Numerical Simulations of Ridge Accretion and Onshore Migration
Based On Field Data From a Steep Meso-Tidal Engineered Beach

36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING

Baltimore, MD, July 30, 2018

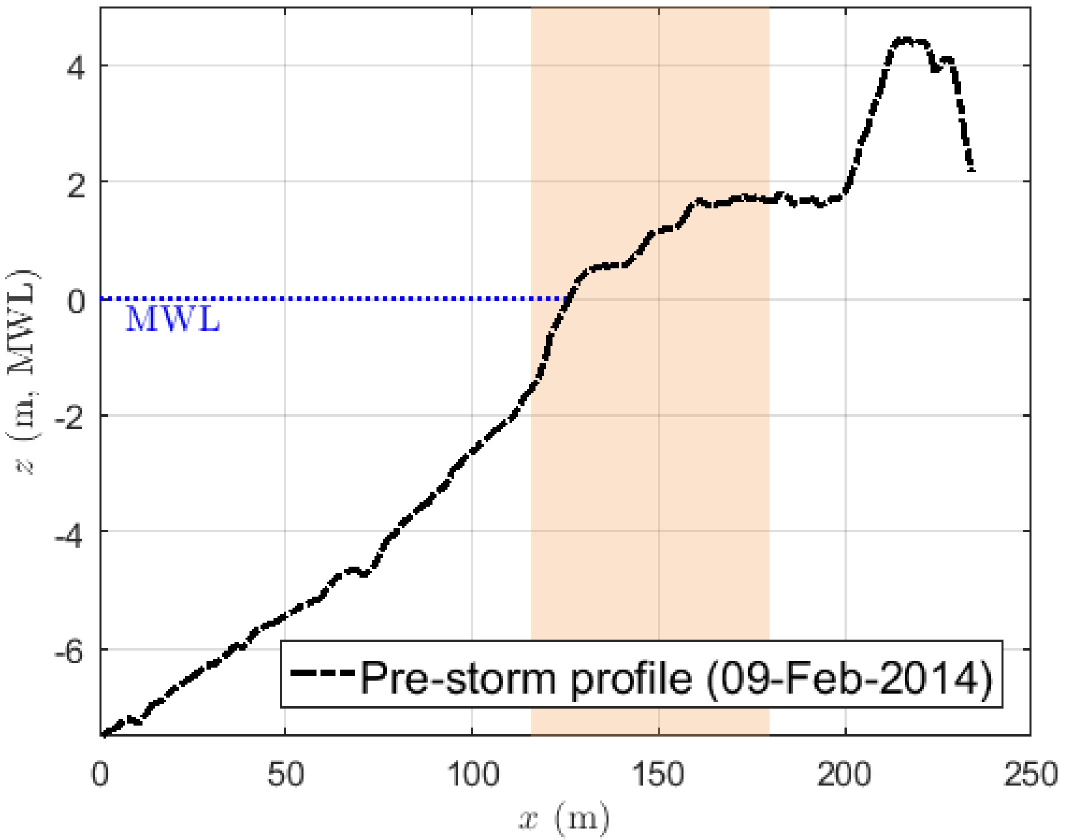
Youn-Kyung Song[1], Jens Figlus[1], Patricia Chardón-Maldonado[2], and Jack A. Puleo[3]

[1] Department of Ocean Engineering, College of Engineering, Texas A&M University, Galveston, TX 77553 USA

[3] University of Puerto Rico, PR-108, Mayagüez, 00682, Puerto Rico, patricia.chardon@upr.edu

[3] Department of Civil Engineering, Center for Applied Coastal Research, University of Delaware, Newark, DE 19716 USA

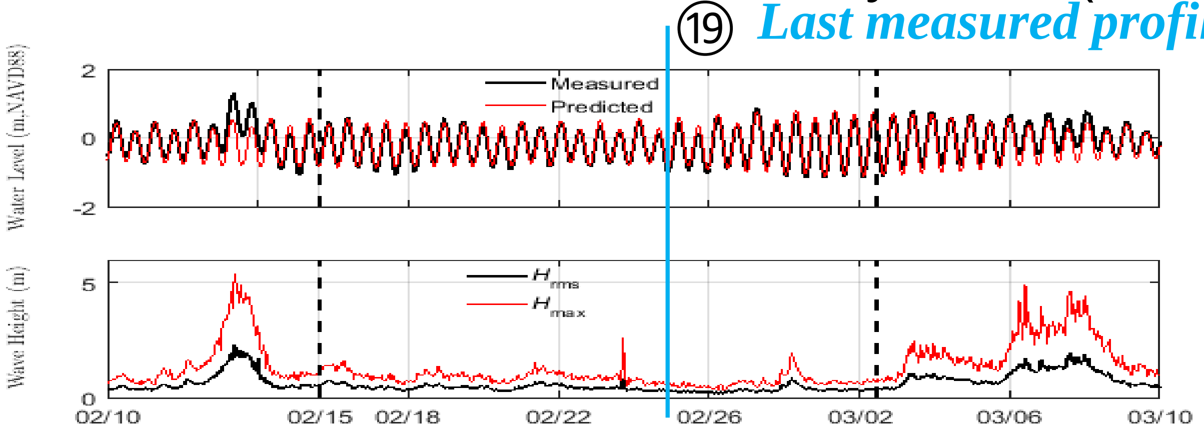
Field Site (South Bethany Beach, DE, USA)

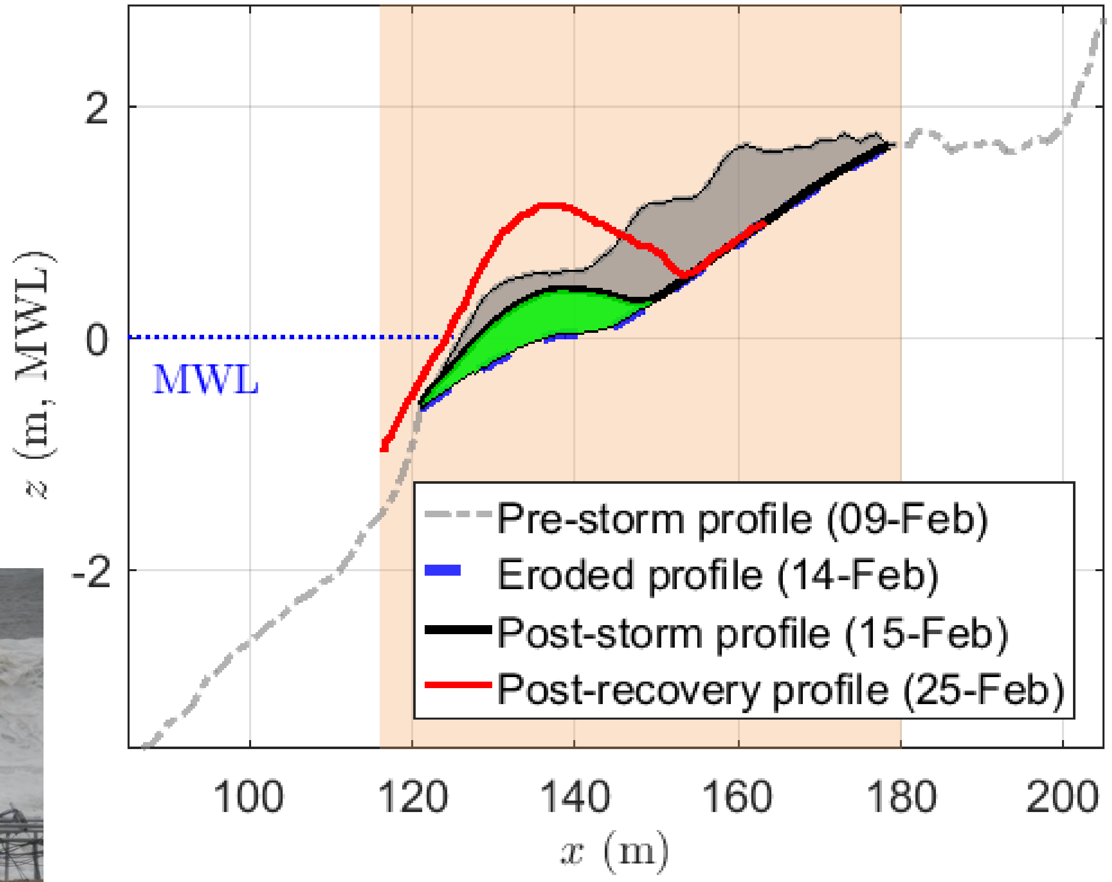


- Steep, meso-tidal, semi-diurnal, engineered beach
- d_{50} = 0.7 mm
- Restored in September 2013 (Berm-Dune template)

- February 12 to 25, 2014 (2 weeks incl. storm)
- 21 wading-depth profiles (incl. pre- and post- storm)
- 5 velocity profiles, 6 water depth

NOR'EASTER – Valentine's Day 2014 (Feb. 14, 2014)





…tal 26 m^3/m accretion (85 % of initial erosion)

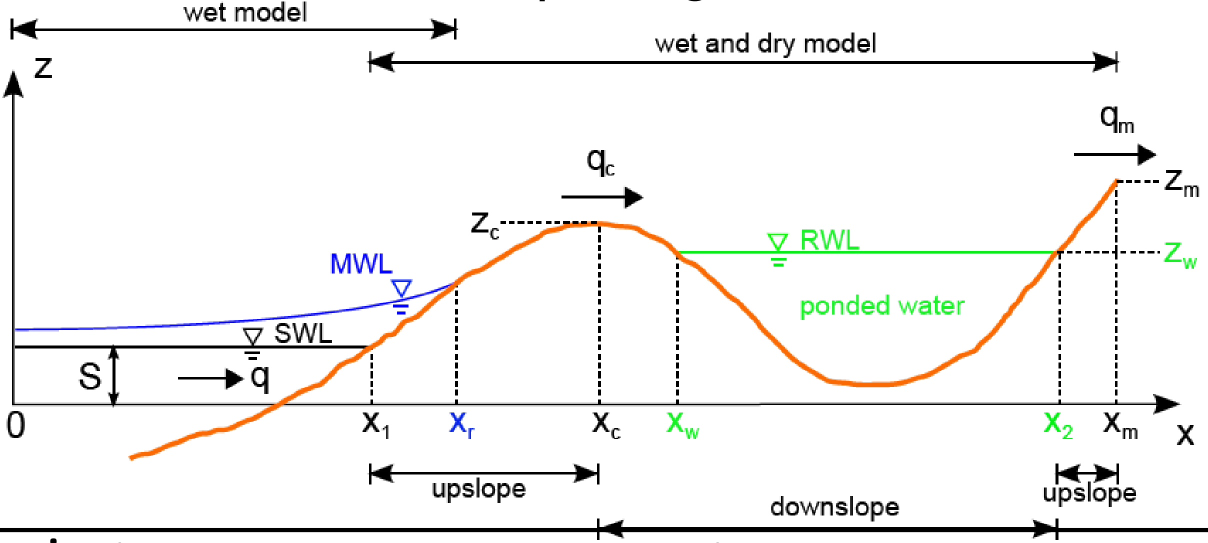
…er 19 tidal cycles

Research Questions

What would be the morphological sequences that lead to accretion and migration of the Ridge-Runnel system in response to varying hydrodynamic forcing conditions ?

What would be the role of Ridge-Runnel system in the overall beach recovery process ?

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



- Available in a public domain (USACE W912BU-09-C-0023)
- Time-averaged, depth-averaged continuity and momentum Eqns.
- Empirical formulas for irregular wave runup, overtopping, and overflow (Kobayashi et al., 2008)
- Ponded water effect to account for velocity asymmetry
- A time-averaged probabilistic sediment dynamics model
- Uniform bottom sediment: d_{50}, s, ψ_c
- Bed load b, suspended load a, wave overtopping a_o, and suspension efficiency e_b and e_f

CSHORE NUMERICAL MODELING

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

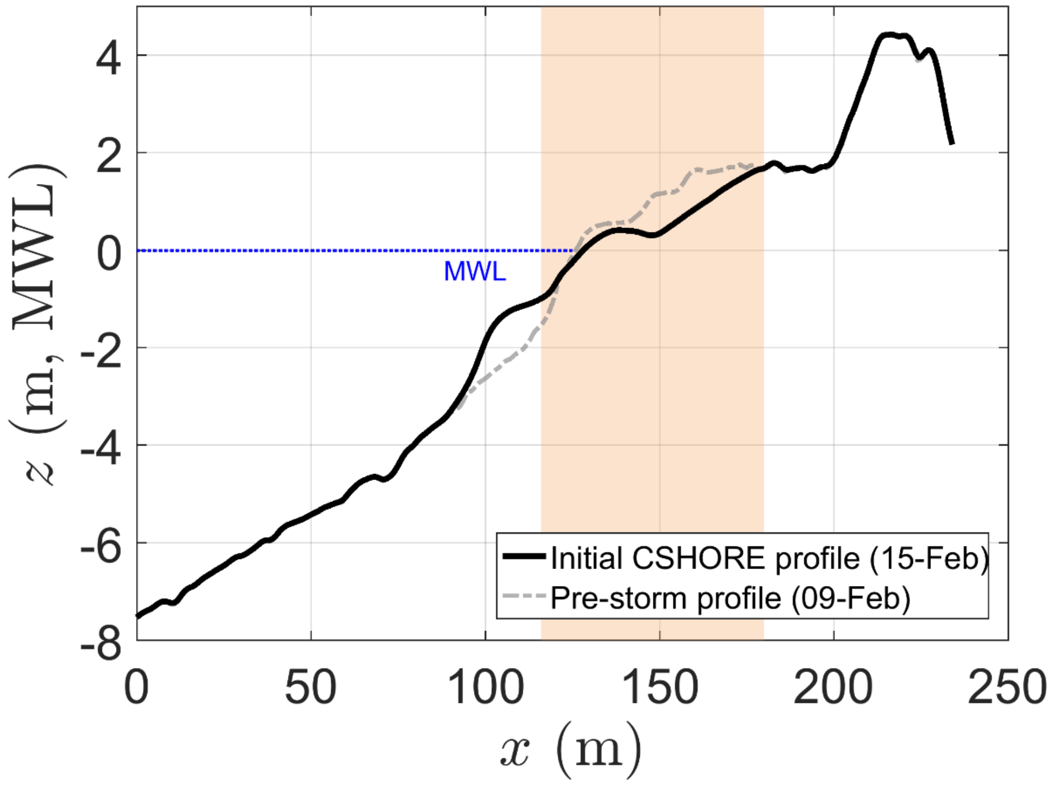
$$q_s = \left(a\overline{U} + a_o U_a\right)V_s \qquad V_s = P_s\left(\frac{e_b D_r + e_f D_f}{\rho g(s-1)w_f}\right)(1+S_b^2)^{0.5} \qquad q_b = \frac{b P_b G_s \sigma_U^3}{g(s-1)}$$

