Inner Surf/Swash Zone Morphodynamics:

Numerical Model Simulation of an Accreting Ridge during Low-Energy Wave Conditions

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OUTLINE

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BACKGROUND

FIELD EXPERIMENT

CSHORE NUMERICAL MODELING

RESULTS

BACKGROUND: INTERTIDAL BARS

Ridge-Runnel (RR) System

- Dynamic intertidal bar and trough system
- Forms usually right after storm
- Migrates onshore carrying sediment landwards
- Assessment for beach recovery process/ coastal sediment budget


NOAA

Ridge-Runnel System with Rip Channel Vero Beach, FL


Rip current on South Bethany, DE

Longshore uniform ridge-runnel system at South Bethany, DE, USA


DNREC

BACKGROUND: INTERTIDAL BARS

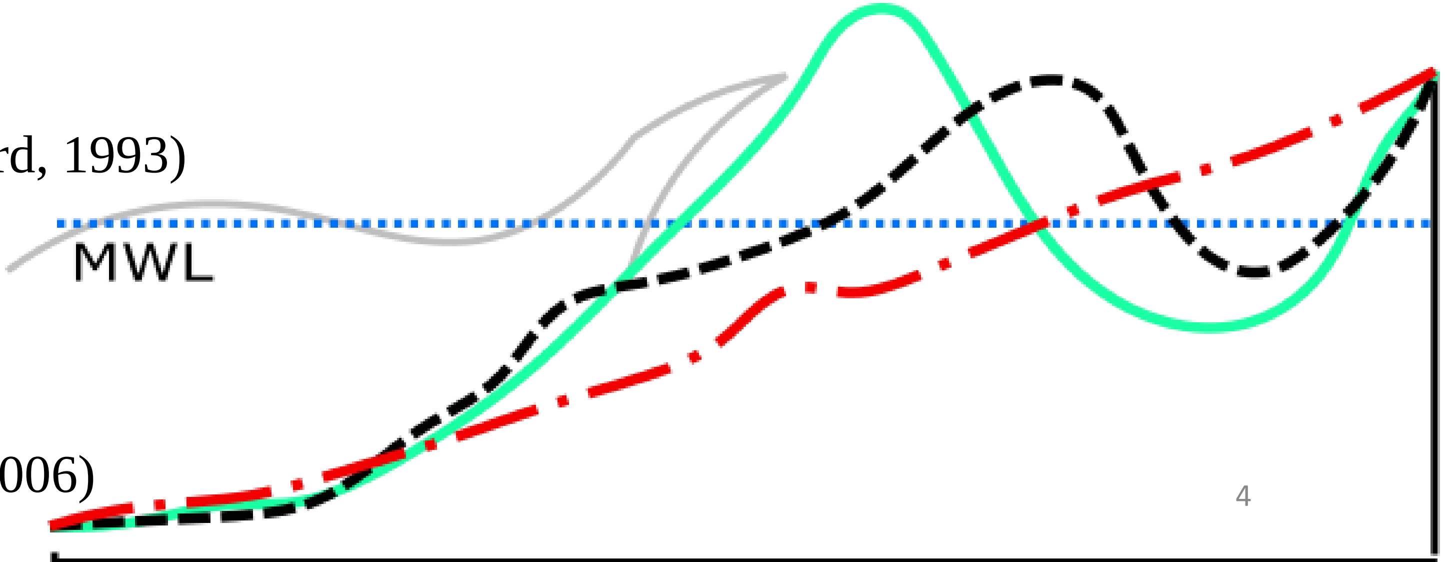
Ridge-Runnel (RR) System

Formation and migration:

- **Tidal range**
  (Davis et al., 1972; Wijnberg and Kroon, 2002)
- **Emergence level of bar crest**
  (Dawson et al., 2002, Aagaard et al., 1998)
- **Incident wave energy level**
  (Kroon and Masselink, 2002)
- **Bottom slope**
  (Davidson-Arnott, 1988; Short and Aagaard, 1993)
- **Sediment flux and supply volume**
  (Łabuz, 2013; Blenkinsopp et al., 2011)
- **Infilling and migration**

(Houser and Greenwood, 2007; Aagaard et al., 2006)

Wave overwash and ridge migration (Figlus et al., 2012)



FIELD MEASUREMENT

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South Bethany Beach, Delaware,USA

- Steep, meso-tidal beach with a semi-diurnal tide
- Engineered beach with frequent re-nourishment

- Field campaign

  February 12 to 25, 2014 (2 weeks incl. storm)

  = 36 tidal cycles

  21 wading-depth profiles
  (incl. pre- and post- storm)

  Measurement in the swash zone:
  - velocity profiles, water depth
  - suspended sediment concentration
  - beach profile survey

FIELD MEASUREMENT

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NOR'EASTER – VALENTINE'S DAY 2014

FIELD MEASUREMENT

Wave & Tidal Water Level

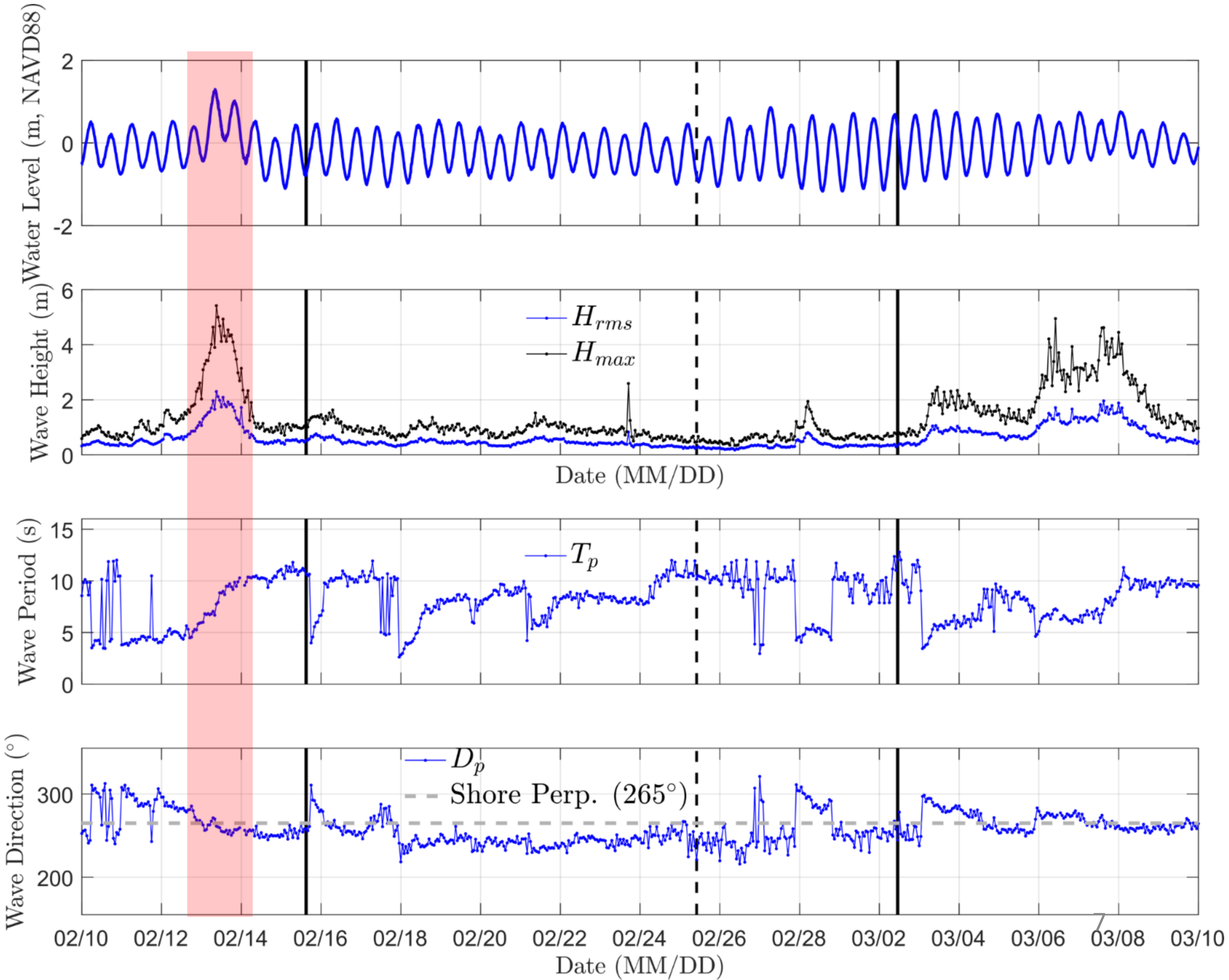
<u>Nor'easter (Feb. 14, 2014)</u>

S_{max} = 1.3 m (NAVD88)

H_{max} = 5.4 m (H_{rms} = 2.3 m)

T_p = 10 s

θ_p = shore-perpendicular



FIELD MEASUREMENT

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T_p = 10 s

θ_p = shore-perpendicular

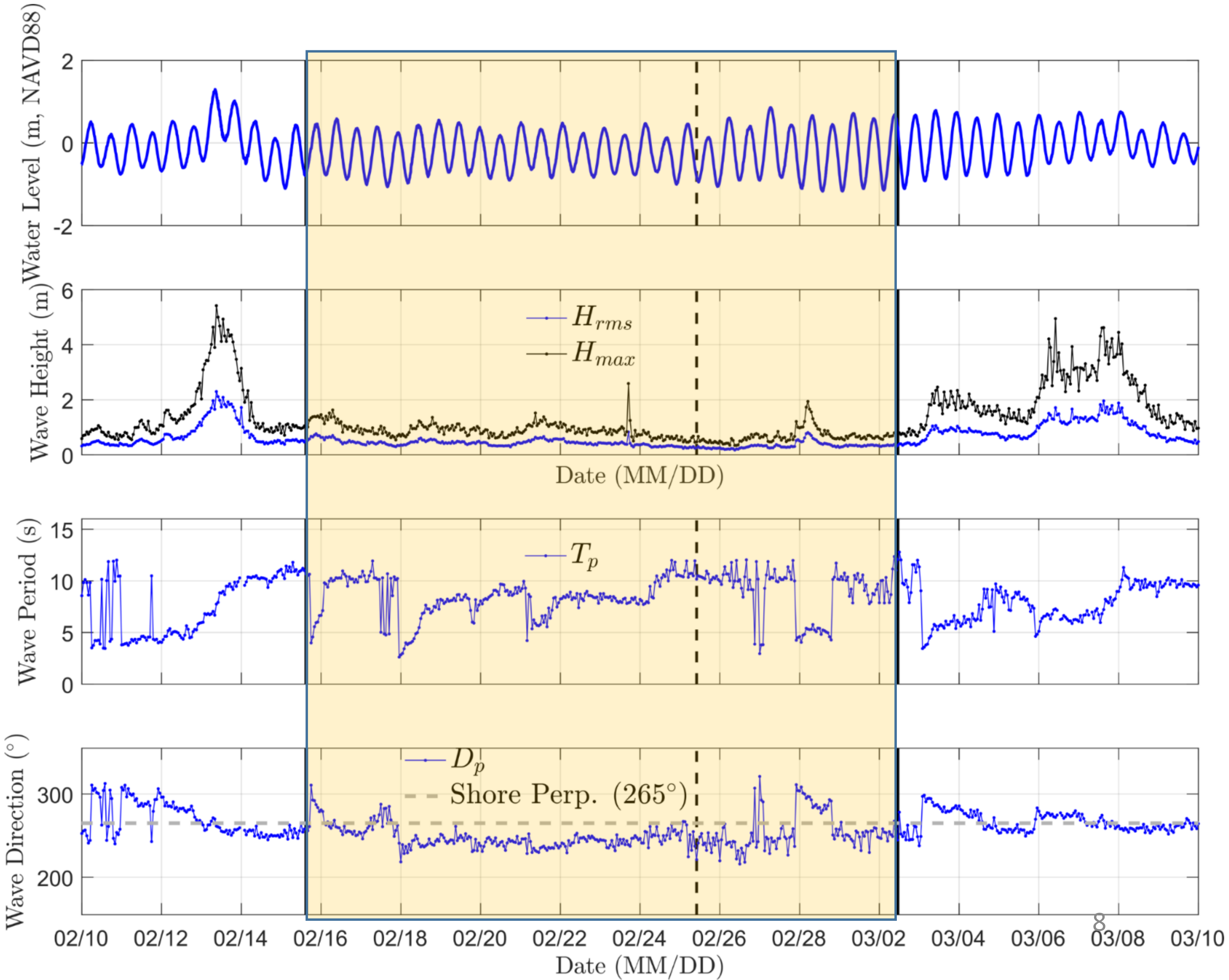
<u>Post-storm recovery (Feb. 15-Mar. 2, 2014)</u>

S_{avg} = -0.2 m (NAVD88)

