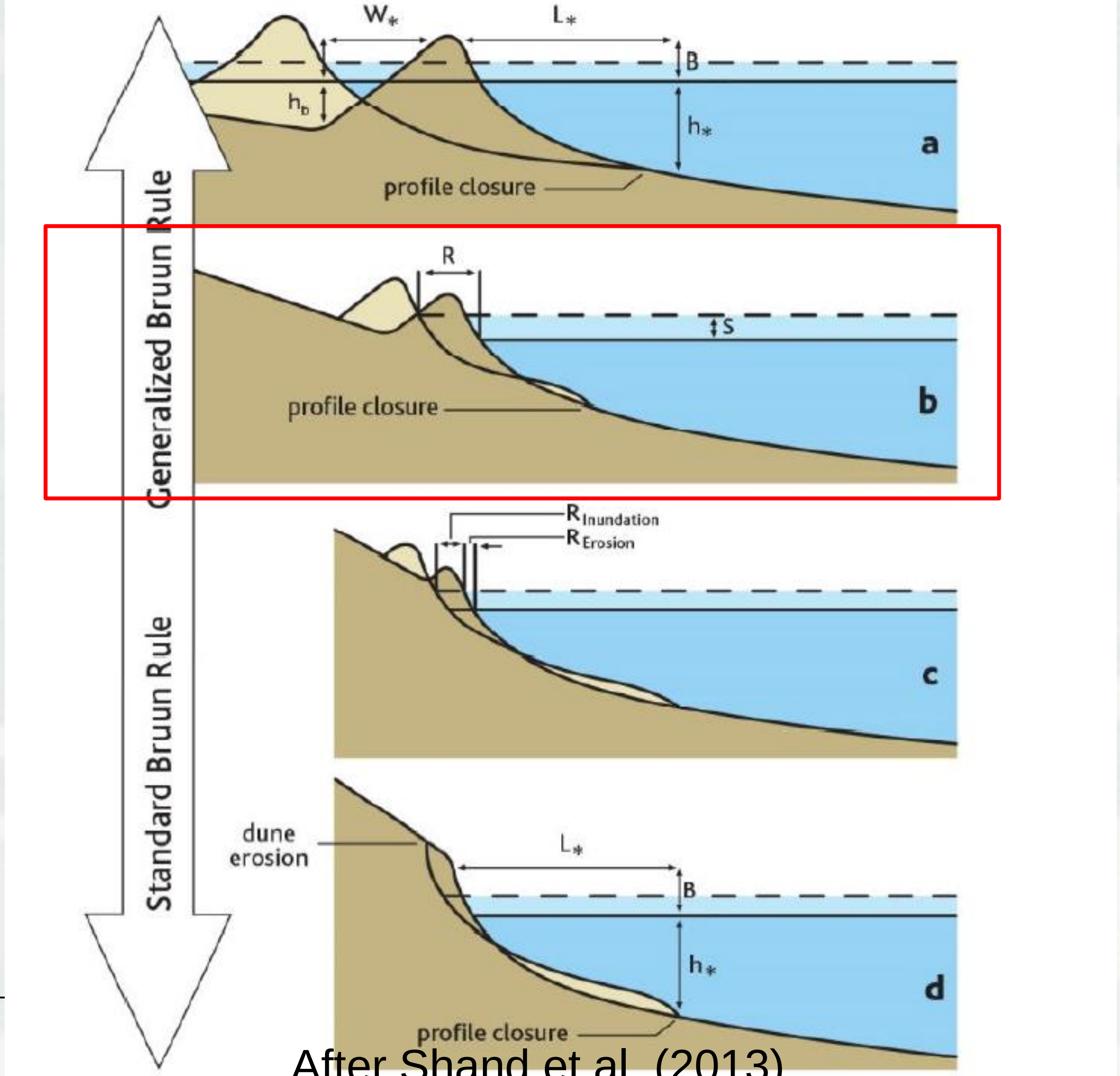
New Feature of GenCade (2)
- Shoreline Recession due to Sea Level Rise:

Shoreline Retreat rate

Bruun Model (1962, 1988)

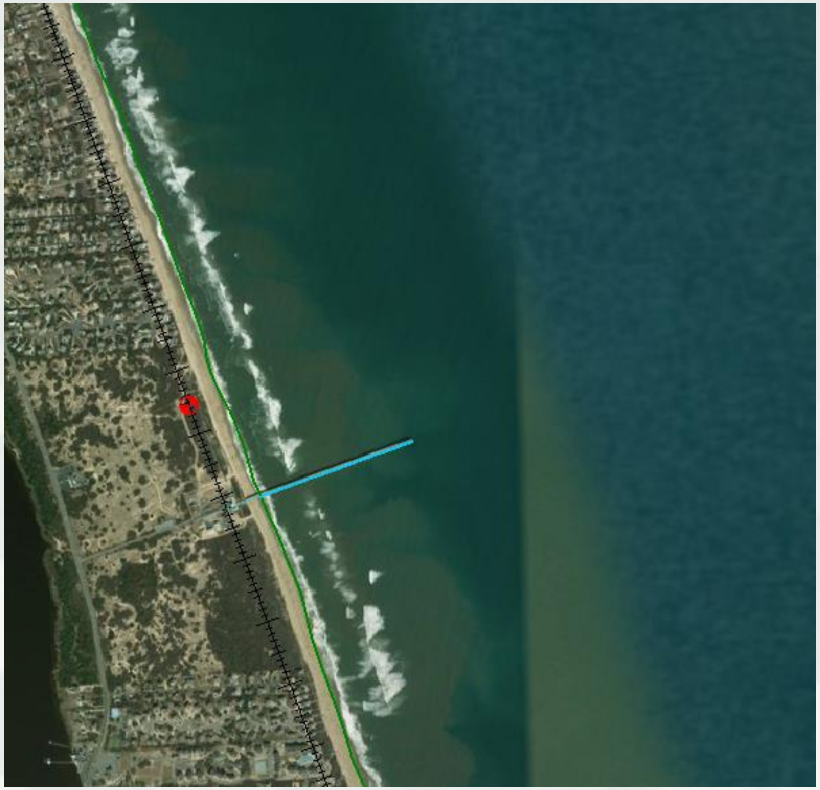
$$R = \frac{SW_*}{h_* + B}$$

S: Sea level rise rate
h* = sediment closure depth
B = Berm Height



After Shand et al. (2013)

Model Validation: Modeling of Shoreline Change in Duck, NC

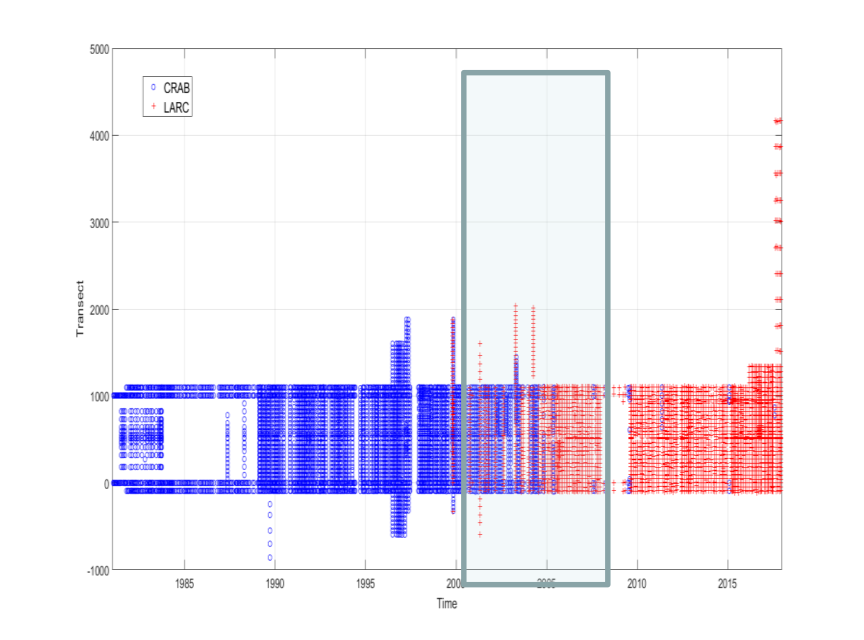


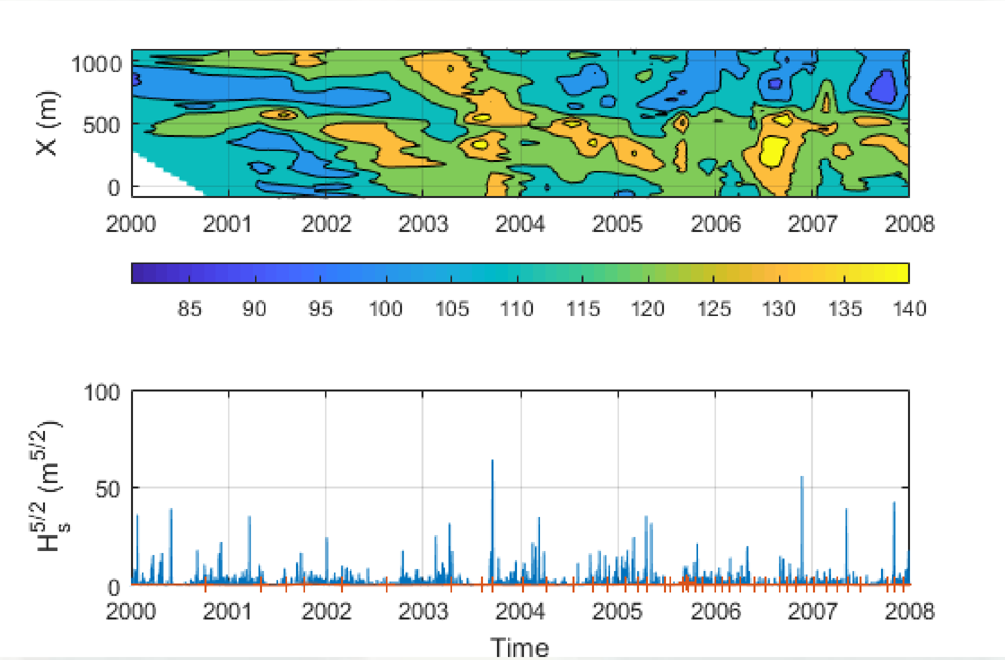
FRF in Duck, NC

Computational Period: 6 years
1999/10/23 0:00 - 2005/10/23 0:00
Time step = 3 minutes
Grain size = 0.20 mm
Berm Height = 1.0 m
Closure depth = 7.0
Smooth parameter = 1 (no smoothing)
Boundary Conditions: Pined
Grid Size = 20 m
Sea Level Rise rate: 4.55mm/year
Subsidence : 0.0 (N/A)

Calibrated Model Parameters:
K1 = 0.40
K2 = 0.25
Permeability of Pier = 0.6 (no diffracting):
Scaling parameter α_D= 0.182
C_w, C_C, ε_B, ε_S by Fernández-Mora et al. (2015)

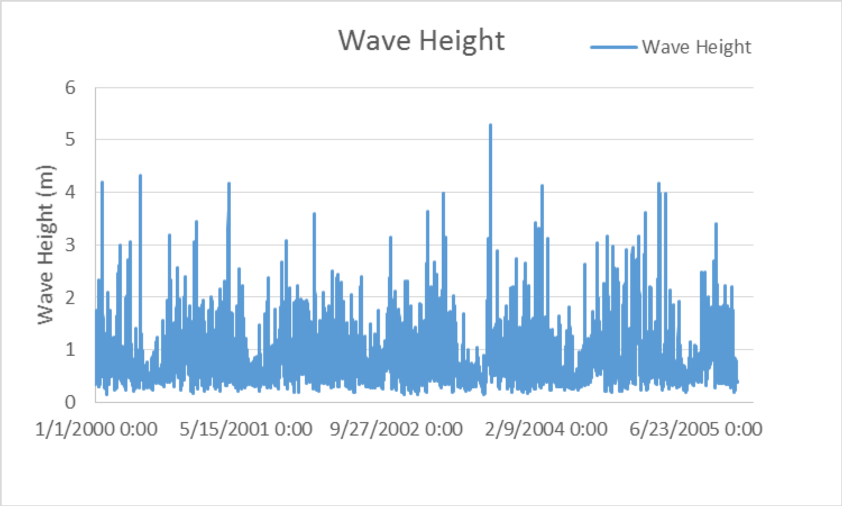
V&V of GenCade for FRF Shoreline: Data Analyses

