# New Capabilities: Cross-Shore Transport and Monte-Carlo Simulation


Yan Ding, Ph.D.

Research Civil Engineer

U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Coastal Processes Branch


CIRP Training on CMS and GenCade, Sept. 19-23, 2022

US Army Corps of Engineers®

ERDC

ENGINEER RESEARCH & DEVELOPMENT CENTER

CIRP

Mission Support

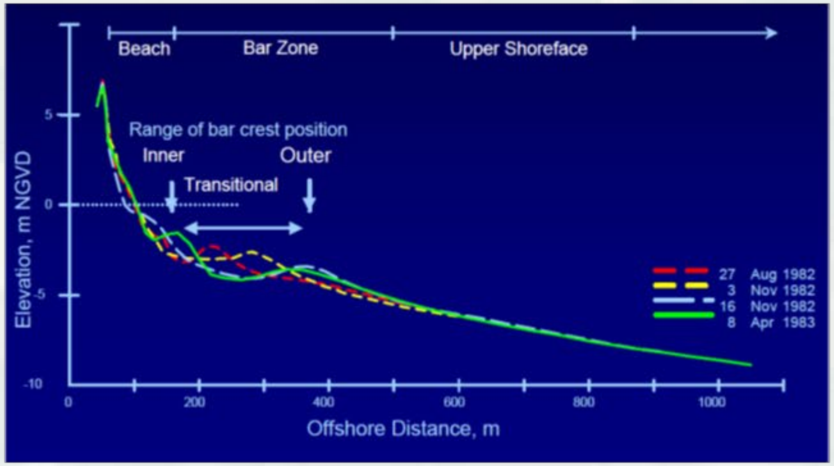
Technology Transfer

Research & Development

# Outline

- New Capabilities
  - ➢ Estimation of Cross-shore Sediment Transport, Shoreline Retreat due to Sea Level Rise and Subsidence
  - ➢ New Simulation Approach: Probabilistic Shoreline Change Modeling using Monte-Carlo Simulation
- Application Examples of GenCade :
  - ➢ Cross-Shore Transport: Duck coast, NC
  - ➢ GenCade-based Monte-Carlo Simulation for Risk Estimation of Shoreline Change

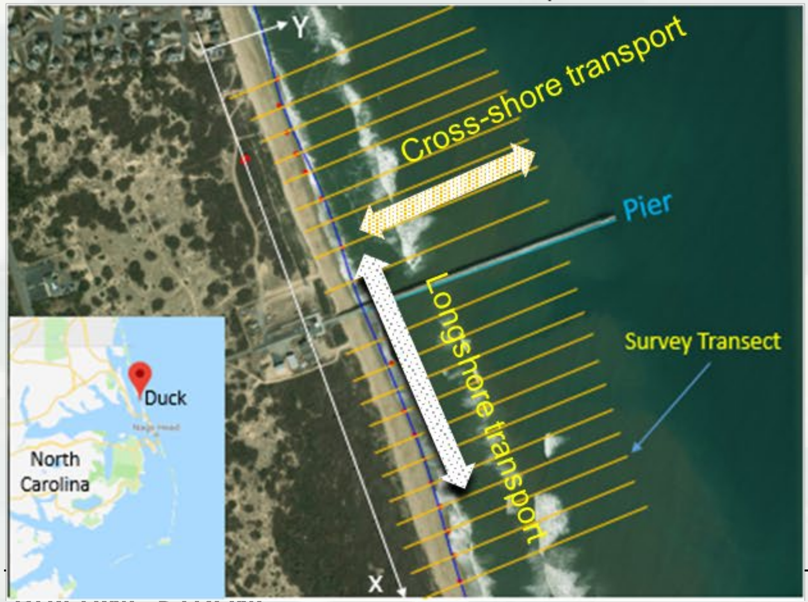
# New Capability: Cross-Shore Sediment Transport vs Nearshore Wave Asymmetry and Nonlinearity




Beach Profile Changes in Duck, NC (Birkemeier, 2001)

Contributors to Cross-Shore Transport:

- Sandy bar migration (on-offshore directions)
- Undertow due to storm waves (offshore)
- Orbital motion of small waves (onshore)
- Overwash and overtopping
- …



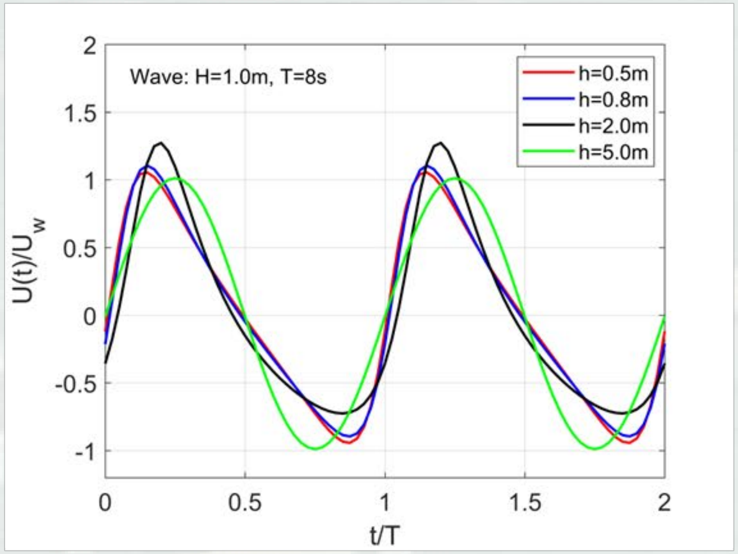




Figure. Near-bed orbital velocities for a wave (height $H$=1.0 m and period $T$=8 s) at four water depths. The positive sign denotes onshore direction

# Cross-shore Sediment Transport due to Wave Asymmetry and Nonlinearity

Cross-Shore Transport Rate due to Velocity Skewness

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

$\alpha_D$=empirical parameters (=1~2), $p$=porosity of sediment

$Q_v$ and $Q_C$ are the net sediment transport due to waves and currents (Bailaid & Inman 1981, Hsu et al. 2006)

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

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

Energy Dissipation

Wave Skewness

$U_0$ = wave orbital velocity vector,
$U_t$ = the total velocity vector (waves plus currents), and
$U$ = current velocity vector, related to longshore current and undertow current.

$\varphi$ = friction angle
$W_0$ = sediment fall velocity
$C_w$, $C_C$, $\varepsilon_B$, $\varepsilon_S$ = empirical parameters obtained by Fernández-Mora et al. (2015)

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

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

$\lambda_D$, $v$=empirical parameters

# Calculation of Near-Bed Horizontal Orbital Velocity: An Asymmetrical Wave Shape Model

- Abreu et al. (2010) introduced a simple analytical expression for the free-stream near-bed horizontal orbital motion

$$\tilde{U}_0(t) = U_w f \frac{\sin(\omega t) + \dfrac{r \sin \varphi_w}{1+\sqrt{1-r^2}}}{1 - r\cos(\omega t + \varphi_w)}$$

*r* = nonlinearity measure calculated by Skewness and Asymmetry parameters (Ruessink et al. 2012)

$$f = \sqrt{1-r^2}$$

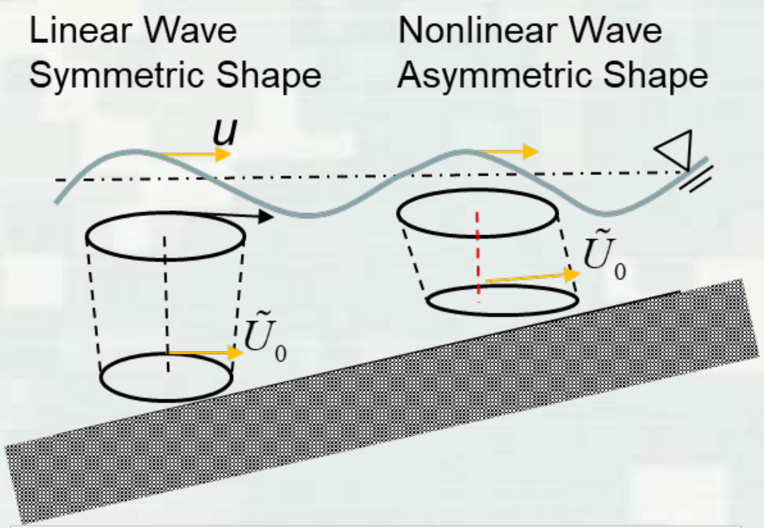
Combination of mean current and orbital velocity

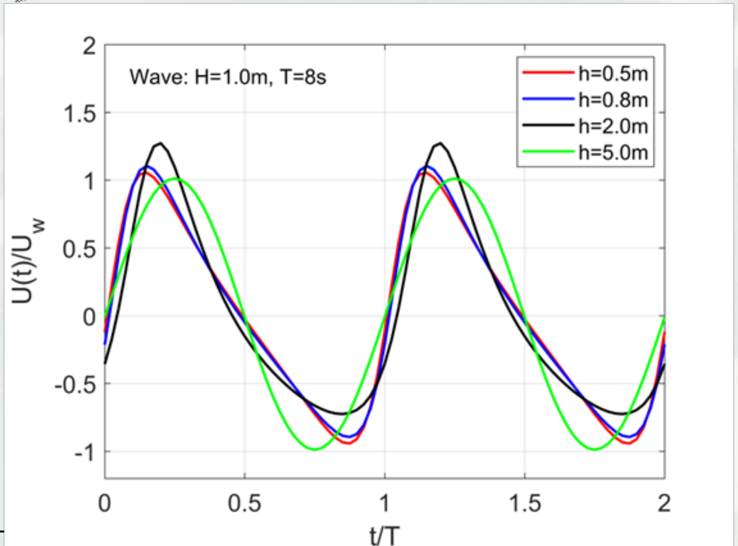
$$\vec{U}_0(t) = (U_{undertow} + \tilde{U}_0(t)\cos\theta)\vec{i} + (U_{alongshore} + \tilde{U}_0(t)\cos\theta)\vec{j}$$

*i*: cross-shore direction, *j*=alongshore direction

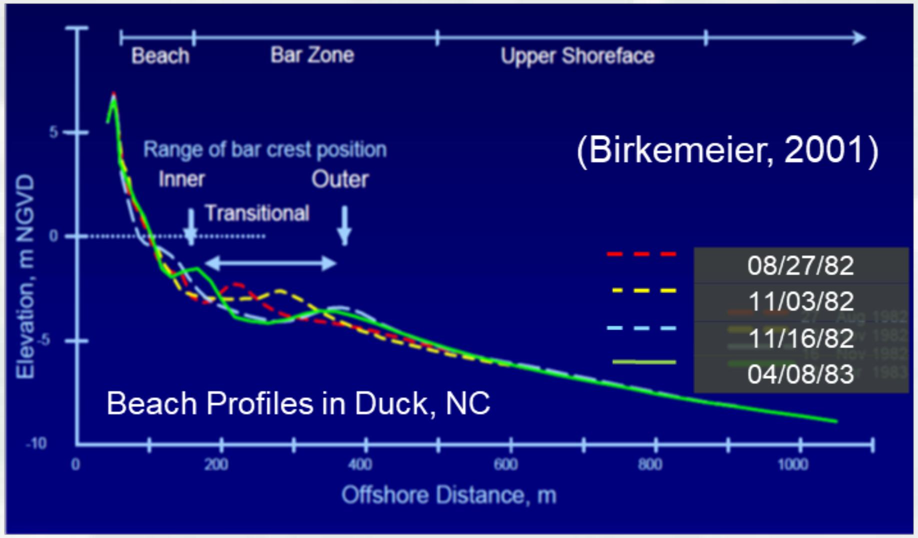
$U_{undertow}$ = undertow current in cross-shore direction

$U_{alongshore}$ =mean current alongshore



# Cross-Shore Sediment Transport Using Nonlinear Wave Shape Model

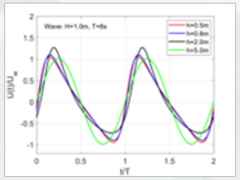



## Contributors to Cross-Shore Transport:

- Orbital motion of small waves (onshore)
- Sandy bar migration (on-offshore directions)
- Undertow due to high-energy waves (offshore)
- Overwash and overtopping
- Gravitational Slope Effect (offshore)

**Nonlinear Wave Shape model**: Near-bed horizontal orbital velocity (Abreu et al 2010, Ruessink et al. 2012)

$$\tilde{U}_0(t) = U_w f \frac{\sin(\omega t) + \dfrac{r \sin\varphi_w}{1+\sqrt{1-r^2}}}{1 - r\cos(\omega t + \varphi_w)}$$



## Cross-Shore Transport Rate

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

$Q_V$ and $Q_C$ are the net sediment transport due to waves and currents (Bailaid & Inman 1981, Hsu et al. 2006)

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

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

Energy Dissipation | Wave Skewness

$C_W$, $C_C$, $\varepsilon_B$, $\varepsilon_S$ = empirical parameters (Fernández-Mora et al. 2015)

$$\vec{U}_0(t) = (U_{undertow} + \tilde{U}_0(t)\cos\theta)\vec{i} + (U_{alongshore} + \tilde{U}_0(t)\cos\theta)\vec{j}$$

$U_{undertow}$ undertow current (Kuriyama 2010)

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

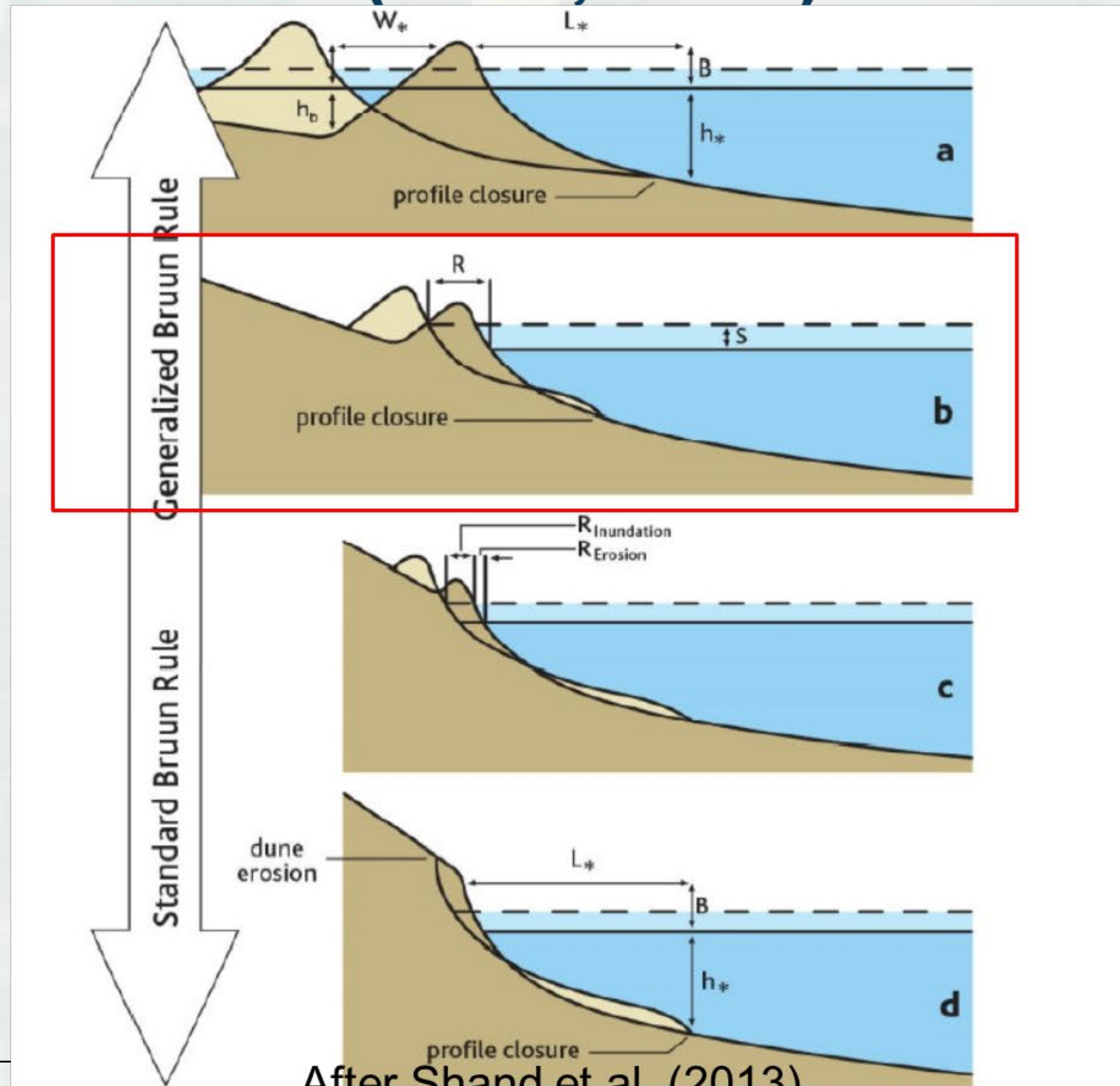
$$Q_D = \frac{\lambda_d \nu \tan\beta}{\tan\varphi(\tan\varphi - \tan\beta)}$$

# Shoreline Recession due to Sea Level Rise: Bruun Model (1962, 1988)

Shoreline Retreat rate

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

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



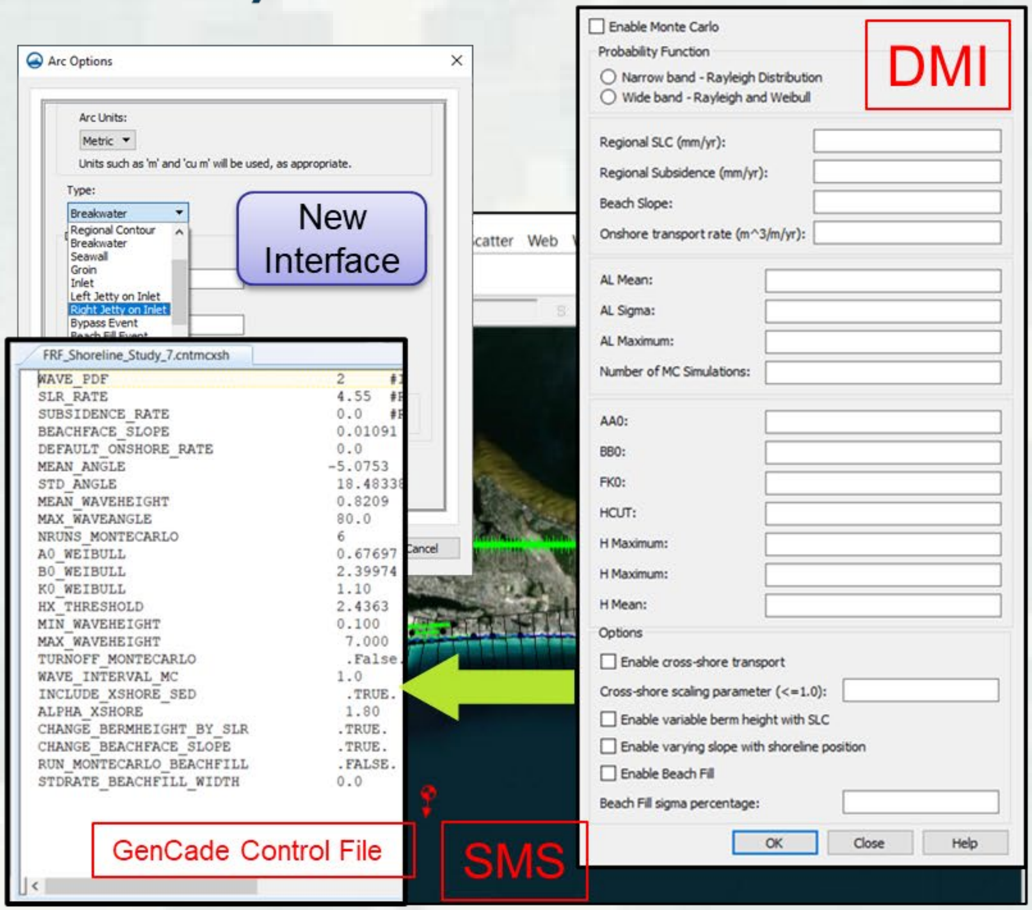

After Shand et al. (2013)