$H_{rms,avg}$ = 0.4 m

T_p = 6 s

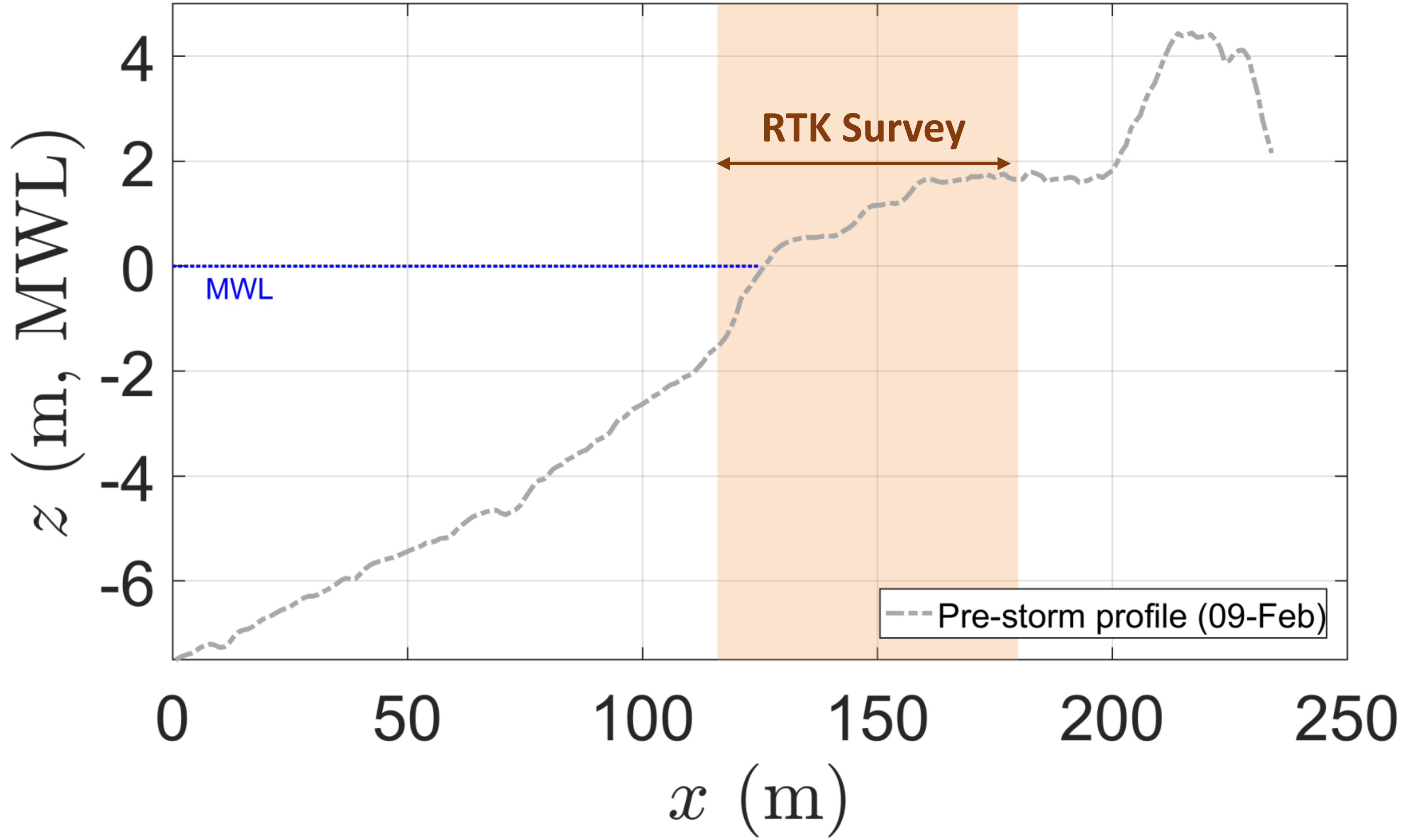
θ_p = southwest heading

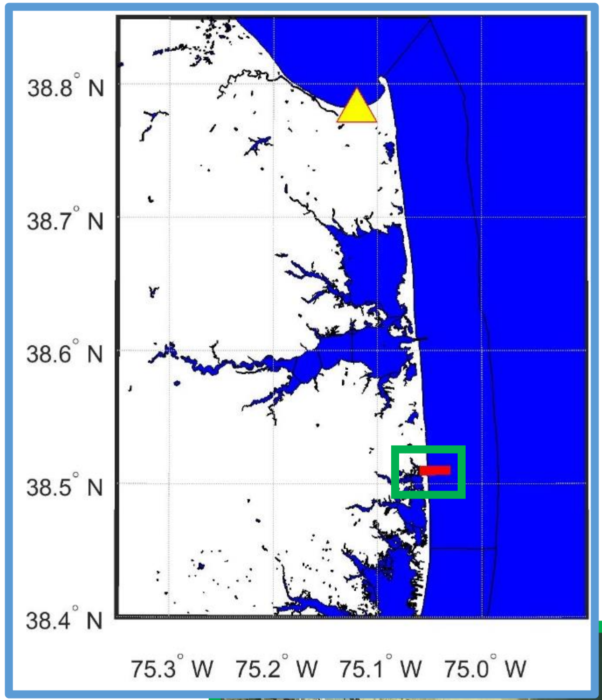


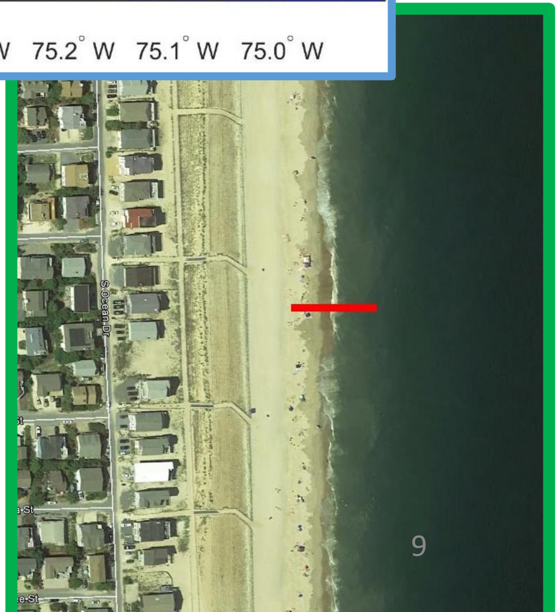
FIELD MEASUREMENT

Beach Profiles: Real-Time kinematic (RTK) Survey

Beach profile data were collected twice per day around low tide







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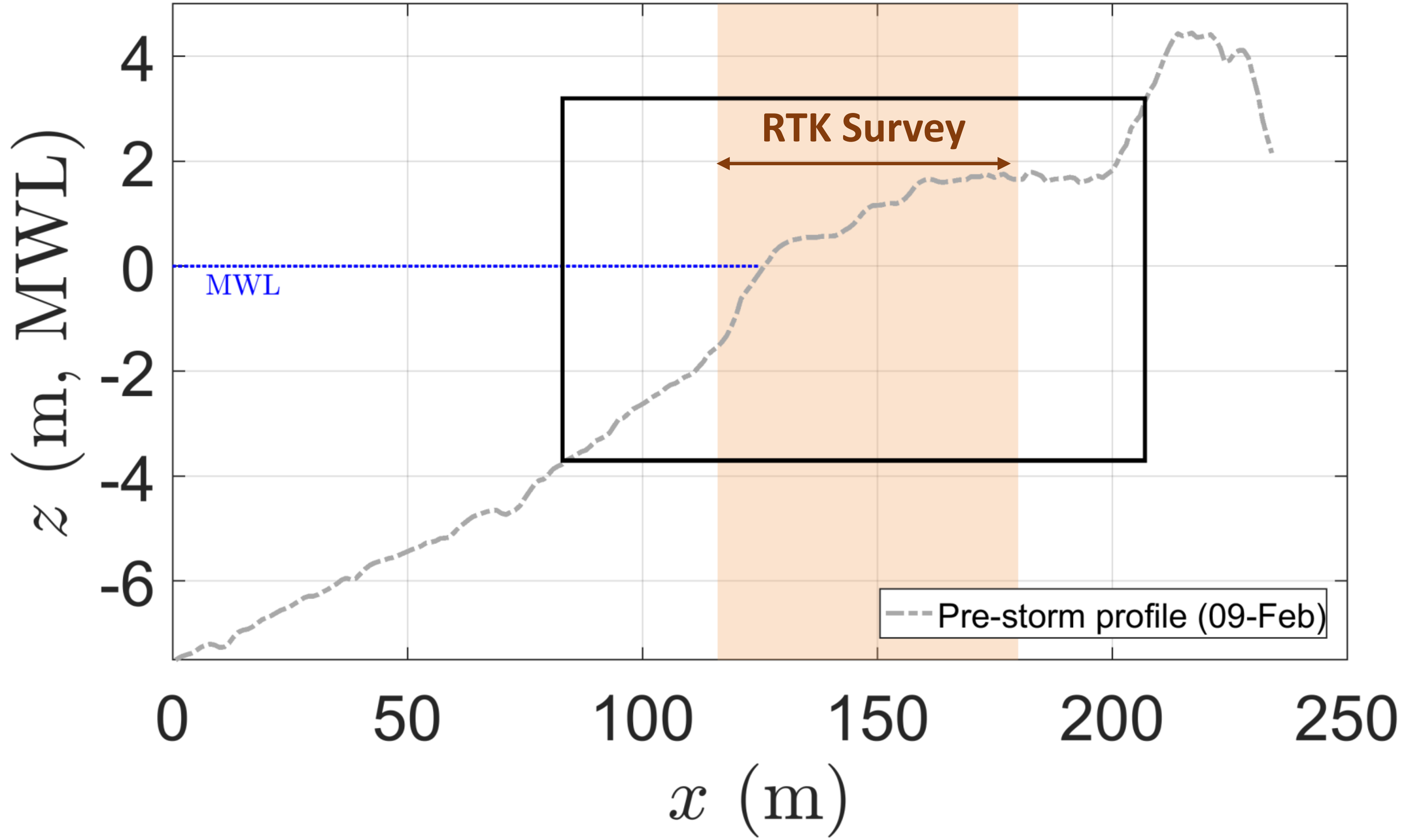