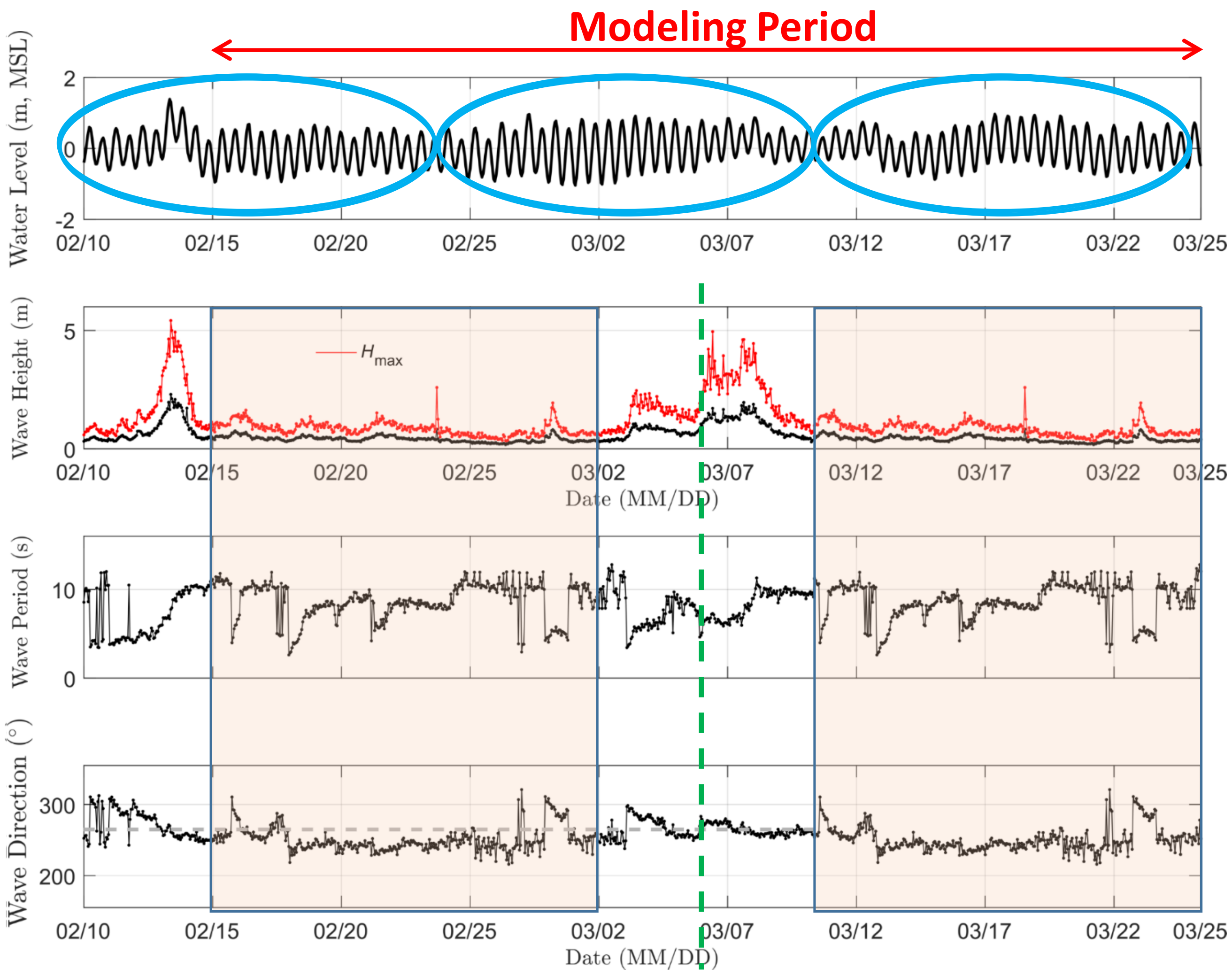
- Available in a public domain (USACE W912BU-09-C-0023)
- Time-averaged, depth-averaged continuity and momentum Eqns.
- Uniform bottom sediment: d_{50}, s, ψ_c
- Empirical formulas for irregular wave runup, overtopping, and overflow (Kobayashi et al., 2008)
- Ponded water effect to account for velocity asymmetry
- A time-averaged probabilistic sediment dynamics model
- Bed load b, suspended load a, wave overtopping a_o, and suspension efficiency e_b and e_f

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

Computational very efficient

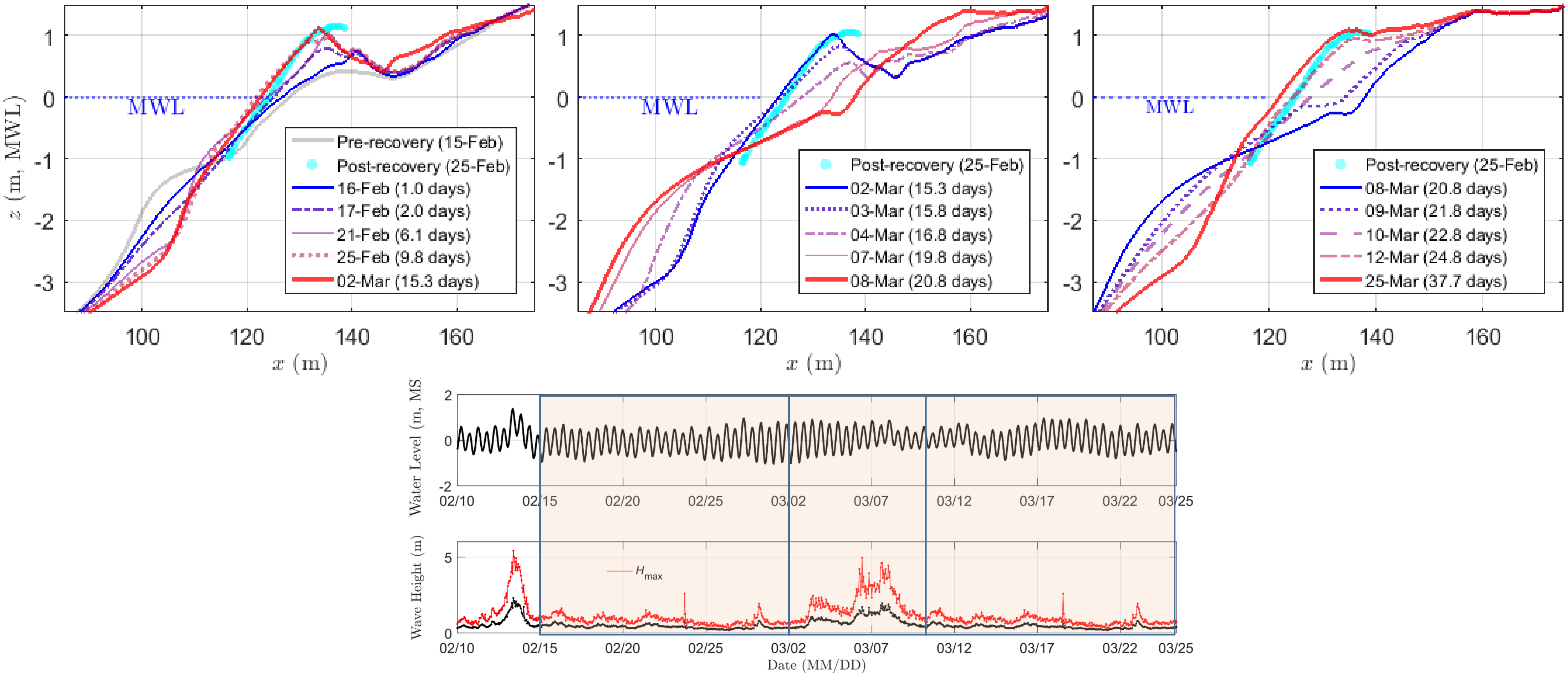
- Model easily calibrated
- Enhanced stability and computational efficiency
- Inputs readily procurable