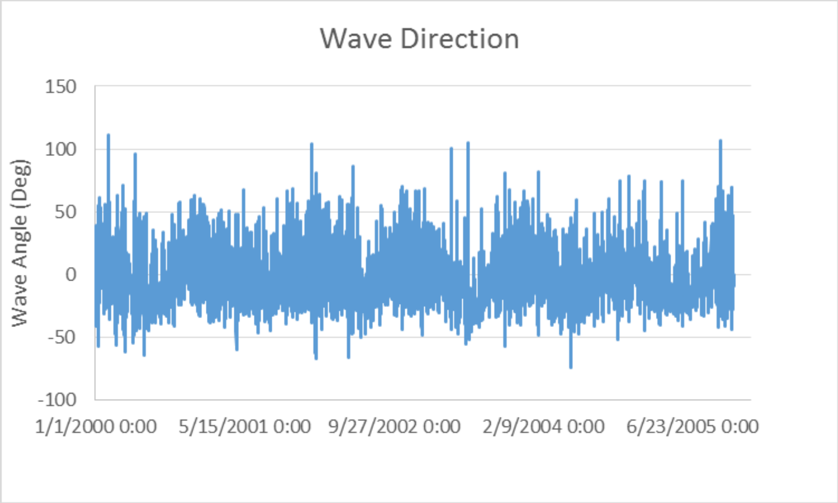




Wave Data (2000/1/1 – 2006/1/1)

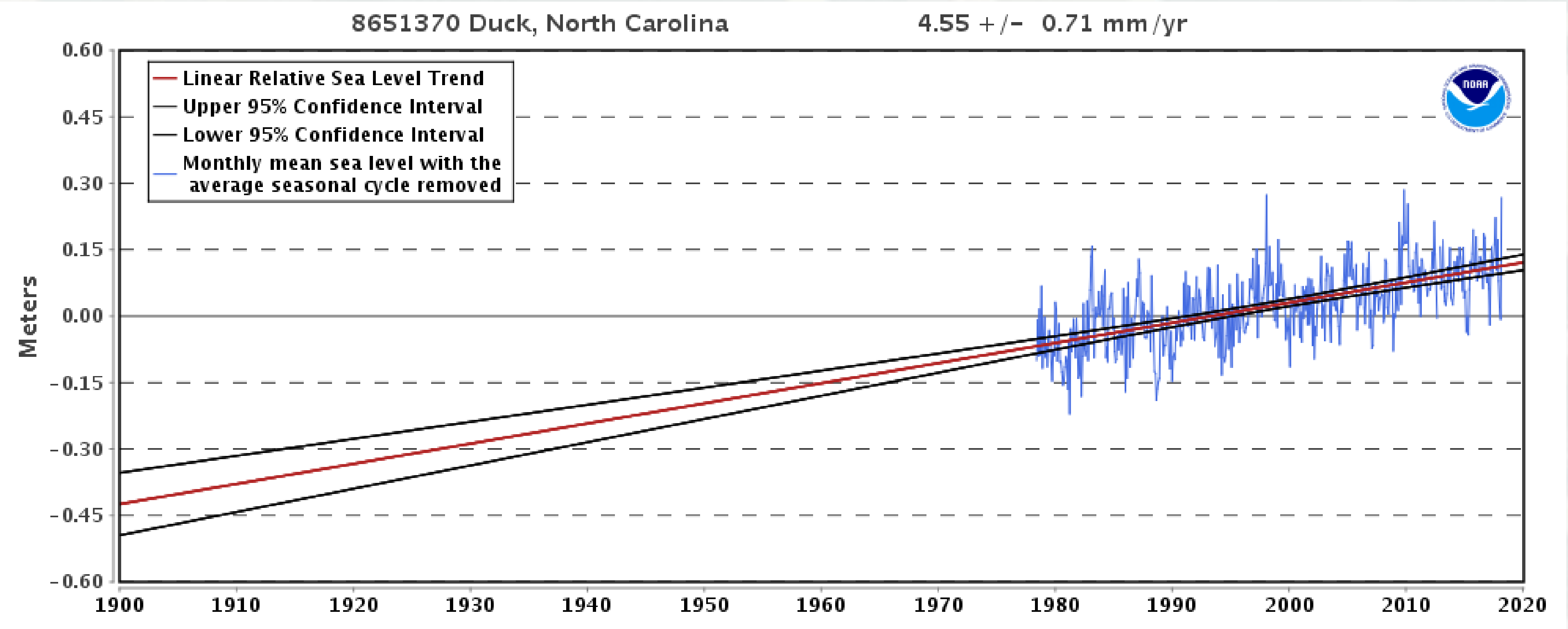
	H (m)	T (s)	alfa (deg)
Average	0.82	9.18	-5.06
Min	0.14	3.09	-74.62
Max	5.28	18.96	111.32
σ	0.53	2.68	18.52





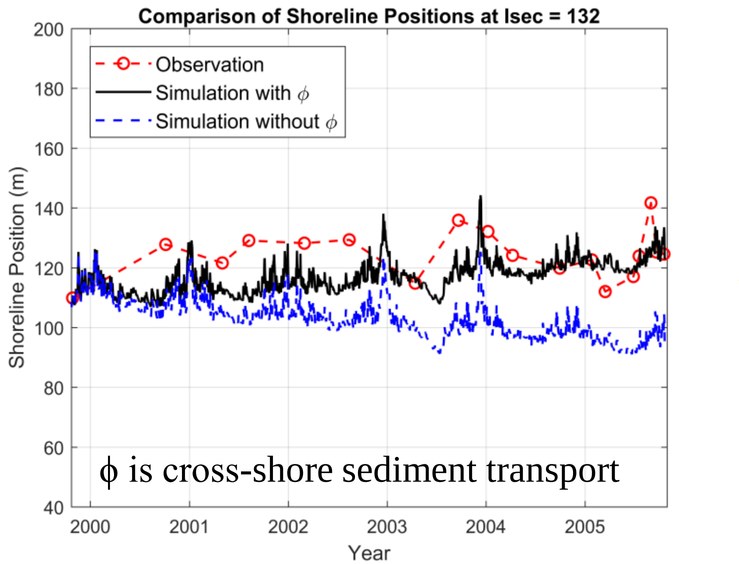
Sea Level Rise Trend

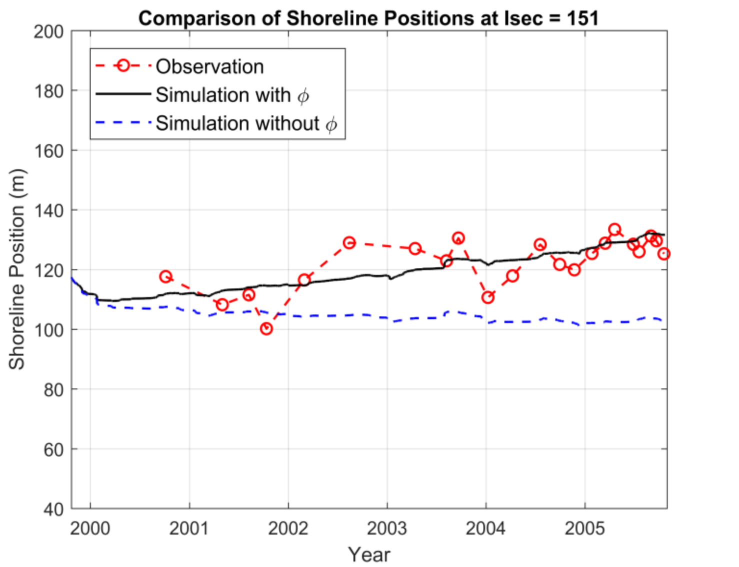
NOAA-NOS #8651370 Duck, North Carolina

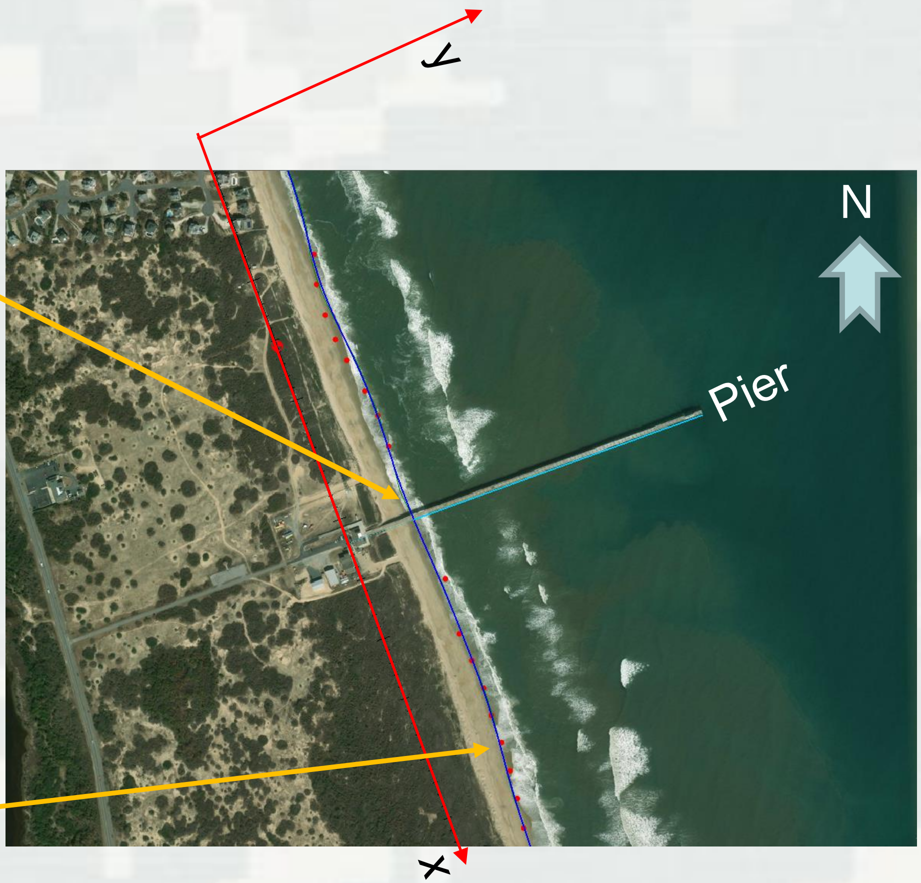


https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8651370

Model Validation: Comparison of Shoreline Evolution (1999-2005) at FRF, Duck, NC







FRF in Duck, NC

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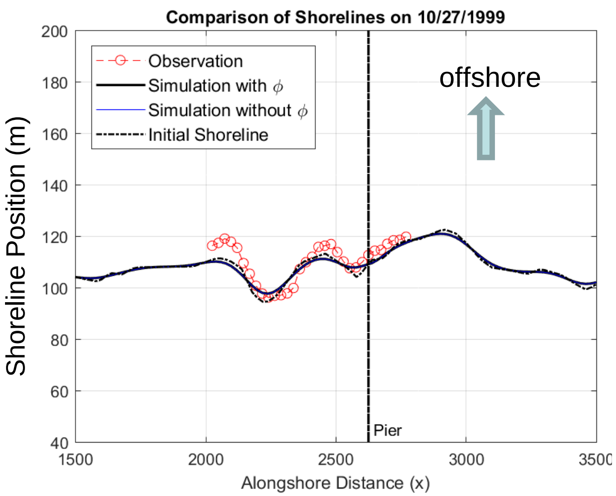
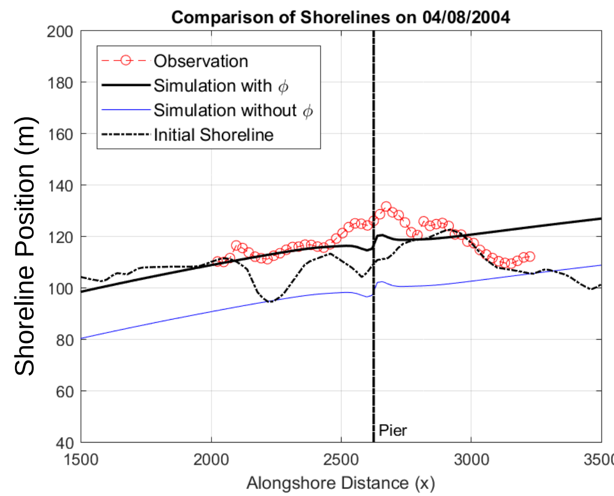
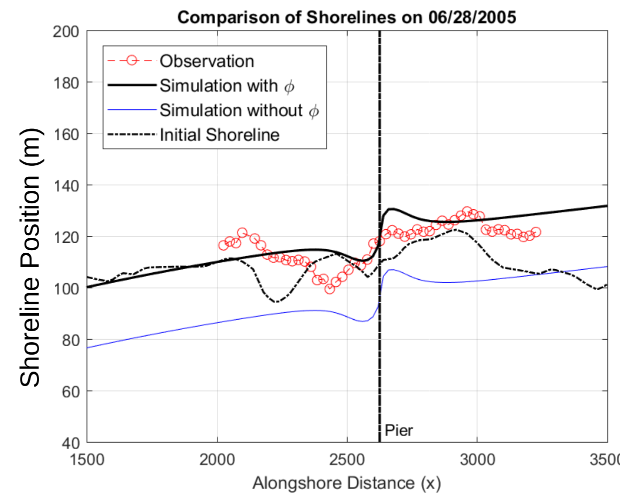
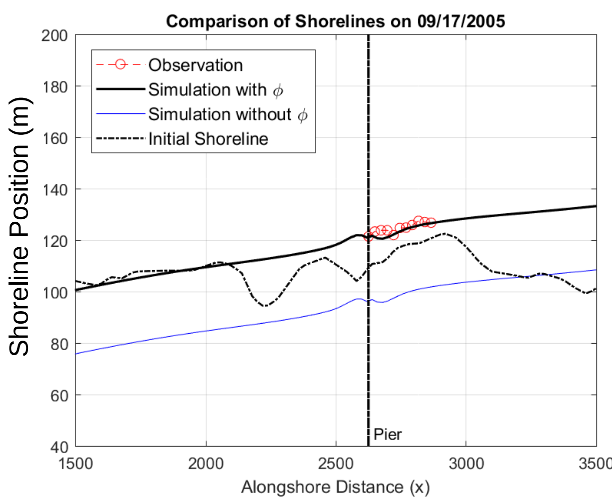
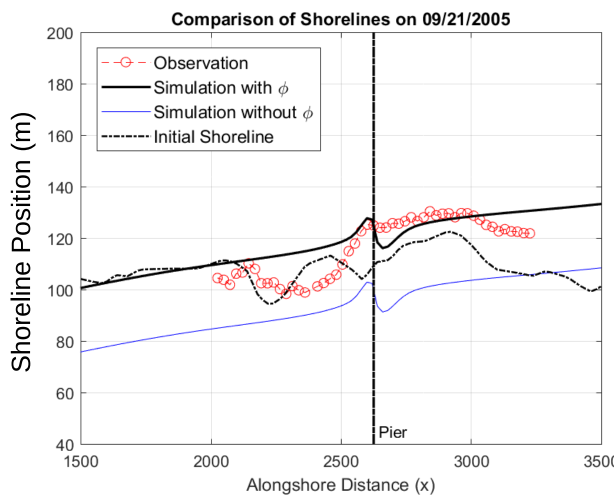
Model Validation:
Comparisons of Shoreline Positions (1999-2005)