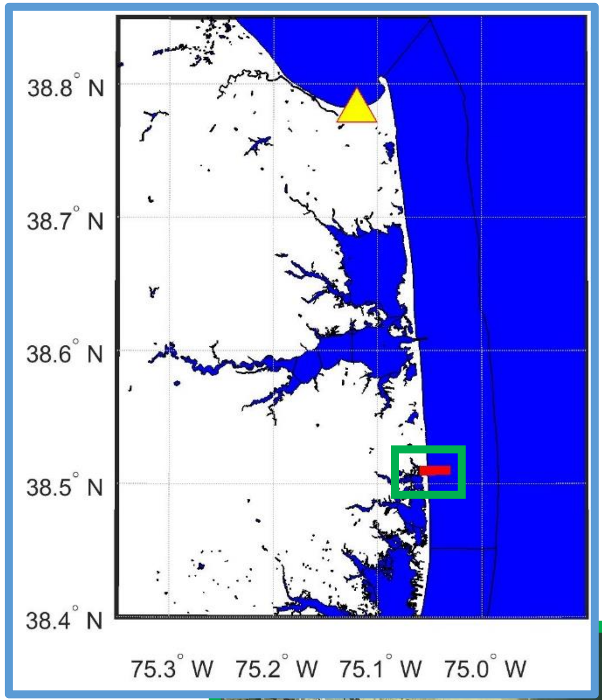

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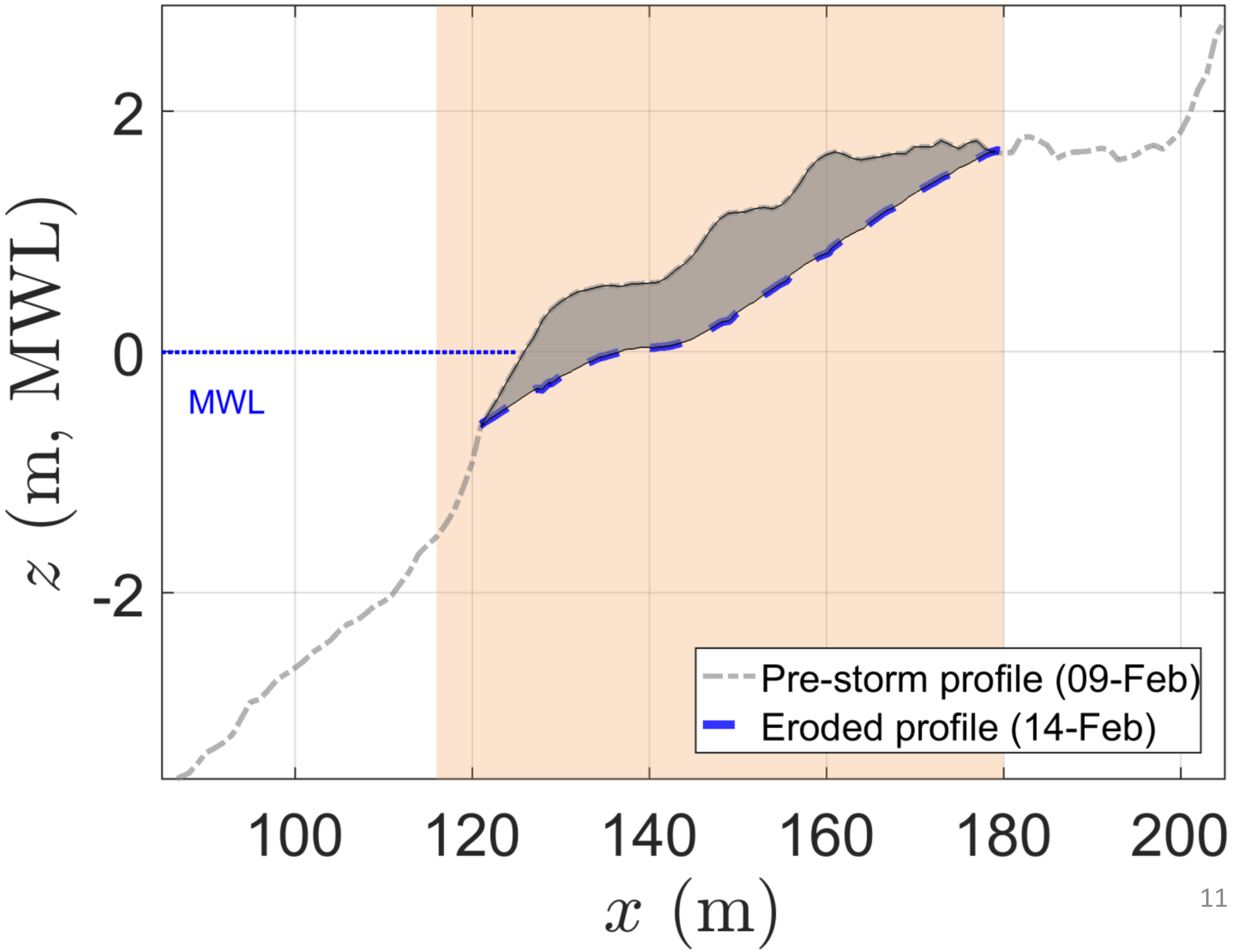
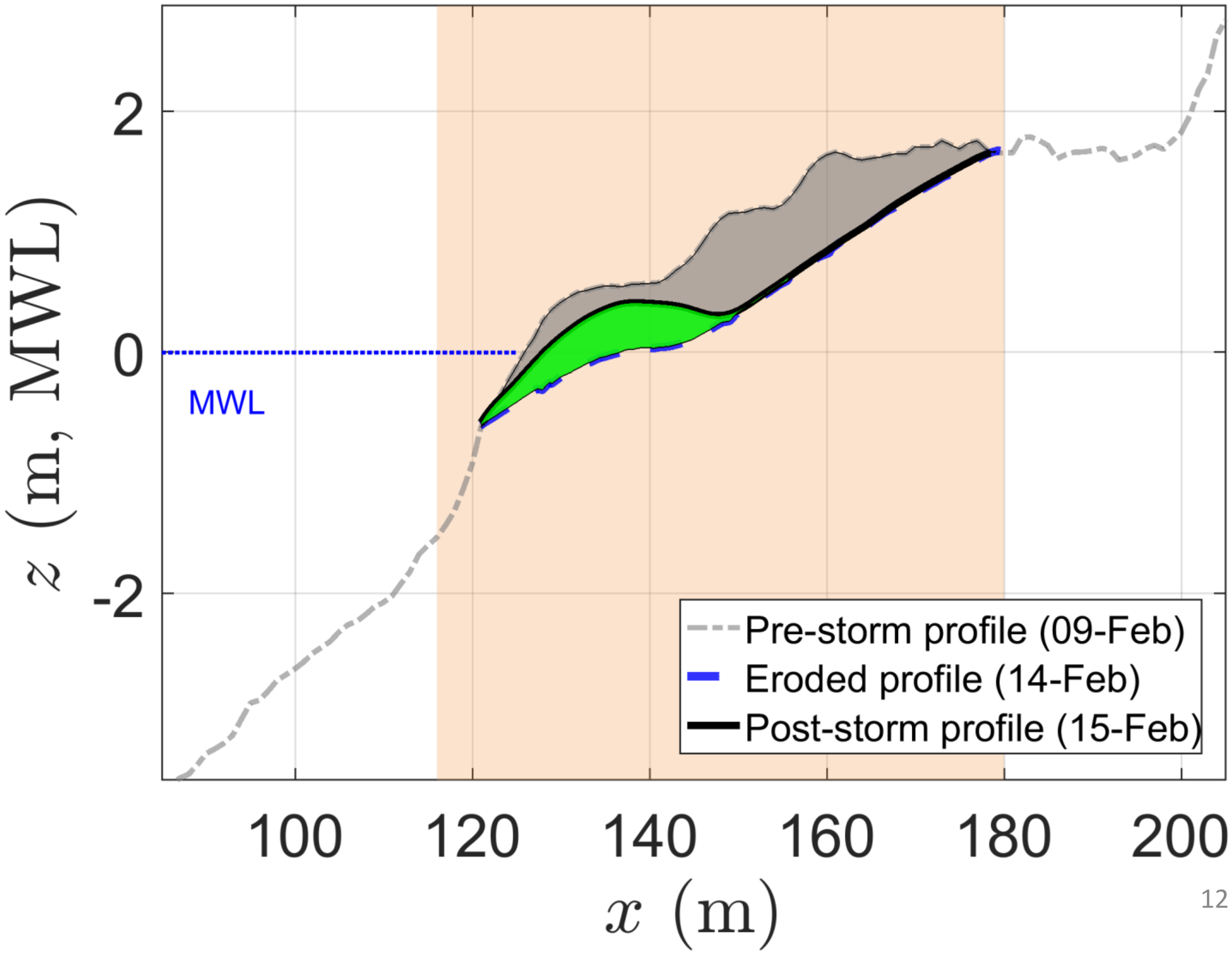
NOR'EASTER – VALENTINE'S DAY 2014 (Feb. 14, 2014)

- Severe erosion:
  washed off the entire berm face
- Eroded volume: 32 m^3/m
  (between 09-Feb and 14-Feb)
- Foreshore slope $\tan\beta = 0.13 \rightarrow 0.05$



POST-STORM PROFILE (Feb. 15, 2014)

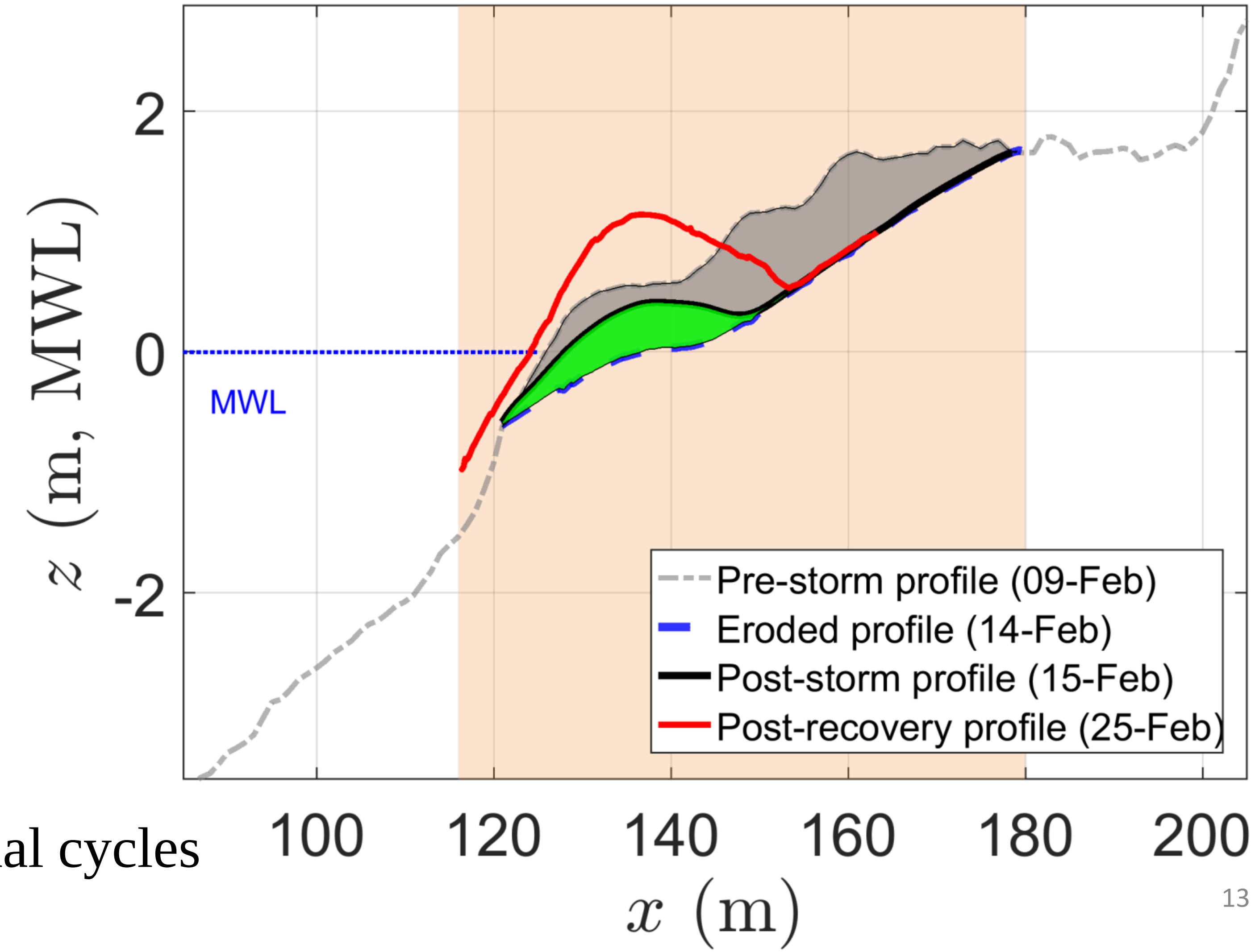
- Rapid ridge formation
- Max. crest elevation:
  0.4 m above MWL
- Accreting volume:
  8 m^3/m over two tidal cycles
  (between 14-Feb and 15-Feb)



FIELD MEASUREMENT

BEACH PROFILE RECOVERY (Feb. 25, 2014)

- Rapid ridge formation
- Max. crest elevation:
  1.2 m above MWL
- Accreting volume:
  Additional 18 m^3/m
  (between 15-Feb and 25-Feb)
- Shoreface slope $\tan\beta = 0.10$



Total 26 m^3/m accretion over 19 tidal cycles

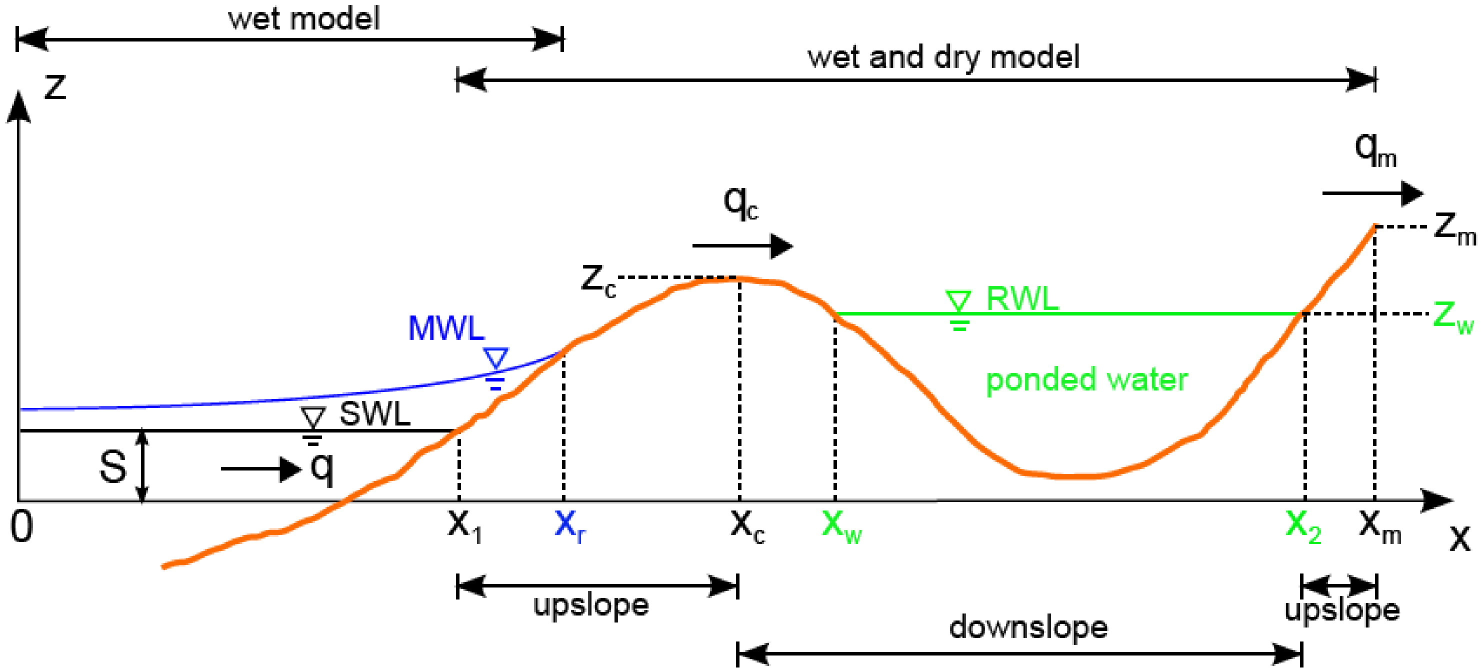
CSHORE: Process-based, 1D Cross-shore Morphological Numerical Model (Kobayashi, 2009)

Wet Model

- Gaussian distribution of η and u
- Wave and current model
- Linear-wave theory
- Wave action eq. (energy dissipation: D_B and D_f)

Wet and Dry Model

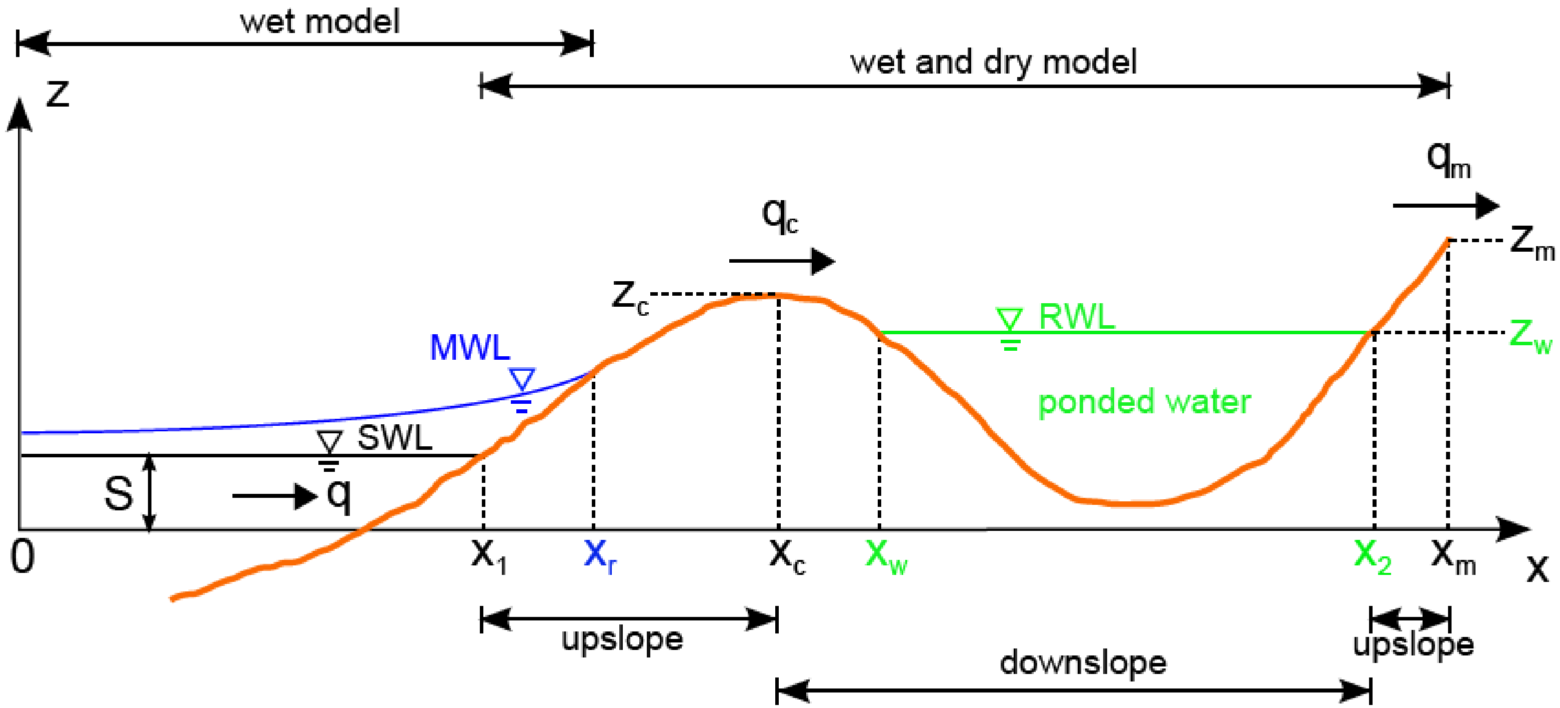
- Exponential distribution of h
- Probabilistic averaging only during h>0
- Continuity and momentum Eq. from NSW Eqs.