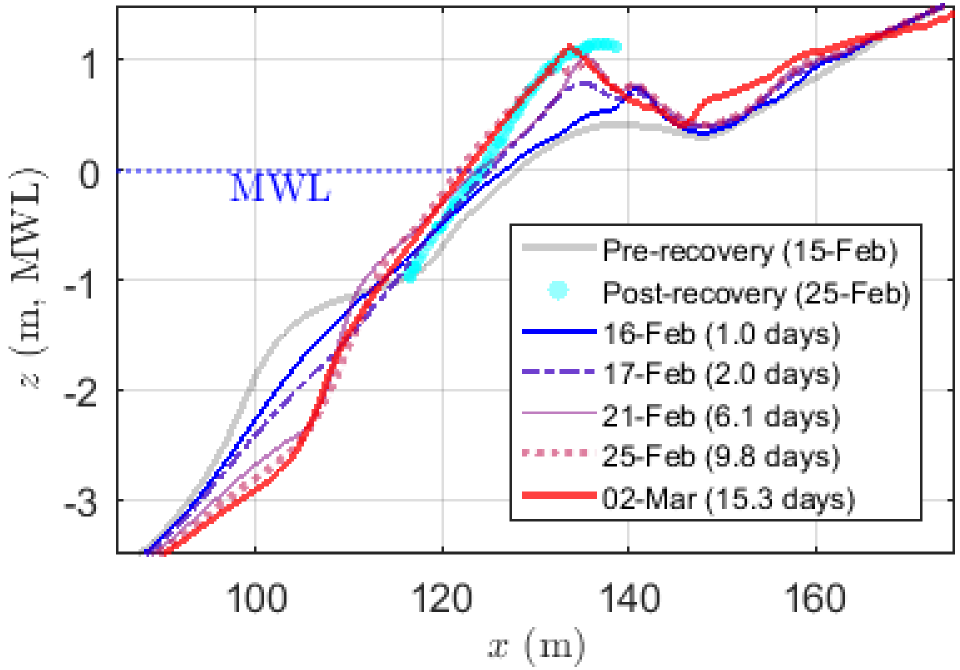


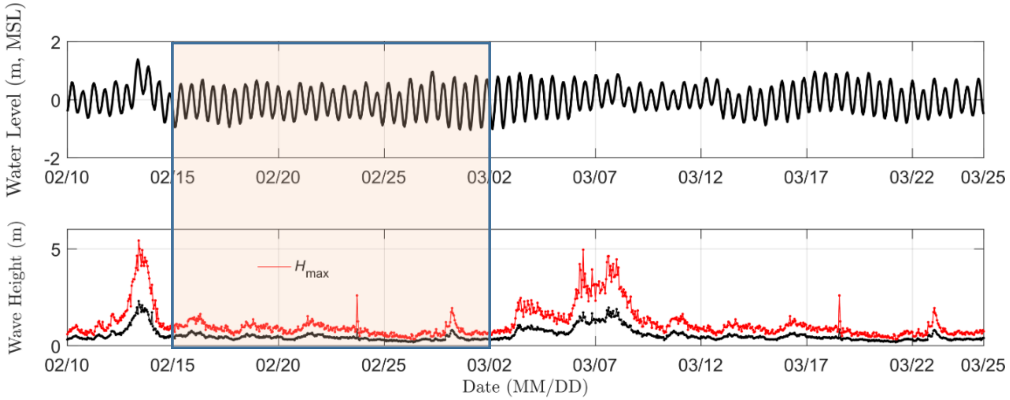
RESULTS: BEACH PROFILE EVOLUTION

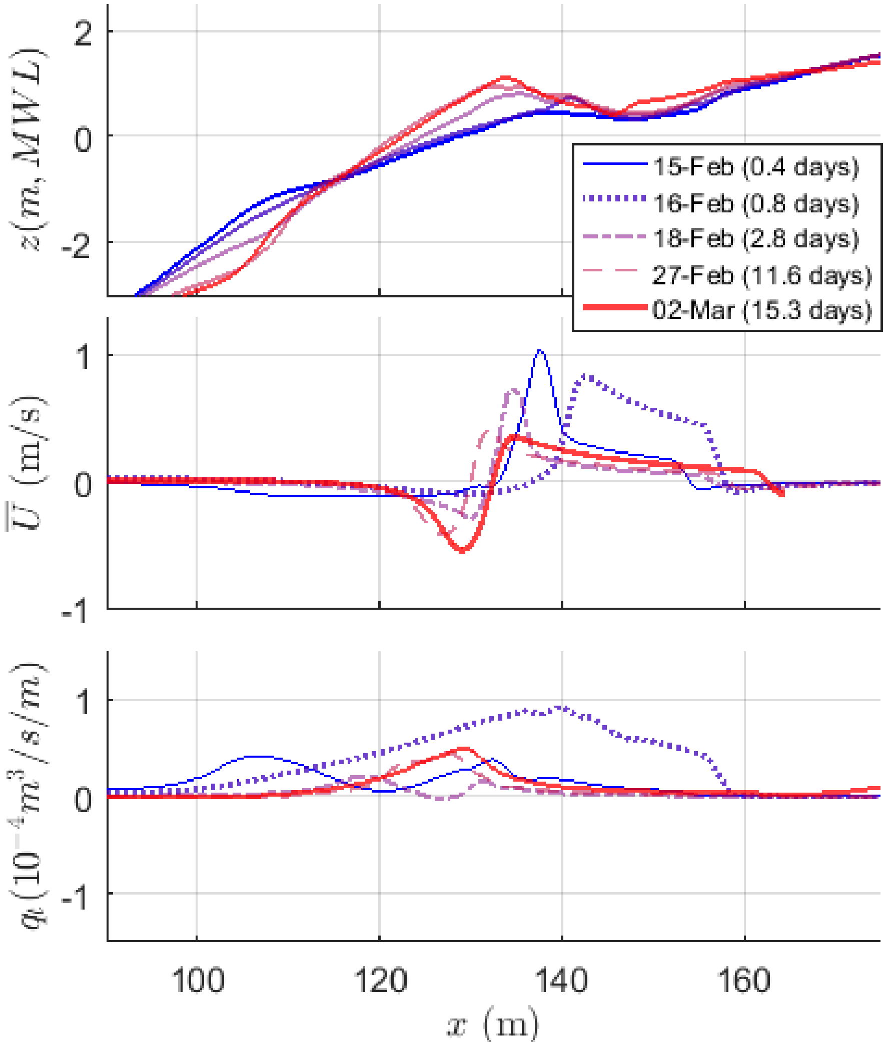
Ridge-Runnel Evolution



Profile Evolution: Ridge-Runnel Formation & Stabilization

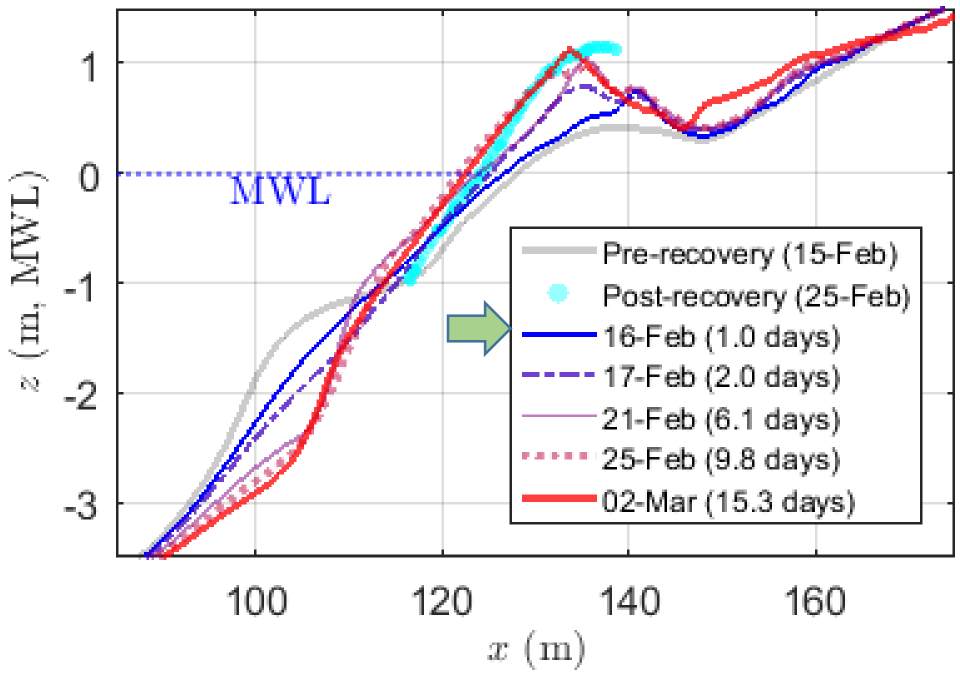


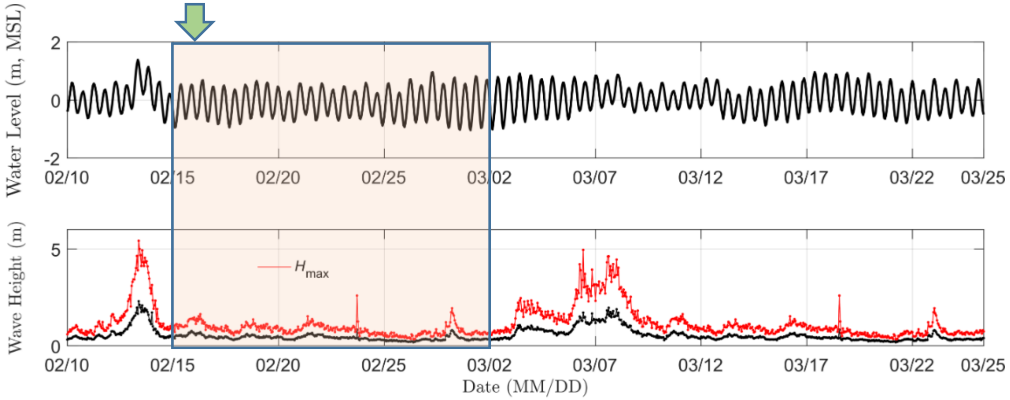




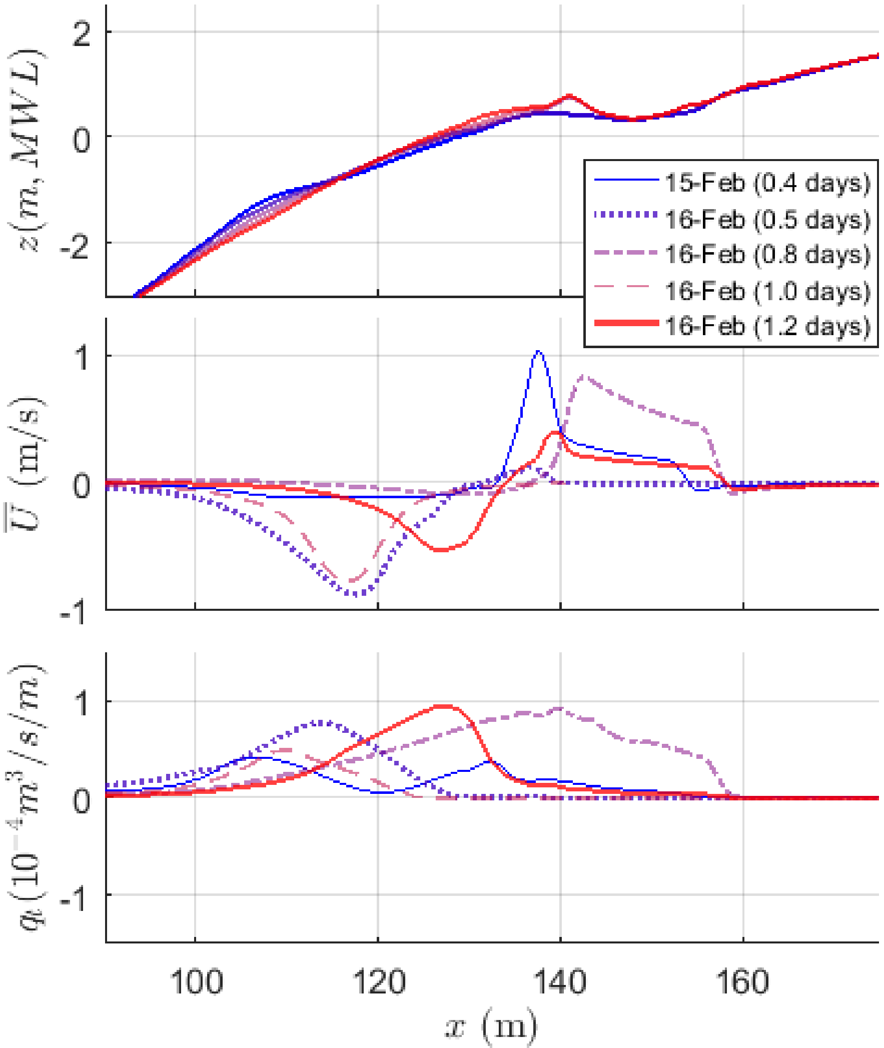
RESULTS: BEACH PROFILE EVOLUTION

Profile Evolution: Ridge-Runnel Formation & Stabilization



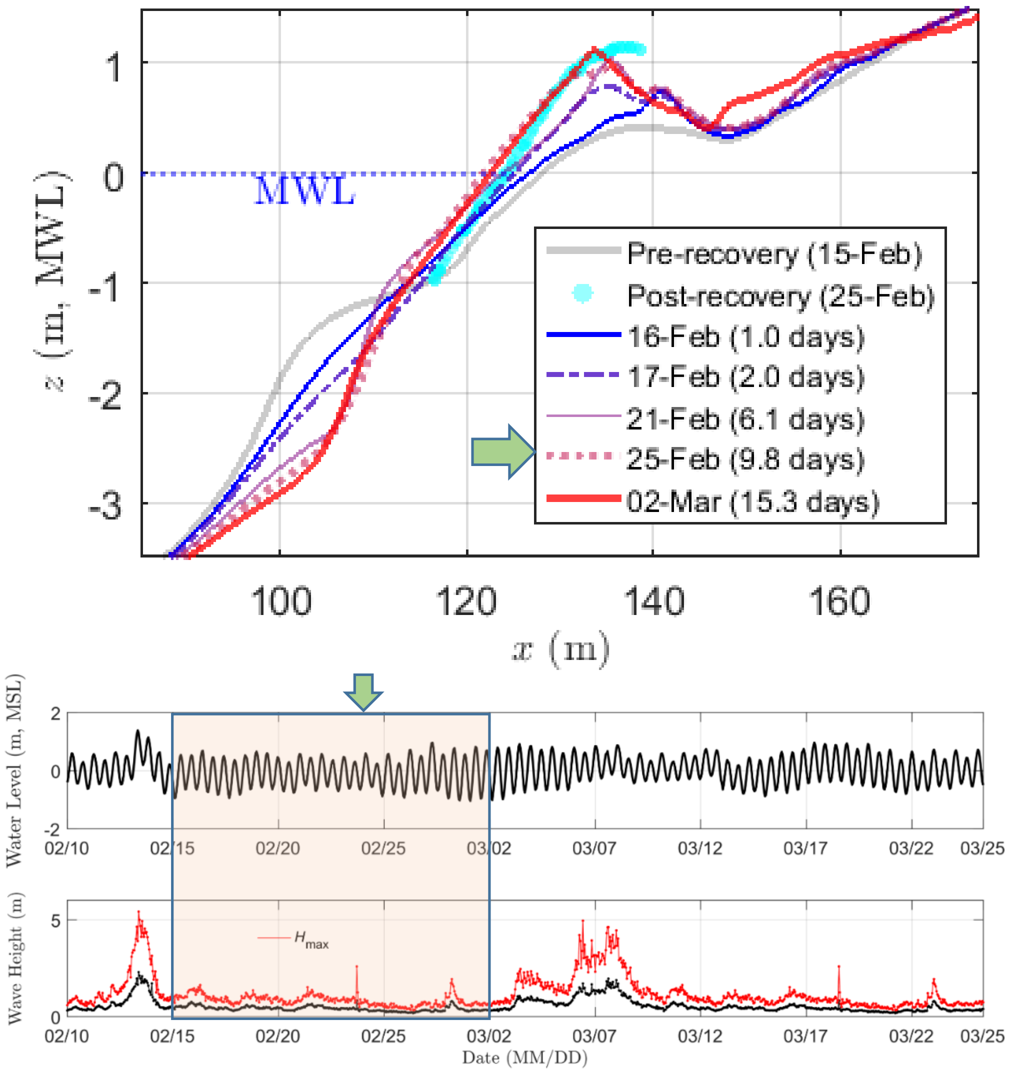


Ridge grows rapidly in both vertical and seaward directions

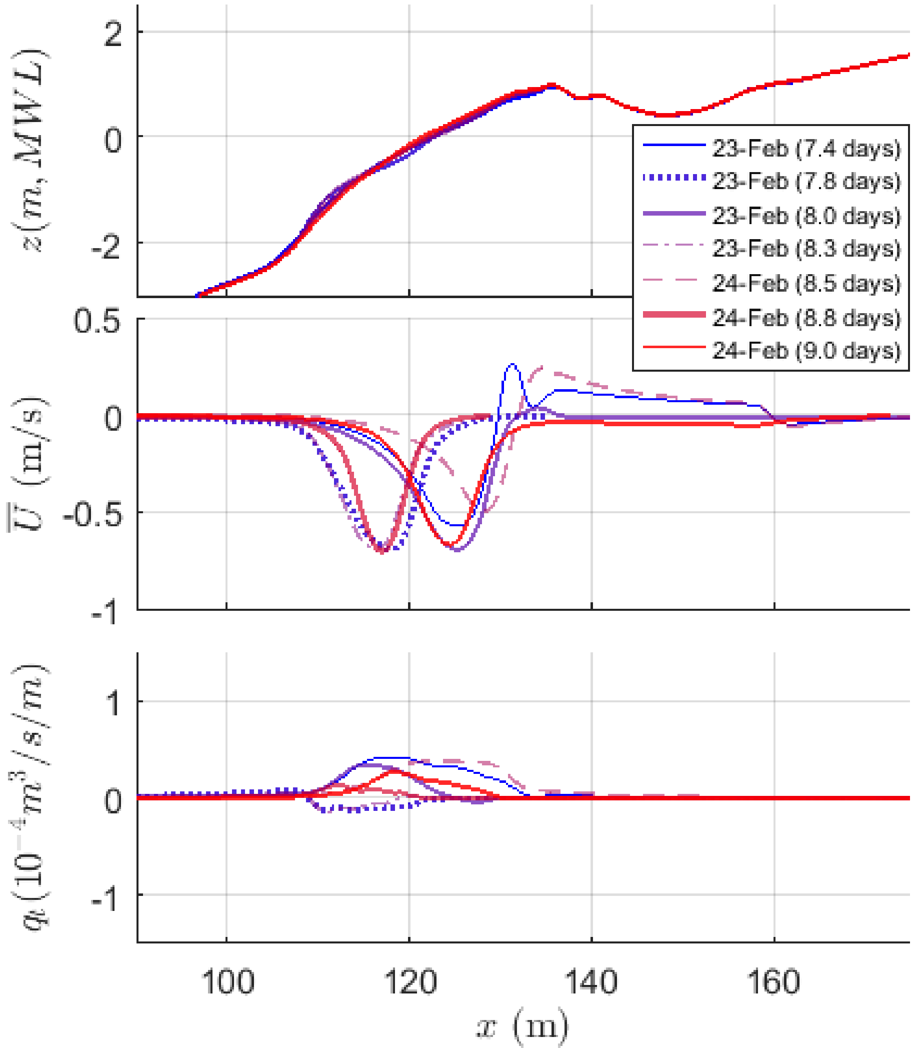


RESULTS: BEACH PROFILE EVOLUTION

Profile Evolution: Ridge-Runnel Formation & Stabilization



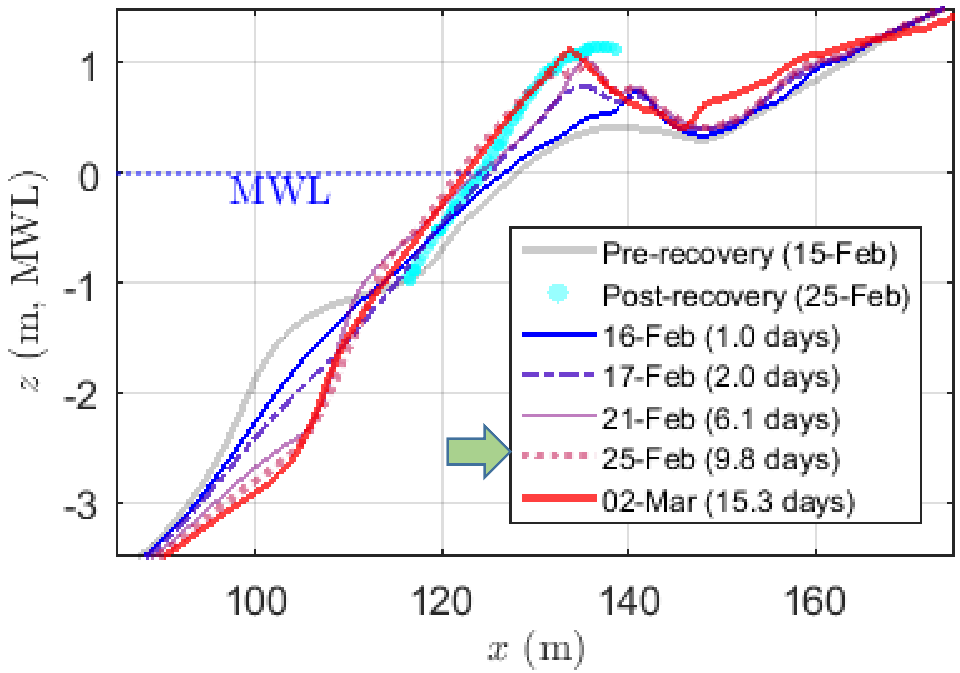
Ridge grows slowly in the seaward direction