# GenCade 2.0 – SMS 13.x+ interface (DMI and others)

– Add Cross-shore

(DMI design completed, Aquaveo hold for SMS implementation)

– Add Monte Carlo




Under Development

# Control File (*.cntmcxsh)

FRF_Shoreline_Study_7.cntmcxsh

```
WAVE_PDF                          2     #IWAVE_PROB=1, Rayleigh Distribution; =2, Rayleigh + Weibull Distribution
SLR_RATE                          4.55  #RSLR (mm/yr)
SUBSIDENCE_RATE                   0.0   #RSUBSID(mm/year), BFSLOPE0, PHIONSHORE
BEACHFACE_SLOPE                   0.01091  #Beach face slope (BFSLOPE0)
DEFAULT_ONSHORE_RATE              0.0     #PHIONSHORE (mm/yr)
MEAN_ANGLE                       -5.0753  #Mean wave angle (deg), "ALMEAN"
STD_ANGLE                         18.48338545     # (ALSIGMA) standard deviation of angle (deg)
MEAN_WAVEHEIGHT                   0.8209          #Mean Wave height (m) HMEAN
MAX_WAVEANGLE                     80.0            #Max. Absolute Wave Angle (deg): ALMAX
NRUNS_MONTECARLO                  1               #NMONTECARLO: Number of Monte Carlo runs (by default =1)
A0_WEIBULL                        0.55574         #AA0: A parameter of a Weibull distribution
B0_WEIBULL                        1.97002         #BB0: B parameter of a Weibull distribution
K0_WEIBULL                        1.10            #FK0: K parameter of a Weibull distribution
HX_THRESHOLD                      2.000           #HCUT (m): A threshold value of wave height for switching pdf between Rayleigh and We
MIN_WAVEHEIGHT                    0.100           #HMIN: Minimum wave height (m)
MAX_WAVEHEIGHT                     6.000           #HMAX: Maximum wave height (m)
TURNOFF_MONTECARLO                 .TRUE.          #LnoMC: =True, one-time GenCade simulation, = False, GenCade Monte Carlo Simulation
INCLUDE_XSHORE_SED                 .TRUE.          #LONSHOREX: Including cross-shore sediment transport if = .TRUE.
ALPHA_XSHORE                       1.80           #alfa_phi:  Scaling parameter for cross-shore sediment transport
CHANGE_BERMHEIGHT_BY_SLR          .TRUE.          #LEdelman: Change Berm Height based on SLR
CHANGE_BEACHFACE_SLOPE            .TRUE.          #Lslopevarying: change beach face slope with shoreline position
RUN_MONTECARLO_BEACHFILL          .FALSE.         #LbeachfillMC: Conduct Monte-Carlo simulation of beach fill processes
STDRATE_BEACHFILL_WIDTH           0.0             #psigma_bfill: ratio of standard deviation error of berm width to the planned mean be
                                                   #for development purpose
GROIN_BYPASS_MODEL                .FALSE.         #LPERMMODEL, =.T. a model to control PERM rate of groin by wave heights (Yan Ding, Fe
MIN_WAVEHEIGHT_PERM               4.0             #H_PERM_MIN: lower bound for applying the PERM model
MAX_WAVEHEIGHT_PERM               6.0             #H_PERM_MAX: a upper bound for applying the PERM model
MIN_PERM_RATE                     0.6             #PERM_MIN: Minimum permeability of a groin in the PERM model
ADD_XSH_LEFTBC                    .FALSE.         #LADD_XSH_LEFTBC: =.FALSE., cross-shore rate at the left boundary=0; Or, being the on
ADD_XSH_RIGHTBC                   .TRUE.          #LADD_XSH_RIGHTBC: =.FALSE., cross-shore at the right =0
```

# Inputs for Cross-shore Transport and Boundary Conditions

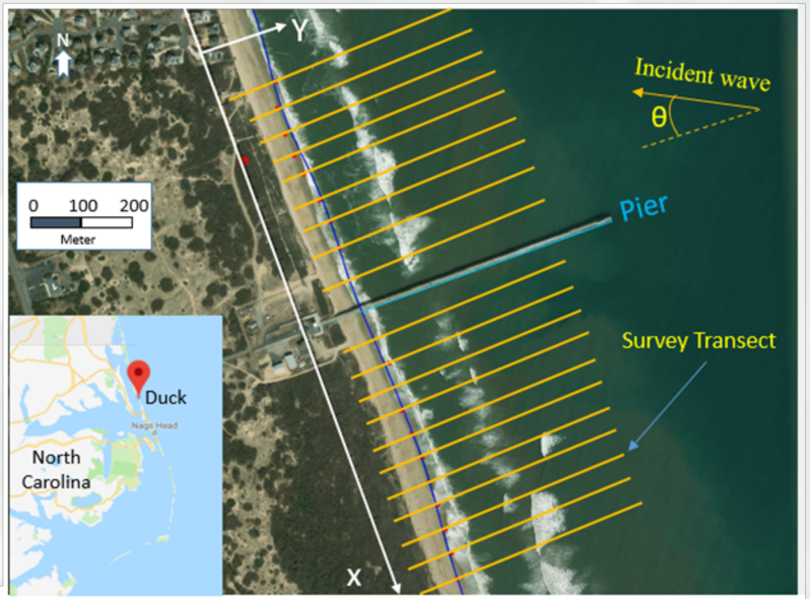
```
INCLUDE_XSHORE_SED             .TRUE.      #LONSHOREX: Including cross-shore sediment transport if = .TRUE.
ALPHA_XSHORE                    1.80       #alfa_phi:  Scaling parameter for cross-shore sediment transport
CHANGE_BERMHEIGHT_BY_SLR       .TRUE.      #LEdelman: Change Berm Height based on SLR
CHANGE_BEACHFACE_SLOPE         .TRUE.      #Lslopevarying: change beach face slope with shoreline position
RUN_MONTECARLO_BEACHFILL       .FALSE.     #LbeachfillMC: Conduct Monte-Carlo simulation of beach fill processes
STDRATE_BEACHFILL_WIDTH        0.0         #psigma_bfill: ratio of standard deviation error of berm width to the
                                            #for development purpose
GROIN_BYPASS_MODEL             .FALSE.     #LPERMMODEL, =.T. a model to control PERM rate of groin by wave height
MIN_WAVEHEIGHT_PERM            4.0         #H_PERM_MIN: lower bound for applying the PERM model
MAX_WAVEHEIGHT_PERM            6.0         #H_PERM_MAX: a upper bound for applying the PERM model
MIN_PERM_RATE                  0.6         #PERM_MIN: Minimum permeability of a groin in the PERM model
ADD_XSH_LEFTBC                 .FALSE.     #LADD_XSH_LEFTBC: =.FALSE., cross-shore rate at the left boundary=0; O
ADD_XSH_RIGHTBC                .TRUE.      #LADD_XSH_RIGHTBC: =.FALSE., cross-shore at the right =0
```

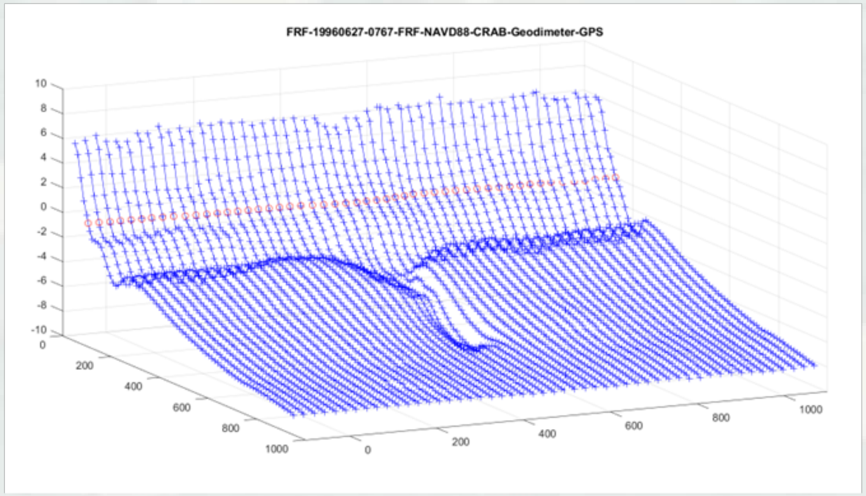
# New Output File Format for GenCade

| Instantaneous Cross-Shore Transport at Output Time (*.xsh) File | |
|---|---|
| **Column 1** | **Column 2 through Column NX** |
| Date (yyyymmdd) | Cross-shore sediment transport (length$^3$/length/year) for each grid cell (+ sign for onshore transport; - sign for offshore transport) |

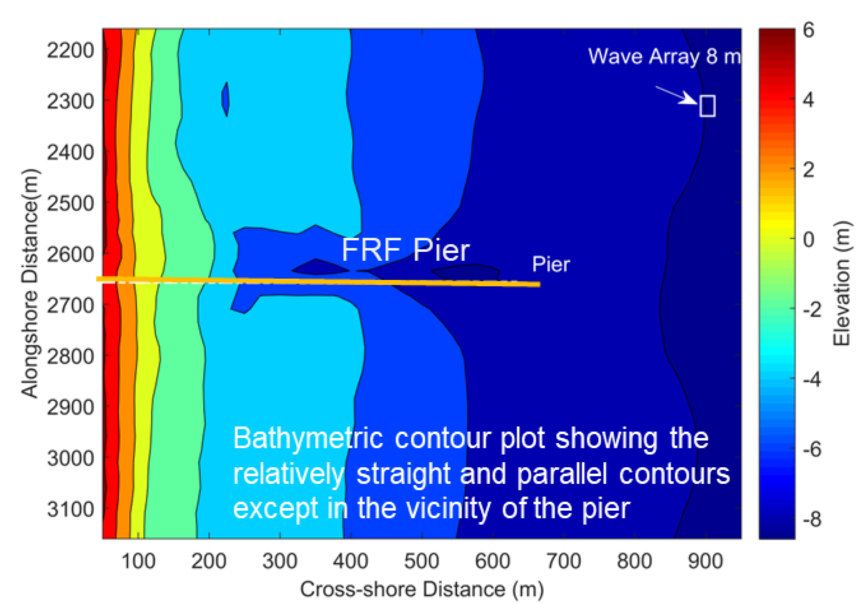
| Instantaneous Breaking wave Heights (*.hso) File | |
|---|---|
| **Column 1** | **Column 2 through Column NX** |
| Date (yyyymmdd) | Break wave height (m) for each grid cell averaged over entire simulation |

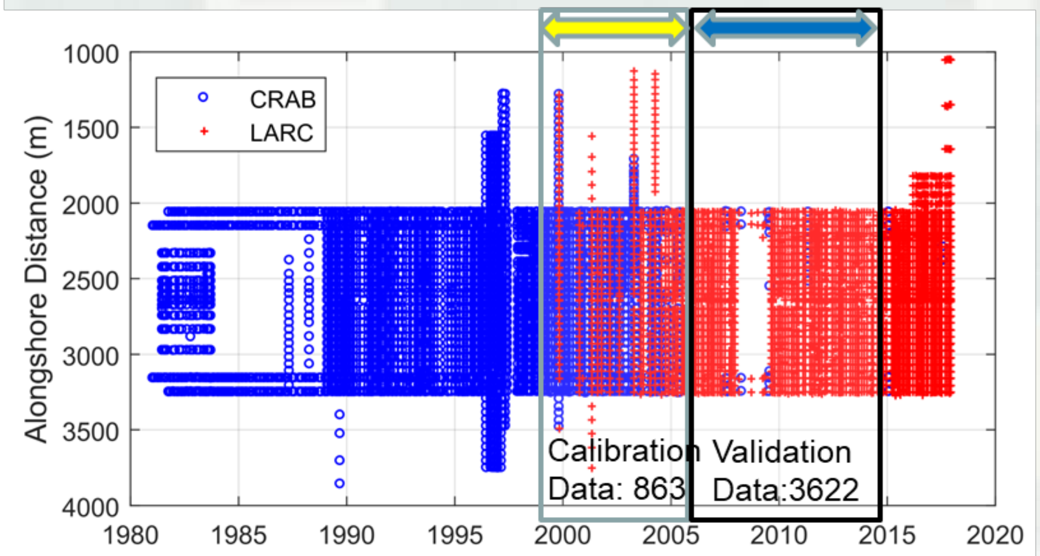
# Simulation of Shoreline Change at Duck, NC
# FRF Survey Data of Beach Profiles




**Available Beach Profile Survey Data (1985-2017)**
CRAB =Coastal Research Amphibious Buggy
LARC=Lighter Amphibious Resupply Cargo

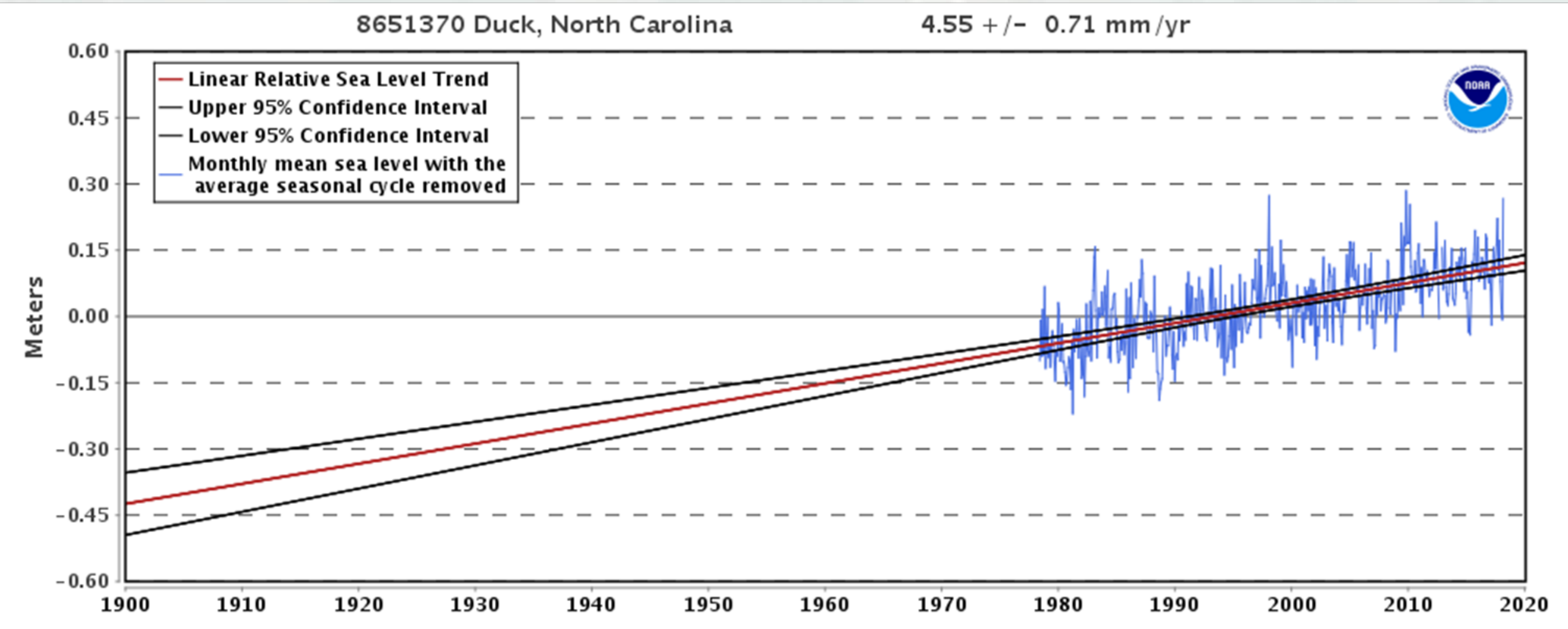



Representative beach profile coverage area along the FRF property.

# Sea Level Rise Trend

## NOAA-NOS #8651370 Duck, North Carolina



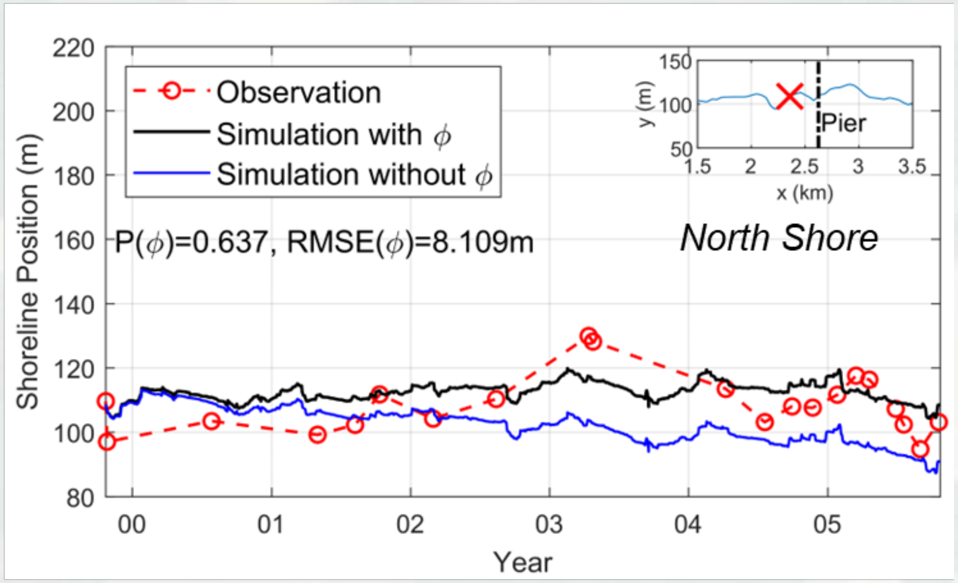

https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8651370

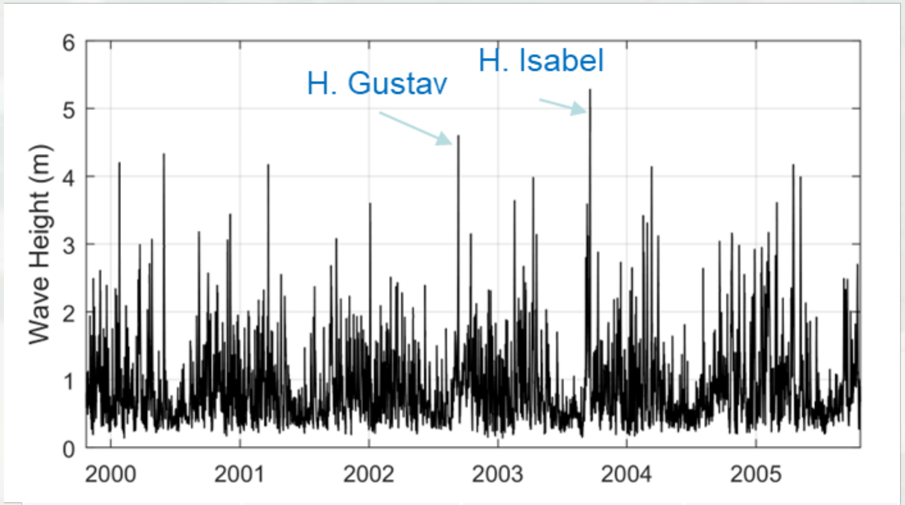
# Shoreline Changes (1999-2005) at FRF, Duck, NC -- Model Parameter Calibration