- Empirical formulas for irregular wave runup, overtopping, and overflow
- Time-averaged, probabilistic sediment transport formulas

CSHORE NUMERICAL MODELING

CSHORE: Process-based, 1D Cross-shore Morphological Numerical Model (Kobayashi, 2009)



Computationally very efficient

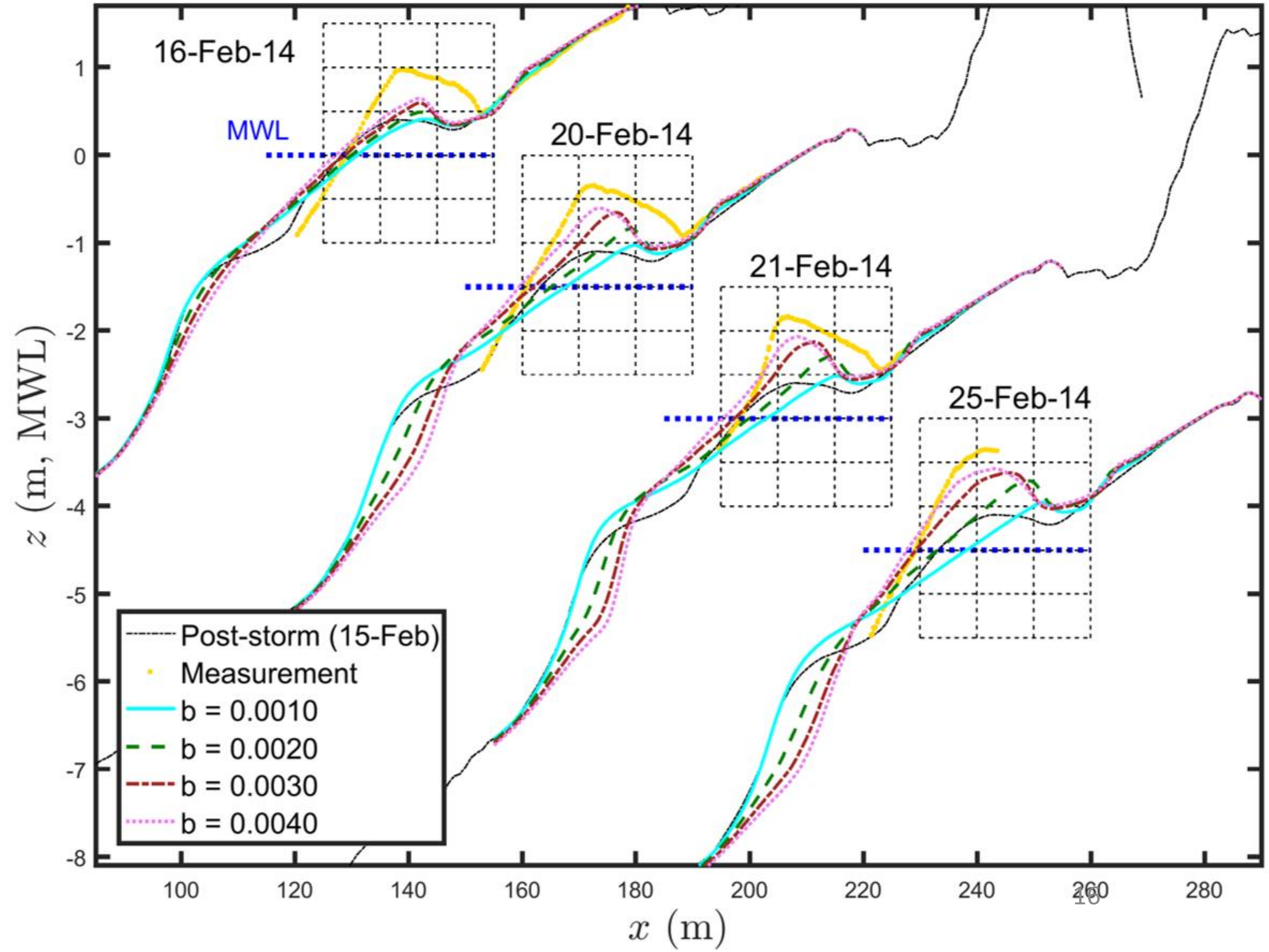
- Computation time: Order of 10^{-3} of the test duration.
- Model easily calibrated

CSHORE NUMERICAL MODELING

CSHORE: Process-based, 1D Cross-shore Morphological Numerical Model (Kobayashi, 2009)

Empirical Sediment Transport Parameters:

- uniform bottom sediment: d_{50}, s, ψ_c
- **bed load b**
- suspended load a
- wave overwash a_o
- suspension efficiency:
  - **wave breaking e_b**
  - bottom friction e_f



CSHORE: Model Input & Parameter Setup

Empirical Parameters:

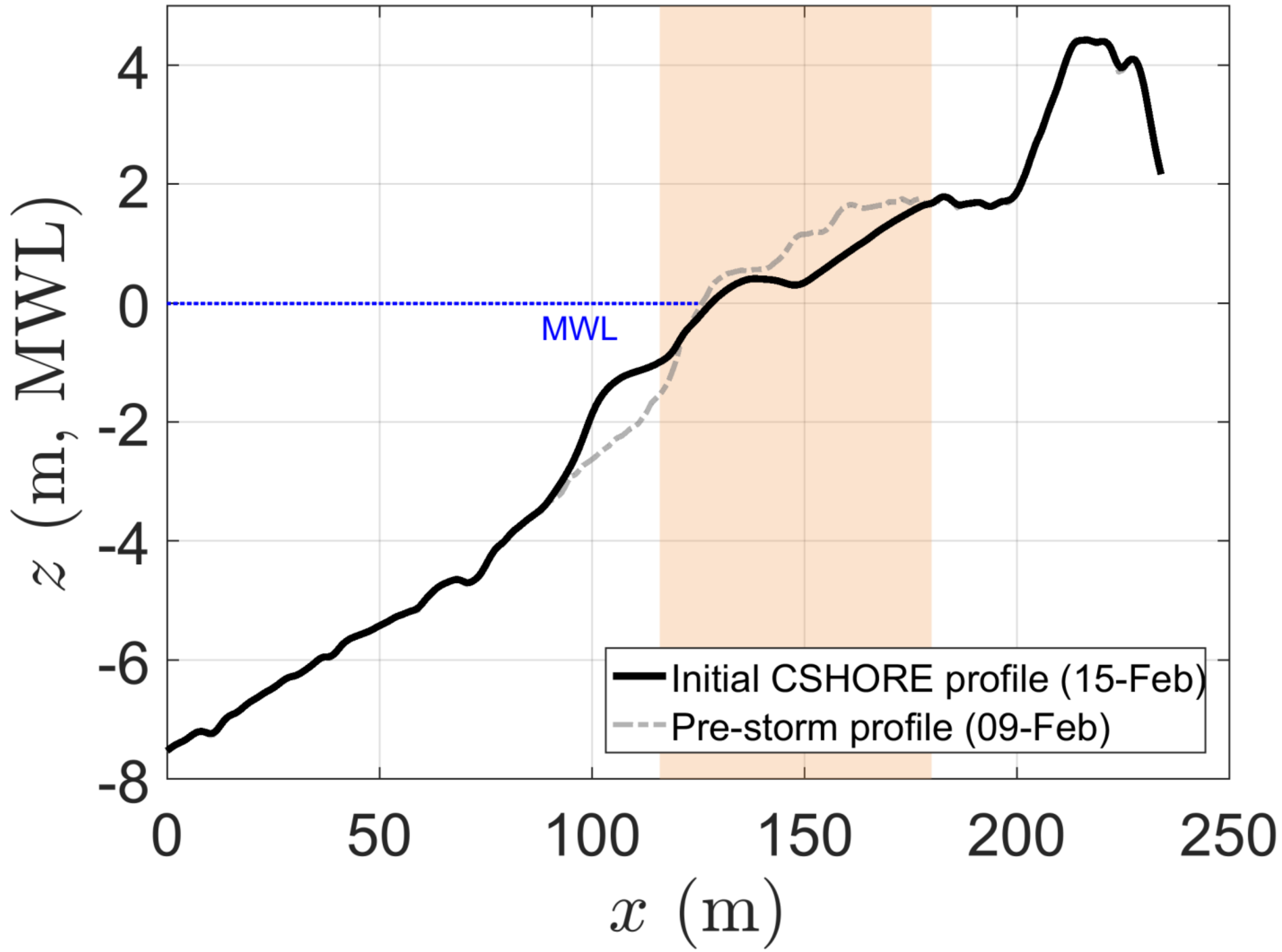
- d_{50} = 0.7 mm, ψ_c = 0.05, γ = 0.5
- b = 0.004, a = 0.100, a_{o} = 0.500, e_{b}= 0.005, e_{f}= 0.010

Offshore Boundary:

- x =0 at 7 m water depth
- simulation period: February 15 – March 2, 2014 (28 tidal cycles)
- 5 seconds simulation time