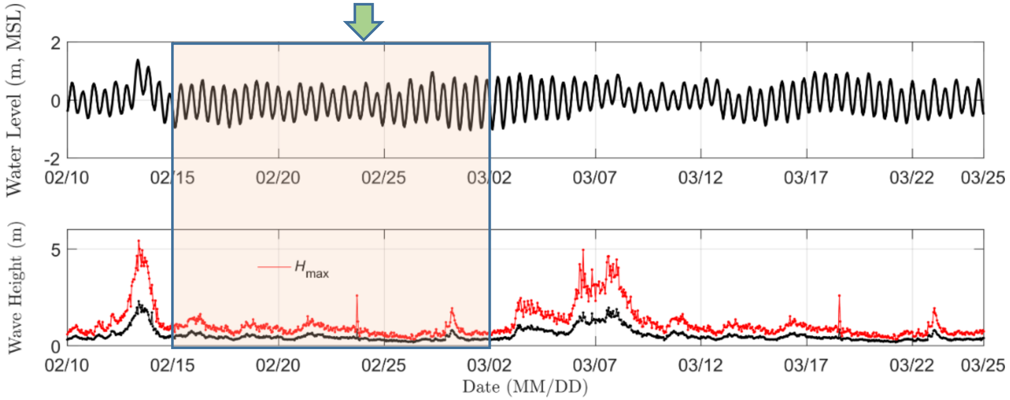


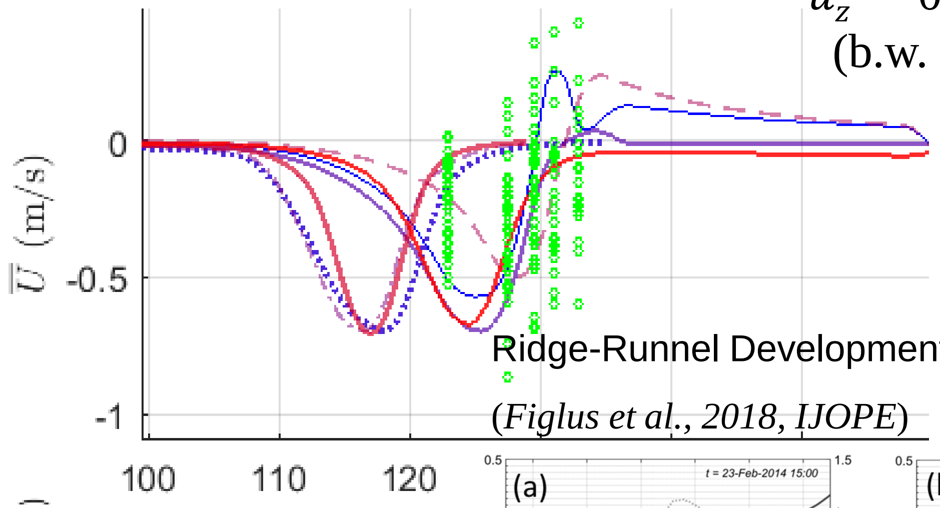
RESULTS: BEACH PROFILE EVOLUTION

Profile Evolution: Ridge-Runnel Formation & Stabilization

- $\overline{u_z}$ = -0.9 m/s - 1.0 m/s (b.w. Feb-22 – Feb-25)

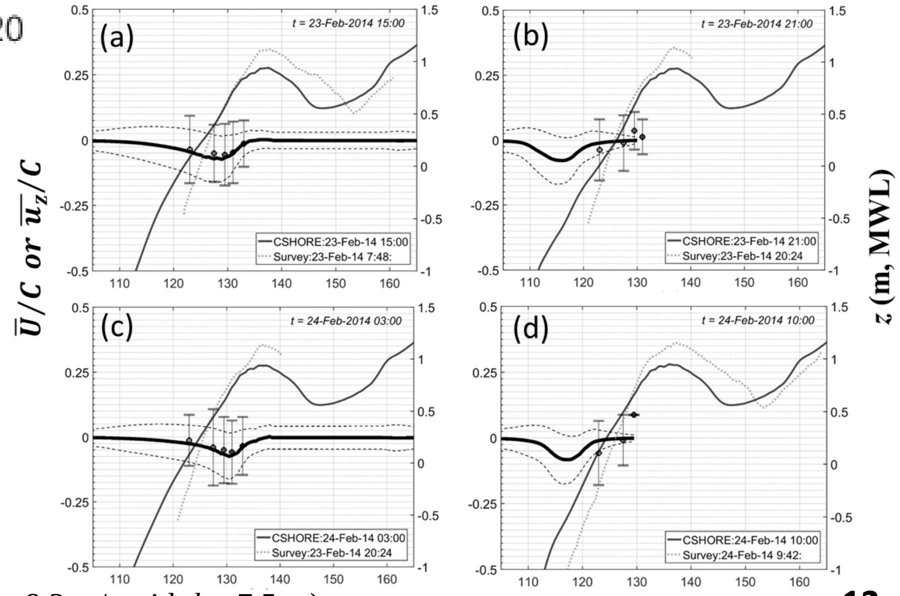






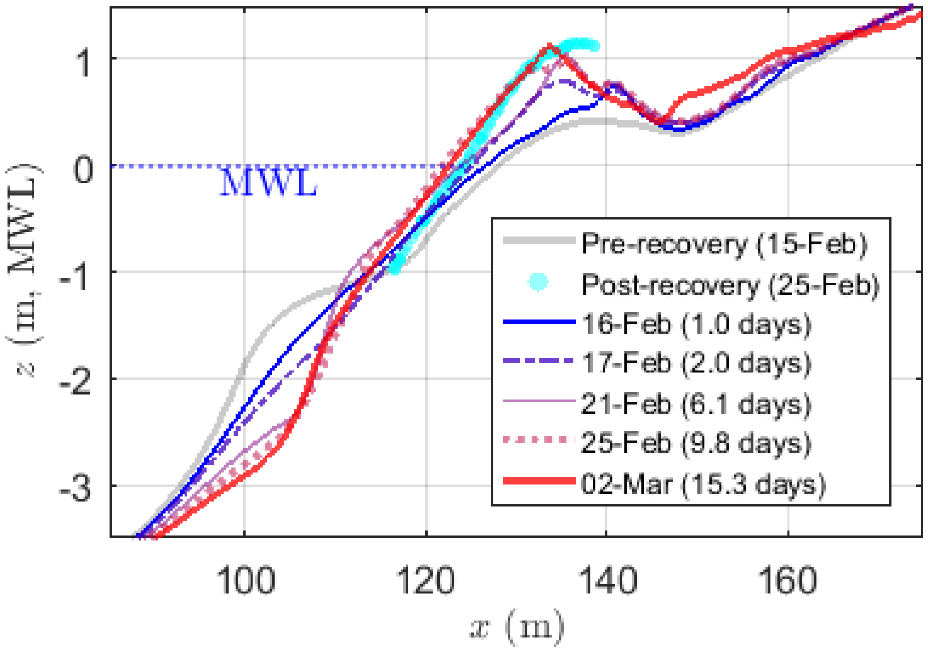
Ridge-Runnel Development & Swash Velocities

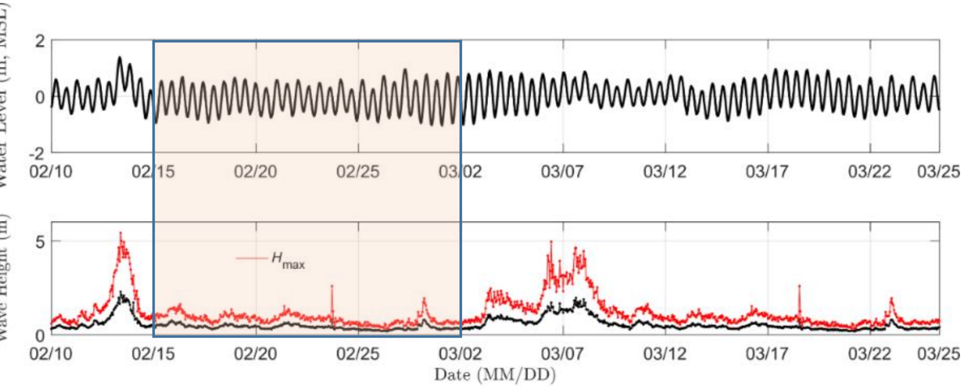
(Figlus et al., 2018, IJOPE)



($C = \sqrt{gh_0}$ =8.3 m/s with h_o=7.5 m)

Profile Evolution: Ridge-Runnel Formation & Stabilization





<u>Ridge-Runnel Formation</u>

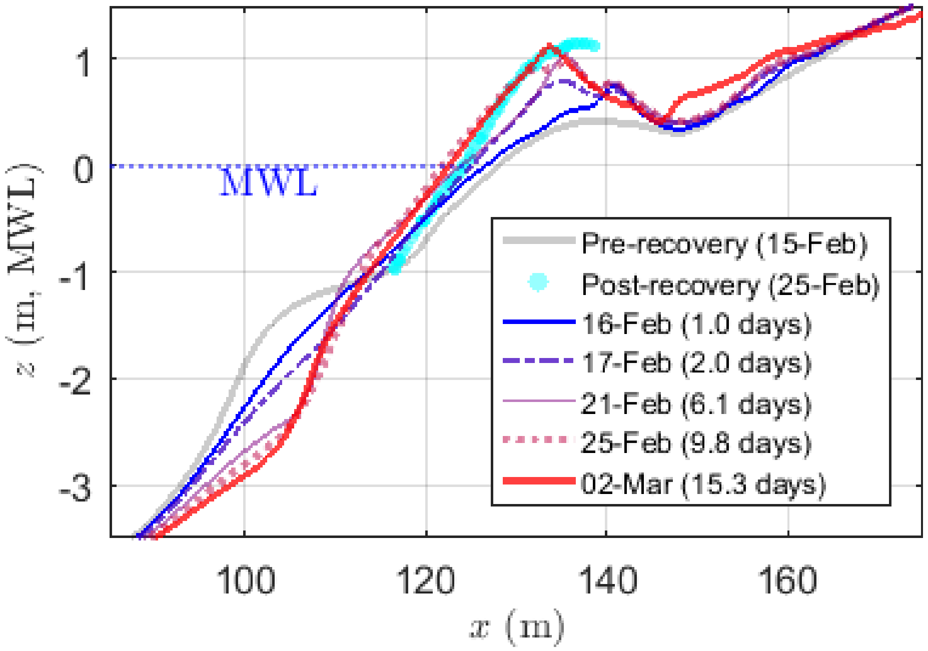
- Buildup of a berm crest above MWL
- The ridge grows rapidly in both vertical and horizontal directions
- Ridge-Runnel development sequence (Hine, 1979) and Berm Growth Mode 1 (Weir et al., 2006)
- Prominent onshore overtopping currents associated with spring high tides

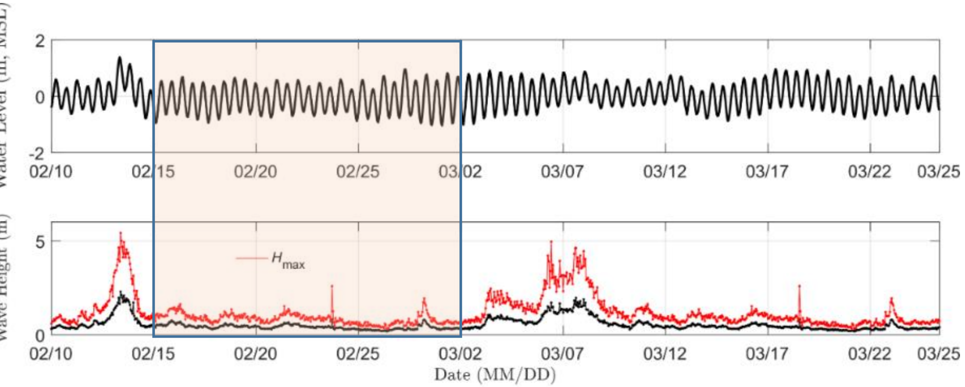
<u>Ridge-Runnel Stabilization</u>

- The ridge grows slowly mainly in the seaward direction, steepening shoreface
- Ridge-Runnel stabilized with decreasing neap tidal water level
- Neap-Berm concept (Hine, 1979) and Berm Growth Mode 2 (Weir et al., 2006)
- Strong, steady offshore return current just below MWL

Landward net sed. transport: main source is inner-surf and low swash

Profile Evolution: Ridge-Runnel Formation & Stabilization





CSHORE Predicted

- 25-Feb (Last field day)

  z_b = 1.0 m
  $\tan\beta$ = 1.11
  V_{CSH} = 85 % (26.0 m^3/m)

- 02-Mar (+11 tidal cycles)

  z_b = 1.1 m
  $\tan\beta$ = 1.13
  V_{CSH} = 87 % (26.8 m^3/m)

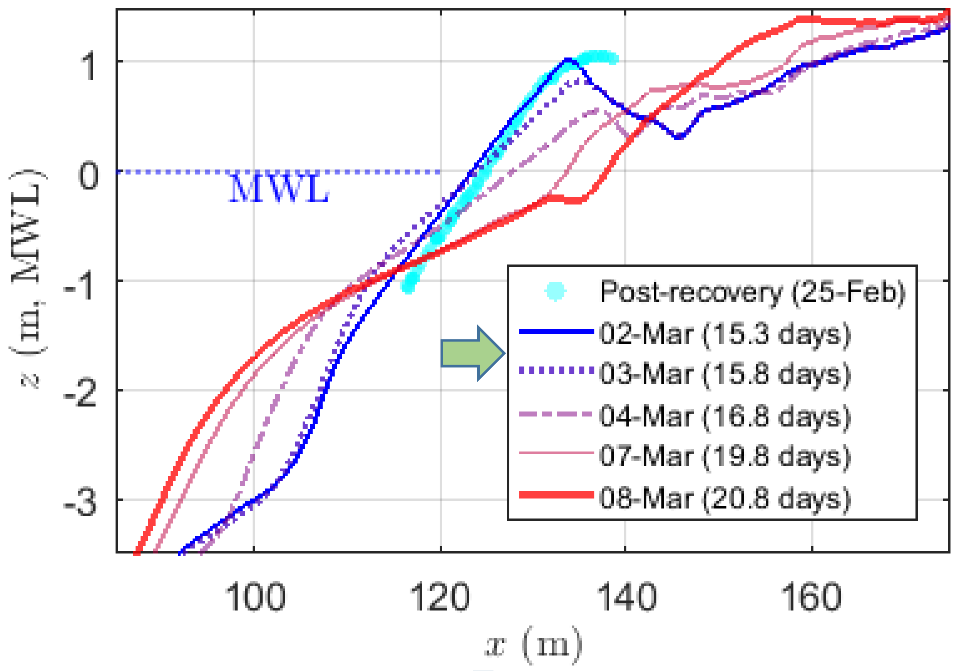
Field Observation

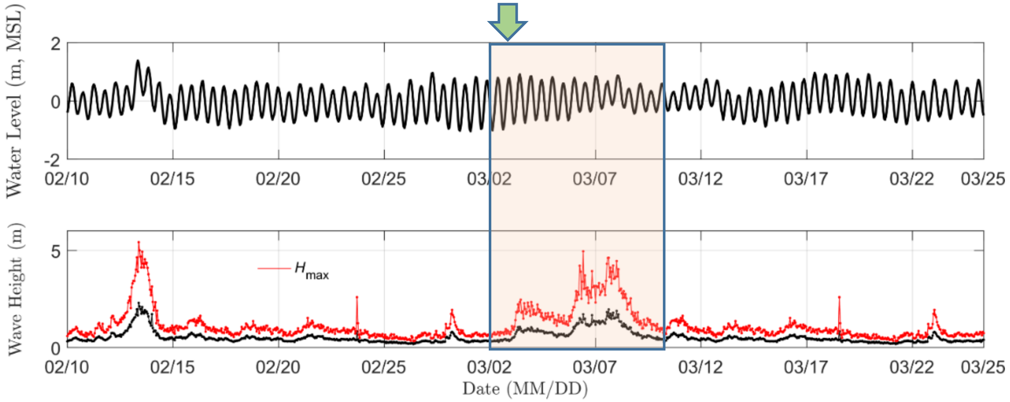
- 25-Feb (Last field day)