Model Parameters

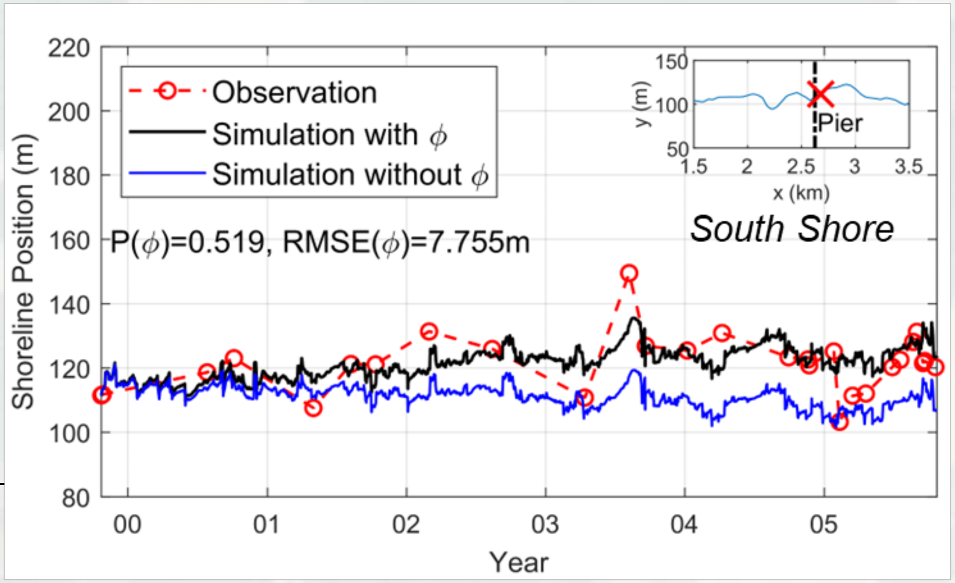
| $d_c$ (m) | $d_b$ (m) | $d_{50}$ (mm) | $\alpha_D$ | $K_1$ | $K_2$ | $\Delta t$ (min) | tan $\beta$ | $\Delta x$ (m) |
|---|---|---|---|---|---|---|---|---|
| 7.0 | 1.0 | 0.2 | 1.75 | 0.40 | 0.25 | 1.5 | 1:92 | 20. |

Wave: Senso-Metric 8m Array
Boundary Conditions: Pined
Permeability of Pier = 0.6 (no diffracting):
Parameters for Cross-Shore Transport
$C_w$, $C_C$, $\varepsilon_B$, $\varepsilon_S$ by Fernández-Mora et al. (2015)



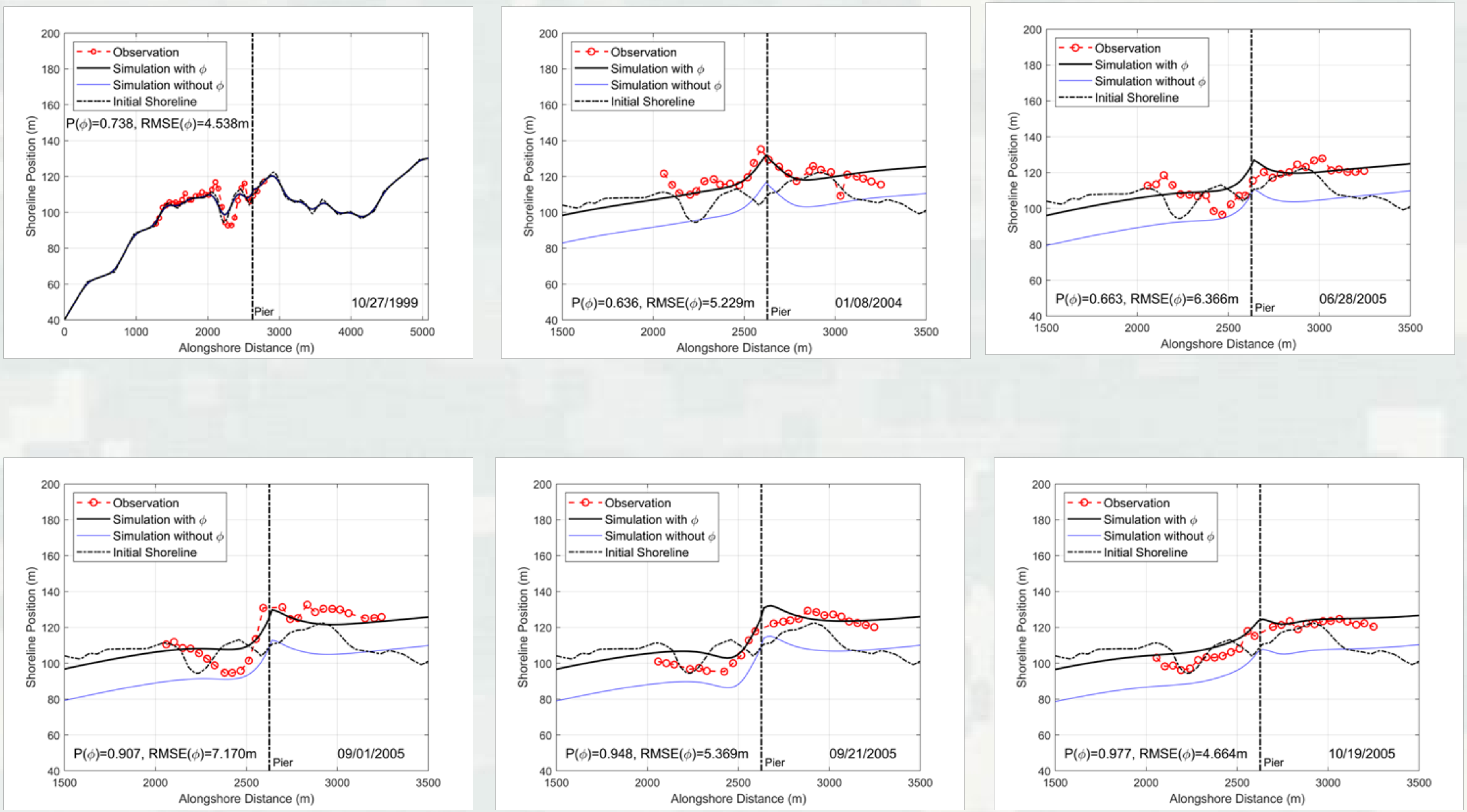




$\phi$: cross-shore sediment transport



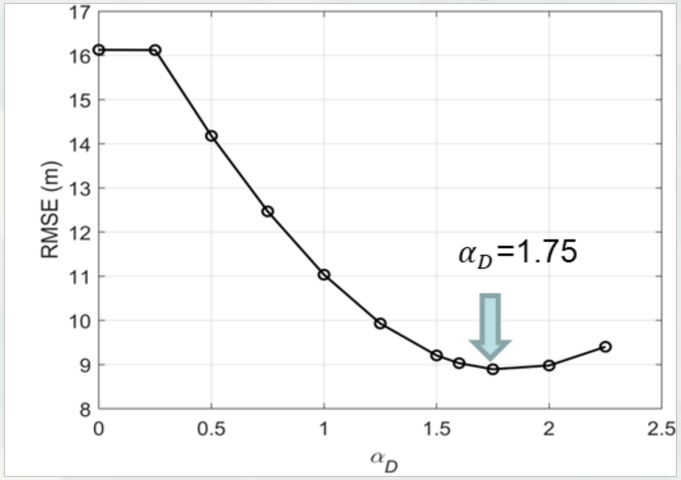

| | H (m) | T (s) | alfa (deg) |
|---|---|---|---|
| Average | 0.82 | 9.18 | -5.06 |
| Min | 0.14 | 3.09 | -74.62 |
| Max | 5.28 | 18.96 | 111.32 |
| σ | 0.53 | 2.68 | 18.52 |

# Comparisons of Shoreline Positions (1999-2005) -- Model Calibration



# Model Skill Assessment: (1999-2005)

Calibration process: $\alpha_D$ vs. RMSE

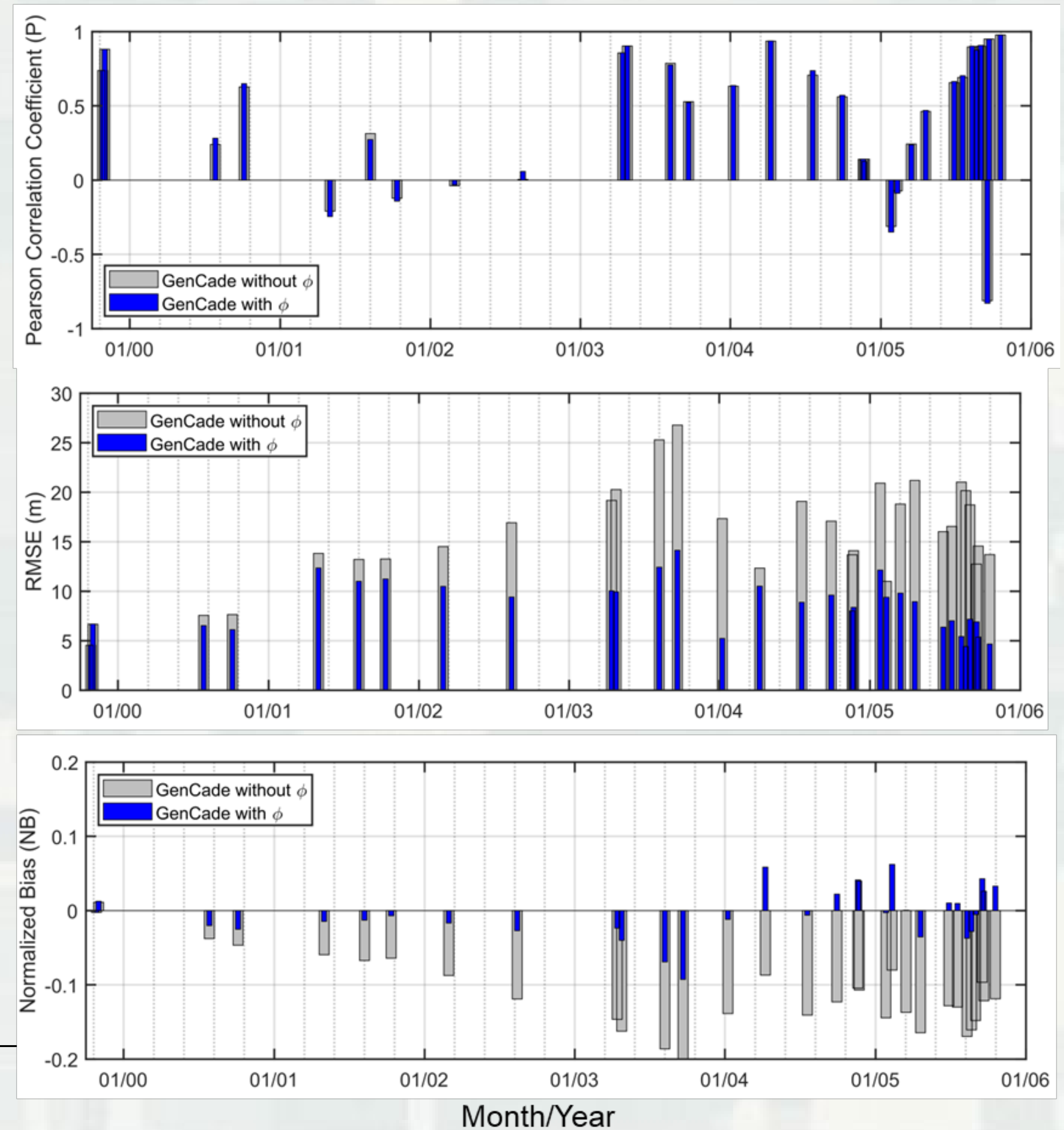



$$P = \frac{\sum_{i=1}^{N}(m_i - \bar{m})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^{N}(m_i - \bar{m})^2 \sum_{i=1}^{N}(O_i - \bar{O})^2}}$$

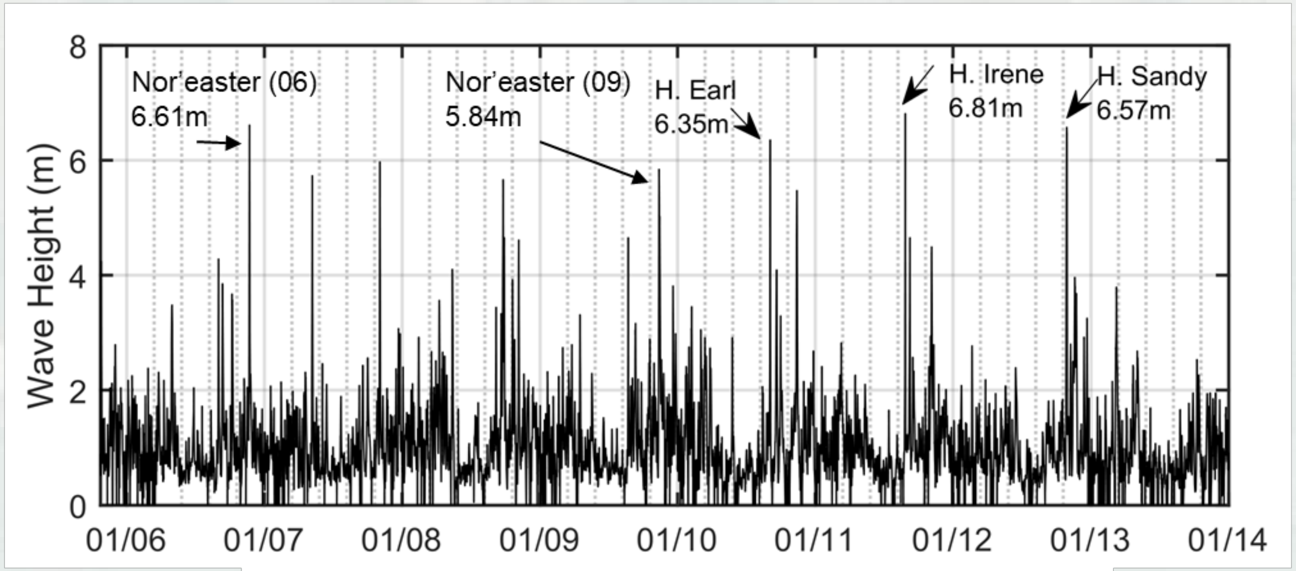
$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(m_i - O_i)^2}$$

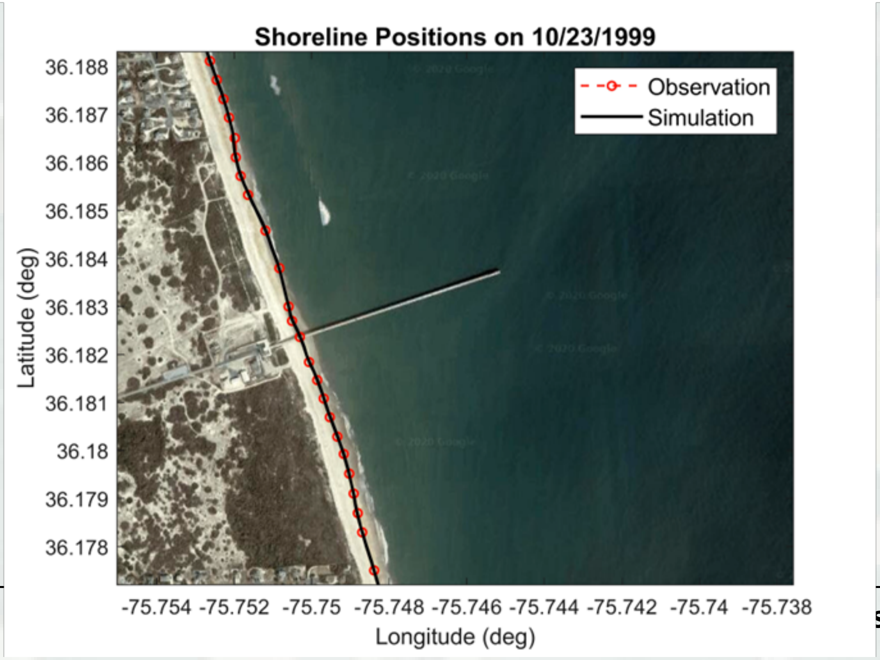
$$\mathrm{NB} = \frac{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}(m_i - O_i)}{\frac{1}{\mathrm{N}}\sum_{i=1}^{N}|O_i|}$$