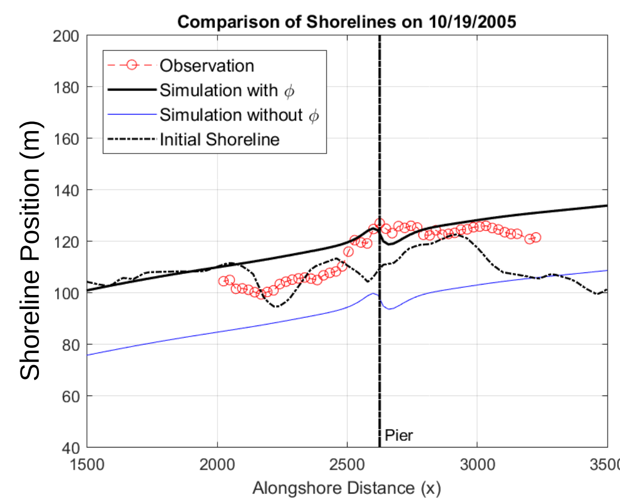






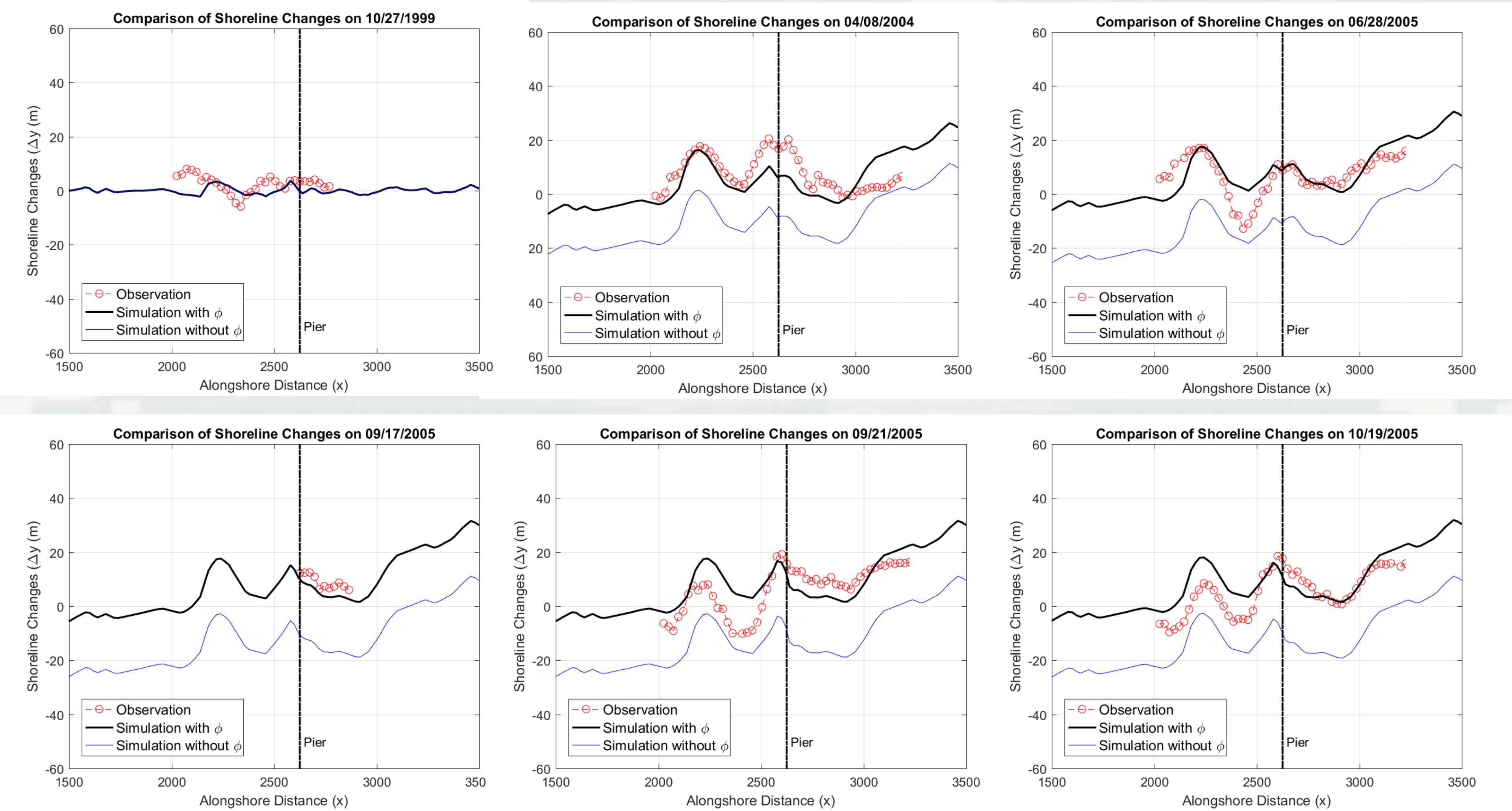




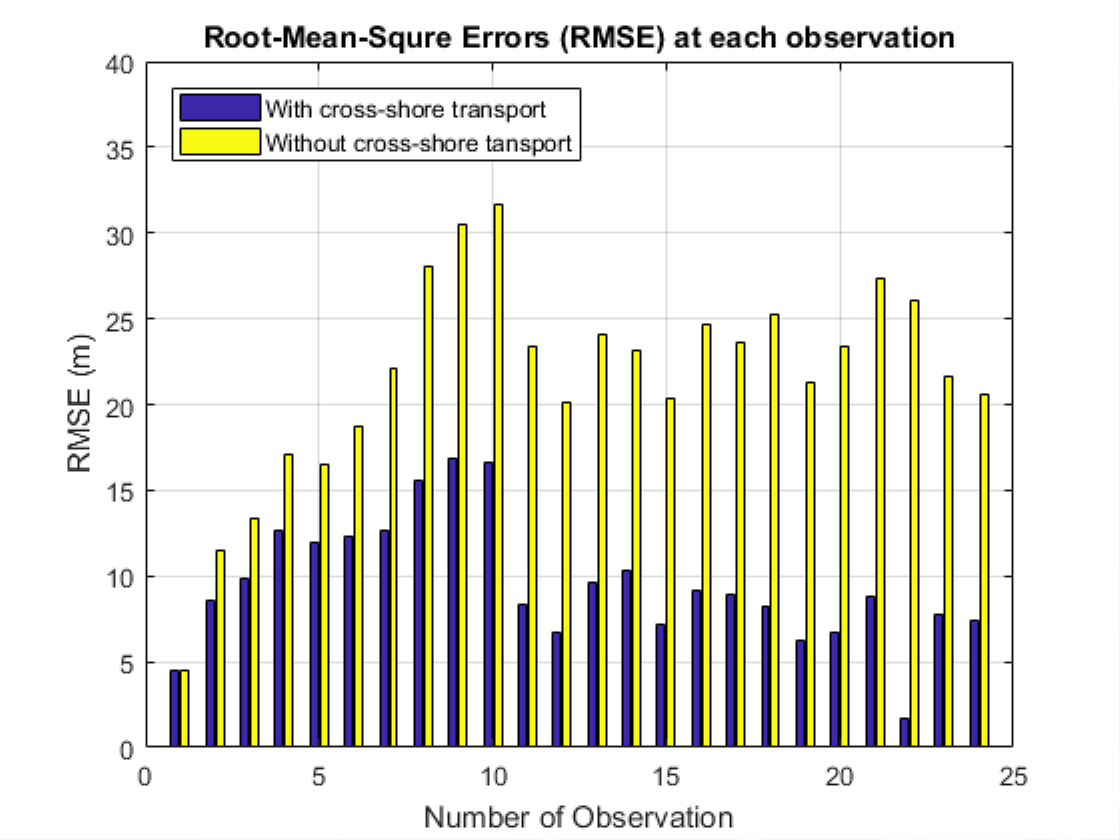


Model Validation: (w or w/o xshore)

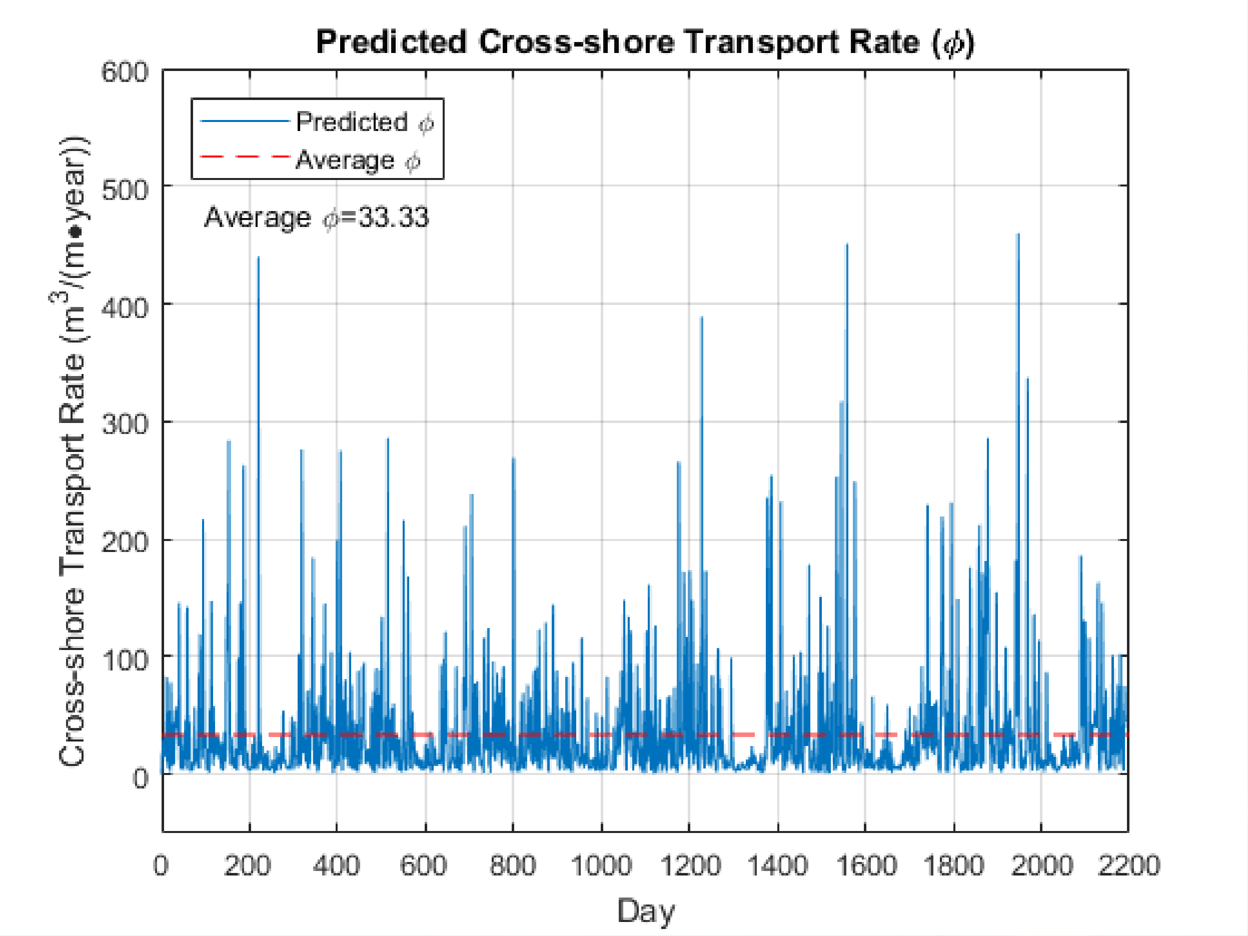
Comparisons of Shoreline Changes (1999-2005)