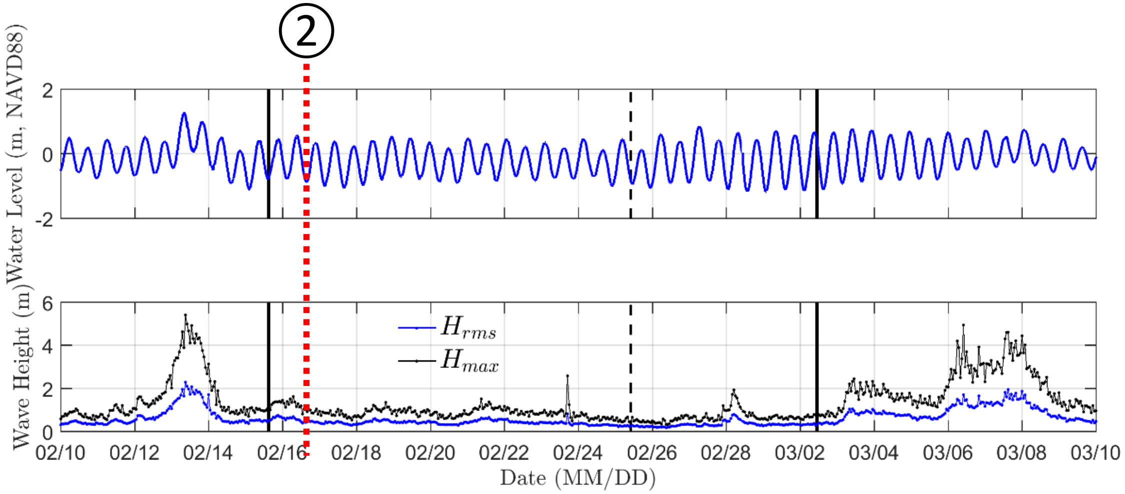
CSHORE: Model Input & Parameter Setup

Offshore Bottom Profile



RESULTS: BEACH PROFILE EVOLUTION

CSHORE Model Profiles

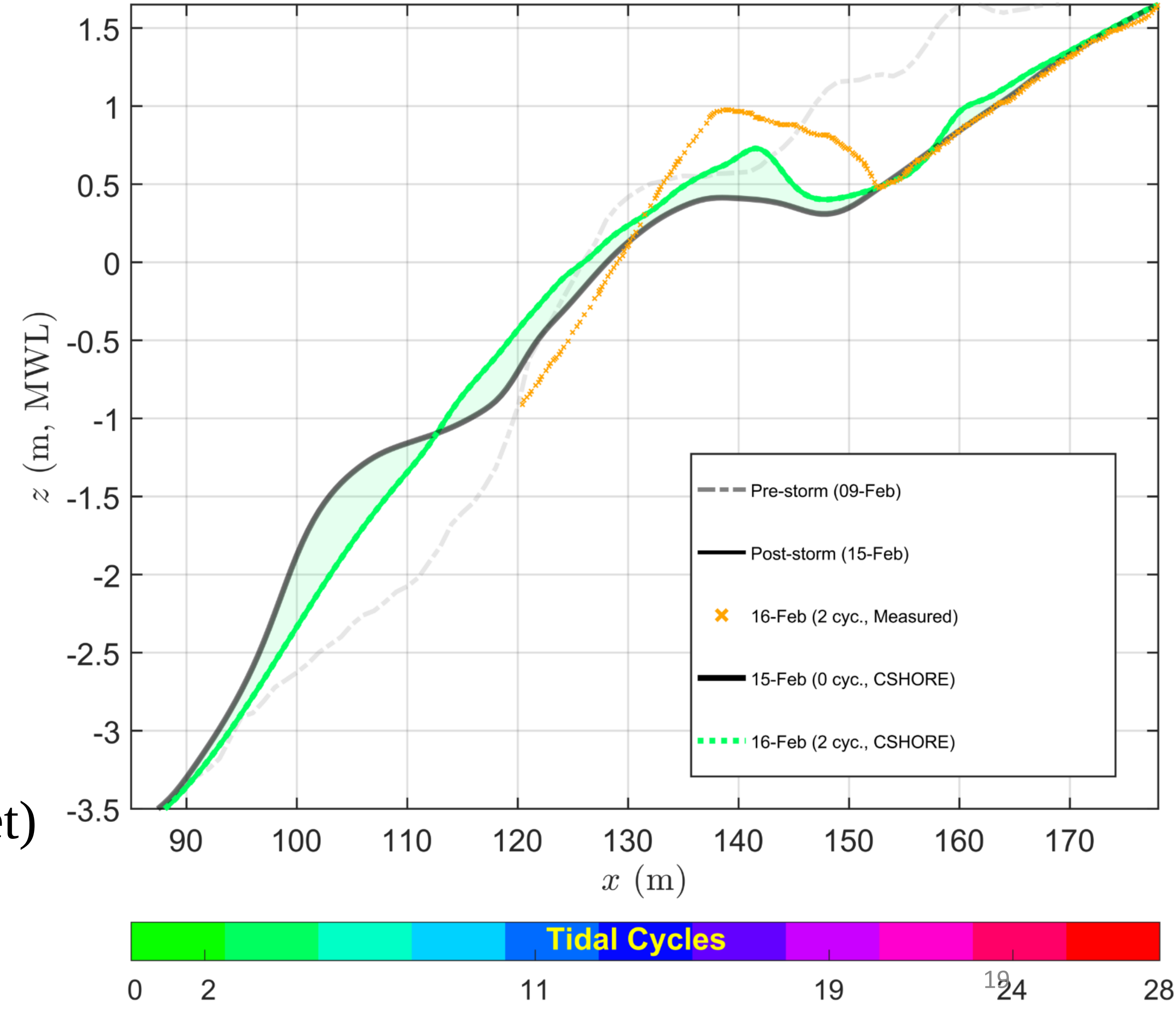


ζ_{MES} = 0.98 m, ζ_{CSH} **= 0.73 m (83 %)**

RMSE = 0.24 m (in swash zone)

V_{CSH} = 7.5 m^3/m (Accretion), 0.5 m^3/m (Net)

$\Delta V_{CSH\text{-}MES}$ **= - 0.9 m^3/m(in swash zone)**



RESULTS: BEACH PROFILE EVOLUTION

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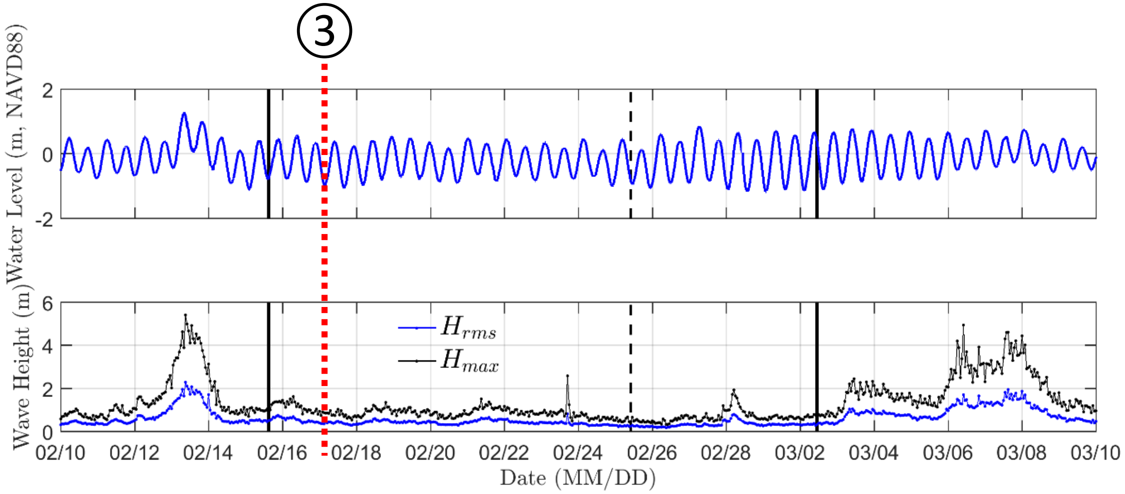

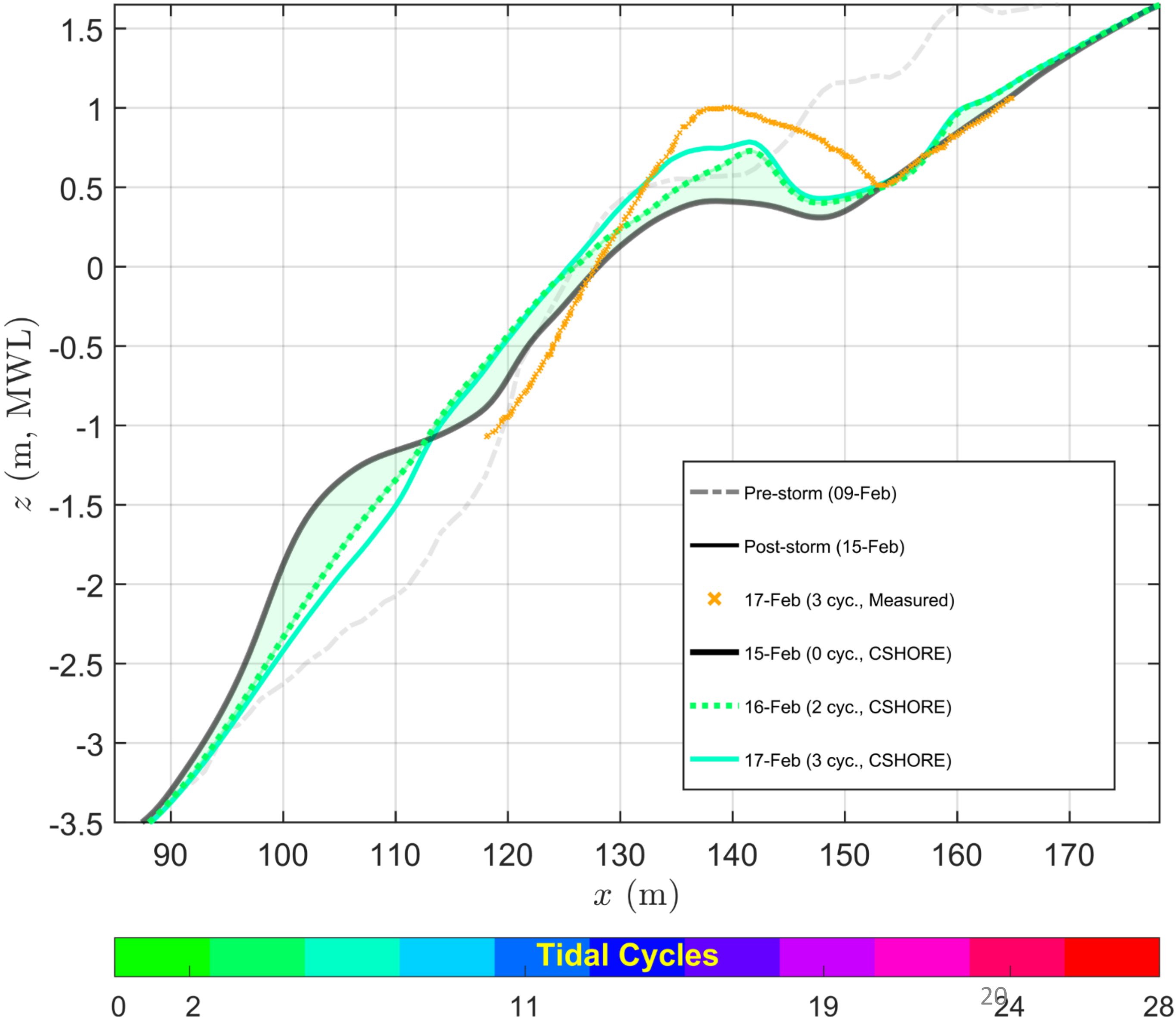

- Seaward growth of ridge face
- Widening crest depth
- Steepening of foreshore slope
- Only subtle changes in ζ_{CSH}

RESULTS: BEACH PROFILE EVOLUTION

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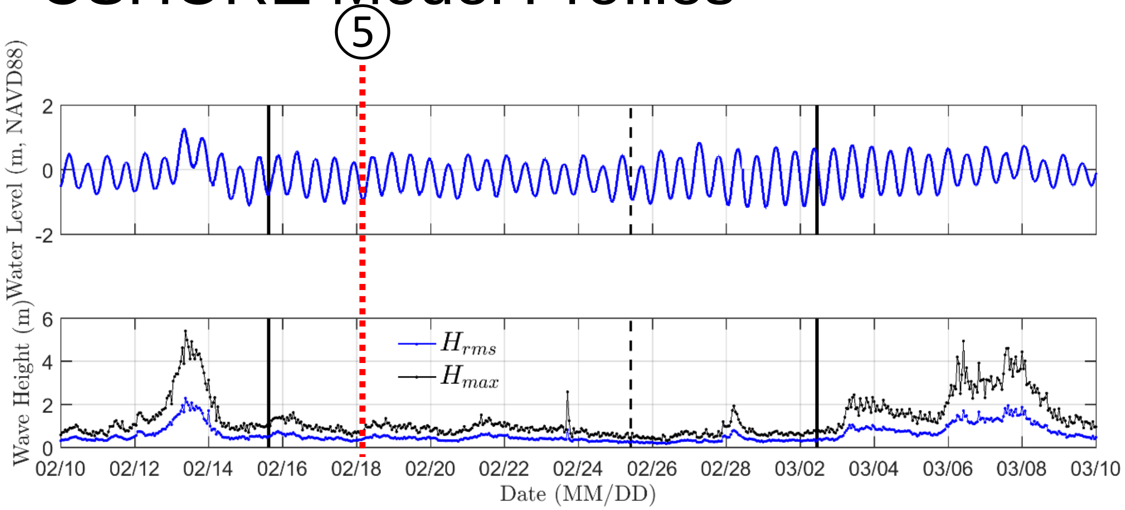
CSHORE Model Profiles



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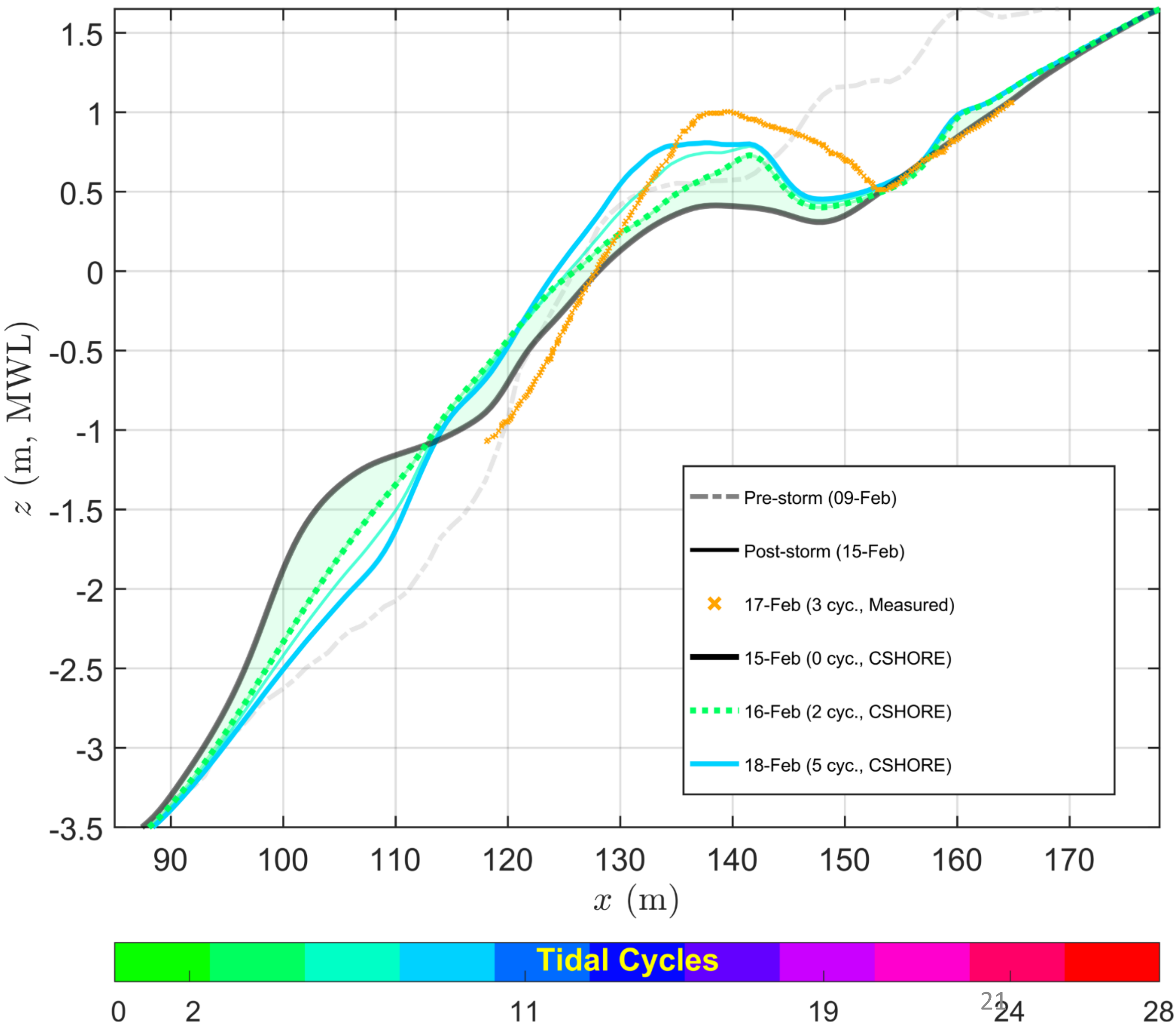