$m_i$: model values
$O_i$: Observation data

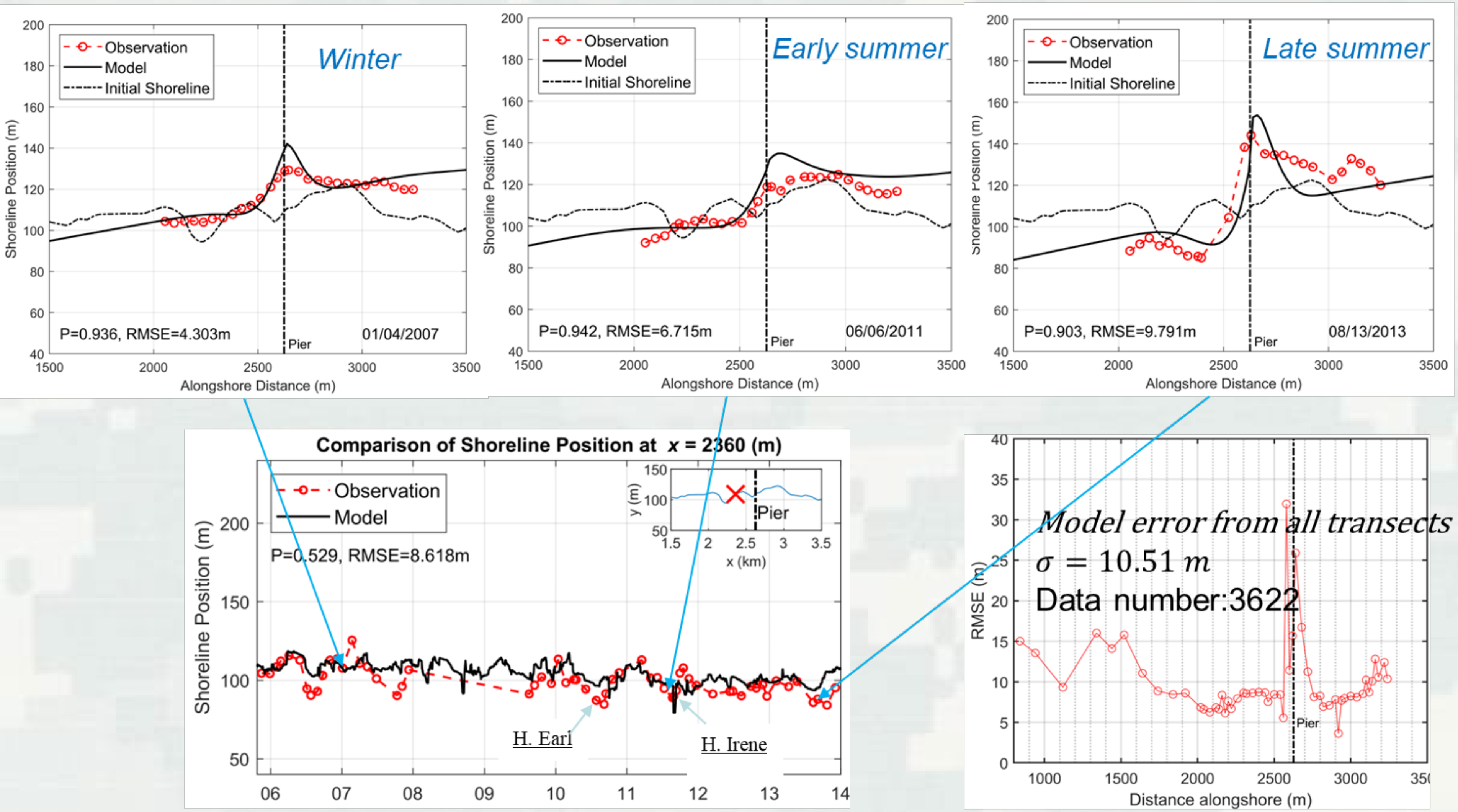


# Model Validation: 2006-2014

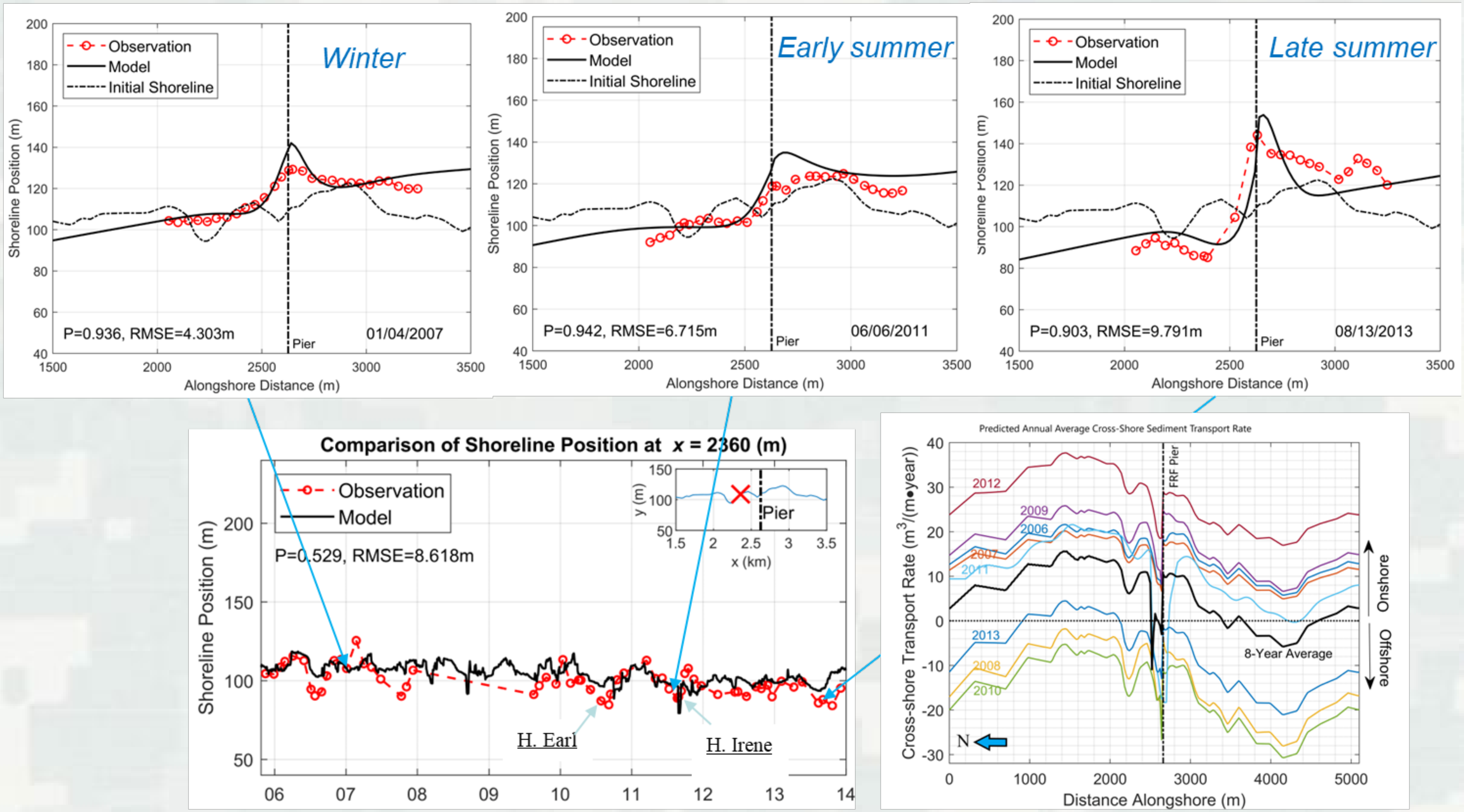


# Model Validation: 2006-2014 – Shoreline Shapes in Different Seasons

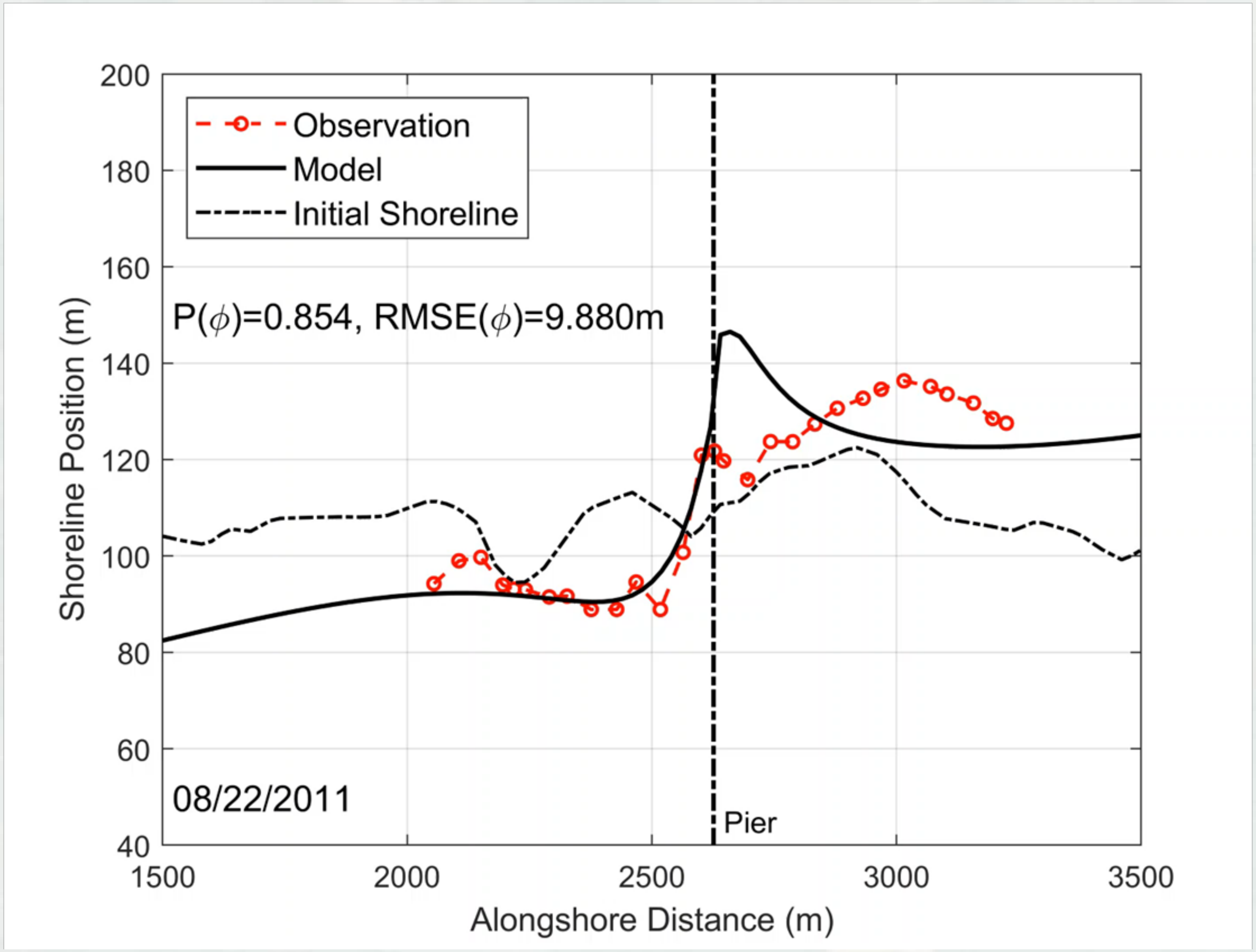


# Shoreline Positions and Cross-shore Sediment Transport Rate around FRF Pier *



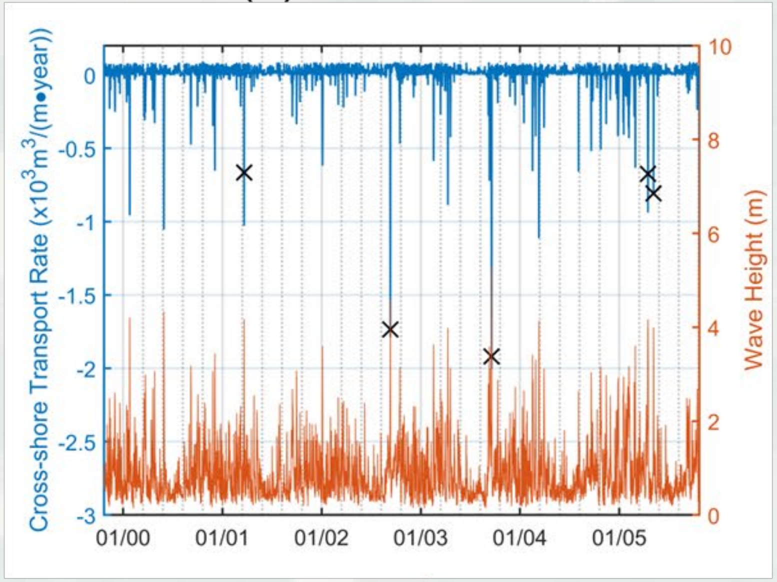

* Ding, Y., et al (2021). Cross-shore sediment transport for modeling long-term shoreline evolution, *J. Waterw. Port Coastal Ocean Eng.*, DOI: 10.1061/(ASCE)WW.1943-5460.0000644

# Validation of Long-Term Shoreline Evolution around FRF pier

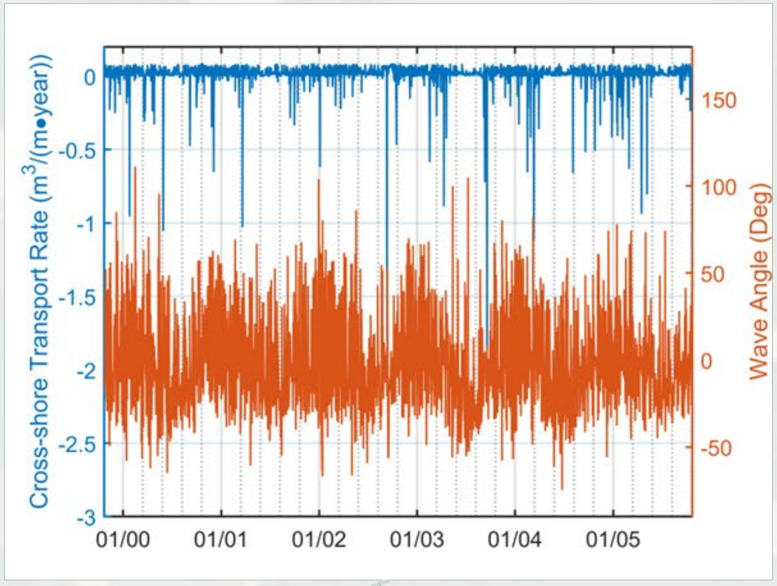


# Predicted Cross-Shore Transport Rate (Φ)

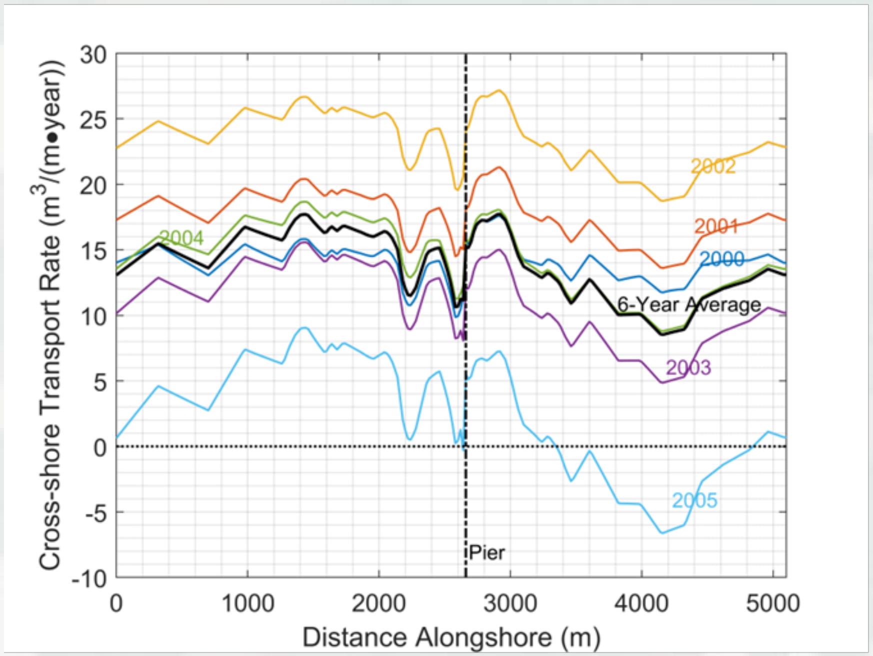
(a) Φ vs Hs



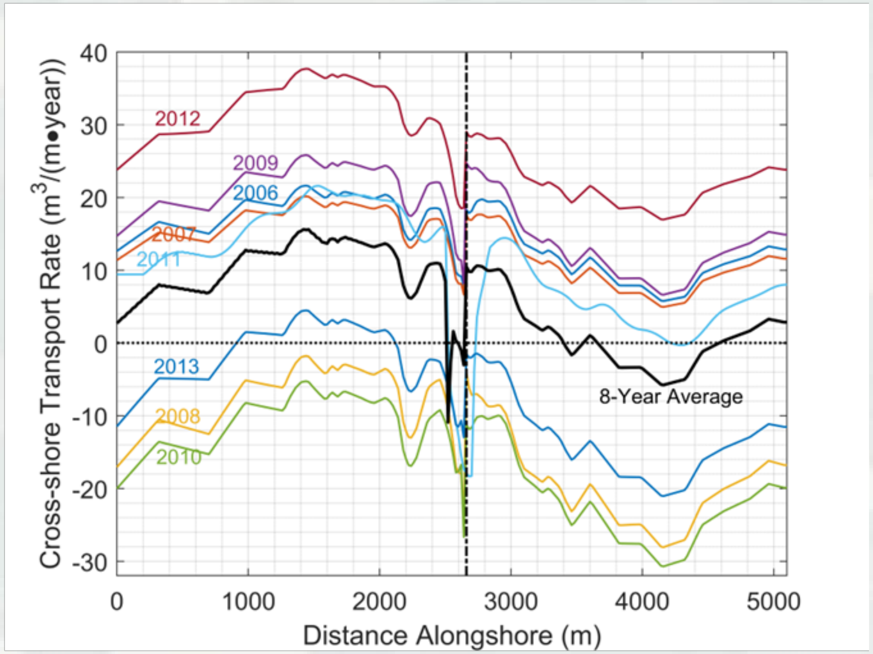

(b) Φ vs α (Wave Angle)




# Annual Cross-Shore Transport Rate




(1) 1999-2005




(2) 2006-2014

# New Capability:
# Monte-Carlo Simulation for Probabilistic Shoreline Prediction

# GenCade-Based Monte Carlo Simulation

$$p(x)=\begin{cases} R(x) & x\in[0,x_0) \\ \varepsilon W(x) & x\in(x_0,+\infty) \end{cases}$$

Wave Generator → GenCade → Statistic Analysis

- Maximum Likelihood Estimation

Input wave conditions for setting up the probability density functions, i.e. wave heights, periods, angles

↓

Generate time series of wave heights and angles based on probability density functions (pdfs)

↓

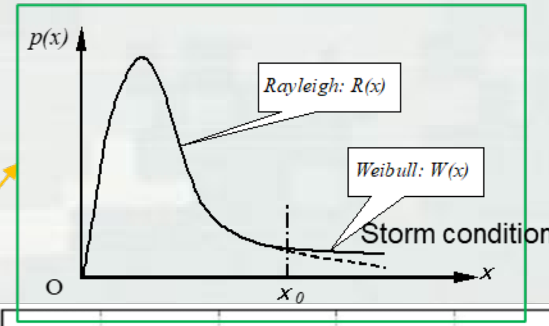
Simulation of shoreline changes by the one-line model, **GenCade**

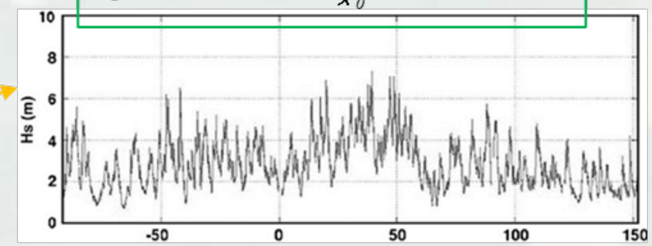
↓ Repeat $N$ times

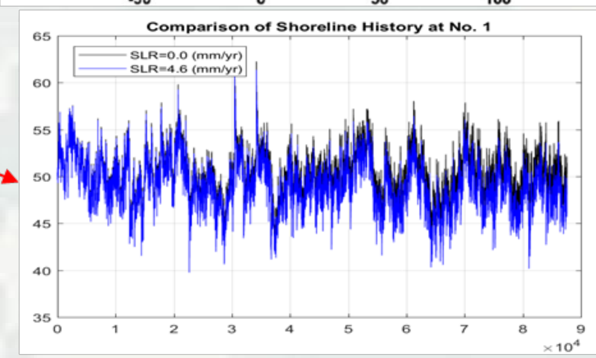
Statistic analysis of shoreline changes

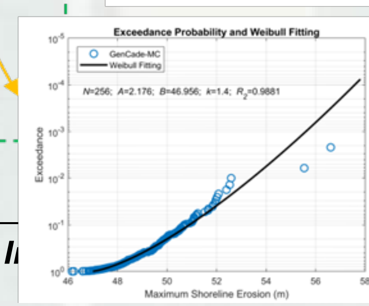
↓

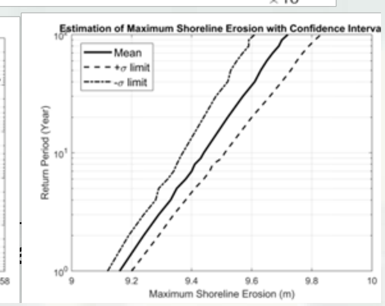
Stop



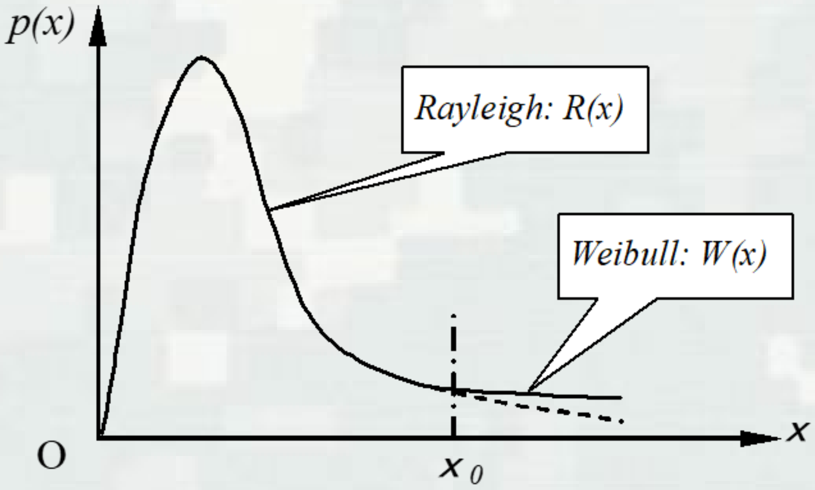

*The more test samples (N), the better statistic results*

# Probabilistic Distribution of Wave Height

$$p(x) = \begin{cases} R(x) & x \in [0, x_0) \\ \varepsilon W(x) & x \in (x_0, +\infty) \end{cases}$$