Model Skill Assessment:
Root-Mean-Square Errors at Observation Times (1999-2005)

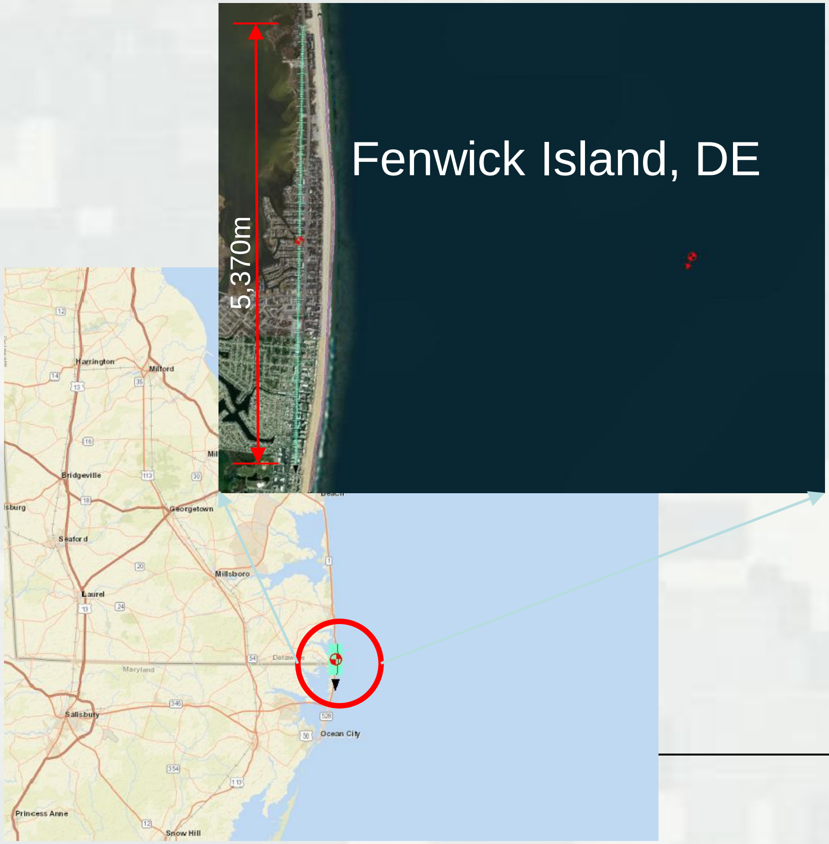


Predicted Cross-Shore Transport Rate (1999-2005)



Modeling of Shoreline Change in Fenwick Island, DE

Objectives: (1) to validate the GenCade model by using shoreline survey data provided by NAP and DNREC, and (2) to evaluate shoreline erosion after beach fill completed in Sept. 2013.



Computational Parameters

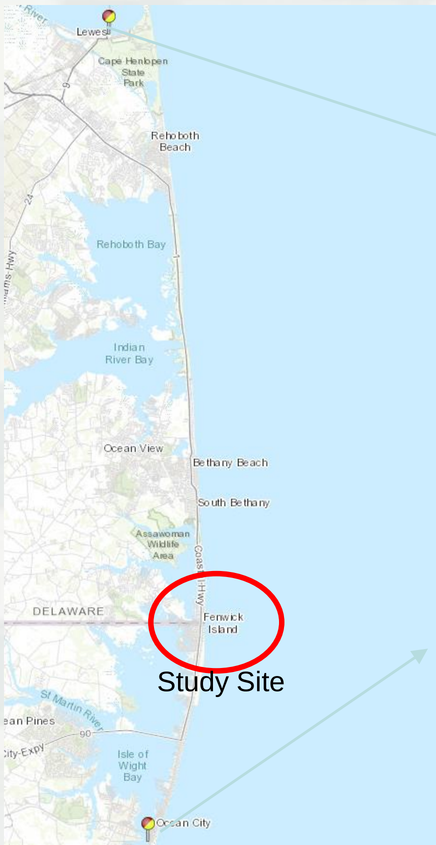
Computational Period: 3.5 years
2013/09/13 0:00 - 2017/01/01 0:00
after the beach fill in Sept. 2013

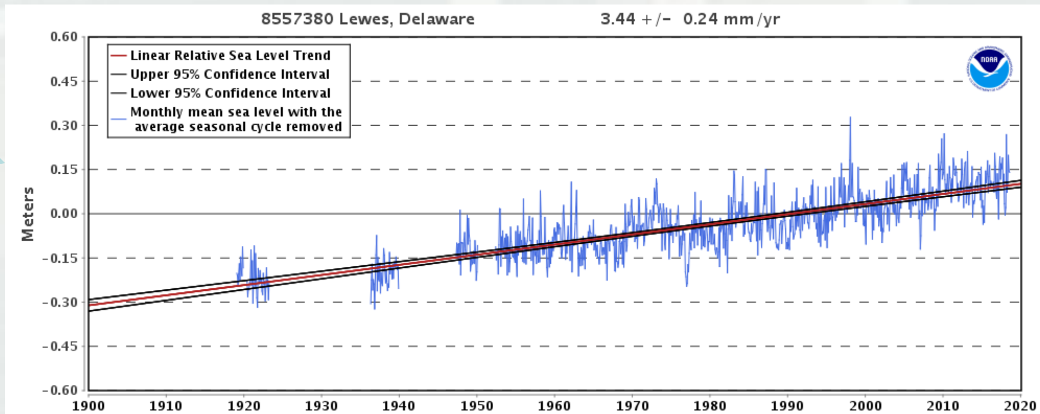
Time step = 3 minutes
Grain size = 0.30 mm
Berm Height = 1.0 m
Closure depth = 10.0m
Smooth parameter = 1 (no smoothing)
No regional contour
Boundary Conditions: Moving (retreat 2.5 ft/year)
Grid Size = 20 m
Sea Level Rise rate: 4.50mm/year (based on tide gauges)
Subsidence : included

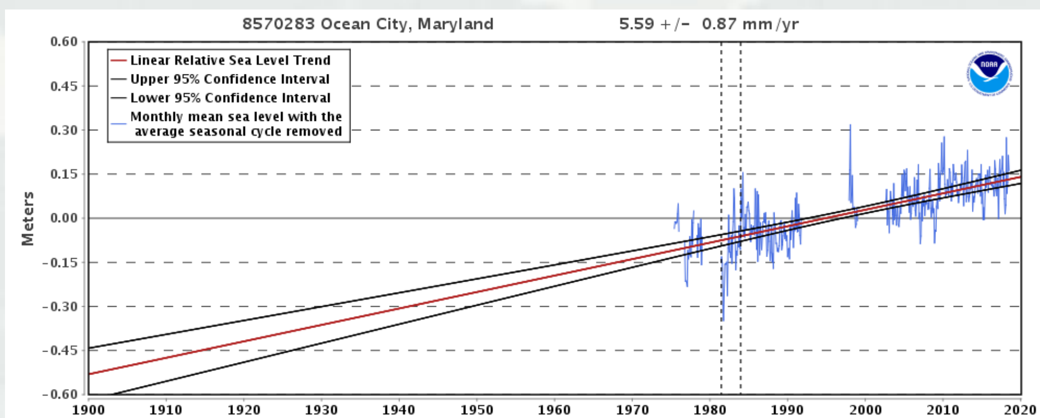
Calibrated Model Parameters:
K1 = 0.90
K2 = 0.35

Cross-shore transport included
Scaling parameter α_D= 0.16
C_w, C_C, ε_B, ε_S by Fernández-Mora et al. (2015)