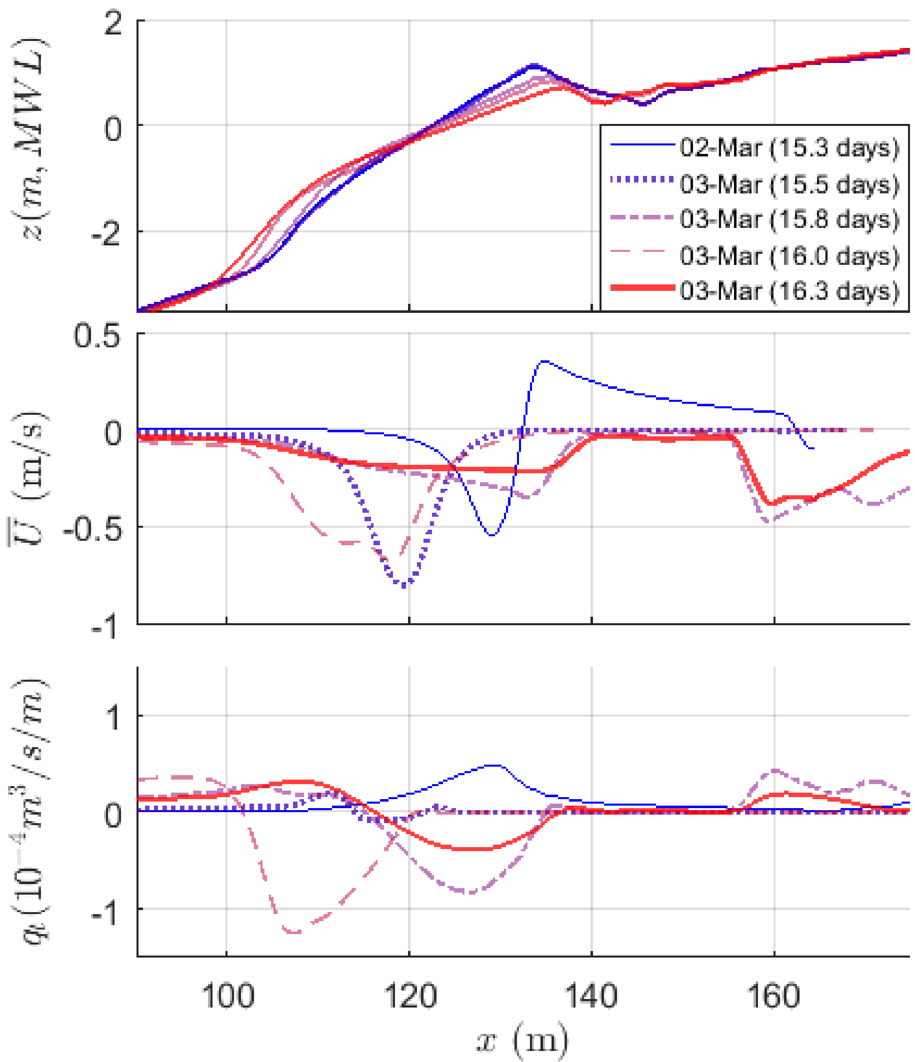
  z_b = 1.1 m
  $\tan\beta$ = 1.14
  V_M = 85 % (26.0 m^3/m)

- $\overline{u_z}$ = -0.9 m/s - 1.0 m/s
- $\overline{U}$ = -0.7 m/s - 1.1 m/s
  (b.w. Feb-22 – Feb-25)

Profile Evolution: Ridge-Runnel Onshore Migration



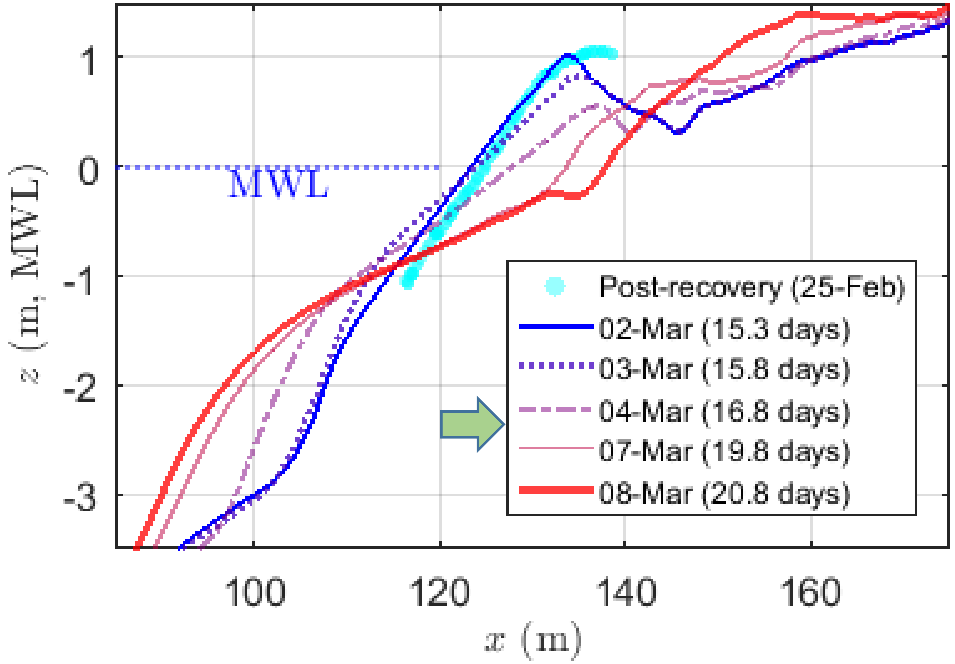


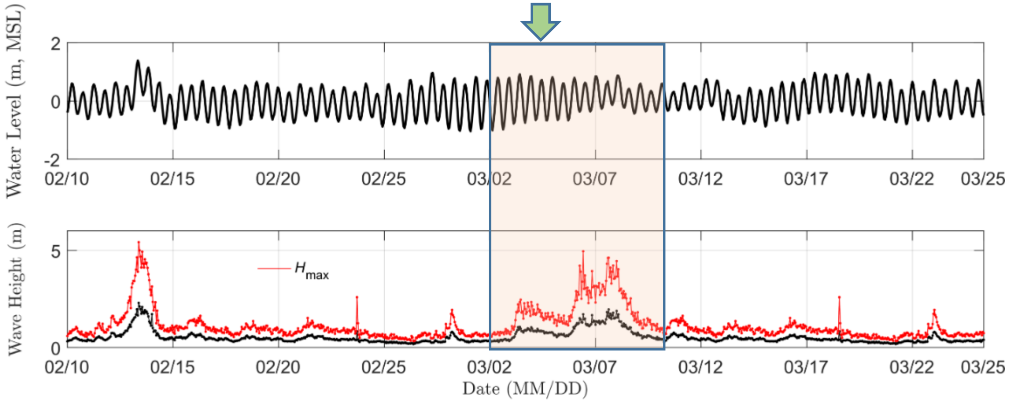


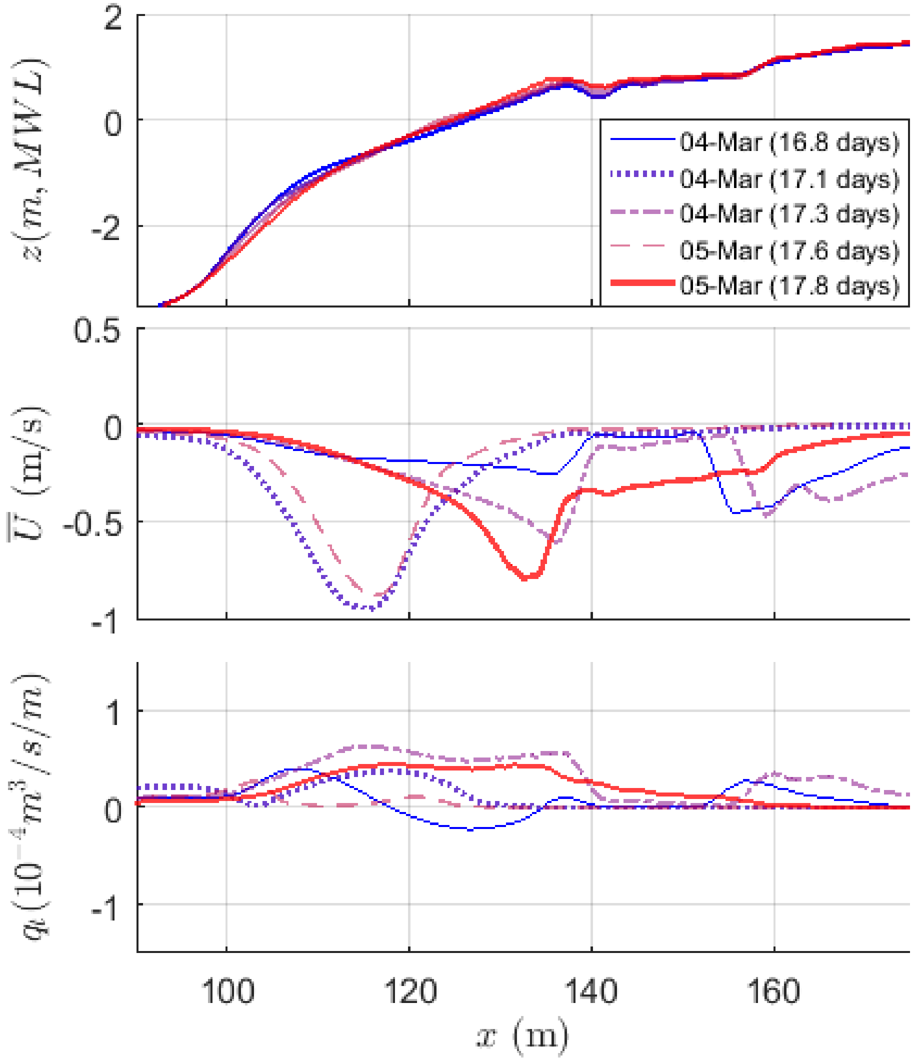
RESULTS: BEACH PROFILE EVOLUTION

OCEAN ENGINEERING TEXAS A&M UNIVERSITY · UNIVERSITY OF DELAWARE · NSF

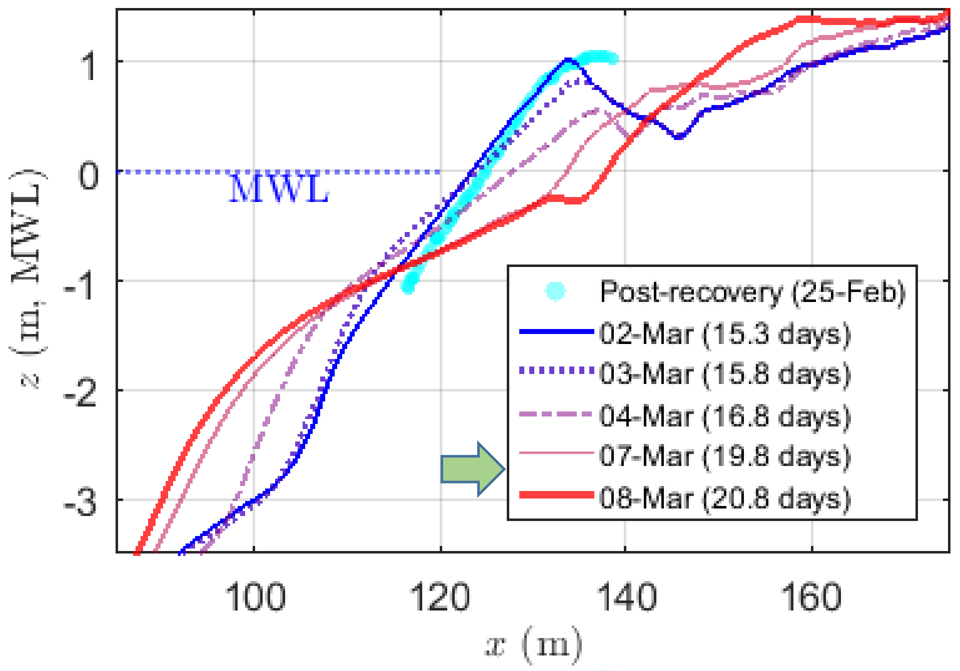
Profile Evolution: Ridge-Runnel Onshore Migration