$\varepsilon$: parameter

$x_0$: a truncated extreme value of wave height




Rayleigh Distribution (for normal waves) :

$$R(x) = -\frac{\pi}{2} x \exp\left(-\frac{\pi}{4} x^2\right)$$

Weibull Distribution (for extreme waves):

$$W(x) = \frac{1}{k}\left(\frac{x-B}{A}\right)^{k-1} \exp\left(-\left(\frac{x-B}{A}\right)^{K}\right)$$

Parameters $k$, $A$, $B$, and $x_0$ are determined from wave observation data

$$\int_{-\infty}^{+\infty} p(x) = 1 \quad \Rightarrow \quad \varepsilon = \frac{e^{-\frac{\pi}{4} x_0^2}}{e^{-\left(\frac{x_0 - B}{A}\right)^K}}$$

# Determining Distribution Parameter from Wave Observation Data

*Density distribution* of wave height is fitted as mixing distribution of Rayleigh and Weibull distributions

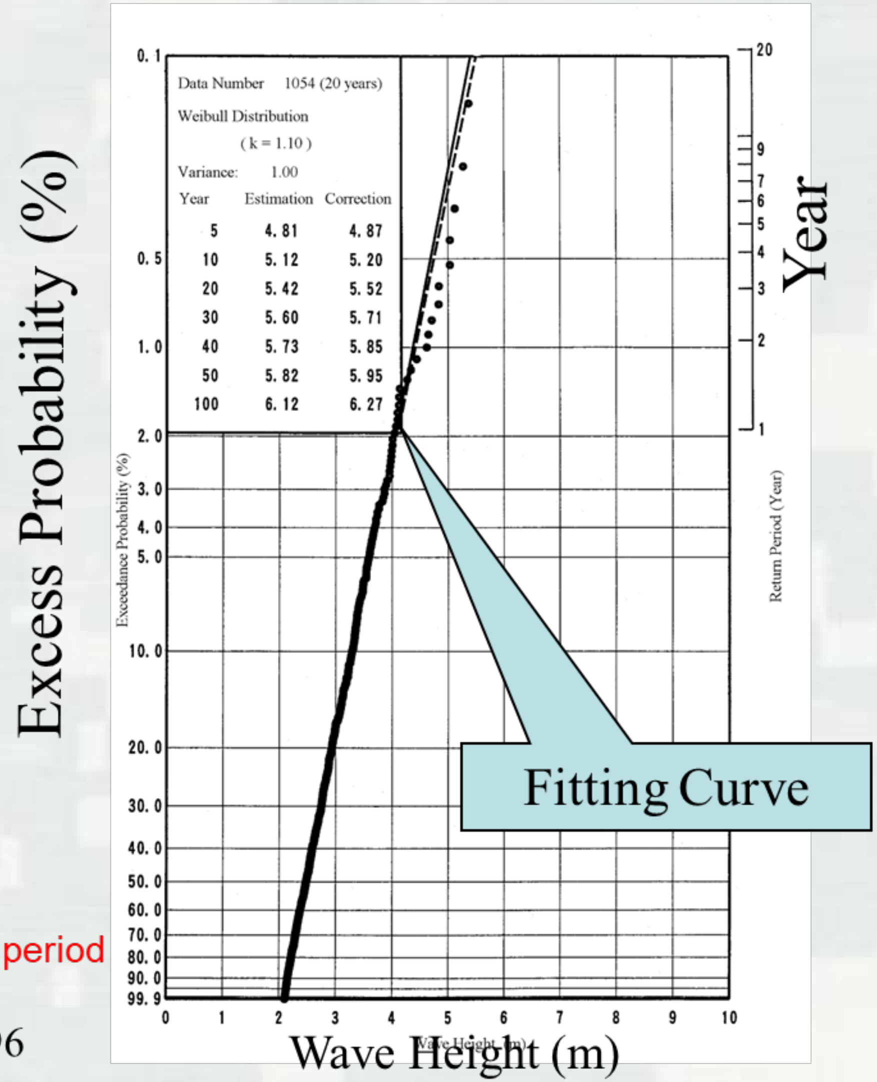
$$p(x)=\begin{cases} R(x) & x\in[0,x_0) \\ \varepsilon W(x) & x\in(x_0,+\infty) \end{cases}$$

where $x = H / H_{mean}$

in $W(x)$, $k = 1.1$, $A = 0.5792$, $B = 2.0554$, $x_0 = 2.1$

$Hmean = 1.19$ m

Observation data: H=4.0 m wave height for one-year return period




Observation data at Naka Port, Japan, from 1980 to 1996

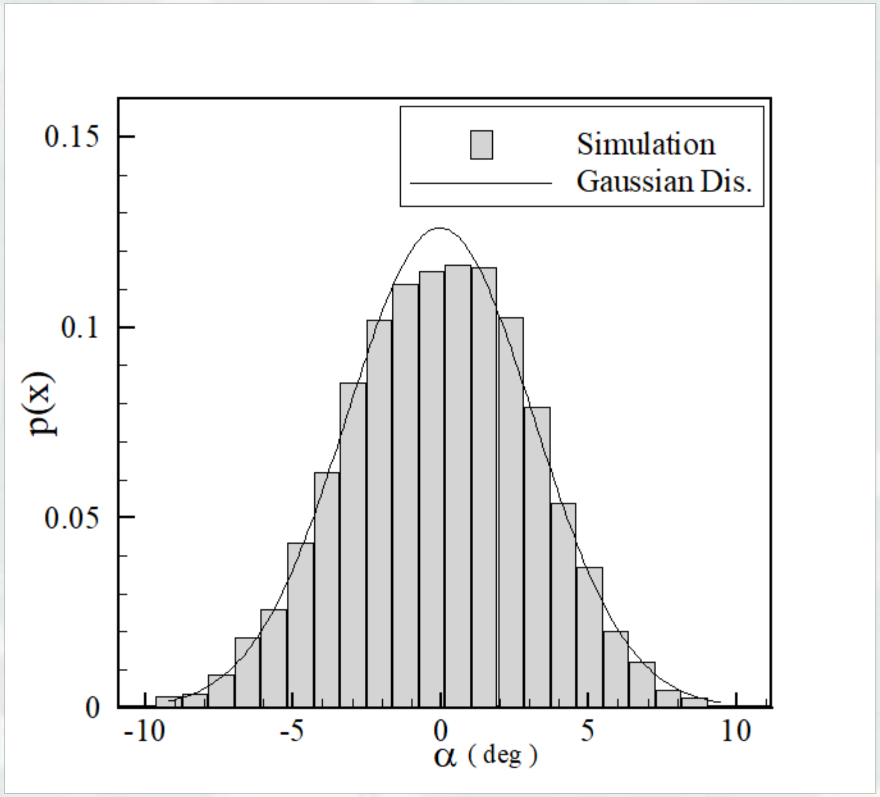
# Wave Direction and Period

Incident Wave Angles: Gaussian Distribution

$$p(x) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left( -\frac{(x-\mu)^2}{2\sigma^2} \right)$$

σ: Standard deviation of wave direction

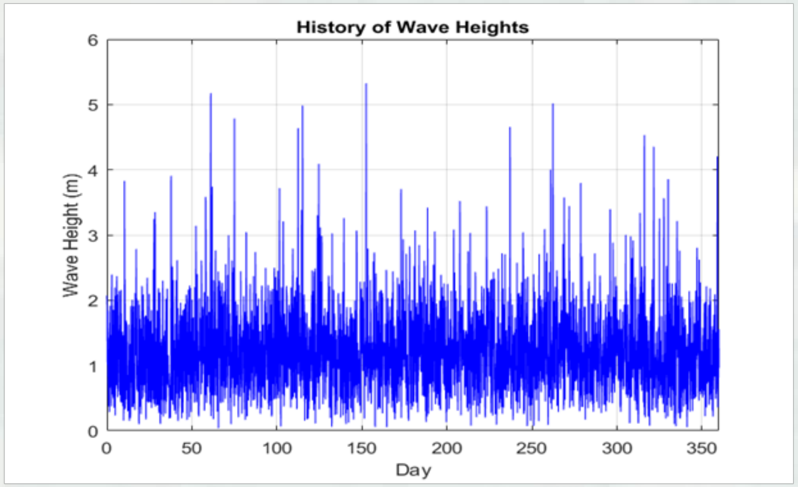
$\mu$ : Mean value of direction

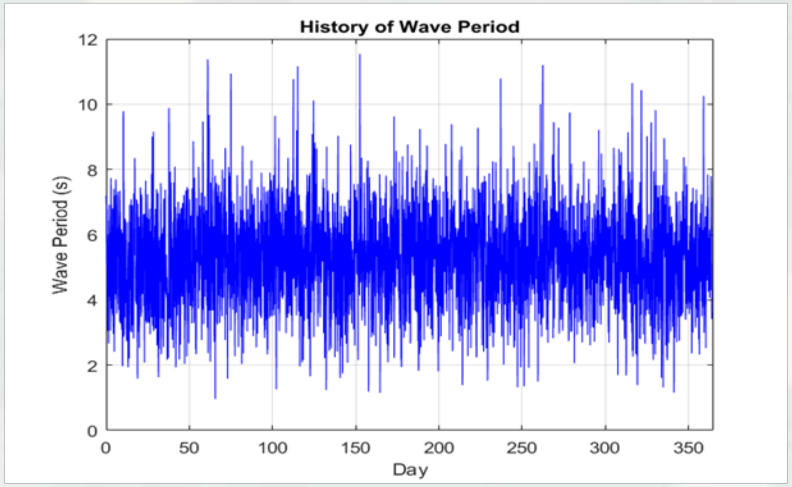


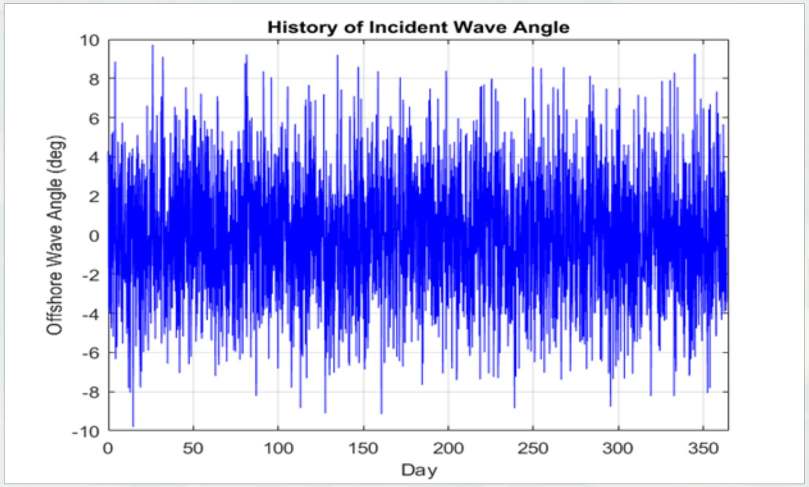

Significant Wave Period: based on Pierson-Moskowitz Spectrum

$$T_s = 5\sqrt{H_s}$$

# Wave Parameters Generated by Wide Band Spectrum ( Case 1: One Year, 256 Monte Carlo Experiments)




- Hmean = 1.19m
- Mean Angle = 0.0 with $\sigma^2$=10
- Data Interval = 3.0 hours

$$p(x)=\begin{cases} R(x) & x\in[0,x_0) \\ \varepsilon W(x) & x\in(x_0,+\infty) \end{cases}$$

H_cut = 2.5 m

# Control File

FRF_Shoreline_Study_7.cntmcxsh

```
WAVE_PDF                      2      #IWAVE_PROB=1, Rayleigh Distribution; =2, Rayleigh + Weibull Distribution
SLR_RATE                      4.55   #RSLR (mm/yr)
SUBSIDENCE_RATE               0.0    #RSUBSID(mm/year), BFSLOPE0, PHIONSHORE
BEACHFACE_SLOPE               0.01091  #Beach face slope (BFSLOPE0)
DEFAULT_ONSHORE_RATE          0.0      #PHIONSHORE (mm/yr)
MEAN_ANGLE                   -5.0753   #Mean wave angle (deg), "ALMEAN"
STD_ANGLE                     18.48338545    # (ALSIGMA) standard deviation of angle (deg)
MEAN_WAVEHEIGHT               0.8209         #Mean Wave height (m) HMEAN
MAX_WAVEANGLE                 80.0           #Max. Absolute Wave Angle (deg): ALMAX
NRUNS_MONTECARLO              3              #NMONTECARLO: Number of Monte Carlo runs (by default =1)
A0_WEIBULL                    0.67697        #AA0: A parameter of a Weibull distribution
B0_WEIBULL                    2.39974        #BB0: B parameter of a Weibull distribution
K0_WEIBULL                    1.10           #FK0: K parameter of a Weibull distribution
HX_THRESHOLD                  2.4363         #HCUT: a nondimensional threadhold value at the trancated point fo
MIN_WAVEHEIGHT                0.100          #HMIN: Minimum wave height (m)
MAX_WAVEHEIGHT                 6.000          #HMAX: Maximum wave height (m)
TURNOFF_MONTECARLO             .False.         #LnoMC: =True, one-time GenCade simulation, = False, GenCade Mon
INCLUDE_XSHORE_SED             .TRUE.         #LONSHOREX: Including cross-shore sediment transport if = .TRUE.
ALPHA_XSHORE                   1.80          #alfa_phi:  Scaling parameter for cross-shore sediment transport
CHANGE_BERMHEIGHT_BY_SLR      .TRUE.         #LEdelman: Change Berm Height based on SLR
CHANGE_BEACHFACE_SLOPE        .TRUE.         #Lslopevarying: change beach face slope with shoreline position
RUN_MONTECARLO_BEACHFILL      .FALSE.        #LbeachfillMC: Conduct Monte-Carlo simulation of beach fill proces
STDRATE_BEACHFILL_WIDTH       0.0            #psigma_bfill: ratio of standard deviation error of berm width to
                                              #for development purpose
GROIN_BYPASS_MODEL            .FALSE.        #LPERMMODEL, =.T. a model to control PERM rate of groin by wave he
MIN_WAVEHEIGHT_PERM           4.0            #H_PERM_MIN: lower bound for applying the PERM model
MAX_WAVEHEIGHT_PERM           6.0            #H_PERM_MAX: a upper bound for applying the PERM model
MIN_PERM_RATE                 0.6            #PERM_MIN: Minimum permeability of a groin in the PERM model
ADD_XSH_LEFTBC                .FALSE.        #LADD_XSH_LEFTBC: =.FALSE., cross-shore rate at the left boundary=
ADD_XSH_RIGHTBC               .TRUE.         #LADD_XSH_RIGHTBC: =.FALSE., cross-shore at the right =0
```

# Input and Control of Monte-Carlo Simulation (GenCade V2.0)

FRF_Shoreline_Study_7.cntmcxsh

```
WAVE_PDF                     2      #IWAVE_PROB=1, Rayleigh Distribution; =2, Rayleigh + Weibull Distri
SLR_RATE                     4.55   #RSLR (mm/yr)
SUBSIDENCE_RATE              0.0    #RSUBSID(mm/year), BFSLOPE0, PHIONSHORE
BEACHFACE_SLOPE              0.01091  #Beach face slope (BFSLOPE0)
DEFAULT_ONSHORE_RATE         0.0      #PHIONSHORE (mm/yr)
MEAN_ANGLE                  -5.0753   #Mean wave angle (deg), "ALMEAN"
STD_ANGLE                    18.48338545     # (ALSIGMA) standard deviation of angle (deg)
MEAN_WAVEHEIGHT              0.8209          #Mean Wave height (m) HMEAN
MAX_WAVEANGLE                80.0            #Max. Absolute Wave Angle (deg): ALMAX
NRUNS_MONTECARLO             3               #NMONTECARLO: Number of Monte Carlo runs (by default =1)
A0_WEIBULL                   0.67697         #AA0: A parameter of a Weibull distribution
B0_WEIBULL                   2.39974         #BB0: B parameter of a Weibull distribution
K0_WEIBULL                   1.10            #FK0: K parameter of a Weibull distribution
HX_THRESHOLD                 2.4363          #HCUT: a nondimensional threadhold value at the trancated
MIN_WAVEHEIGHT               0.100           #HMIN: Minimum wave height (m)
MAX_WAVEHEIGHT                6.000           #HMAX: Maximum wave height (m)
TURNOFF_MONTECARLO            .False.          #LnoMC: =True, one-time GenCade simulation, = False, Gen
INCLUDE_XSHORE_SED            .TRUE.          #LONSHOREX: Including cross-shore sediment transport if =
ALPHA_XSHORE                  1.80           #alfa_phi:  Scaling parameter for cross-shore sediment tra
CHANGE_BERMHEIGHT_BY_SLR     .TRUE.          #LEdelman: Change Berm Height based on SLR
CHANGE_BEACHFACE_SLOPE       .TRUE.          #Lslopevarying: change beach face slope with shoreline pos
RUN_MONTECARLO_BEACHFILL     .FALSE.         #LbeachfillMC: Conduct Monte-Carlo simulation of beach fil
STDRATE_BEACHFILL_WIDTH      0.0             #psigma_bfill: ratio of standard deviation error of berm w
                                              #for development purpose
```

For Beachfill

# New Output File Format for GenCade Monte Carlo

| Shoreline Position at Output Time (*.slo) File | |
|---|---|
| Shoreline Position Output 1 | |
| **Column 1** | **Column 2 through Column NX** |
| Date (yyyymmdd) | Y-position of shoreline (length unit) for each grid cell |
| Shoreline Position Output 2 | |
| **Column 1** | **Column 2 through Column NX** |
| Date (yyyymmdd) | Y-position of shoreline (length unit) for each grid cell |
| Shoreline Position Output …… | |
| **Column 1** | **Column 2 through Column NX** |
| Date (yyyymmdd) | Y-position of shoreline (length unit) for each grid cell |

| Instantaneous Cross-Shore Transport at Output Time (*.xsh) File | |
|---|---|
| **Column 1** | **Column 2 through Column NX** |
| Date (yyyymmdd) | Cross-shore sediment transport ($length^3$/length/year) for each grid cell (+ sign for onshore transport; - sign for offshore transport) |

| Instantaneous Breaking wave Heights (*.hso) File | |
|---|---|
| **Column 1** | **Column 2 through Column NX** |
| Date (yyyymmdd) | Break wave height (m) for each grid cell averaged over entire simulation |