Relative Sea Level Rise in Delaware Coast



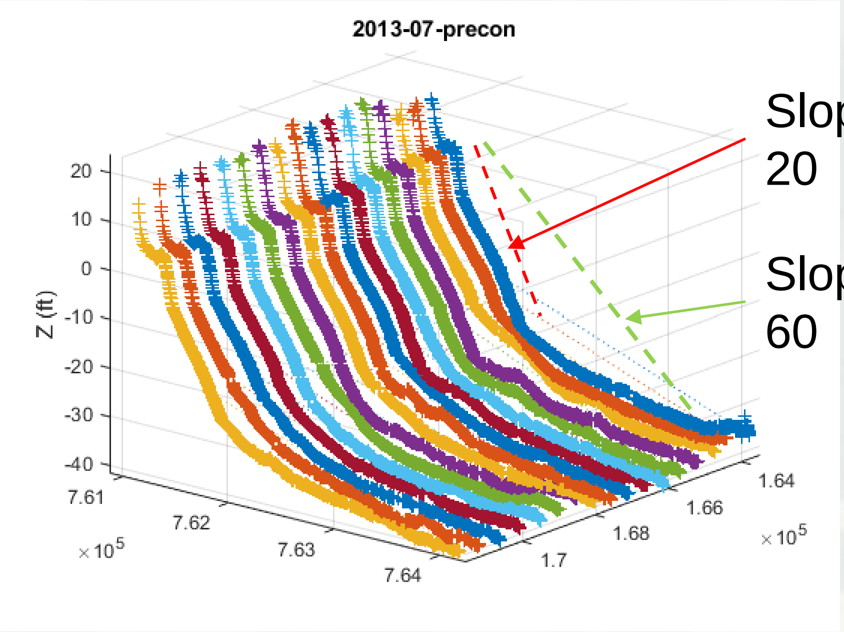




Estimated SLR and Subsidence at Fenwick Island

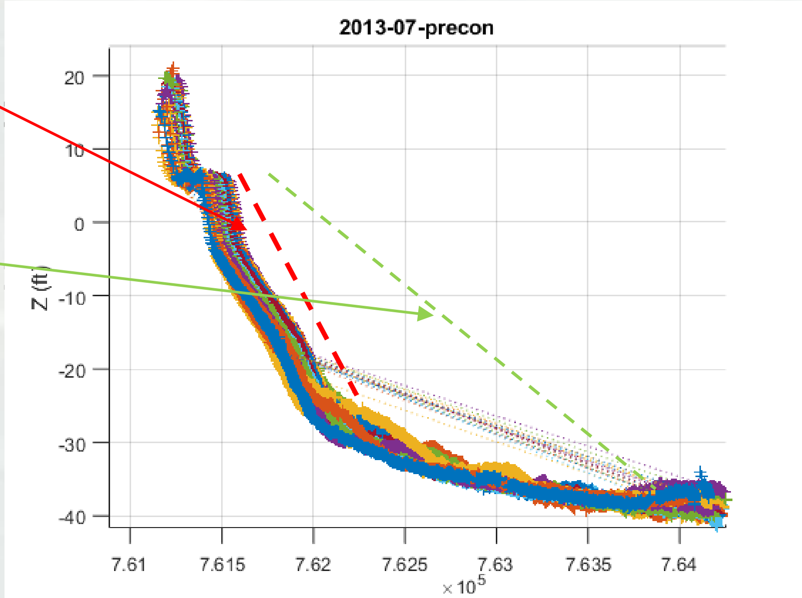
4.52mm/yr

Beach Slope



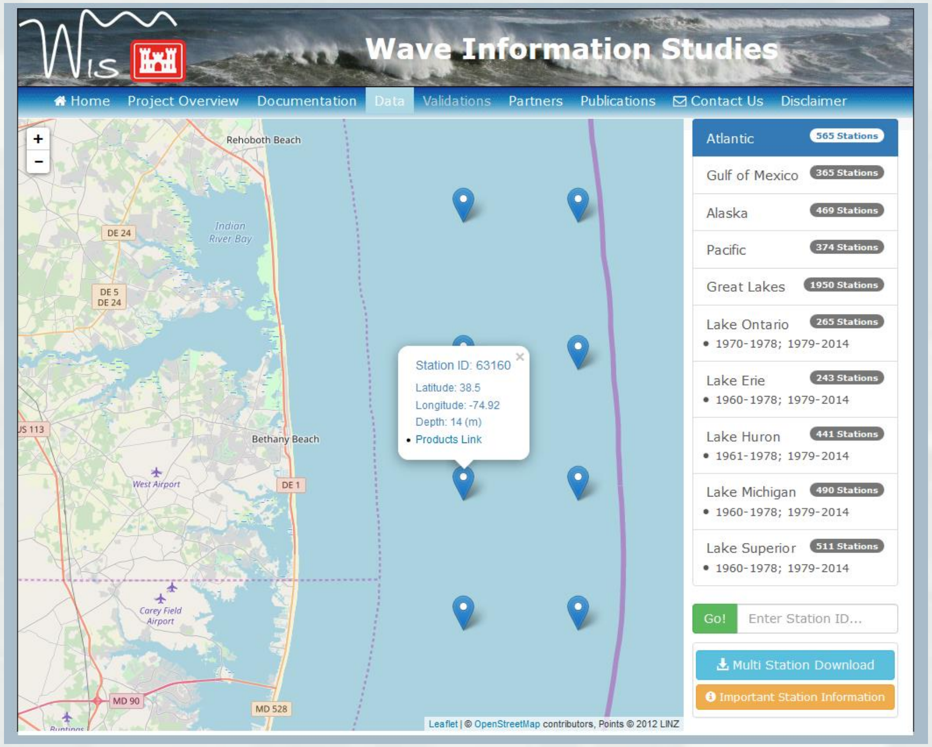
Slope=1
20

Slope=1
60

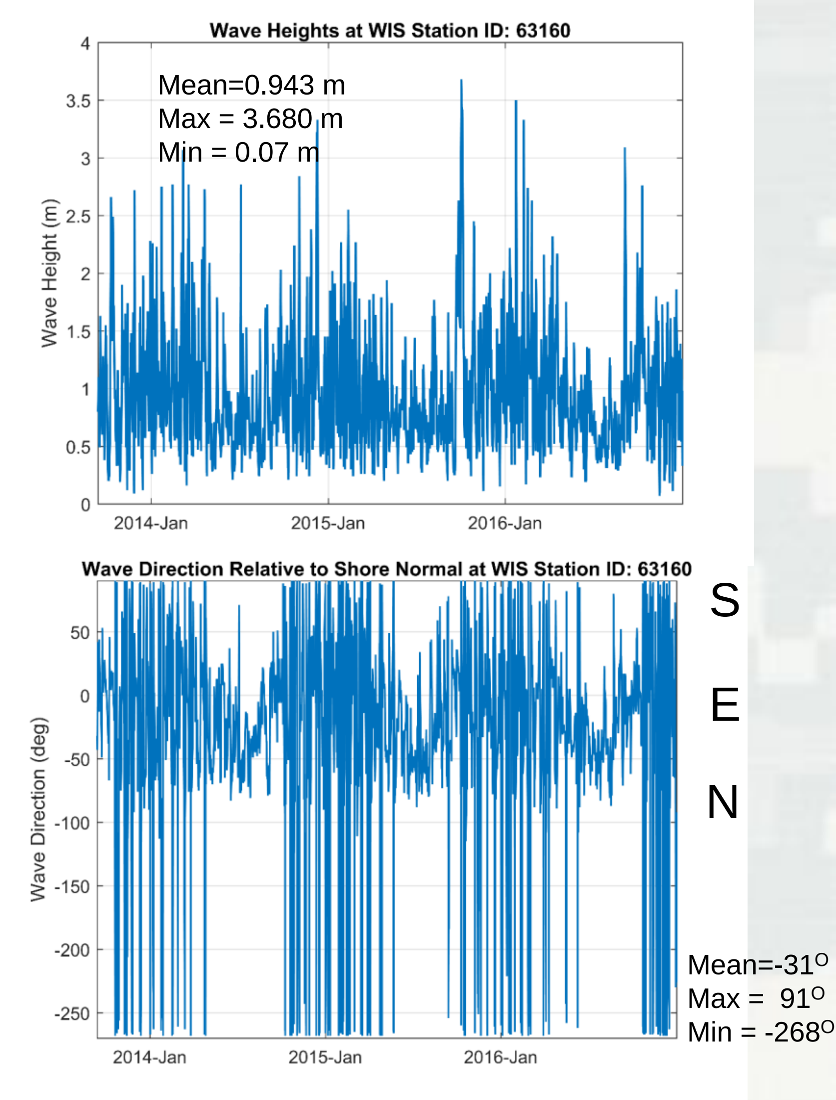


17 Survey Transects

Waves

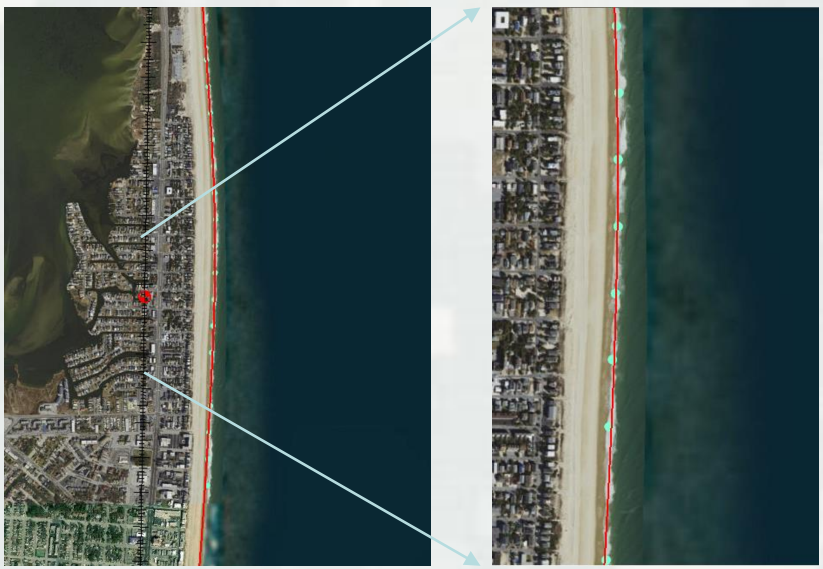


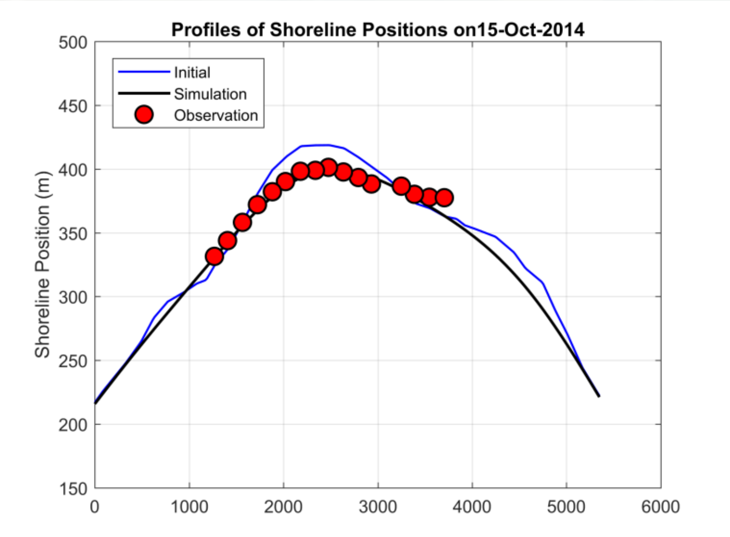
Wave Information Studies
Home
Project Overview
Documentation
Data
Validations
Partners
Publications
Contact Us
Disclaimer
Atlantic 565 Stations
Gulf of Mexico 365 Stations
Alaska 469 Stations
Pacific 374 Stations
Great Lakes 1950 Stations
Lake Ontario 265 Stations
1970-1978; 1979-2014
Lake Erie 243 Stations
1960-1978; 1979-2014
Lake Huron 441 Stations
1961-1978; 1979-2014
Lake Michigan 490 Stations
1960-1978; 1979-2014
Lake Superior 511 Stations
1960-1978; 1979-2014
Go!
Enter Station ID...
Multi Station Download
Important Station Information
Station ID: 63160
Latitude: 38.5
Longitude: -74.92
Depth: 14 (m)
Products Link
Rehoboth Beach
Bethany Beach

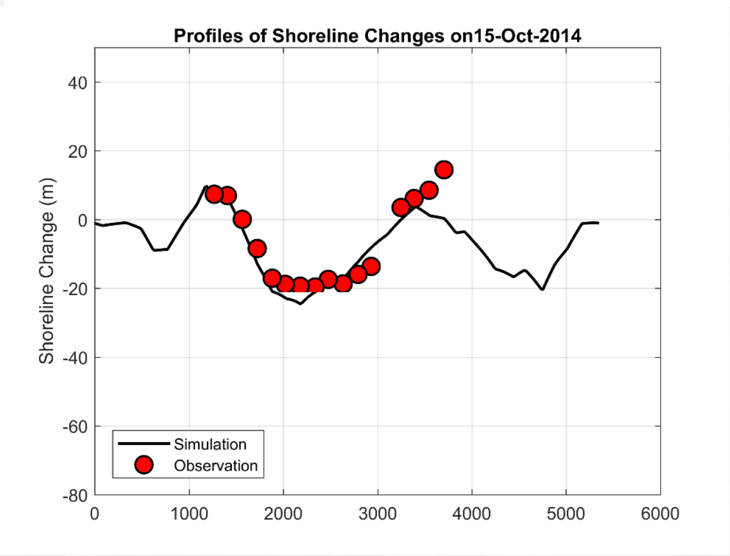


Wave Heights at WIS Station ID: 63160
Mean=0.943 m
Max = 3.680 m
Min = 0.07 m
Wave Height (m)
2014-Jan
2015-Jan
2016-Jan
Wave Direction Relative to Shore Normal at WIS Station ID: 63160
Wave Direction (deg)
S
E
N
Mean=-31^{O}
Max = 91^{O}
Min = -268^{O}

Comparisons of Shoreline Positions on 10/15/2014 (after one year)

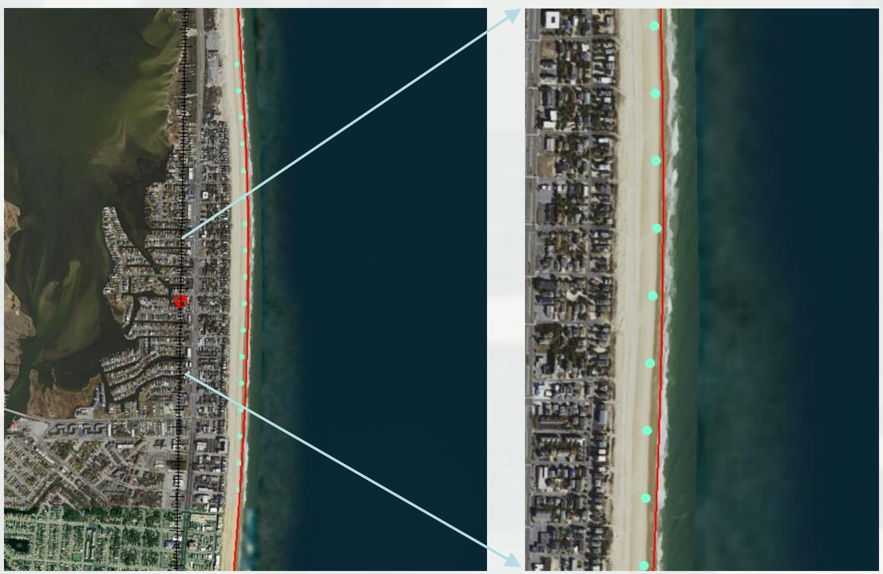


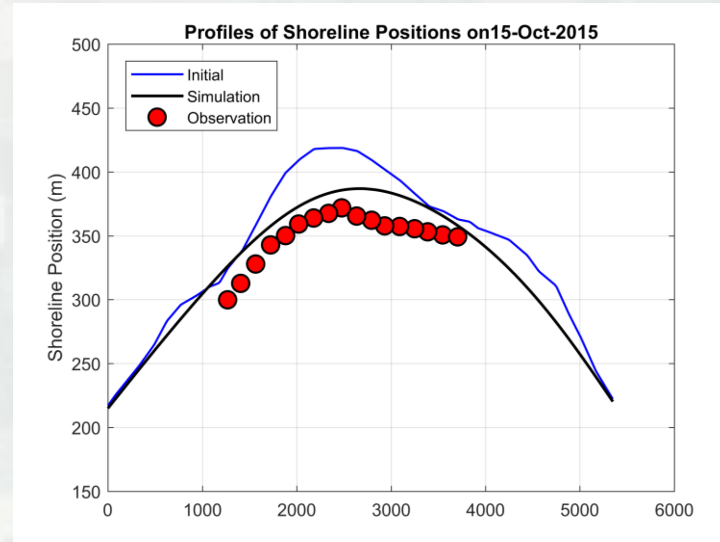


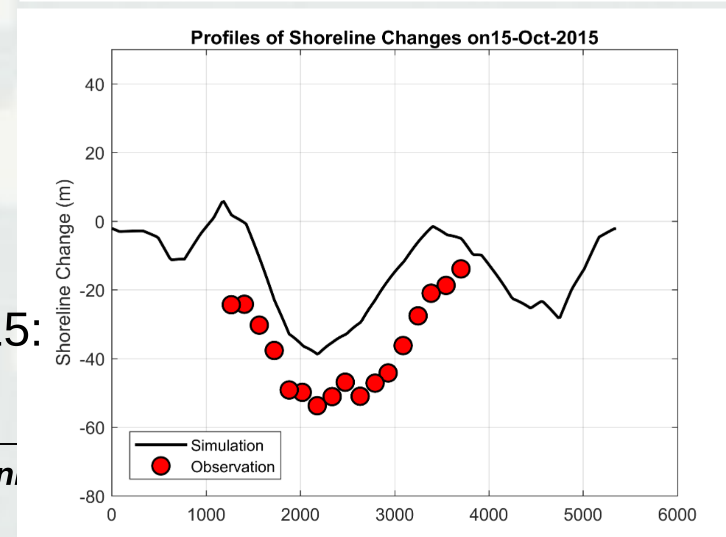


Shoreline Change from Sept. 2013-Oct. 2014:
-20.0m → + 10.0m

Comparisons of Shoreline Positions on 10/15/2015 (after two years)