RESULTS: BEACH PROFILE EVOLUTION

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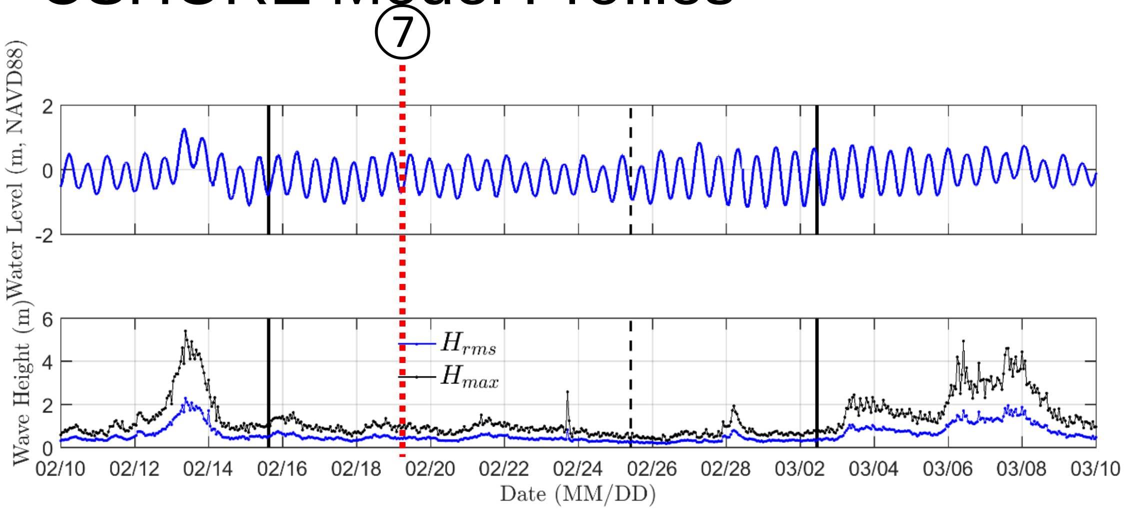
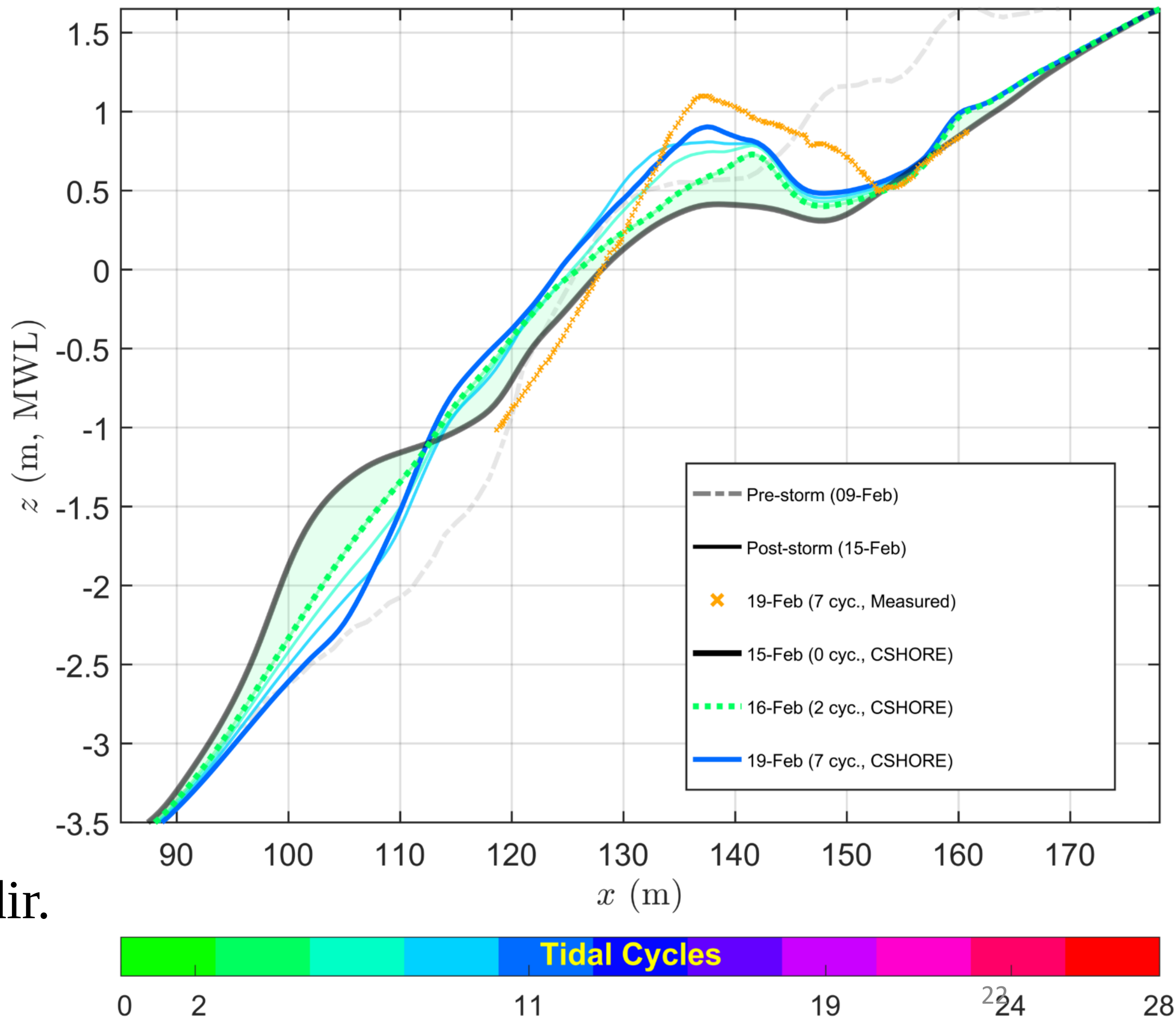
CSHORE Model Profiles





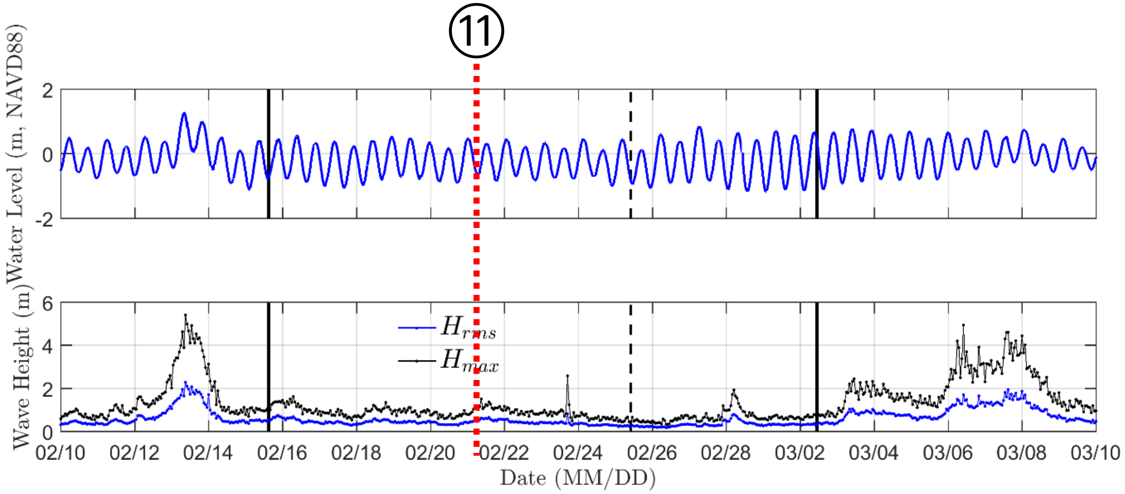
Foreshore slope adjusted

Max. crest height (peakness) increased

Ridge growth in both vertical and seaward dir.

RESULTS: BEACH PROFILE EVOLUTION

CSHORE Model Profiles

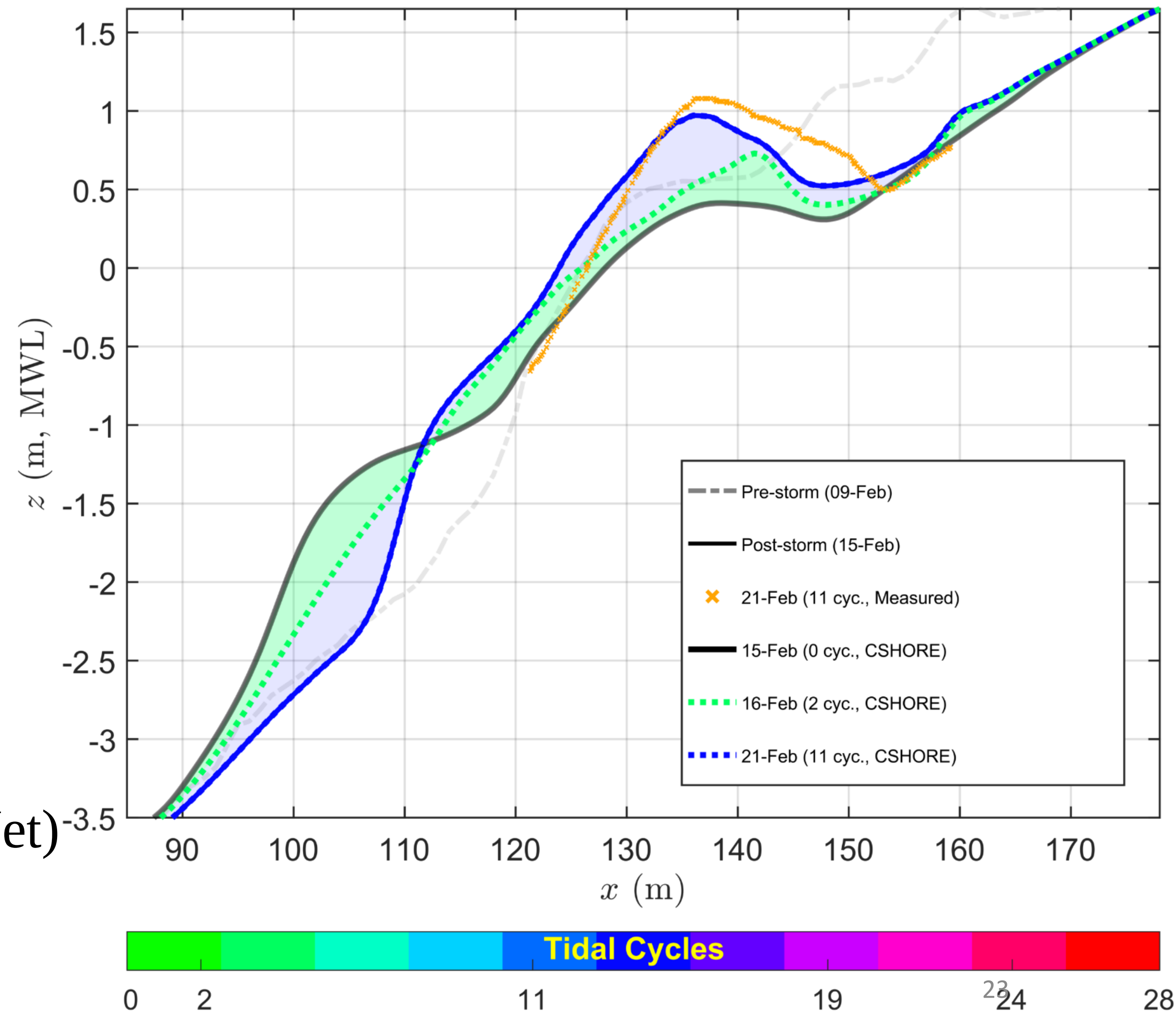


ζ_{MES} = 1.08 m, ζ_{CSH} = 0.97 m (93 %)

$RMSE$ = 0.19 m (in swash zone)

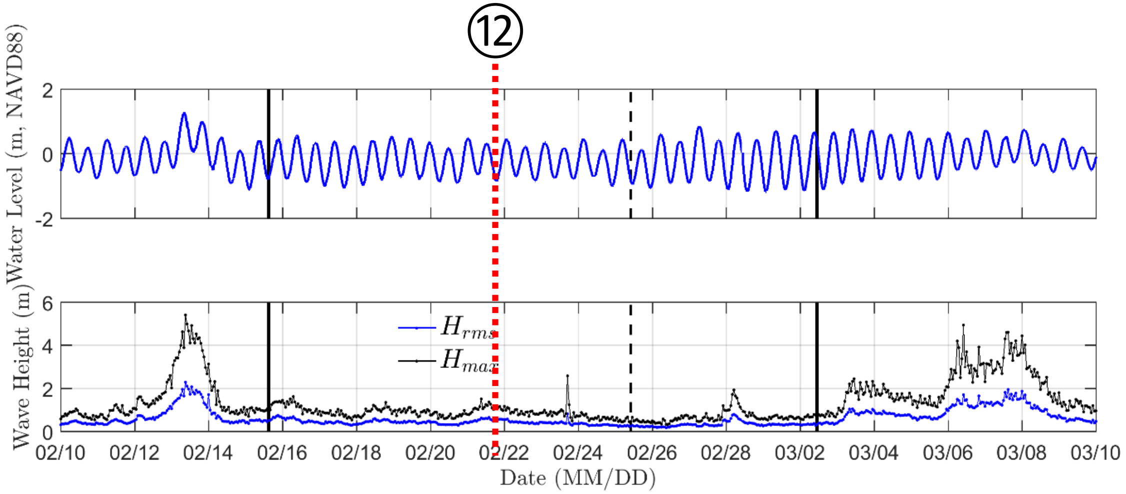
V_{CSH} = 15.7 m^3/m (Accretion), 1.1 m^3/m (Net)