# New Output File Format for GenCade Monte Carlo

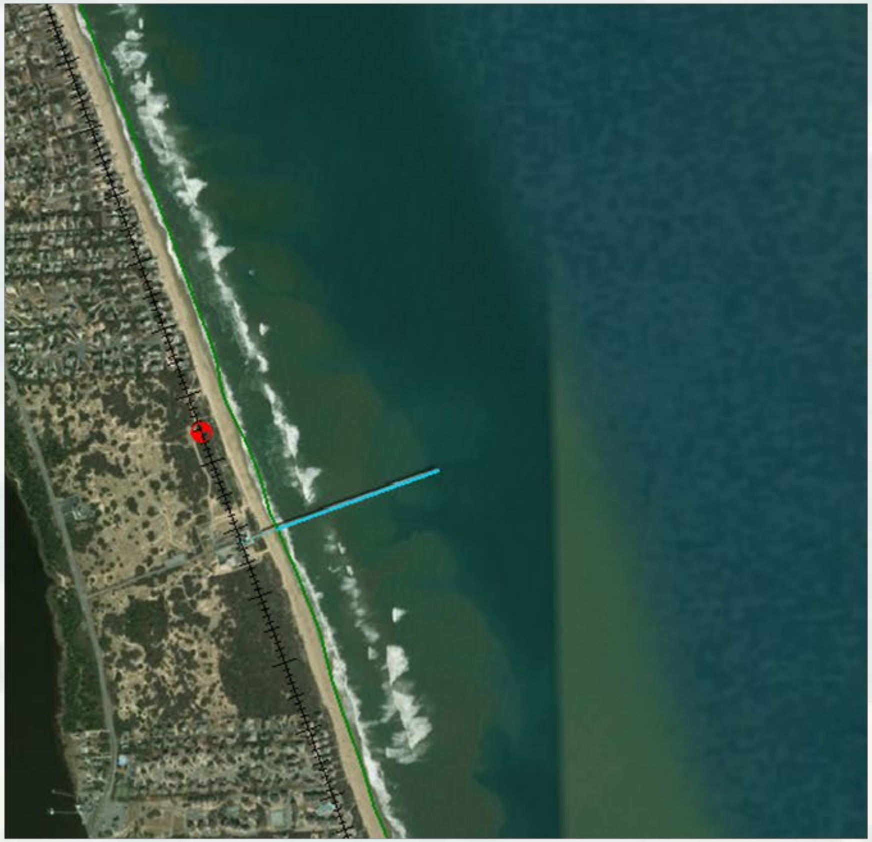
| **Wave_inputs.dat: the time series of offshore waves generated by the given pdf function for each MC run** | | | |
|---|---|---|---|
| No. of MC Run Total Number of MC Run | | | |
| Date (yyyymmdd) | Wave Height (m) | Wave Period (s) | Wave Direction (degree) |

| **LandwardMost.dat: The landwardmost shoreline positions for each MC run** |
|---|
| No. of MC Run Total Number of MC Run Total Cell Number (NX) |
| Y-position of shoreline (length unit) for each grid cell |

| **SeawardMost.dat: The seawardmost shoreline positions for each MC run** |
|---|
| No. of MC Run Total Number of MC Run Total Cell Number (NX) |
| Y-position of shoreline (length unit) for each grid cell |

| **Finalshoreline.dat: The shoreline positions at the end of simulation for each MC run** |
|---|
| No. of MC Run Total Number of MC Run Total Cell Number (NX) |
| Y-position of shoreline (length unit) for each grid cell |

# Monte Carlo Simulation of Shoreline Change in Duck, NC



FRF in Duck, NC

Number of Monte Carlo = **128**

**Wave Conditions:**

- **Wave Height: Rayleigh+Weibull**
- **Direction: Gaussian**
- **Period: PM Spectrum**
- **Truncated Wave Height: 2.0 m**

Computational Period: 6 years

1999/10/23 0:00 - 2005/10/23 0:00

time step = 3 minutes

K1 = 0.40; K2 = 0.25

Grain size = 0.20 mm

Berm Height = 1.0 m

Closure depth = 7.0

Sea Level Rise Rate = 4.55 mm/year

Smooth parameter = 1 (no smoothing)

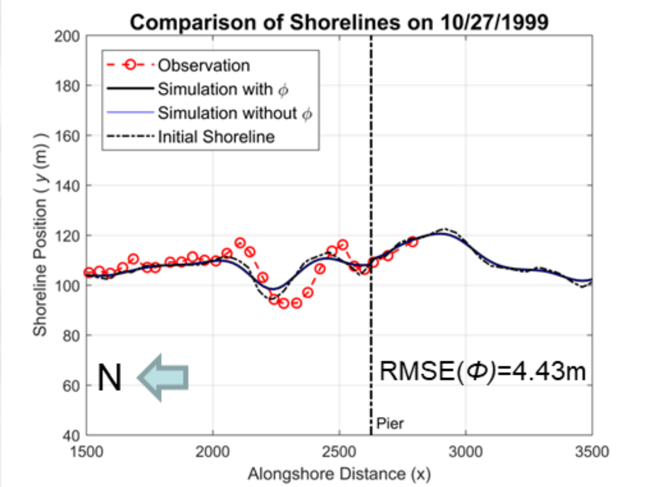
Boundary Conditions: Pined

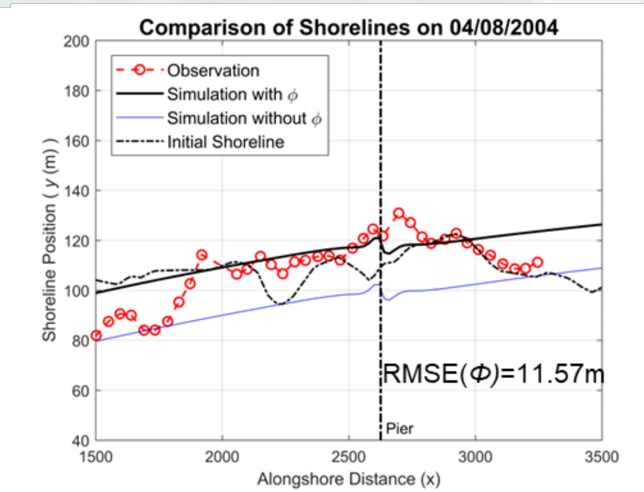
Grid Size = 20 m

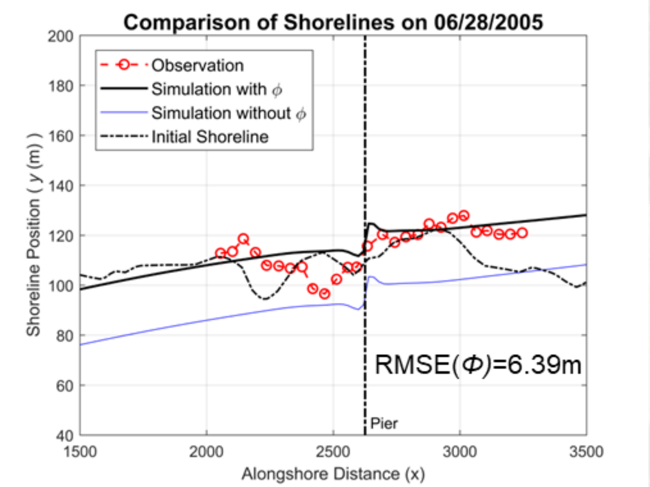
Permeability of Pier = 0.6 (no diffracting)

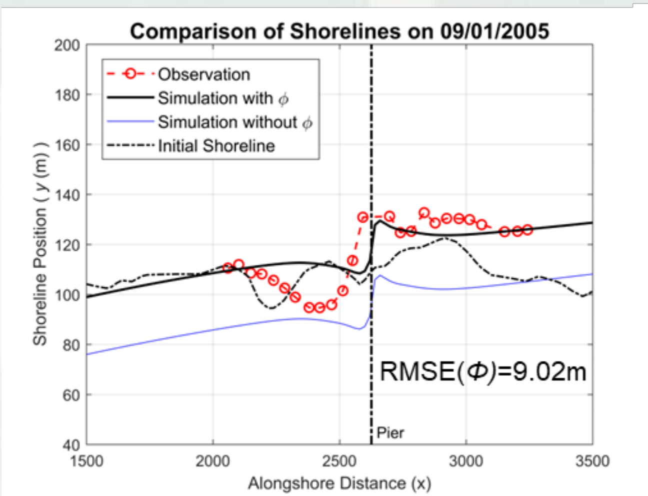
Scaling parameter of cross-shore transport: 0.182

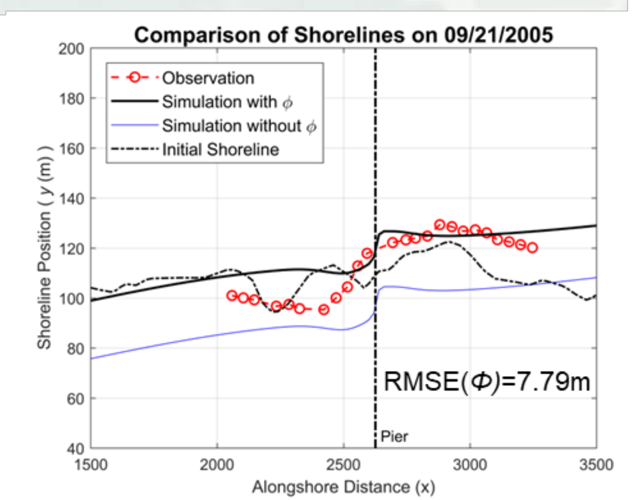
# Model Validation -Determine System Errors

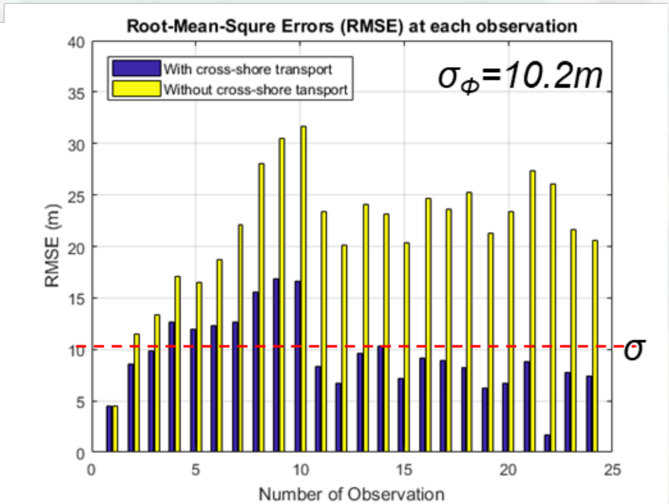


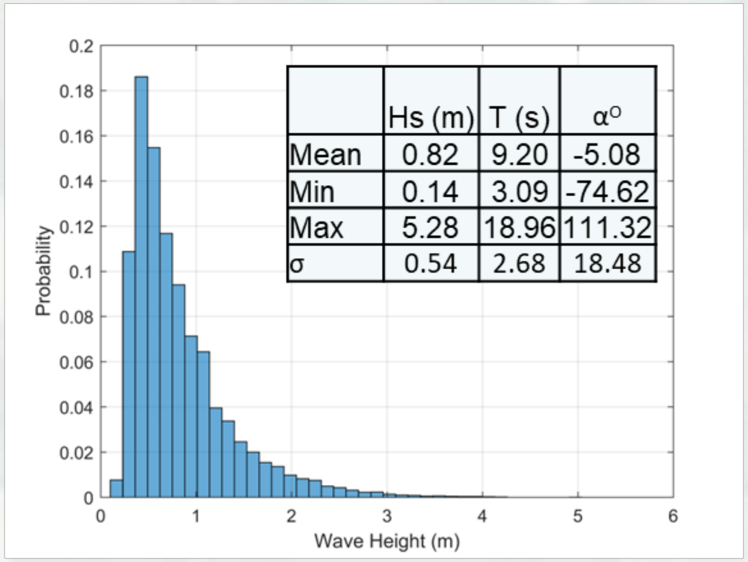



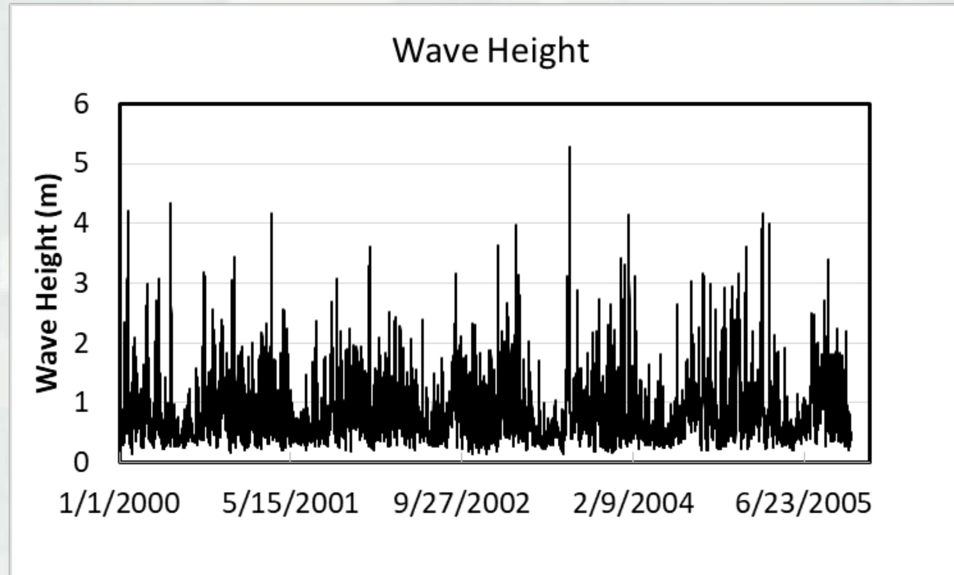



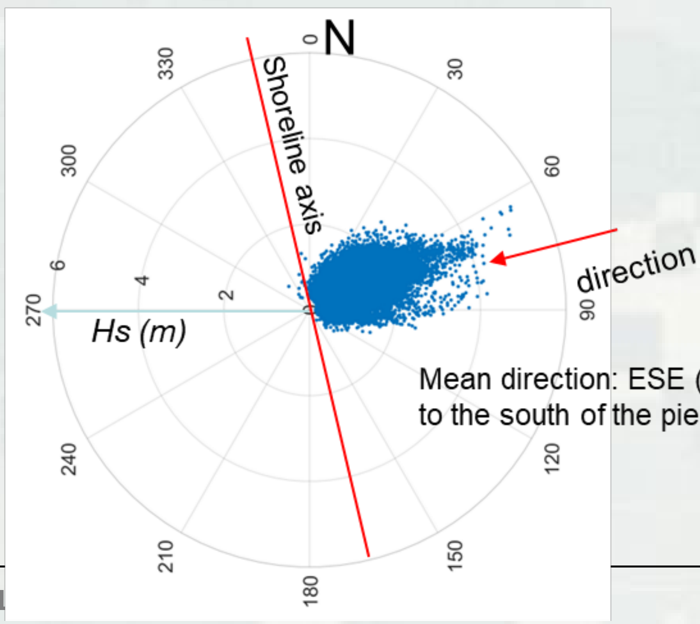



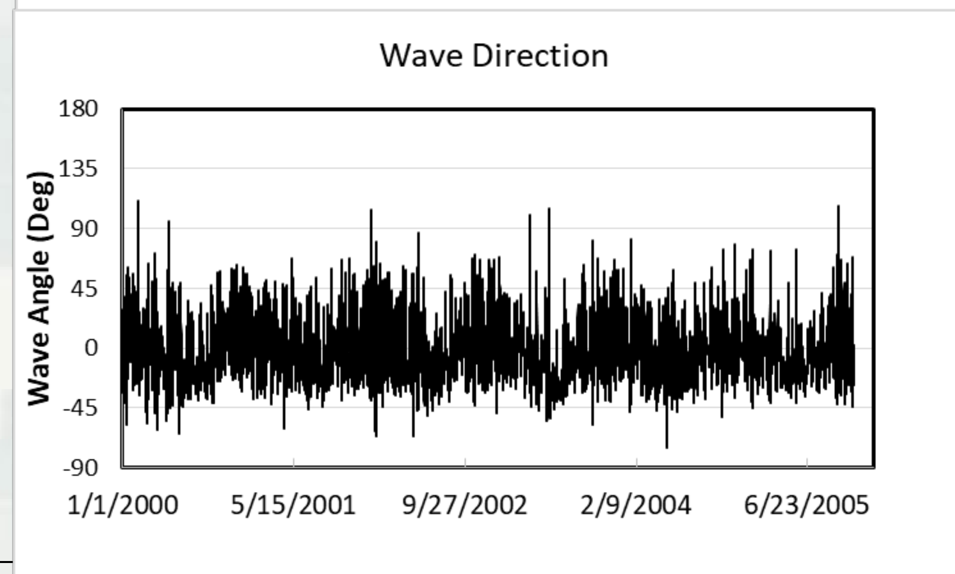
# Wave Data for Creating PDFs




| | Hs (m) | T (s) | α° |
|---|---|---|---|
| Mean | 0.82 | 9.20 | -5.08 |
| Min | 0.14 | 3.09 | -74.62 |
| Max | 5.28 | 18.96 | 111.32 |
| σ | 0.54 | 2.68 | 18.48 |



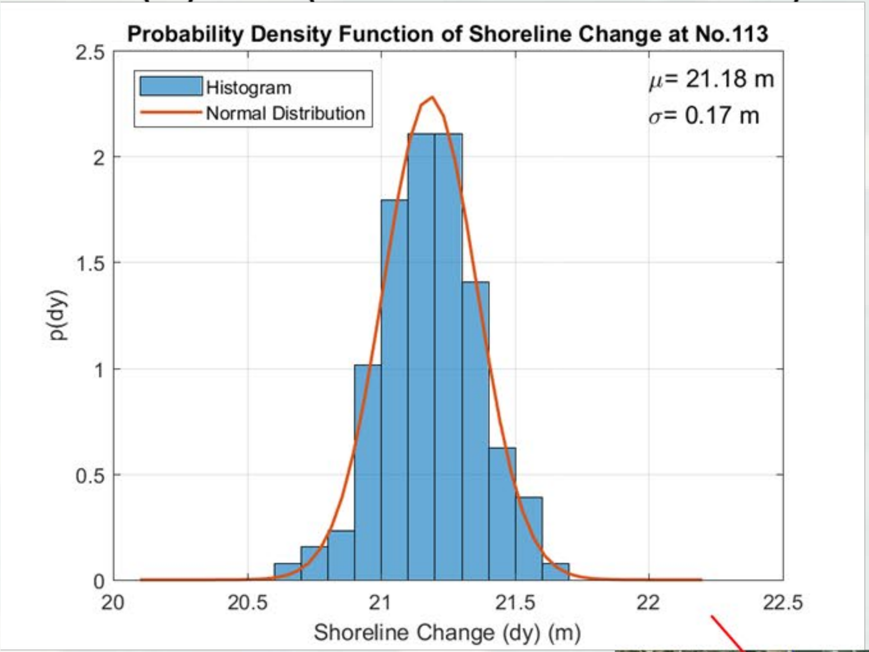



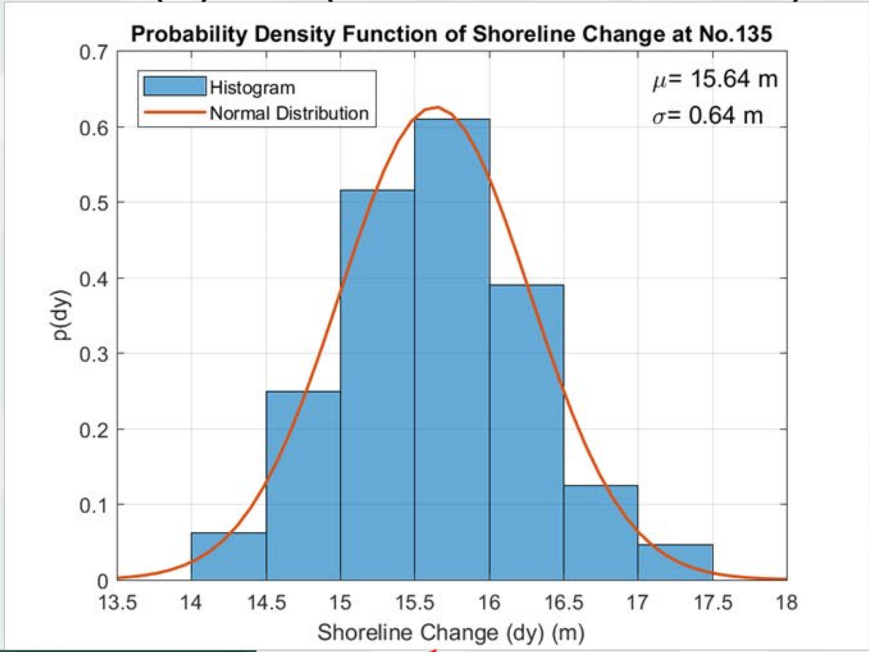



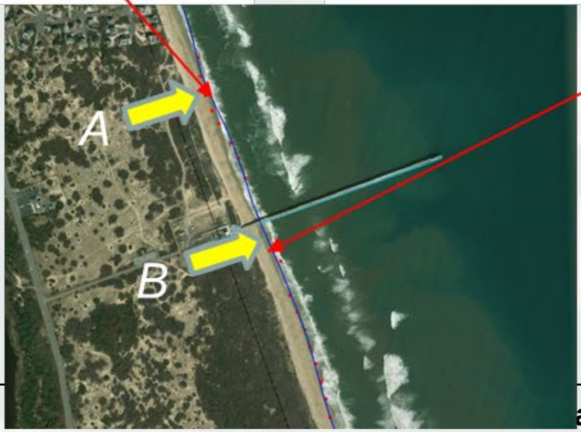
# Probability Density Functions: 6-Years Shoreline Change