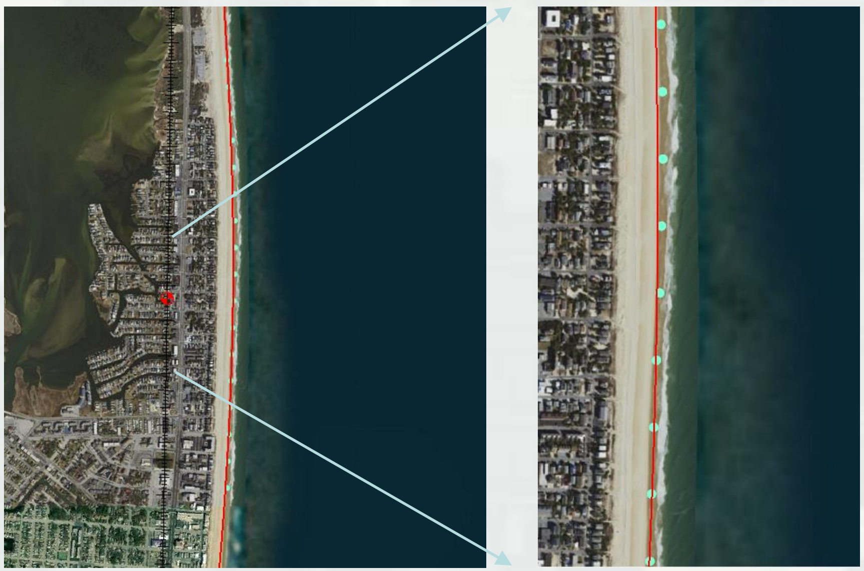


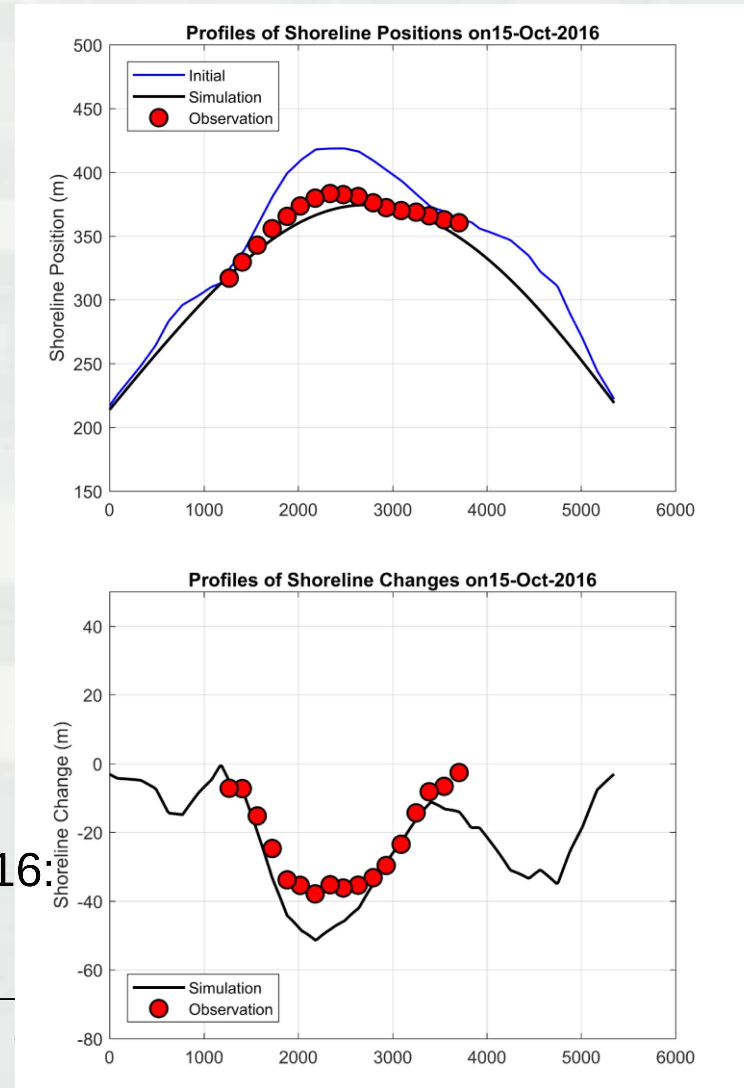




2.5-year Shoreline Change from Sept. 2013-Oct. 2015:
-50.0m → + 5.0m

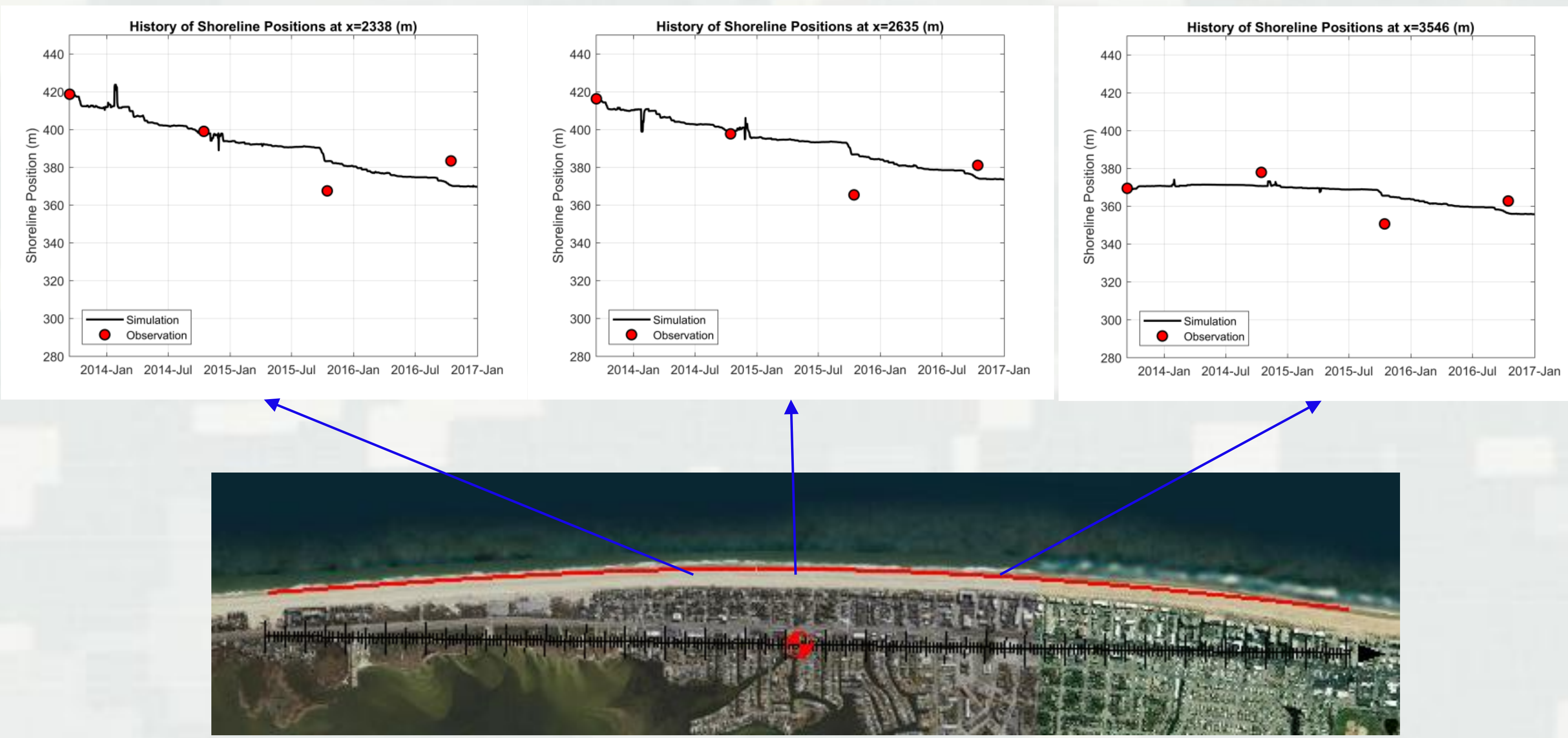
Comparisons of Shoreline Positions on 10/15/2016 (after three years)