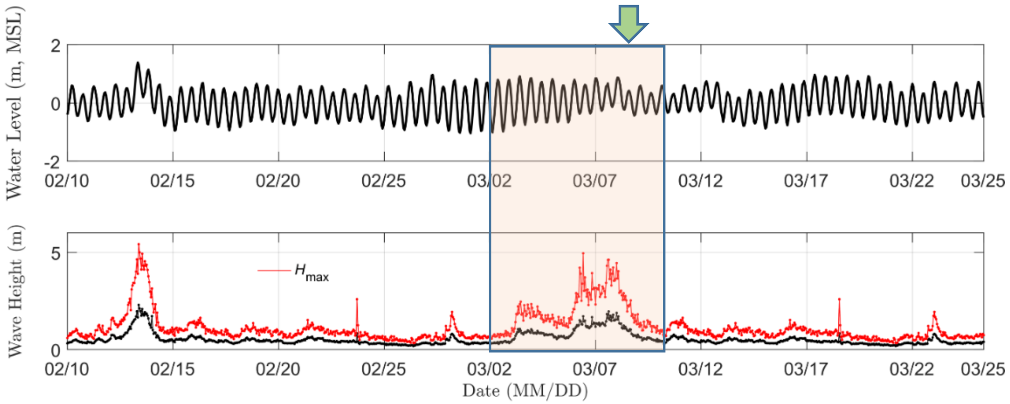


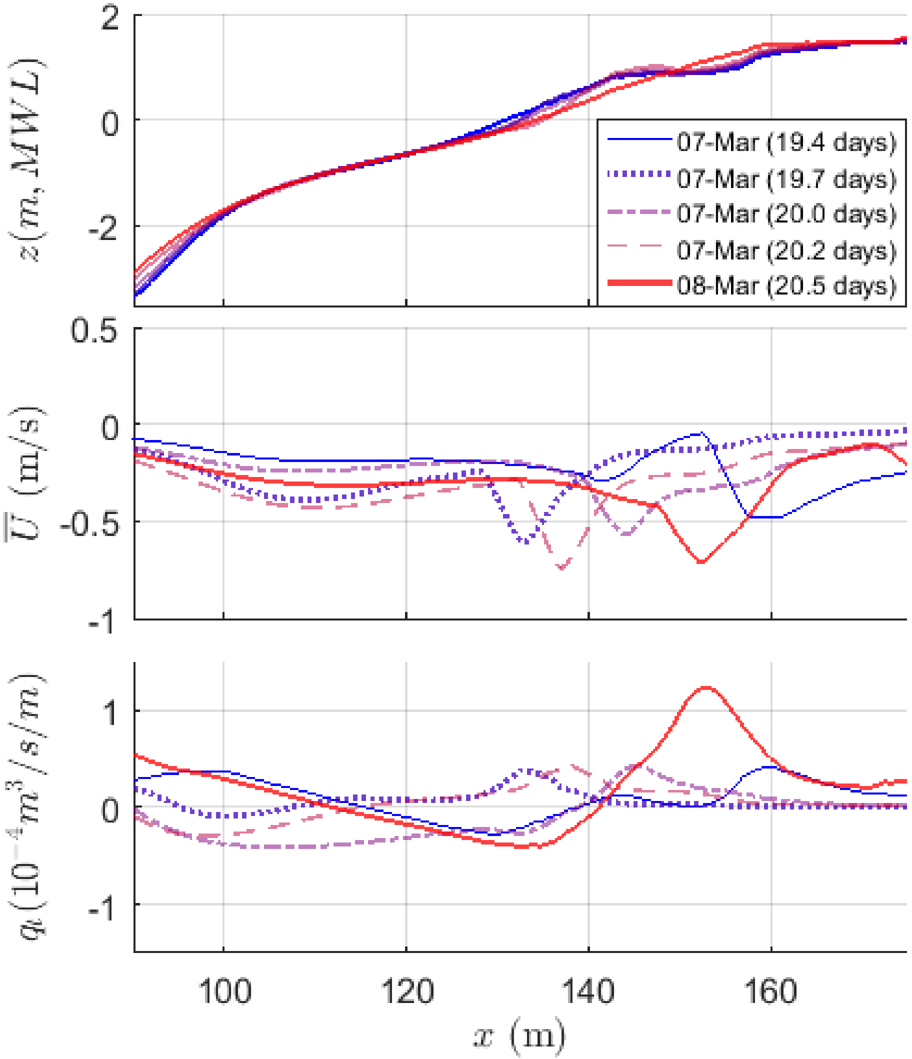




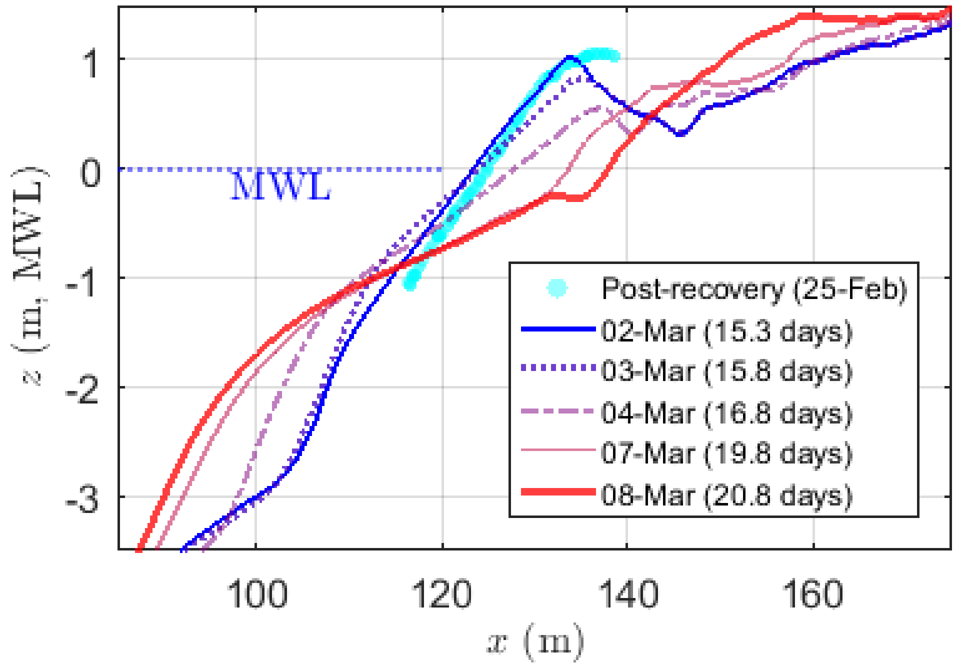
Profile Evolution: Ridge-Runnel Onshore Migration

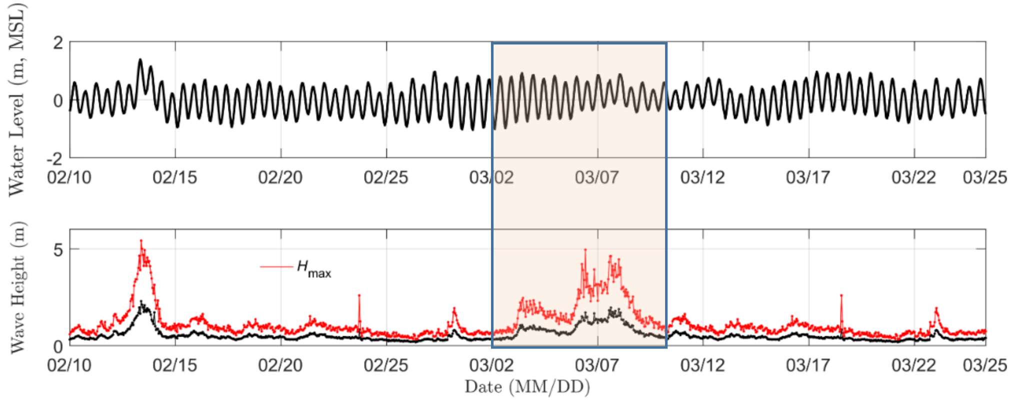






Profile Evolution: Ridge-Runnel Onshore Migration





<u>By 08-Mar (42 tidal cycles)</u>

- Initial upper shoreface wash-off
- Ridge migrates landward, welding to the upper beach profile
- Velocity deficit due to the runnel promotes sediment settlement
- Strong offshore return flows upto $\overline{U}$ = -0.9 m/s during infilling
- Sediment onshore transport is largely by wave swash action
- Sediment remained migrates to upper beach
- A new berm crest develops on upper swash

z_b = 1.4 m (vs 1.1 m)

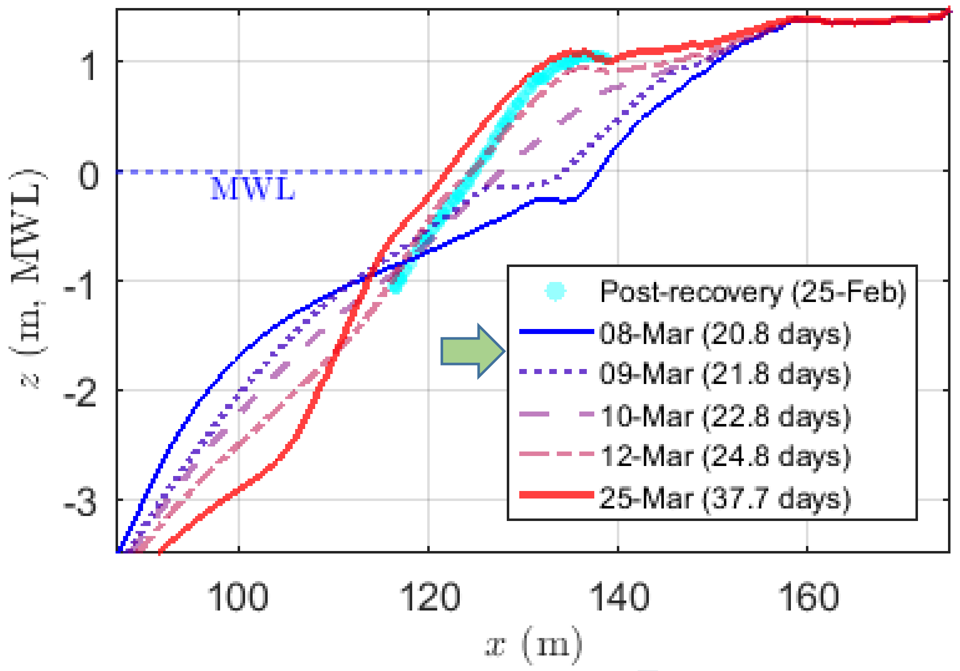
x = 159 m (+23 m landward)

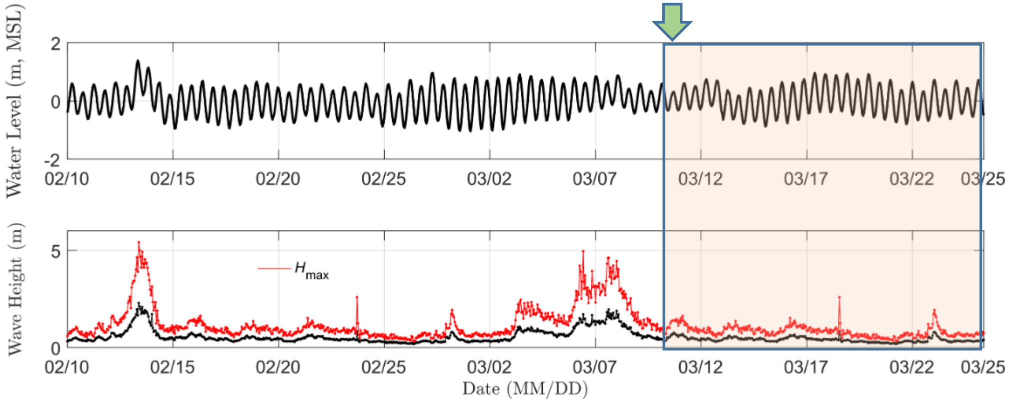
$\tan\beta$ = 0.07

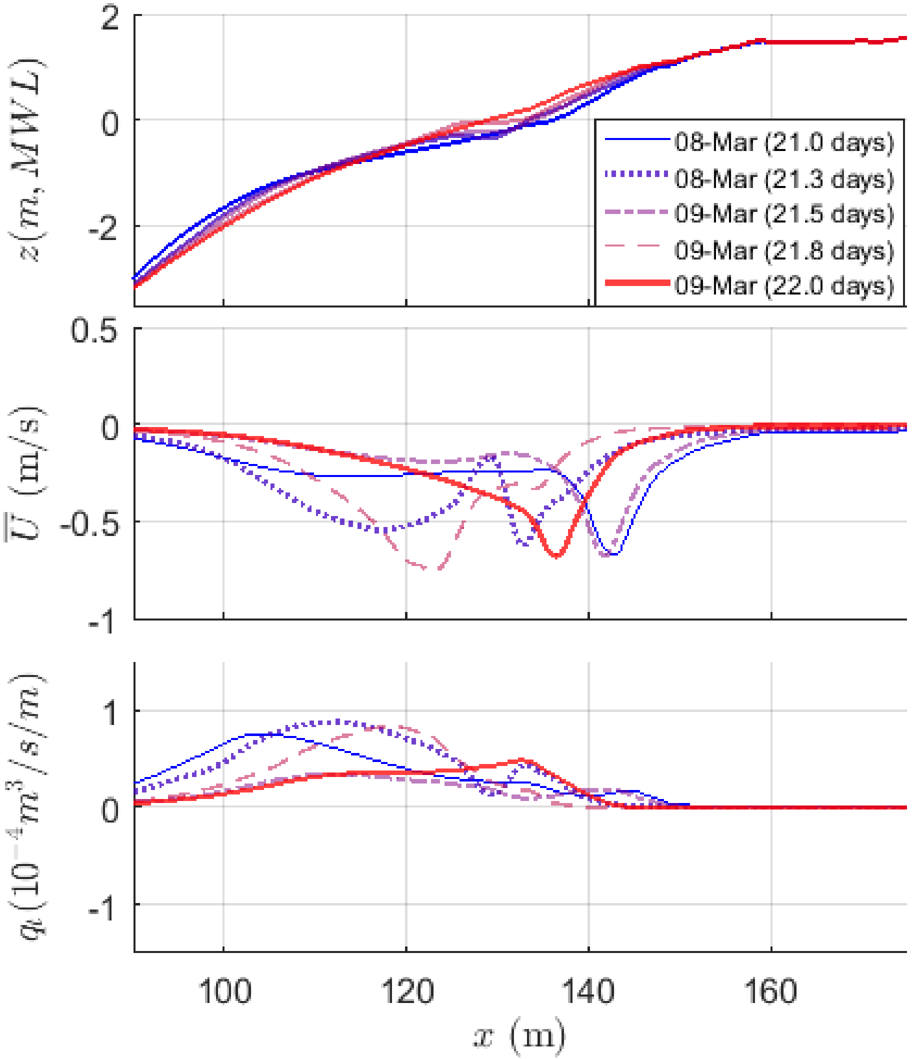
V_{CSH} = 105 % (32.4 m^3/m)