(a) at A (400-m north from Pier)

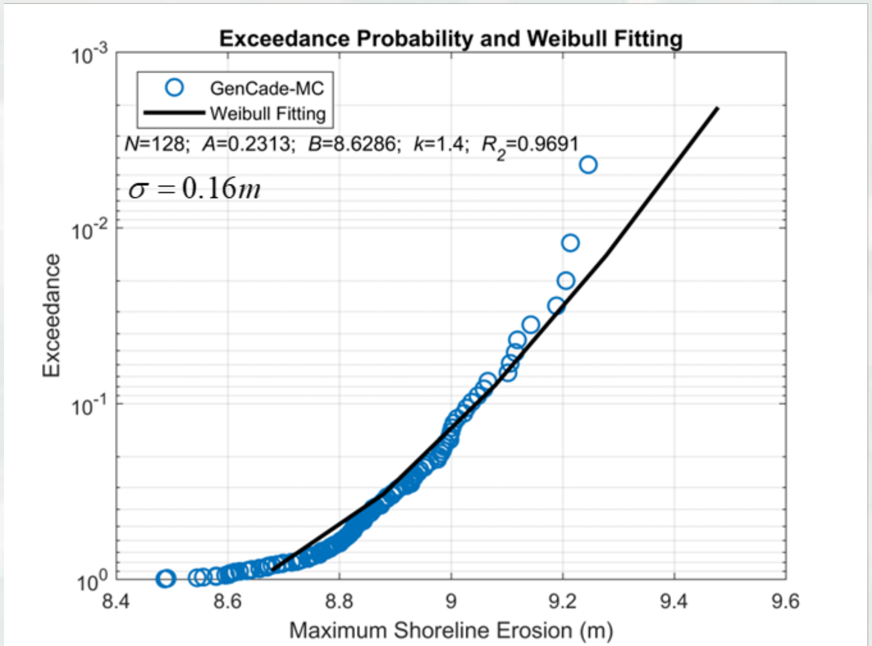
(b) at B (40-m south from Pier)

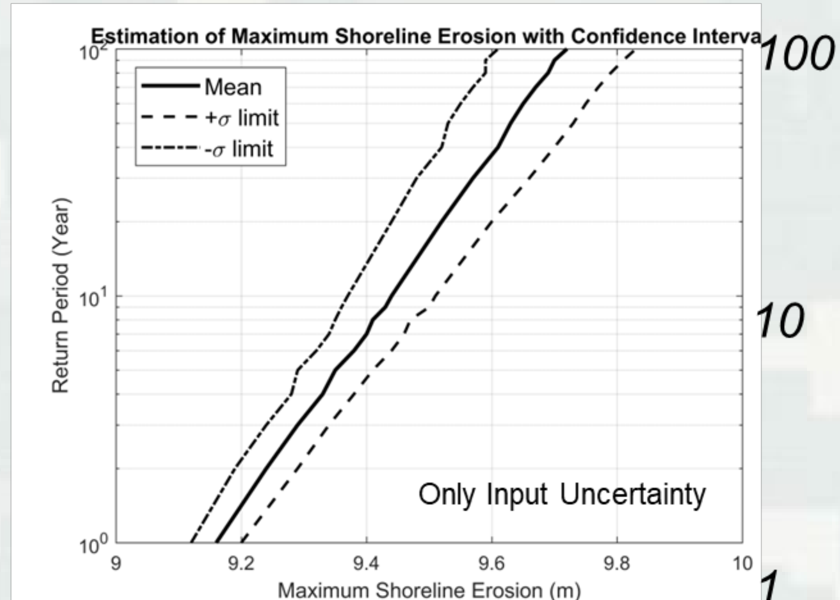


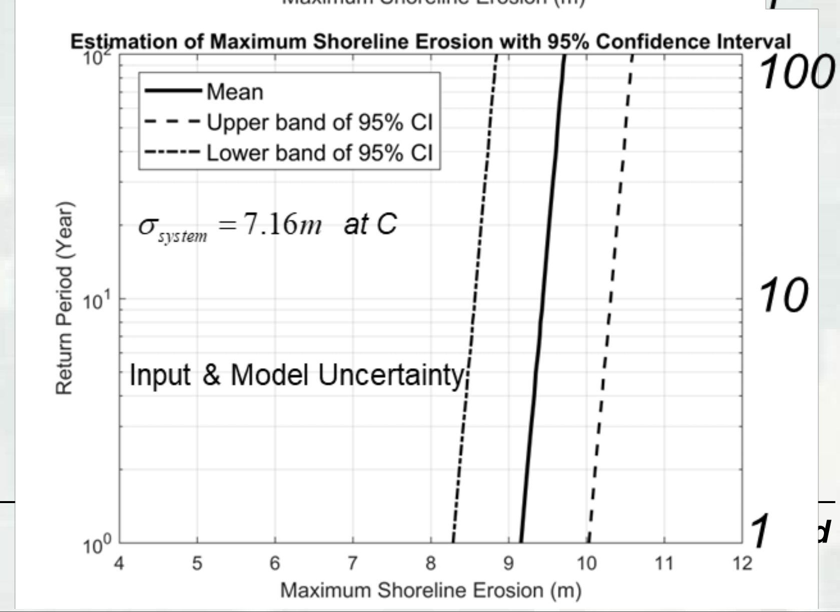



# Uncertainty Estimation of Maximum Erosion at Point C



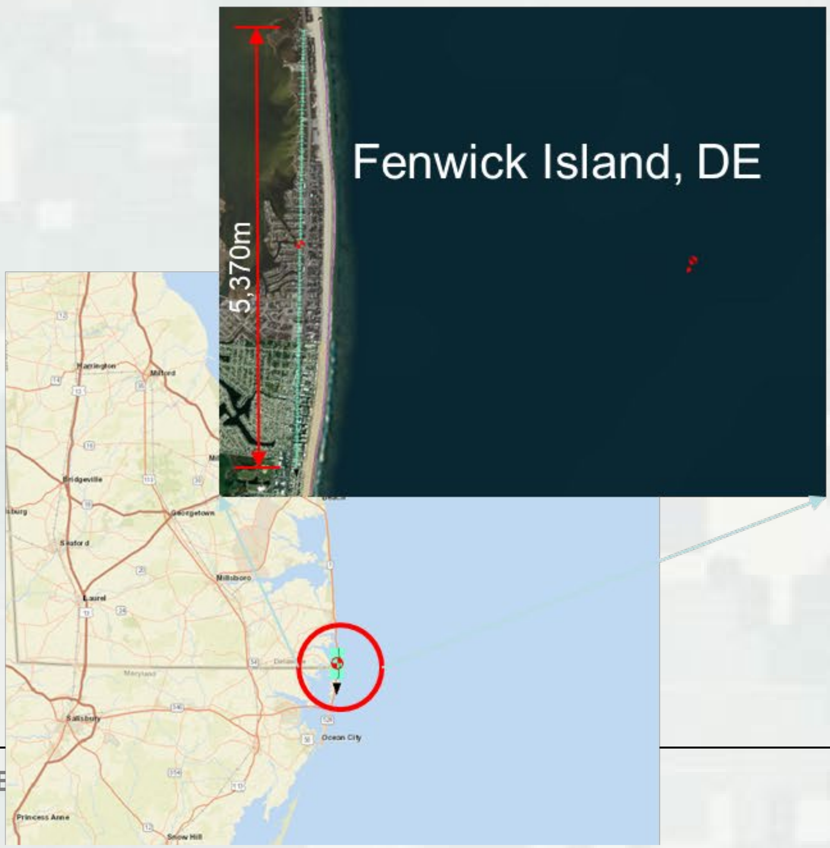




# Monte-Carlo Simulation for Beach Fill

# 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

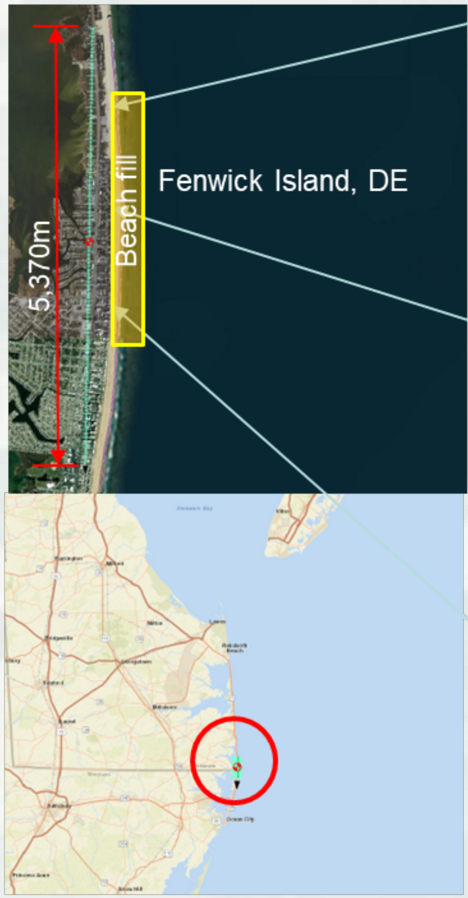
Wave: WIS **Station ID: 63160**

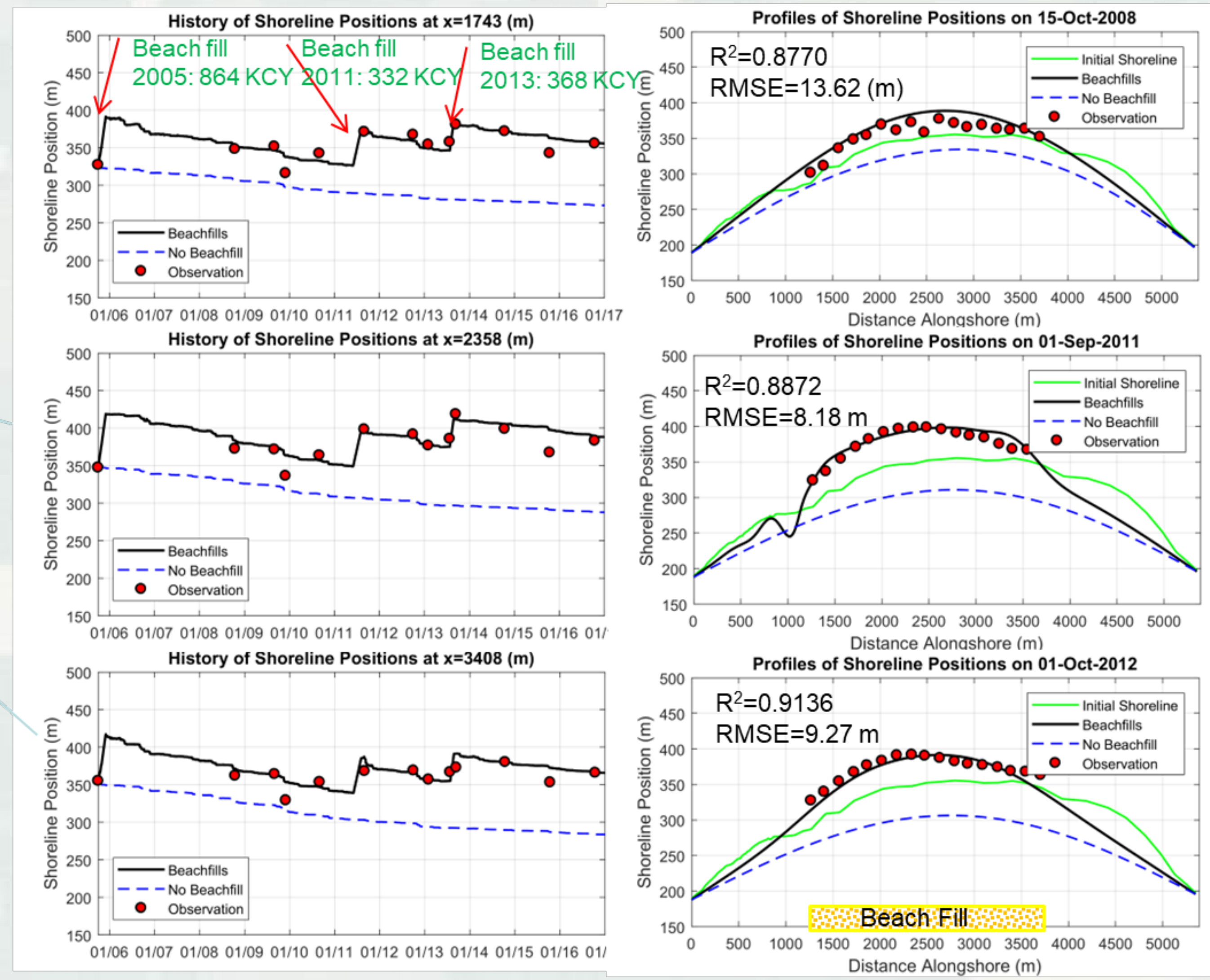
Time step = 3 minutes
Grain size = 0.30 mm
Berm Height = 1.0 m
Closure depth = 10.0m
Smooth parameter = 1 (no smoothing)
No regional contour
Boundary Conditions: Moving (retreat 2.5 ft/year)
Grid Size = 20 m
Sea Level Rise rate: 4.50mm/year (based on tide gauges)
Subsidence : included

Calibrated Model Parameters:
K1 = 0.90
K2 = 0.35

# Long-term Shoreline Change in Fenwick Island, DE

- 12-year Shoreline Changes (2005-2017)
- Periodical beach fills : 2005, 2011, & 2013

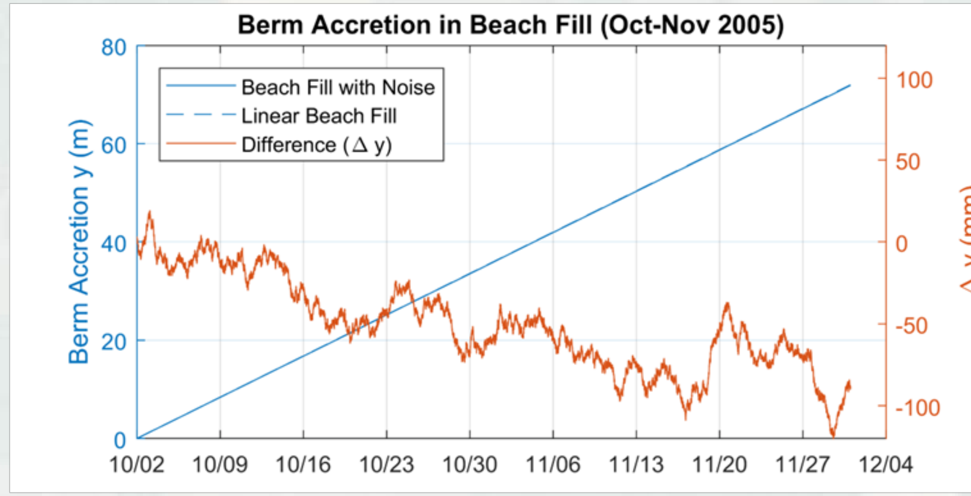


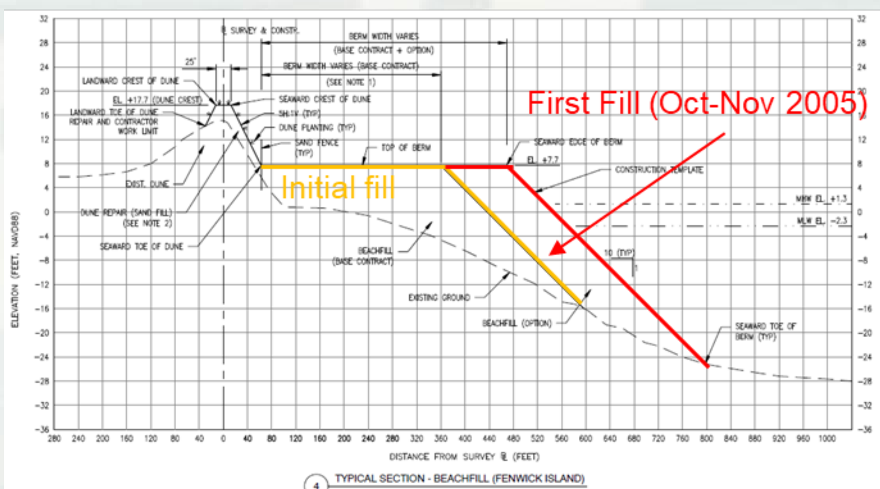



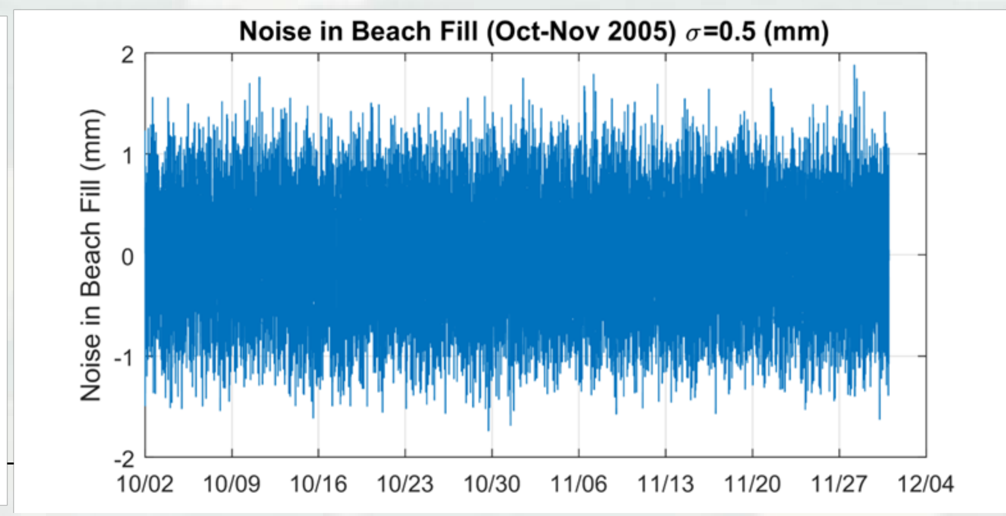
# Uncertainty due to Beach Fill ($\Delta y(t)$)