$\Delta V_{CSH\text{-}MES}$ = + 0.1 m^3/m (in swash zone)



RESULTS: BEACH PROFILE EVOLUTION

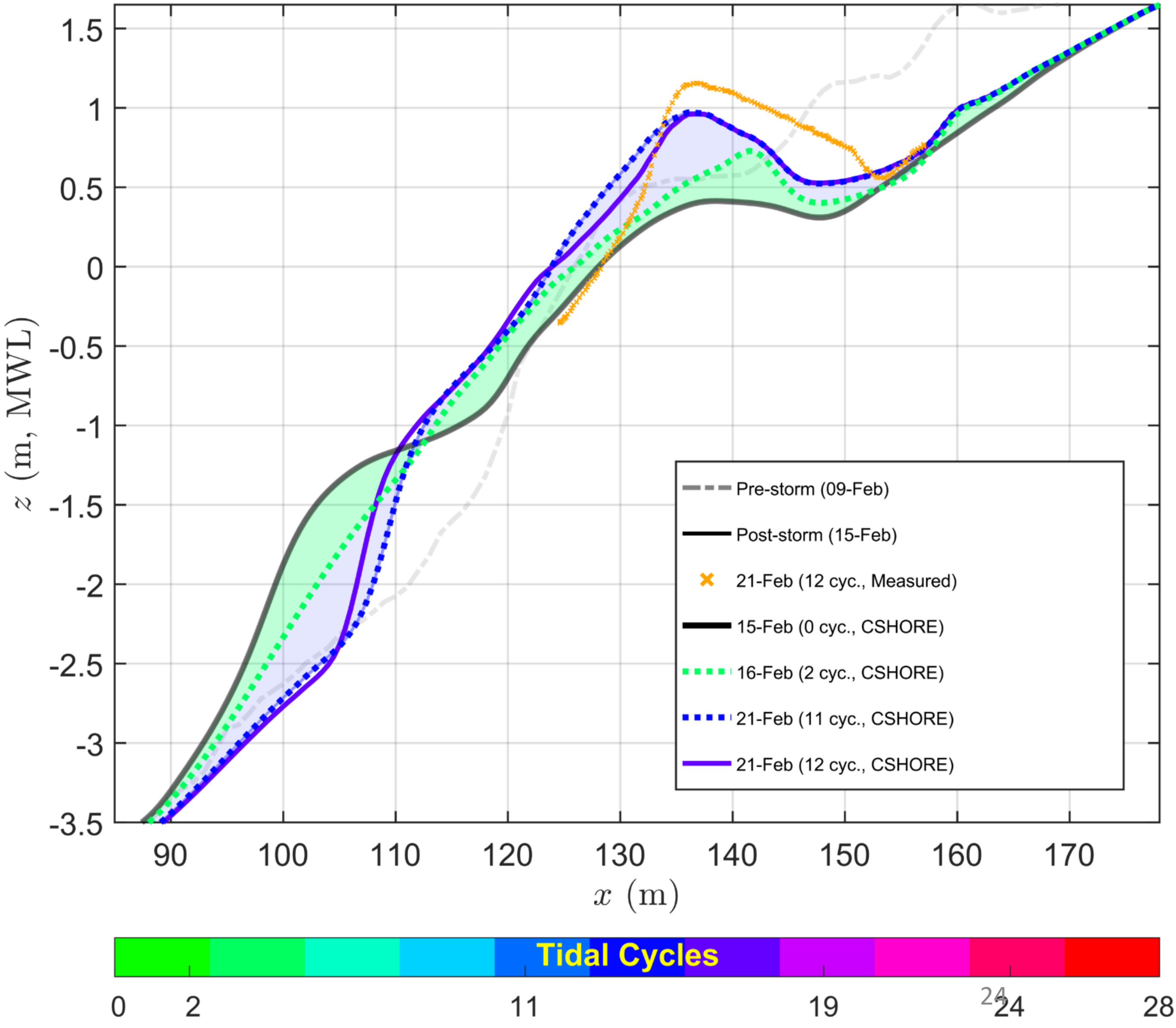
CSHORE Model Profiles



Temporary eroded upper shoreface

Recovered to a monotonic slope in next cyc.

Seaward growth resumes without crest elevation increase



RESULTS: BEACH PROFILE EVOLUTION

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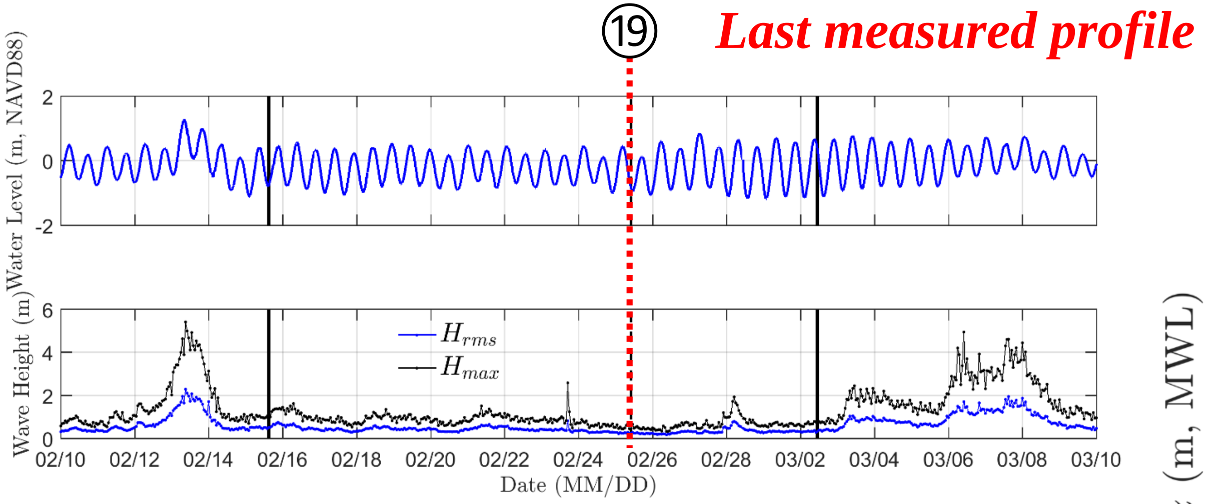
CSHORE Model Profiles

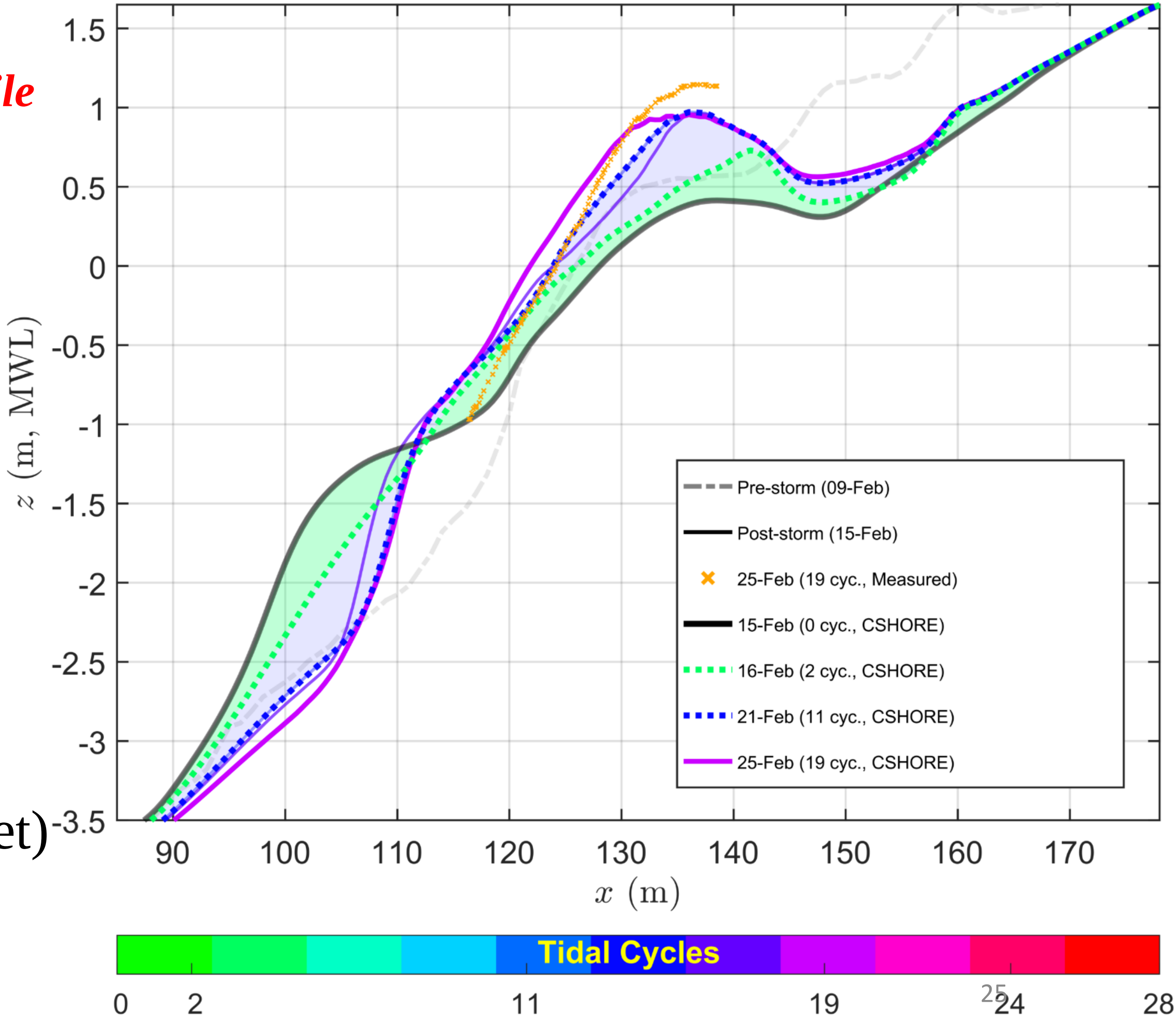


ζ_{MES} = 1.14 m, $\boldsymbol{\zeta_{CSH}}$ **= 0.96 m (89 %)**

$RMSE$ = 0.20 m (in swash zone)

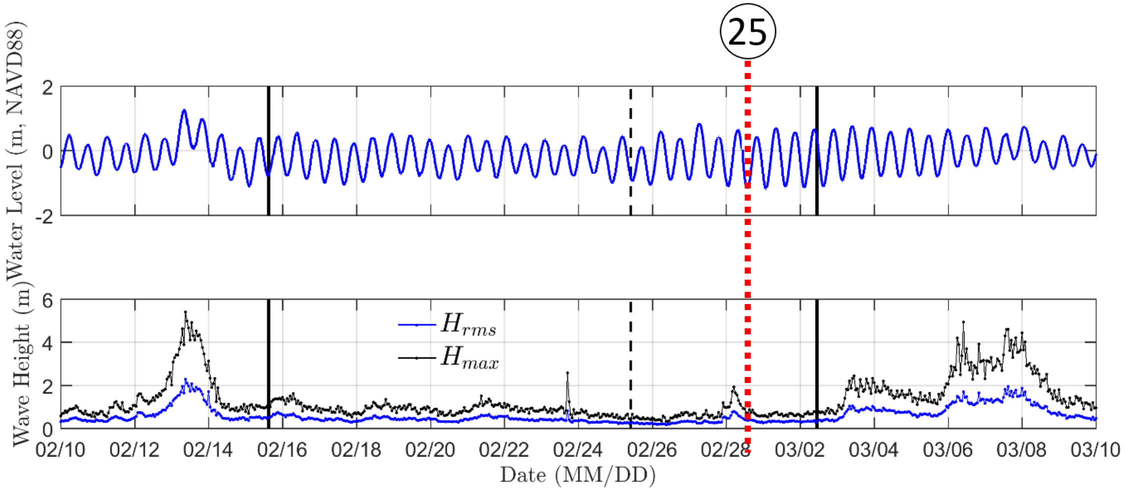
V_{CSH} = 19.2 m^3/m (Accretion), 1.6 m^3/m (Net)