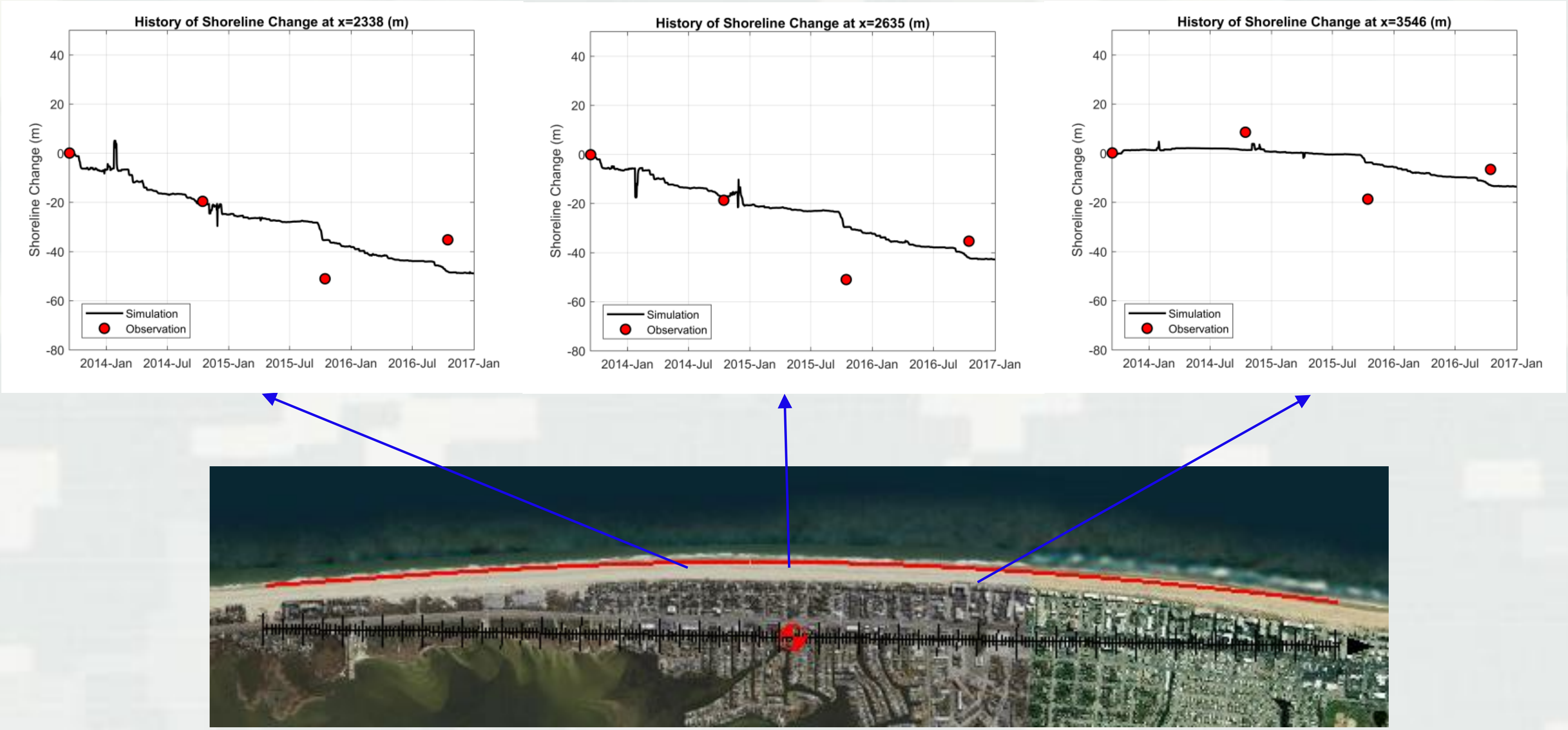


3.5-year Shoreline Change from Sept. 2013-Oct. 2016:
-50.0m → + 0.0m

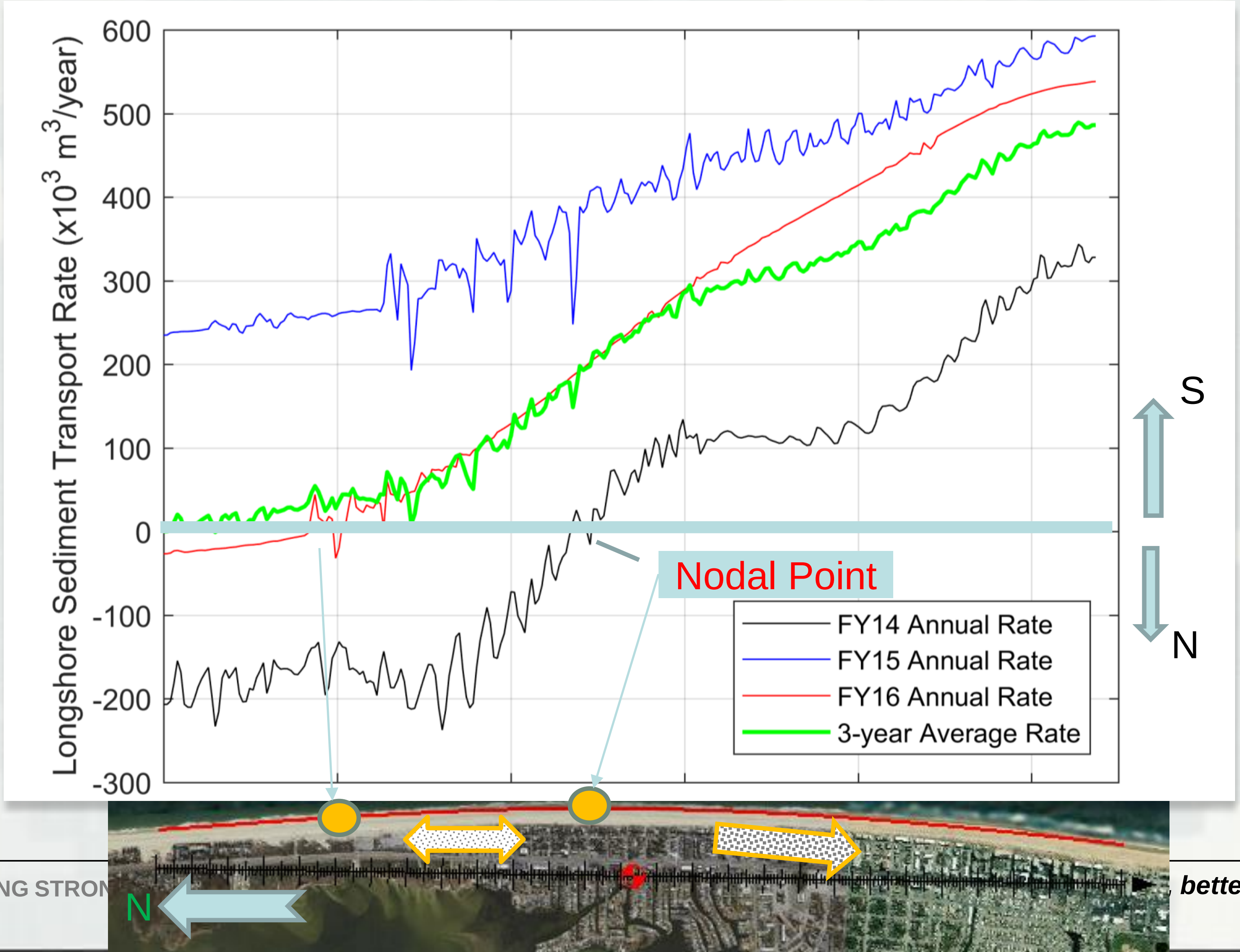
History of Shoreline Positions in Fenwick Island, DE



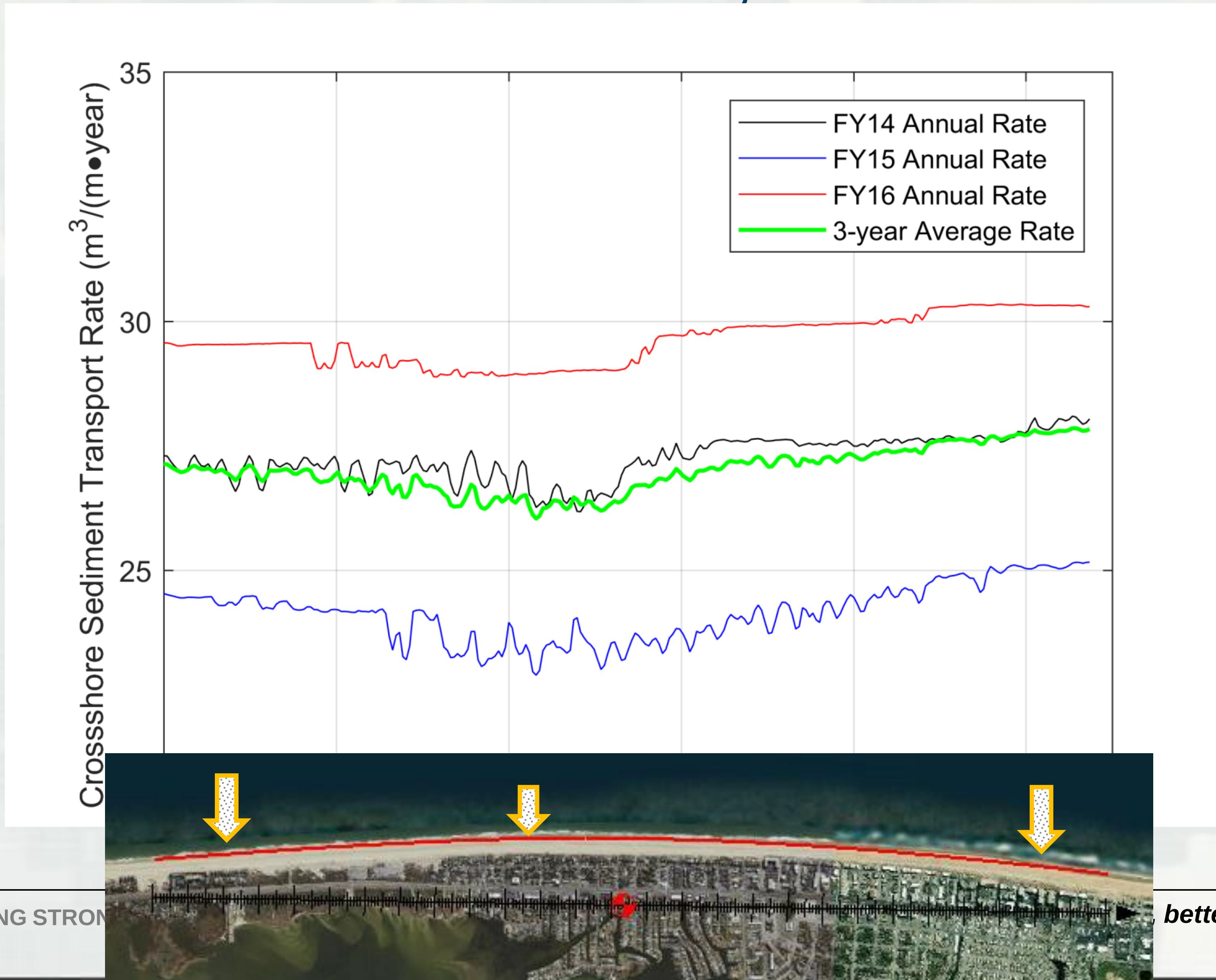
History of Shoreline Changes in Fenwick Island, DE



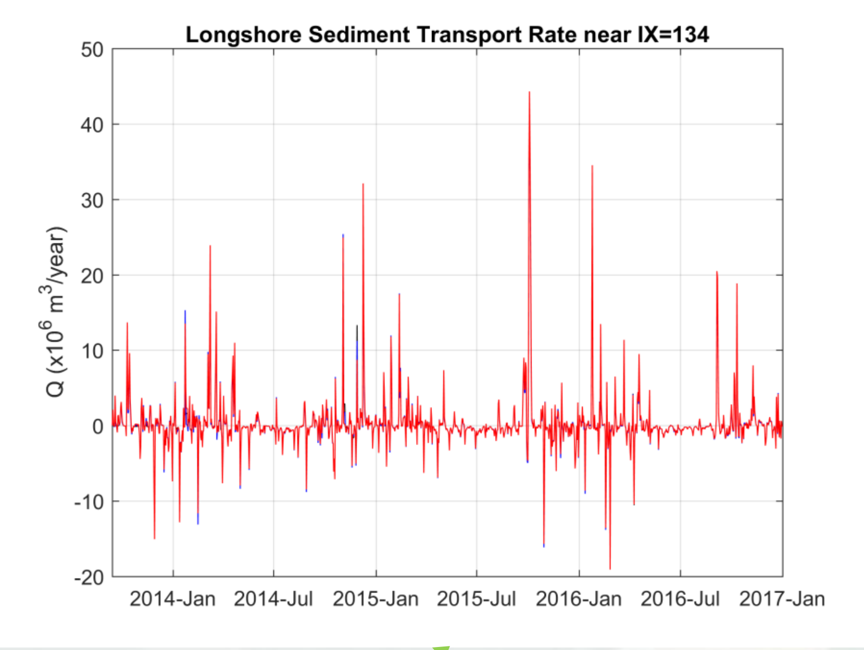
Annual Longshore Sediment Transport Rate in Fenwick Island, DE

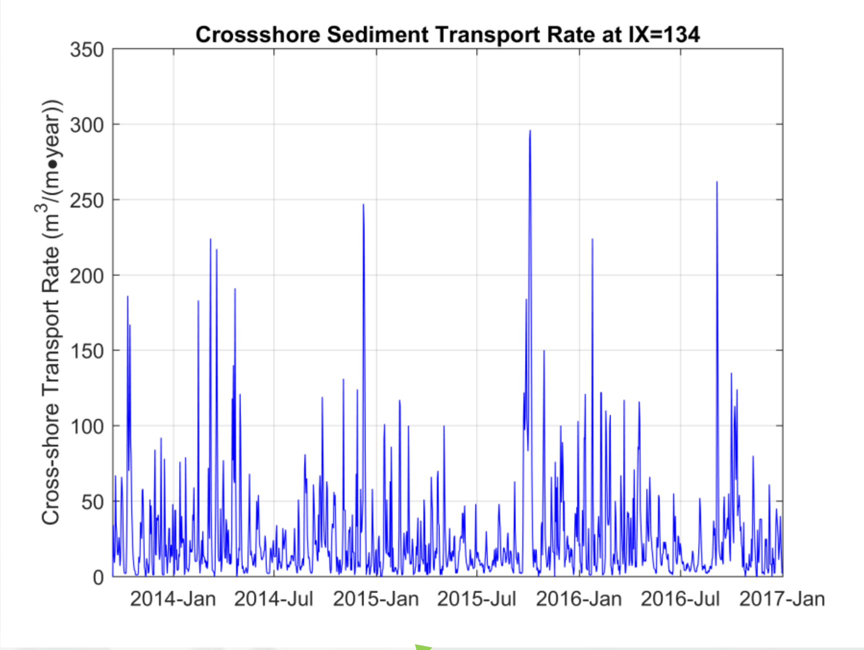


Annual Crossshore Sediment Transport Rate in Fenwick Island, DE

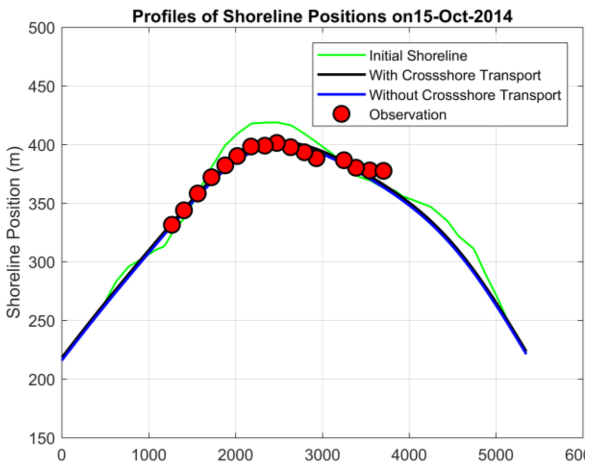


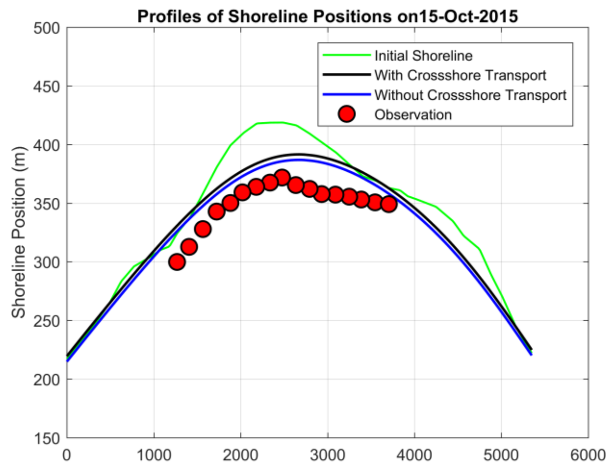
History of Longshore and Crossshore Sediment Transport Rate

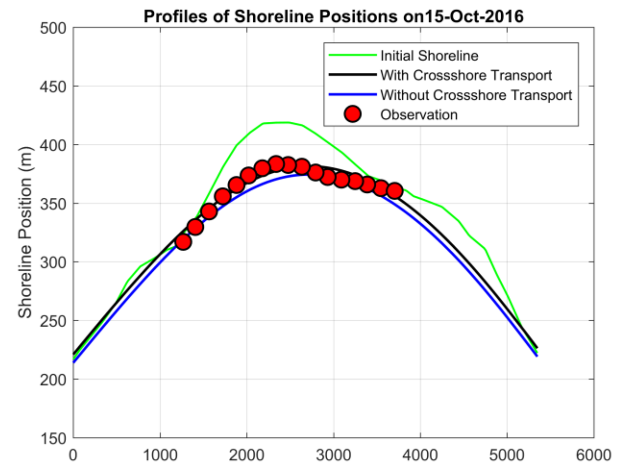




Comparisons of Shoreline Positions Computed with and without Crossshore Transport