Beach fill (Δy) = Planned Beach Fill ($\overline{\Delta y}(t)$ )+ White Noise

$$\Delta y(t) = \overline{\Delta y}(t) + N(0, \sigma^2)$$

# Input and Control of Monte-Carlo Simulation (GenCade V2.0)

Fenwick_2005_prefill.cntmcxsh

```
WAVE_PDF                    2      #IWAVE_PROB=1, Rayleigh Distribution; =2, Rayleigh + Weibull Distributio
SLR_RATE                    4.55   #RSLR (mm/yr)
SUBSIDENCE_RATE             0.0    #RSUBSID(mm/year), BFSLOPE0, PHIONSHORE
BEACHFACE_SLOPE             0.01091  #Beach face slope (BFSLOPE0)
DEFAULT_ONSHORE_RATE        0.0      #PHIONSHORE (mm/yr)
MEAN_ANGLE                 -5.0753   #Mean wave angle (deg), "ALMEAN"
STD_ANGLE                   18.48338545    # (ALSIGMA) standard deviation of angle (deg)
MEAN_WAVEHEIGHT             0.8209         #Mean Wave height (m) HMEAN
MAX_WAVEANGLE               80.0           #Max. Absolute Wave Angle (deg): ALMAX
NRUNS_MONTECARLO            3              #NMONTECARLO: Number of Monte Carlo runs (by default =1)
A0_WEIBULL                  0.67697        #AA0: A parameter of a Weibull distribution
B0_WEIBULL                  2.39974        #BB0: B parameter of a Weibull distribution
K0_WEIBULL                  1.10           #FK0: K parameter of a Weibull distribution
HX_THRESHOLD                2.4363         #HCUT: a nondimensional threadhold value at the trancated point
MIN_WAVEHEIGHT              0.100          #HMIN: Minimum wave height (m)
MAX_WAVEHEIGHT               6.000          #HMAX: Maximum wave height (m)
TURNOFF_MONTECARLO           .TRUE.         #LnoMC: =True, one-time GenCade simulation, = False, GenCade Mo
INCLUDE_XSHORE_SED           .FALSE.         #LONSHOREX: Including cross-shore sediment transport if = .TRU
ALPHA_XSHORE                 1.80           #alfa_phi:  Scaling parameter for cross-shore sediment transport
CHANGE_BERMHEIGHT_BY_SLR    .TRUE.         #LEdelman: Change Berm Height based on SLR
CHANGE_BEACHFACE_SLOPE      .TRUE.         #Lslopevarying: change beach face slope with shoreline position
RUN_MONTECARLO_BEACHFILL    .TRUE.        #LbeachfillMC: Conduct Monte-Carlo simulation of beach fill proce
STDRATE_BEACHFILL_WIDTH     0.2           #psigma_bfill (m): ratio of standard deviation error of berm widt
```

Ratio of standard deviation (σ) to the beachfill increment at each time step (Δt)

For Beachfill

# New Output File Format for GenCade Monte Carlo

| Randsample_Yadd.dat: the time series of beachfill increment at each time step | | | |
|---|---|---|---|
| No. of MC Run Total Number of MC Run | | | |
| Date (yyyymmdd) | Beachfill Increment without noise | Noise | Beachfill increment with noise |

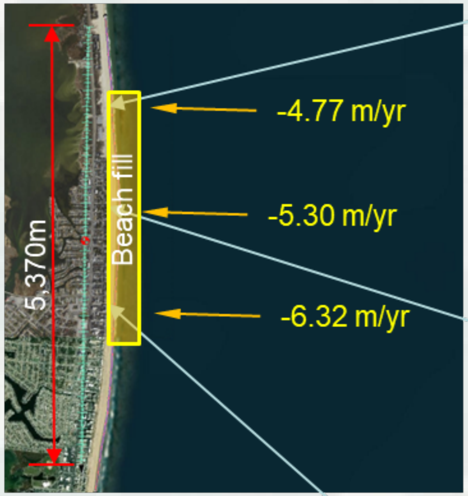
| LandwardMost.dat: The landwardmost shoreline positions for each MC run |
|---|
| No. of MC Run Total Number of MC Run Total Cell Number (NX) |
| Y-position of shoreline (length unit) for each grid cell |

| SeawardMost.dat: The seawardmost shoreline positions for each MC run |
|---|
| No. of MC Run Total Number of MC Run Total Cell Number (NX) |
| Y-position of shoreline (length unit) for each grid cell |

| Finalshoreline.dat: The shoreline positions at the end of simulation for each MC run |
|---|
| No. of MC Run Total Number of MC Run Total Cell Number (NX) |
| Y-position of shoreline (length unit) for each grid cell |

# Uncertainty-Based Assessment of Beachfill Effect (1)

- 12-year Shoreline Changes (2005-2017)
- Periodical beach fills : 2005, 2011, & 2013

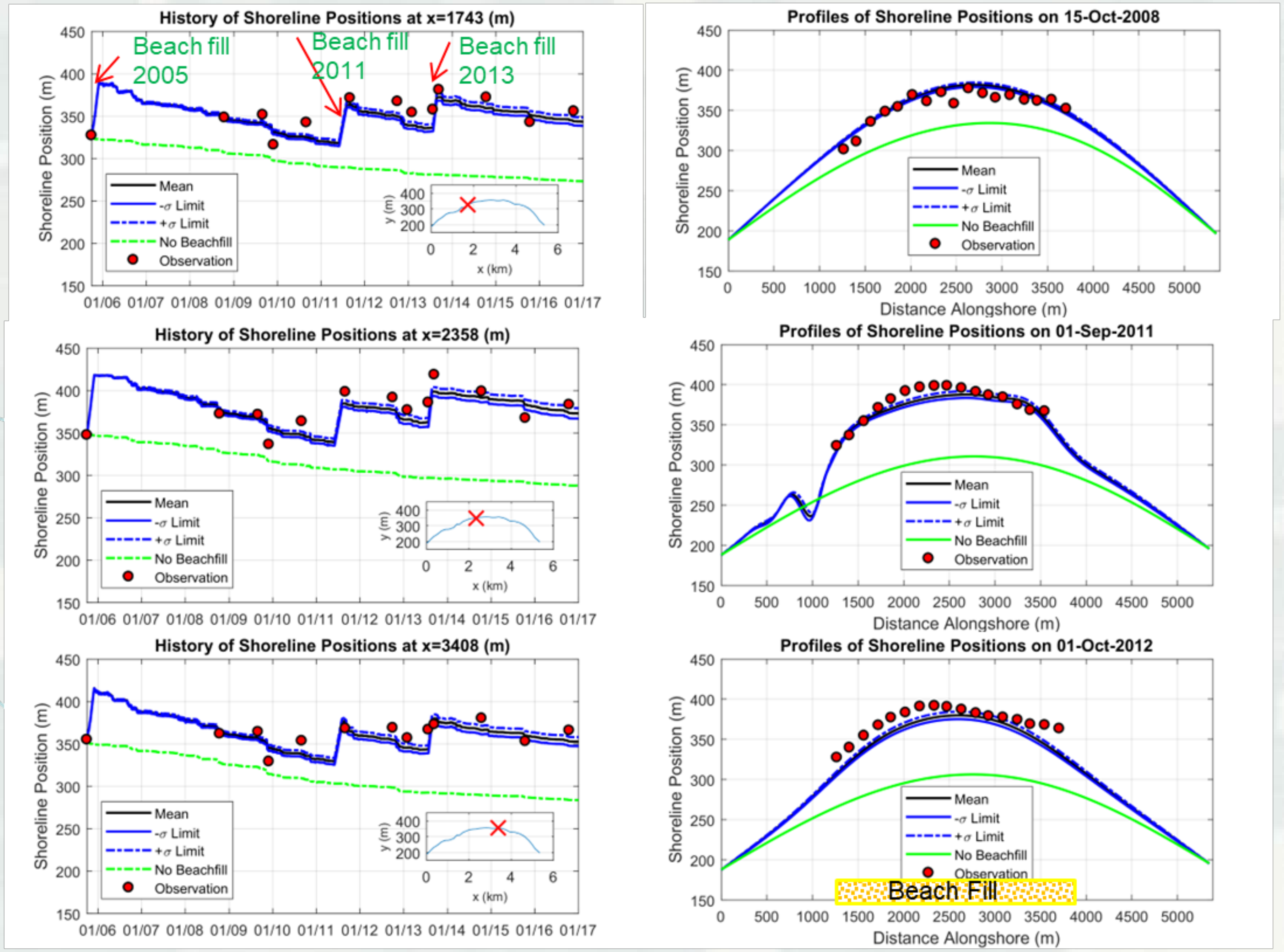



Fenwick Island, DE

- Shoreline retreat rate without beachfill:

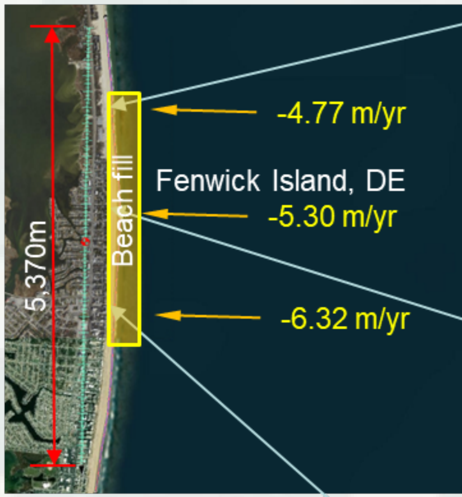
  4.77~6.32 m/yr or

  15.65~20.73 ft/yr



# Uncertainty-Based Assessment of Beachfill Effect (2)

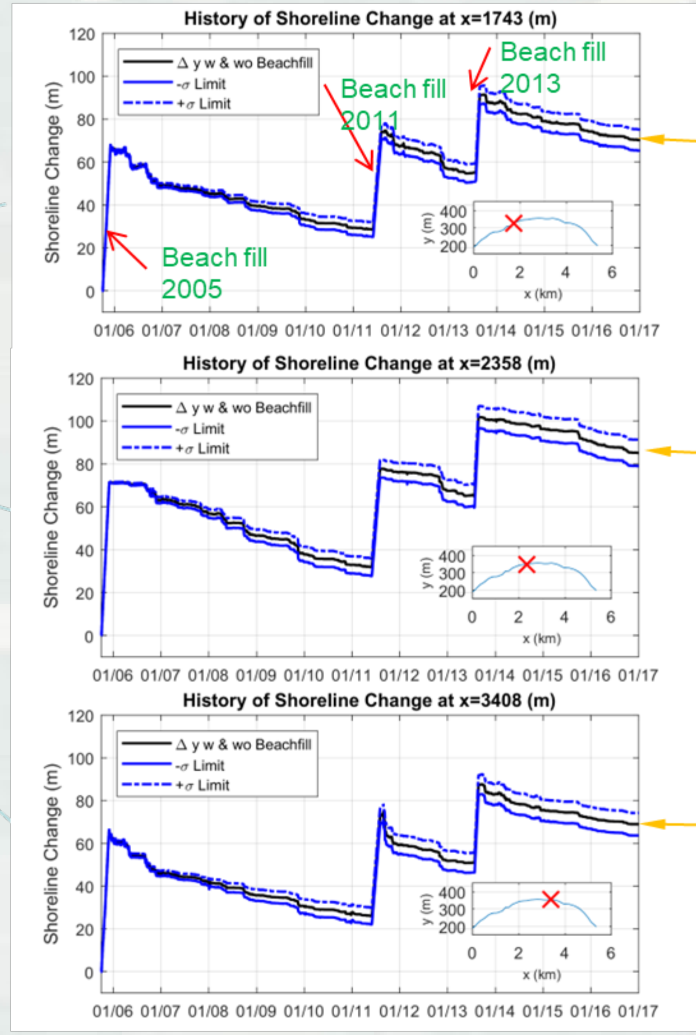
- 12-year Shoreline Changes (2005-2017)
- Periodical beach fills : 2005, 2011, & 2013




- Shoreline retreat rate without beachfill:

  4.77~6.32 m/yr or

  15.65~20.73 ft/yr




After 11 years Shoreline advanced by beachfill

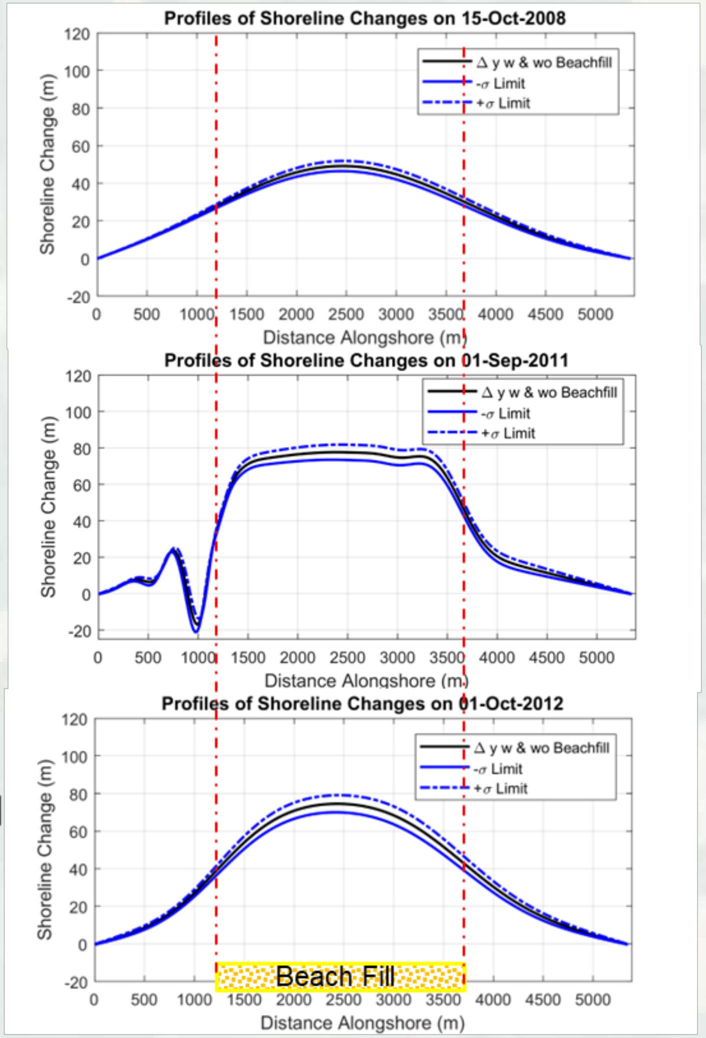
$+70.21 \pm 4.92$m

$+85.06 \pm 6.13$m

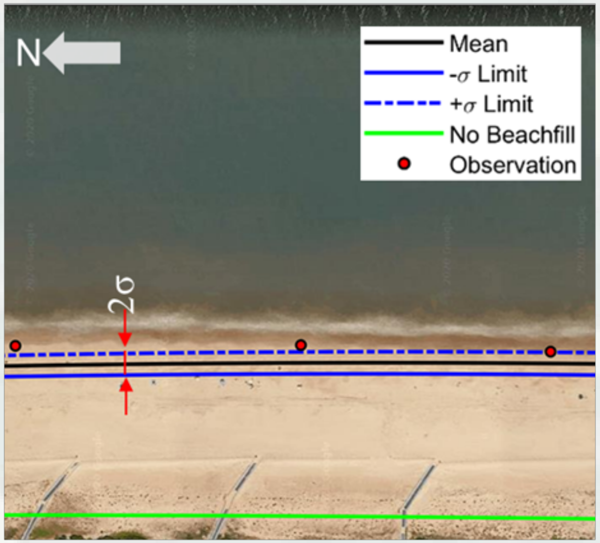
$+68.90 \pm 5.27$m

# Uncertainty-Based Assessment of Beachfill Effect (3)

- 12-year Shoreline Changes (2005-2017)
- Periodical beach fills : 2005, 2011, & 2013


**Uncertainty in Beach Change before/after Beach Nourishment**




➢ Uncertainty of beachfill effect (gain) varies along the beach!

# New Feature Demo

- Cross-shore Transport and Shoreline Change in Duck Coast, NC
  Folder: \FRF_Cross_shore

- GenCade Monte-Carlo Simulation in Duck Coast
  Folder: \FRF_Monte_Carlo_GenCade

- Beachfill Uncertainty in Fenwick Island, DE
  Folder: \Fenwick_Beachfill_GenCade_MC

Code: GenCade_v2p0_XshMC.exe

Run the code using the DOS Command Prompt in Windows

# References


- Abreu, T., Silva, P.A., Sancho, F. and Temperville, A., (2010). Analytical approximate wave form for asymmetric waves. Coastal Engineering, 57(7), pp. 656-667
- Bruun, P., (1962). Sea-level rise as a cause of shore erosion. J. Waterway. Harbours Div. 88: 117–130.
- Birkemeier, W. A. and Thornton, E. B., (1994), The DUCK94 Nearshore Field Experiment, Proceedings of the Conference on Coastal Dynamics '94, 815-821.
- Fernández-Mora, A., Calvete, D., Falqués, A., and de Swart, H. E., (2015). Onshore sandbar migration in the surf zone: New insights into the wave-induced sediment transport mechanisms. Geo. Phys. Res. Ltrs., 10.1002/2014GL063004, 2869-2877.
- FRF (2019). FRF 8m Linear Array Directional Waves, http://www.frf.usace.army.mil/dksrv/dk94/frf/FRF8m.html, accessed on Jan. 22, 2019.
- Rosati, J.D., Dean, R.G., and Walton, T.L. (2013). The modified Bruun rule extended for landward transport, Mar. Geol. 340, 71-81.
- Ruessink, B. G., Ramaekers, G., and van Rijn, L. C., (2012). On the parameterization of the free-stream non-linear wave orbital motion in nearshore morphodynamic models. Coastal Engineering, 65(7), pp. 56-63.
- Thornton, E., Humiston, R., Birkemeier, W., (1996). Bar-trough generation on a natural beach. J. Geophys. Res 101, 12097–12110.

# Recent Publications on GenCade


- Frey, A. E., Connell, K. J., Hanson, H., Larson, M., Thomas, R. C., Munger, S., Zundel, A., (2012) *GenCade version 1 Model theory and user's guide*. US Army, Engineer Research and Development Center, ERDC/CHL TR-12-25, 169 pp.
- Ding, Yan, Kim, Sung-Chan, and Frey, Ashley, (2018). Probabilistic Shoreline Evolution Modeling in Response to Sea Level Changes, In Proceedings of the ASCE-EWRI 2018 Congress, June 3-7, 2018, Minneapolis, NM, 13p. (https://doi.org/10.1061/9780784481424.021)
- Ding, Y., Kim, S.-C., Frey, A.E., Permenter, R. L., and Styles, R. (2018). Probabilistic modeling of long-term shoreline changes in response to sea level rise and waves, In: Scour and Erosion IX: Proceedings of the 9th International Conference on Scour and Erosion, K.-C. Yeh Ed., pp203-211, Taylor & Francis Group, London, ISBN 978-0-367-07467-8
- Ding, Y., Kim, S.-C., Permenter, R.L., Styles, R., and Beck, T.M. (2019). Cross-shore sediment transport for modeling long-term shoreline changes in response to waves and sea level changes, In: Proceedings of Coastal Sediment 2019.
- Ding, Y., Styles, R., Kim, S.-C., Permenter, R.L., and Frey A.E. (2021a). 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
- Ding, Y., S. C. Kim, R. Permenter, R. Styles, and Gebert, J. A. (2021b). 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

# Thank you for your attention!

Yan Ding, Ph.D. Yan.Ding@usace.army.mil

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

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