RESULTS: BEACH PROFILE EVOLUTION

Profile Evolution: Berm Growth

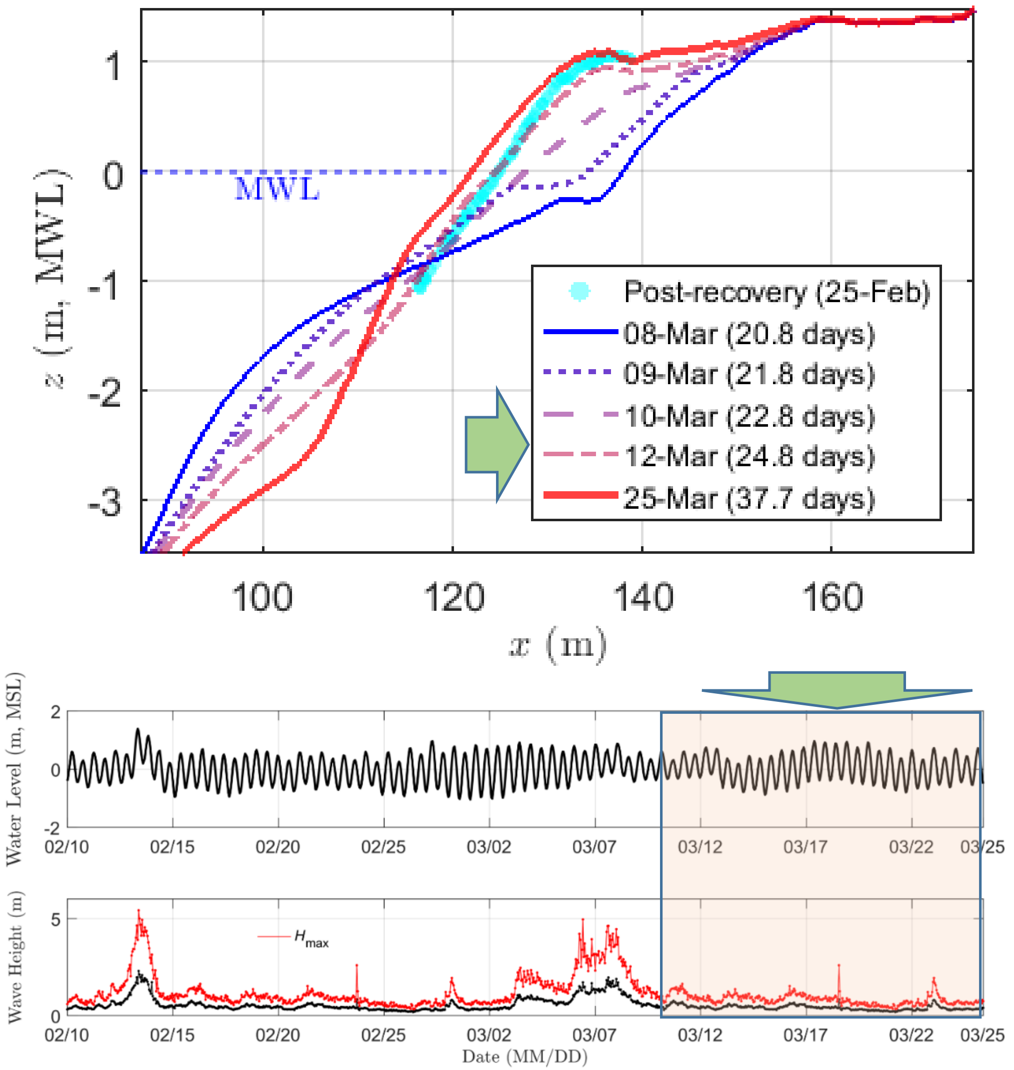


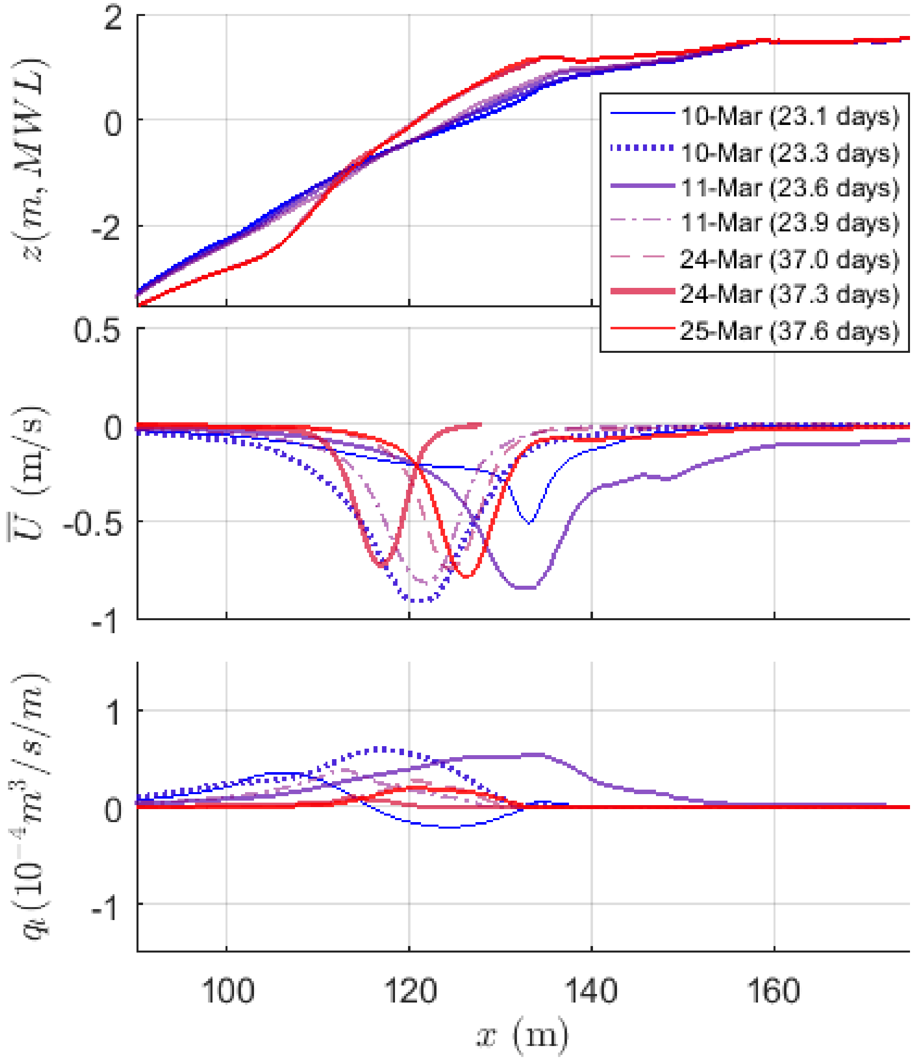




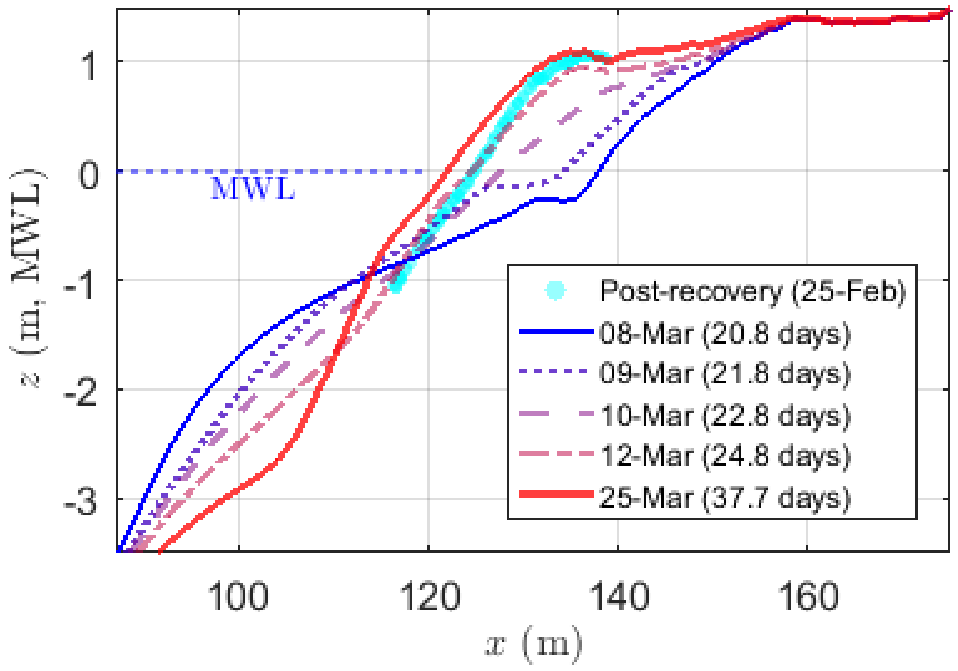
RESULTS: BEACH PROFILE EVOLUTION

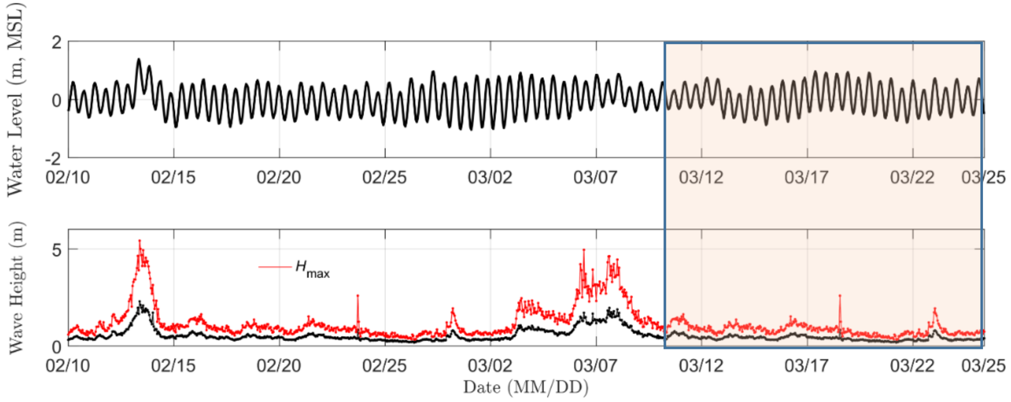
Profile Evolution: Berm Growth





Profile Evolution: Berm Growth





By 25-Mar (76 tidal cycles)

- A new berm grows toward a berm-dune beach template
- Seaward growth starts from a landward, high elevation location
- Neap-Berm concept (Hine, 1979) and Berm Growth Mode 2 (Weir et al., 2006)
- Steady morphological growth and consist velocity distribution
- Sediment carried from the lower swash feeds the upper berm face

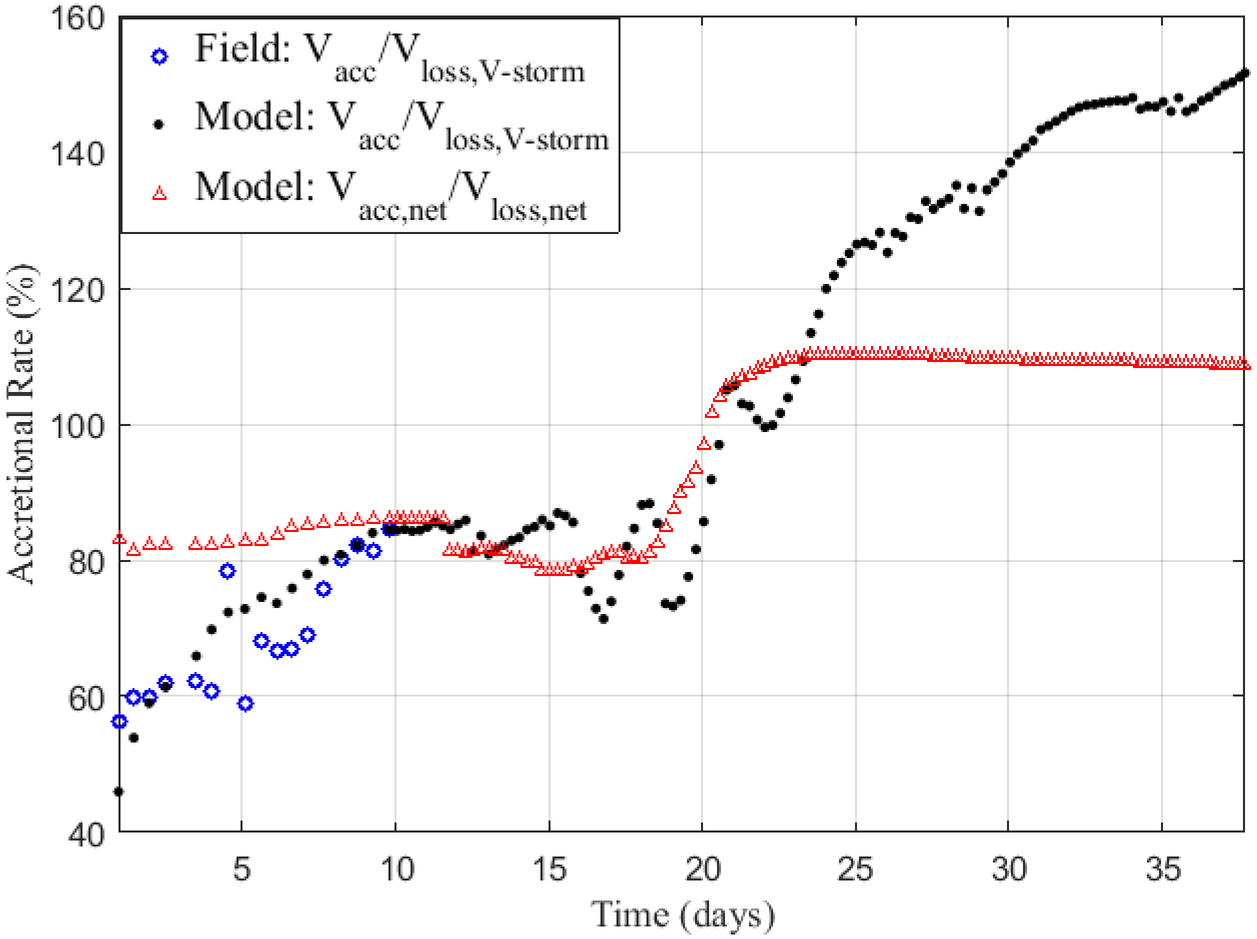
z_b = 1.1 m (vs 1.1 m)

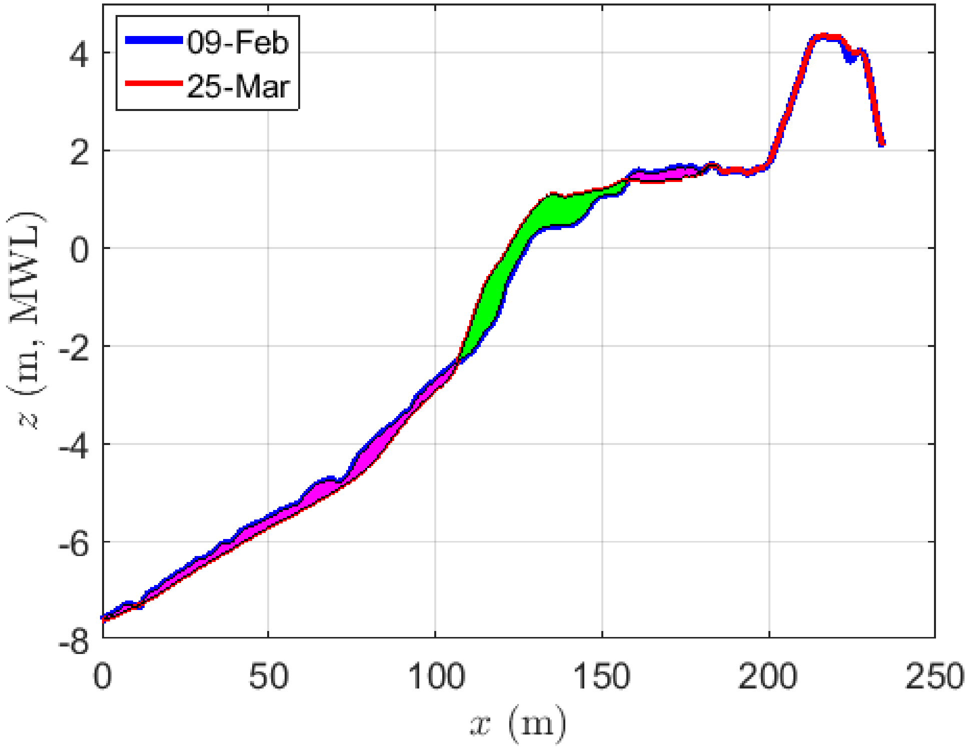
x = 159 m (+0 m landward)

tanβ = 1.12

V_{CSH} = 152 % (46.7 m^3/m)