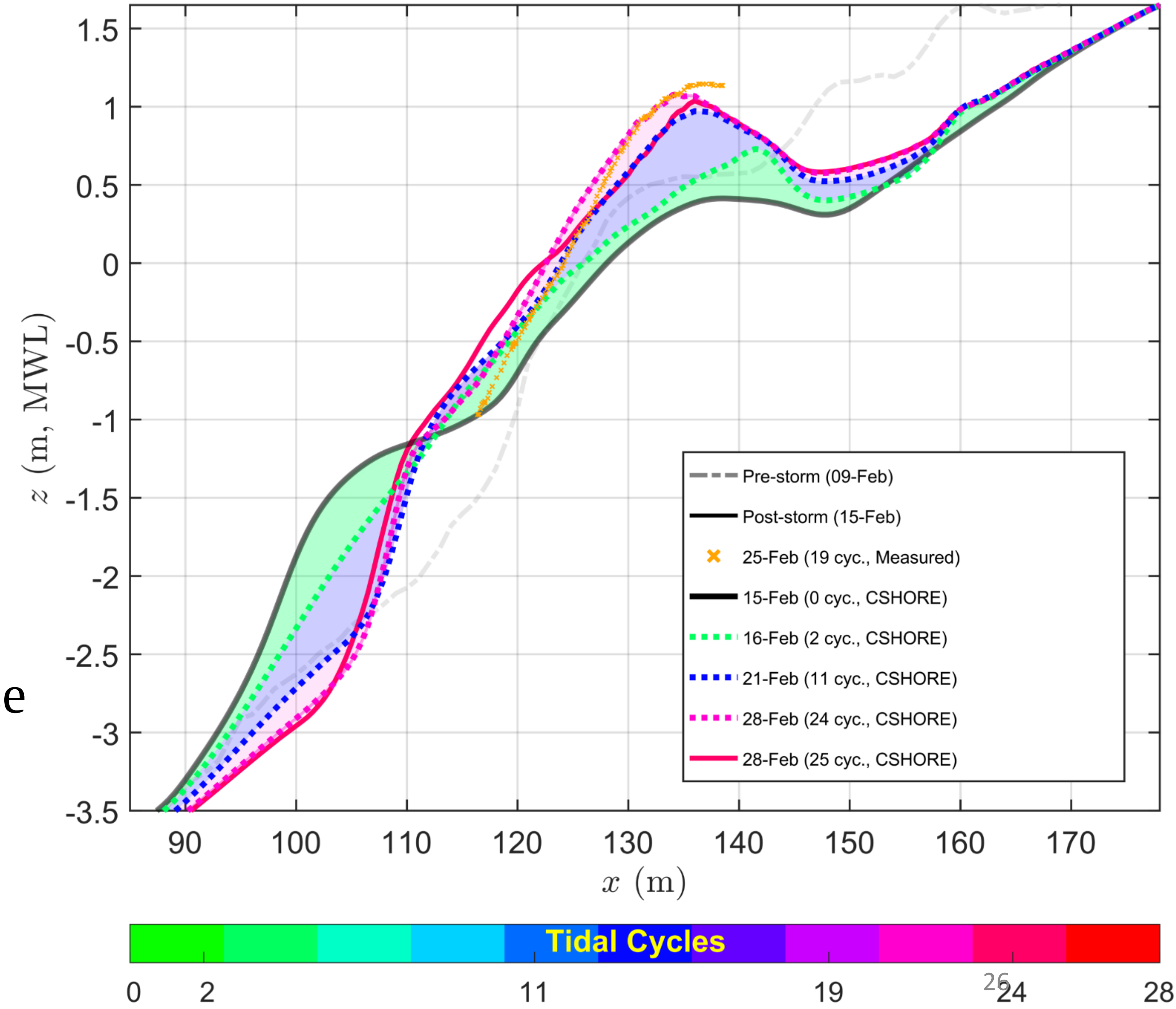
$\boldsymbol{\Delta V_{CSH\text{-}MES}}$ **= + 1.2 m^3/m(in swash zone)**



RESULTS: BEACH PROFILE EVOLUTION

CSHORE Model Profiles



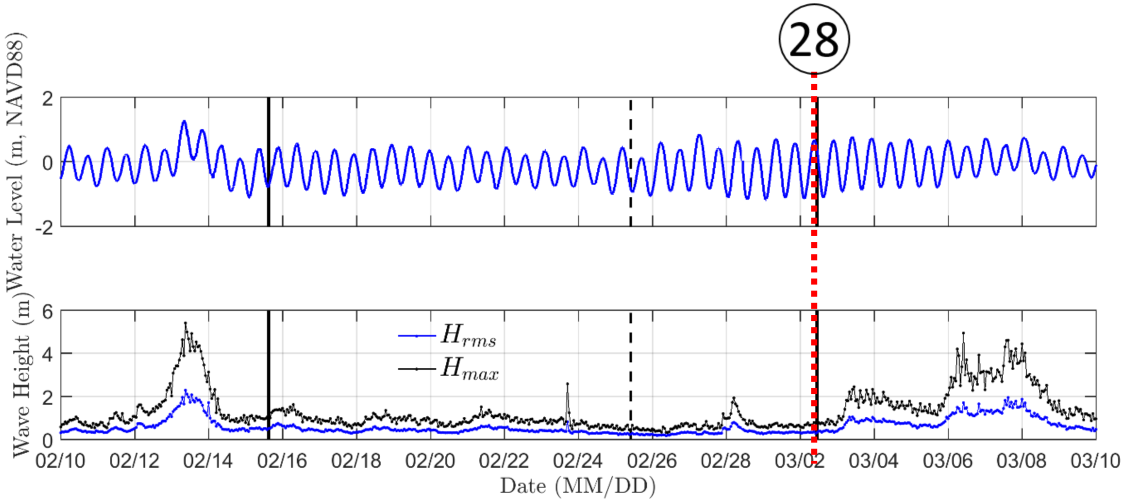


Foreshore slope adjustment by

seaward growth → crest elevation increase

RESULTS: BEACH PROFILE EVOLUTION

CSHORE Model Profiles

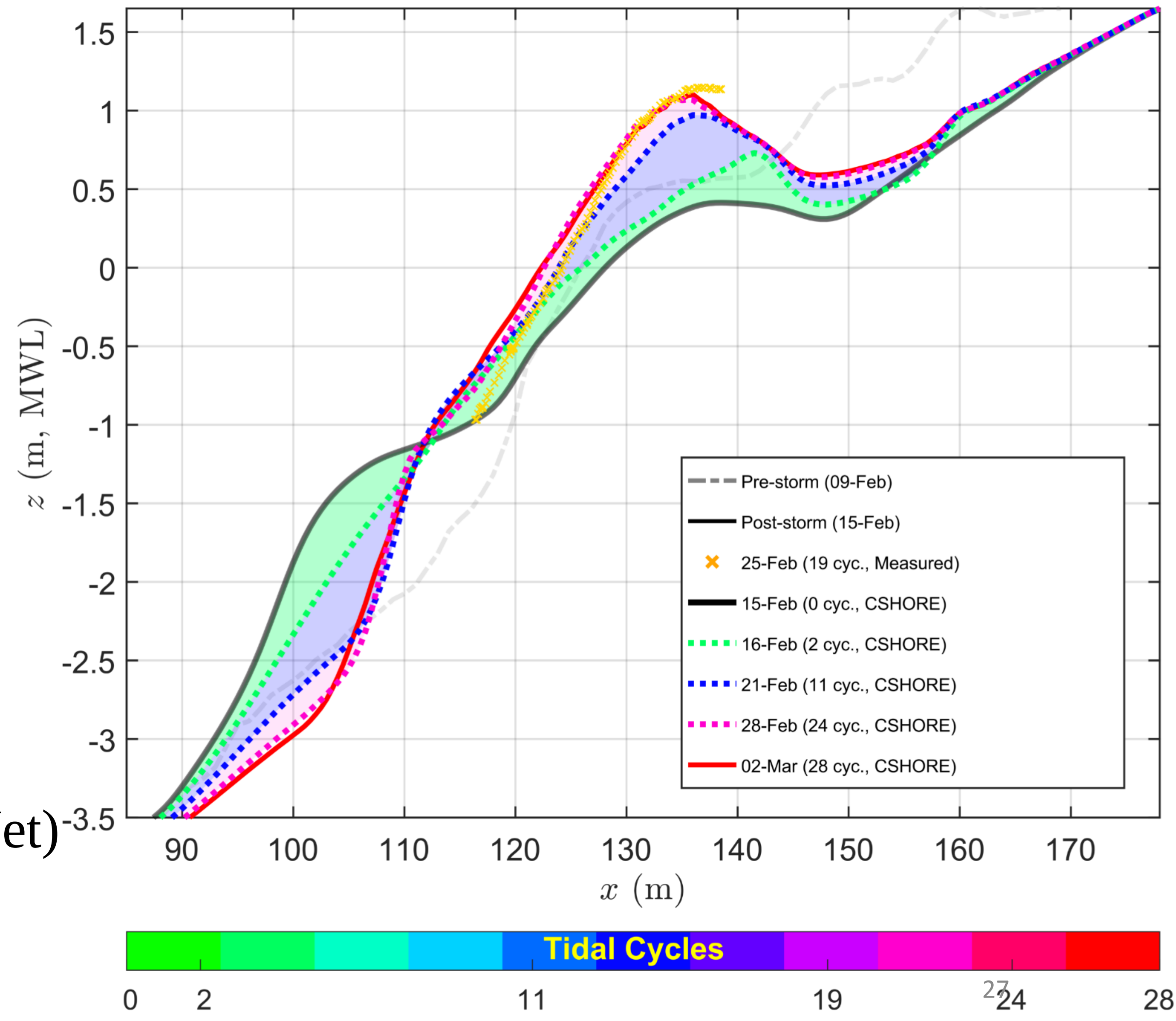


ζ_{MES} = 1.14 m, $\boldsymbol{\zeta_{CSH}}$ **= 1.10 m (97 %)**

$RMSE$ = 0.16 m (in swash zone)

V_{CSH} = 19.8 m^3/m (Accretion), 1.8 m^3/m (Net)

$\boldsymbol{\Delta V_{CSH\text{-}MES}}$ **= + 1.8 m^3/m (in swash zone)**



RESULTS: BEACH PROFILE EVOLUTION

CSHORE v.s. Measured Profiles

- Characteristic morphological features

  - Rapid increase of the ridge crest

  - Cyclic oscillation of upper shoreface

  - Shorefront slope adjustment sequences

- CSHORE prediction

  - ζ_{CSH} = 0.96 m (89 %) at 19th cyc.

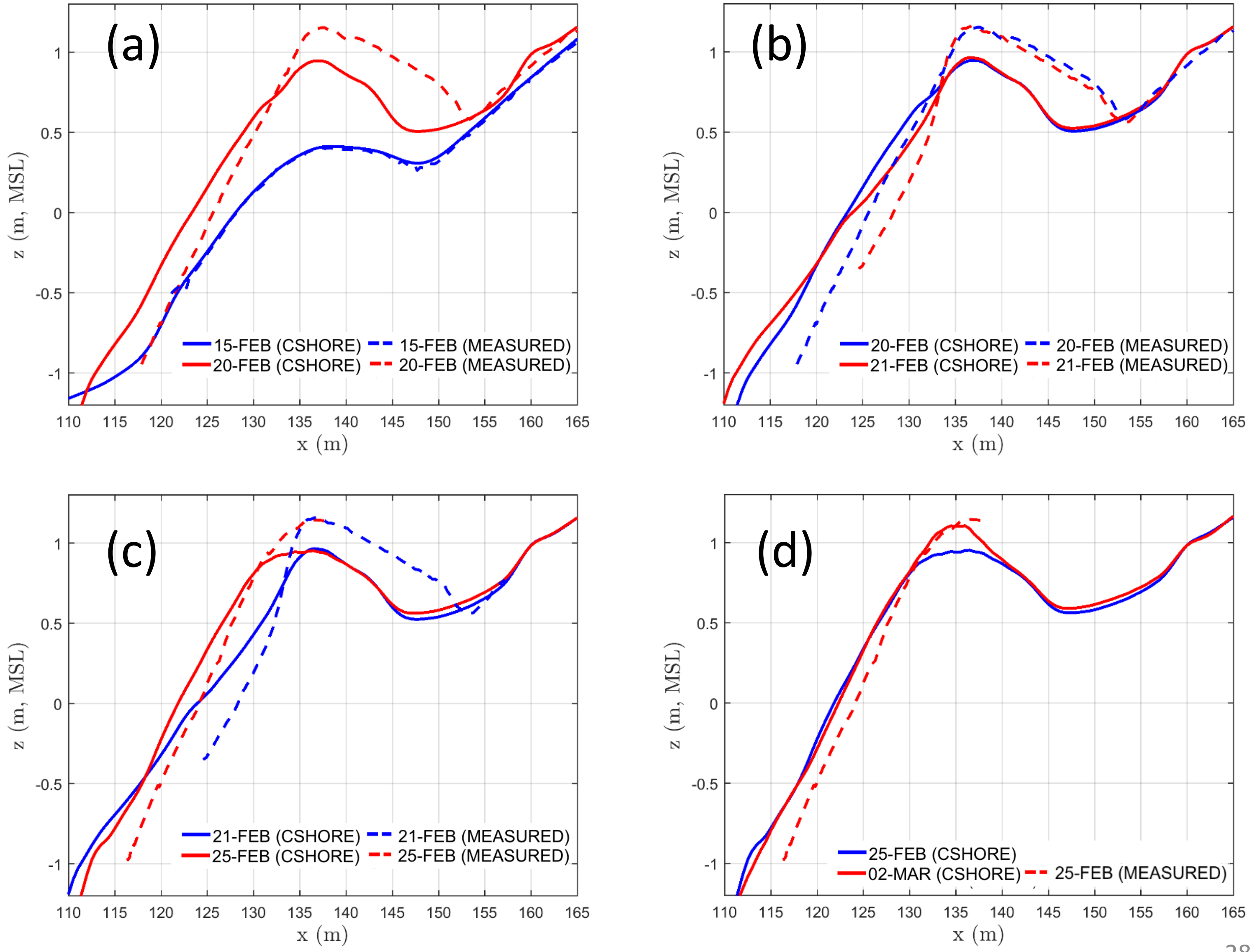
    → longer morphological time

    (i.e., additional 9 cyc.)

  - $\mathit{\Delta V_{CSH\text{-}MES}}$ = + 1.2 m^3/m at 19th cyc.

    (6% higher than observed 18 m^3/m)

    → model calibration



CONCLUSION

Measured post-storm beach recovery was simulated using the process-based, depth-averaged 1-D cross-shore numerical model CSHORE

Field measurement for accreting beach profile

- nourished, engineered sandy beach, South Bethany, US
- 36 tidal cycles
- significant beach erosion during a Nor'easter on February 13, 2014 (33 m^3/m sediment loss)
- formation of a pronounced RR system in the recovery process (18 m^3/m recovered since Feb. 15)

CONCLUSION

CSHORE predictive capability for post-storm beach profile accretion

- formation and rapid growth of a ridge above MWL
- 5 seconds simulation time for 28 tidal cycles
- 0.22 m of RMSE in ridge crest elevation
- accreted sed. volume within 10 % of error
- additional recovery time required (~ 9 cyc.) to reach the observed elevation & foreshore slope

Future work

- parameter reevaluation & model modification based on field data
- continuous simulation from erosion to recovery for a long-term beach profile predictability

DISCUSSION

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Q& A

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