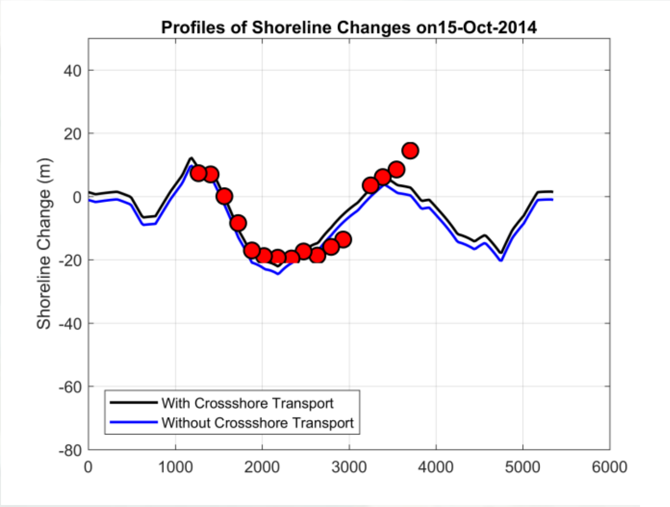


(1) After one year (10/15/2014)

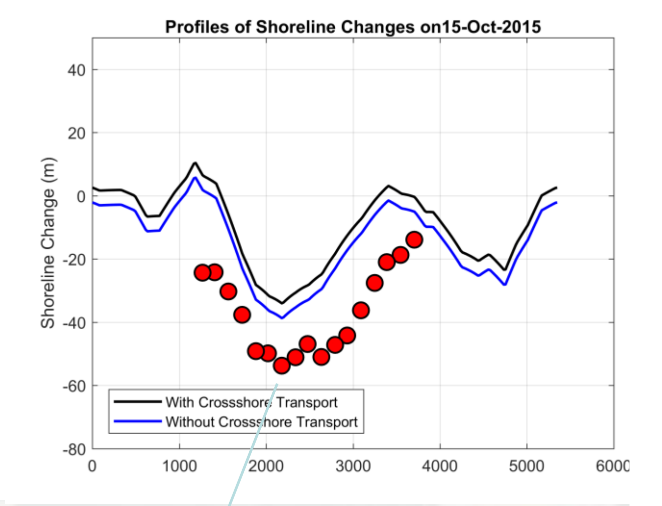
(1) After two years (10/15/2015)

(1) After Three year (10/15/2016)

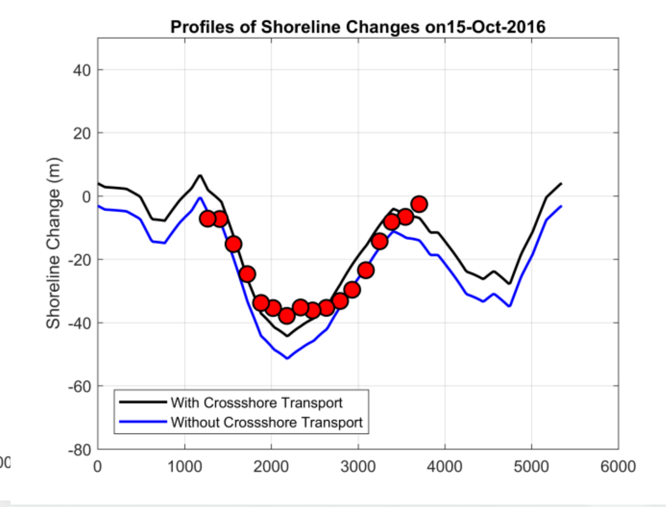
Comparisons of Shoreline Changes Computed with and without Crossshore Transport



(1) After one year (10/15/2014)

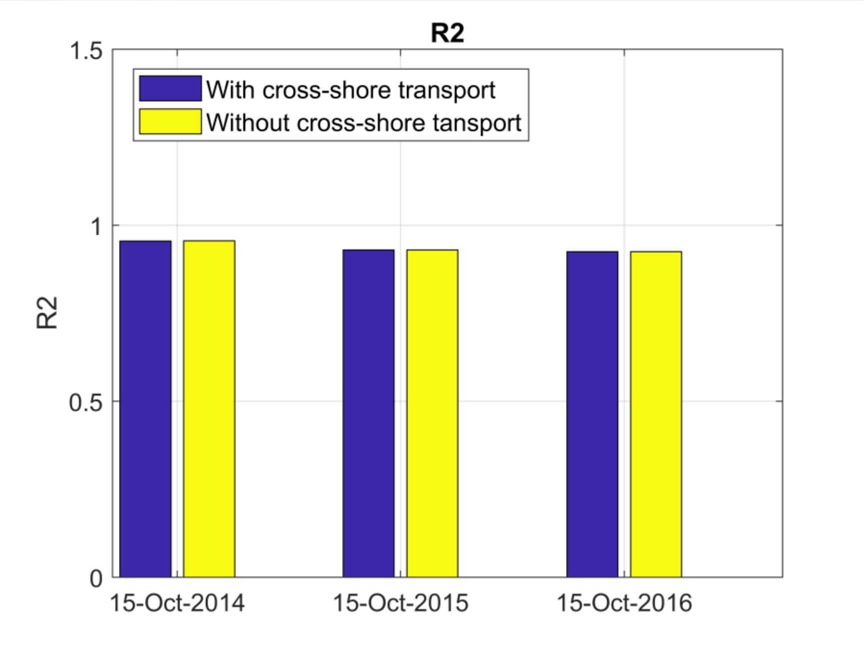


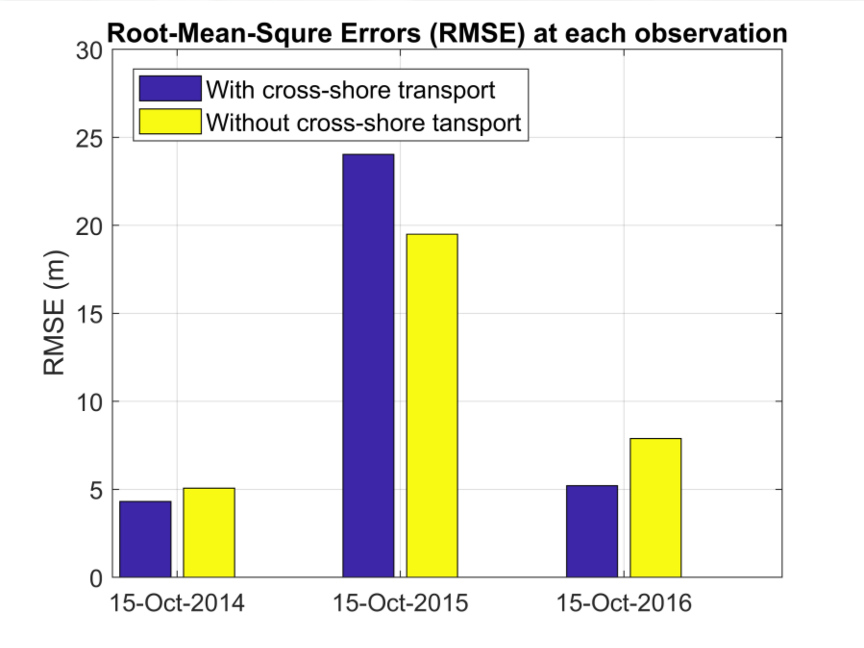
(1) After two years (10/15/2015)



(1) After Three year (10/15/2016)

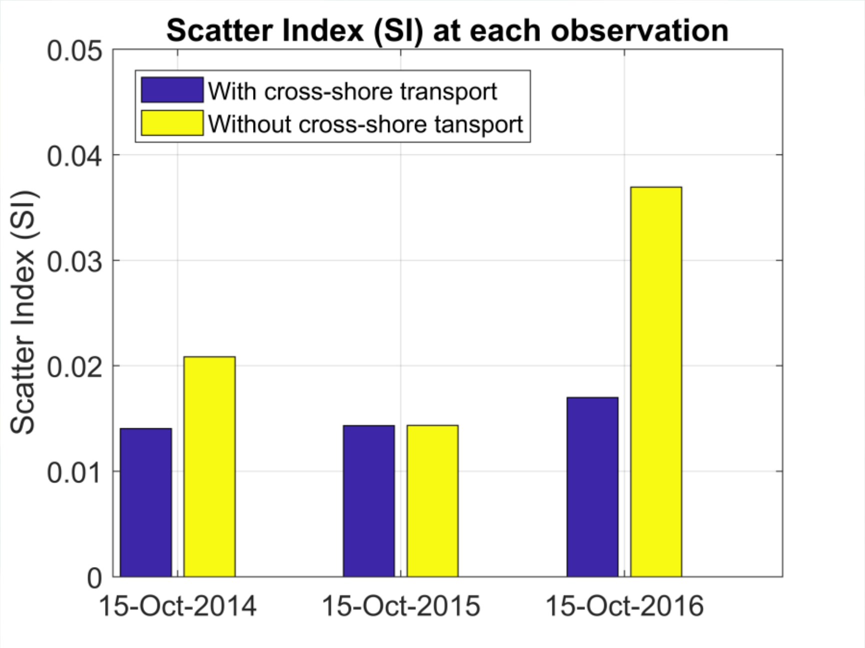
Model Skill Assessment Results (1)

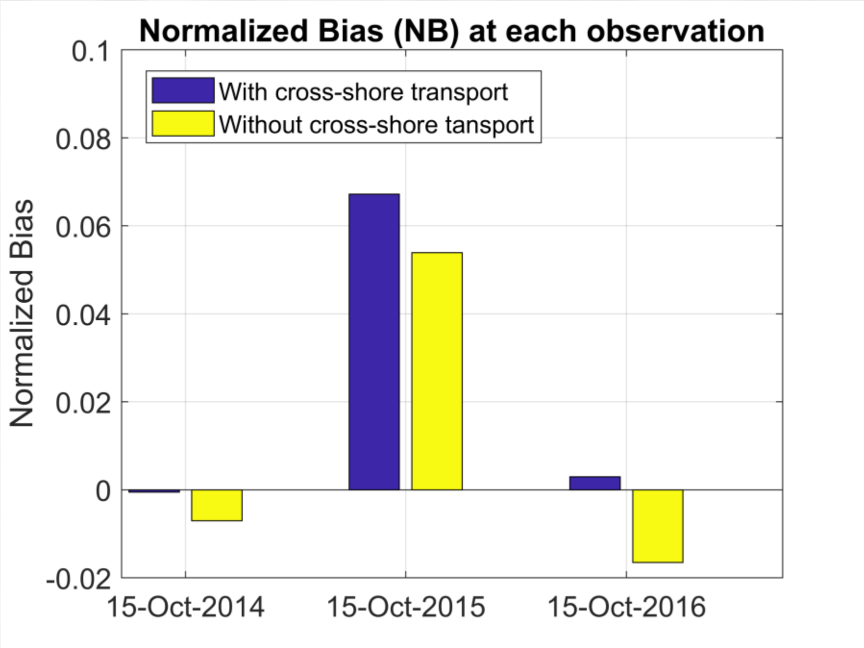




Remarks:
(1) R2 values close to unity → GenCade simulation results are consistent with the real shoreline shores.
(2) Adding crossshore sediment transport improved model results in 2014 and 2016.
(3) Large RMSEs in Oct. 2015 need to be investigated.

Model Skill Assessment Results (2)





$$\mathrm{SI}=\frac{\sqrt{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}\left(E_i-\bar{E}\right)^2}}{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}\left|O_i\right|} \qquad E_i = m_i - O_i \qquad \bar{E}=\frac{1}{N}\sum_{i=1}^{N}\left|m_i-O_i\right|$$

$$\mathrm{NB}=\frac{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}E_i}{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}\left|O_i\right|}$$

Remarks:
With cross-shore transport, the model reduces the scattered results and bias.

Remarks

- Newly-developed model capabilities of GenCade enhance model's applicability to predict shoreline evolution with a higher accuracy driven by multiple physical processes such as longshore and cross-shore sediment transport, shoreline retreat due to sea level rise, nearshore wave processes (nonlinearity, undertow, gravity, etc).
- Cross-shore sediment transport is an important process in simulating shoreline evolution in Duck, NC. Nonlinearity of waves plays an important role in driving net cross-shore transport in nearshore zone.
- Longshore sediment transport is a predominant process to erode the Fenwick Island shoreline, DE. But the crossshore sediment transport in the coast is also important to balance the beach erosion. By taking into account both long- and cross-shore processes GenCade can give a better assessment of beach filling in the DE coasts.
- GenCade with Monte-Carlo simulation provides a useful approach to assess uncertainty of shoreline change prediction. Preliminary results of probabilistic shoreline changes in Duck, NC are reasonable. Estimation of extreme shoreline changes provides risk of erosion in a return-interval manner.
- Sea level change is an important factor for predicting long-term shoreline changes (esp. erosion due to sea level rise).

Thank you!