Volumetric Accretion Rates



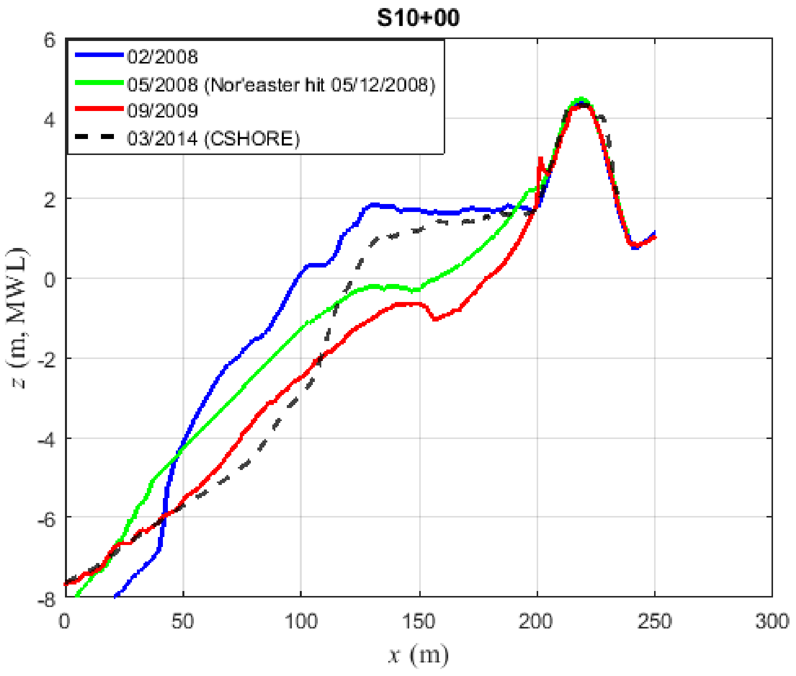


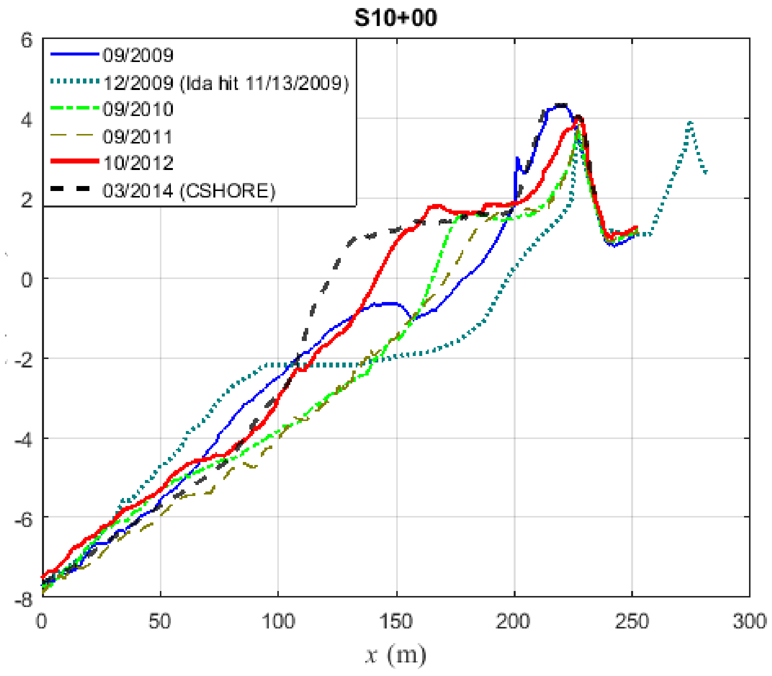
CONCLUSION

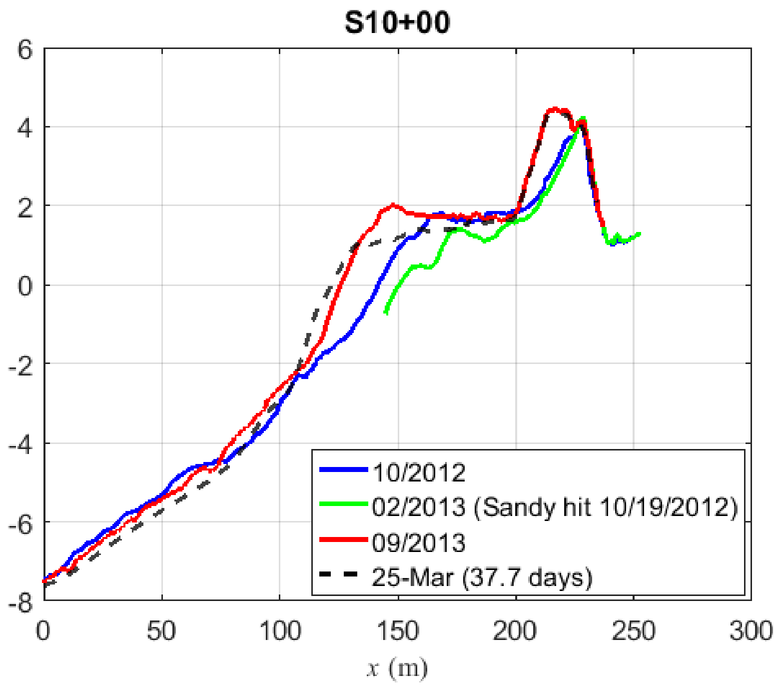
- **Buildup of a ridge crest** can be **associated with onshore directed overtopping current** prominent during **spring high tides**.
- The **Ridge-Runnel System**, once **stabilized**, further **develops to Berm-Ridge profile** under continuing **moderate** wave conditions.
- **Onshore Migration of Ridge-Runnel System** can be realized under **long-lasting (~5-6 days), moderately intense** wave climates during **neap tides**.
- The **R-R** serves to **reestablish the upper swash profile** as **sediment stored in the Runnel** can be kept in the upper beach and partially eroded off to produce **the lower swash profile favorable for onshore sediment transport by wave swash action**.
- Consequently, the **R-R contributes to the overall beach recovery process** by **expediting the dynamic beach equilibrium process**.

South Bethany Monitoring Surveys (USACE, 2008 – 2013)

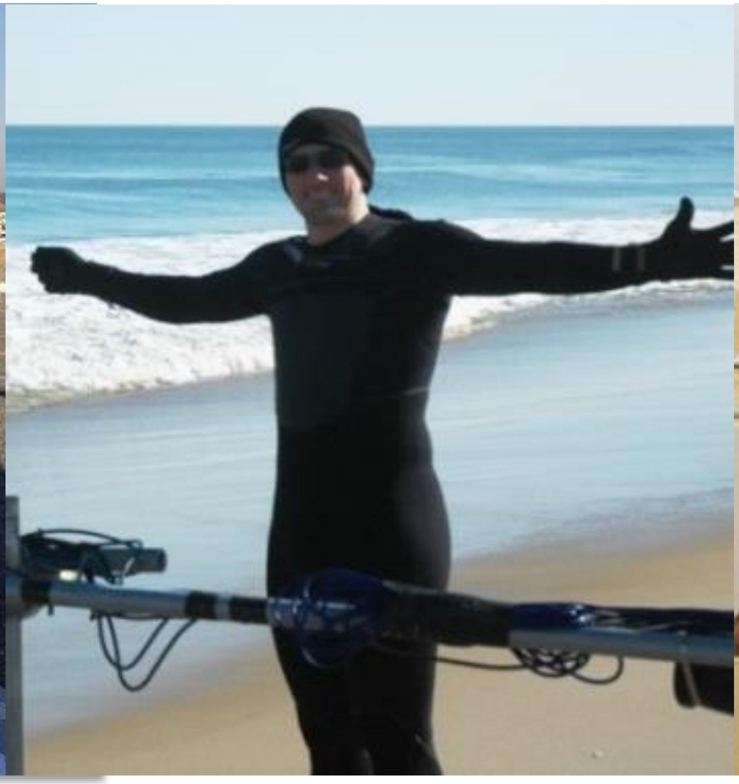
- Initial beach restoration in June 2008
- 2nd renourishment in October 2011
- Restoration completed in September 2013, after Hurricane Sandy







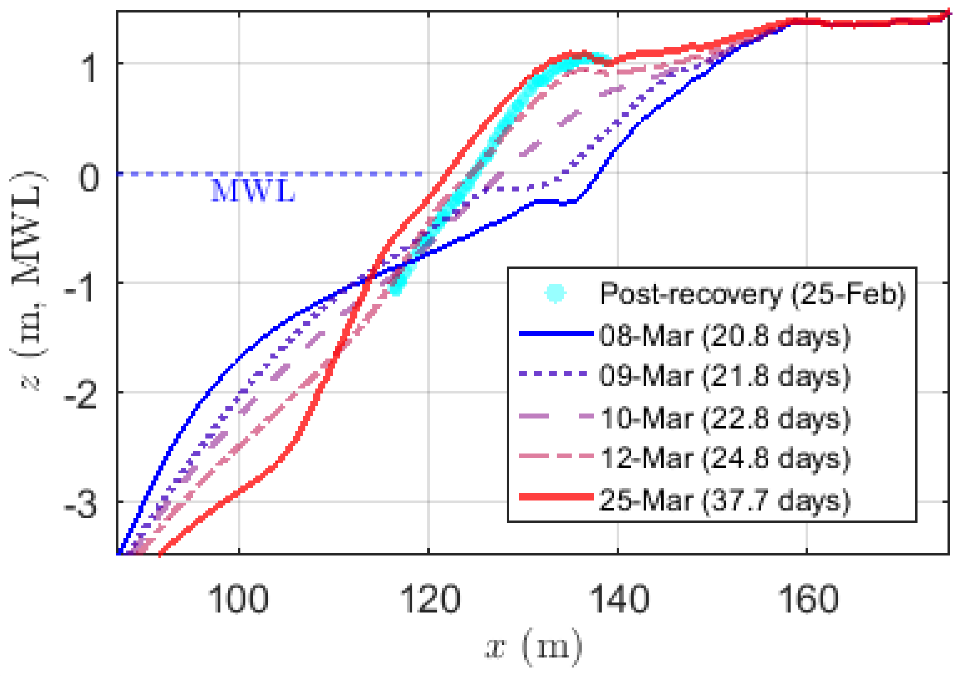
DISCUSSION

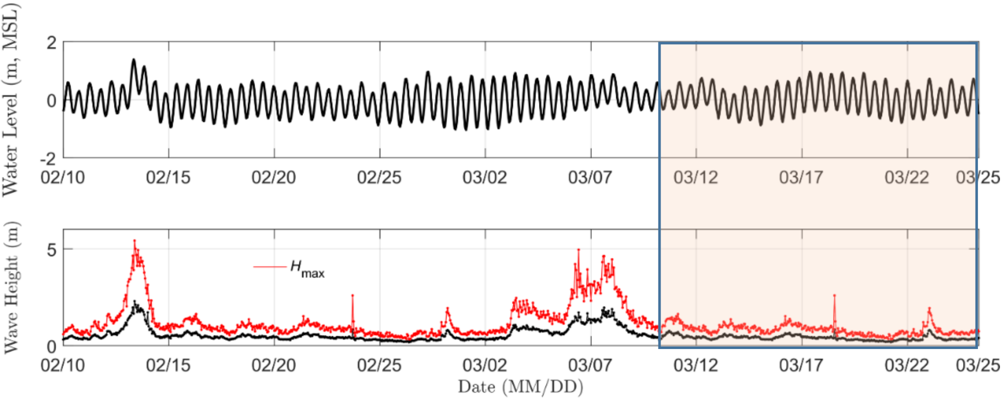


Youn-Kyung Song | Postdoc. Research Associate | yksong@tamu.edu

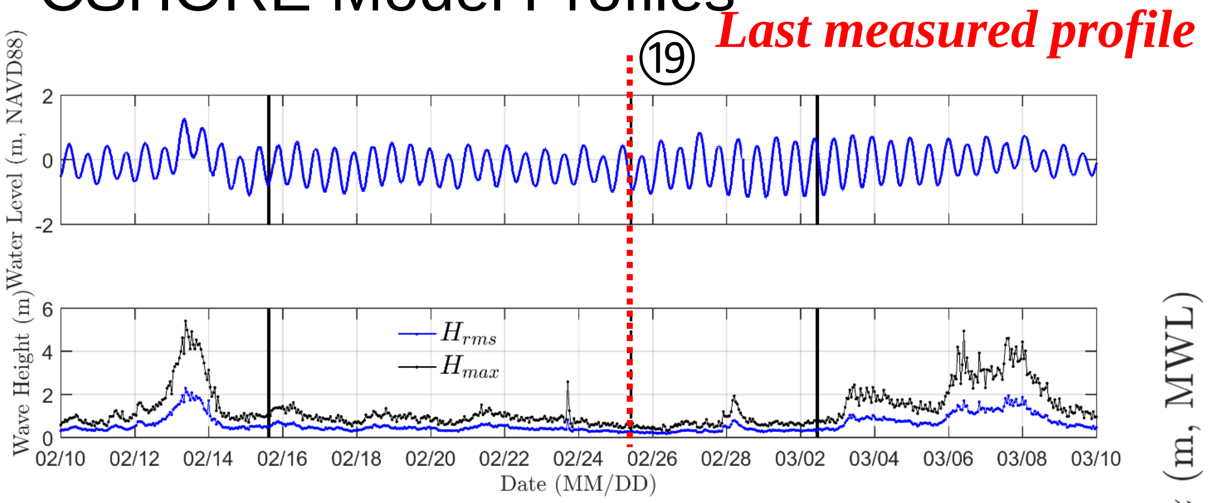
This work was supported by the National Science Foundation under Grants No. OCE-1332872 and No. OCE-0845004, Texas A&M University and the University of Delaware.

Profile Evolution: Berm Growth





CSHORE Model Profiles

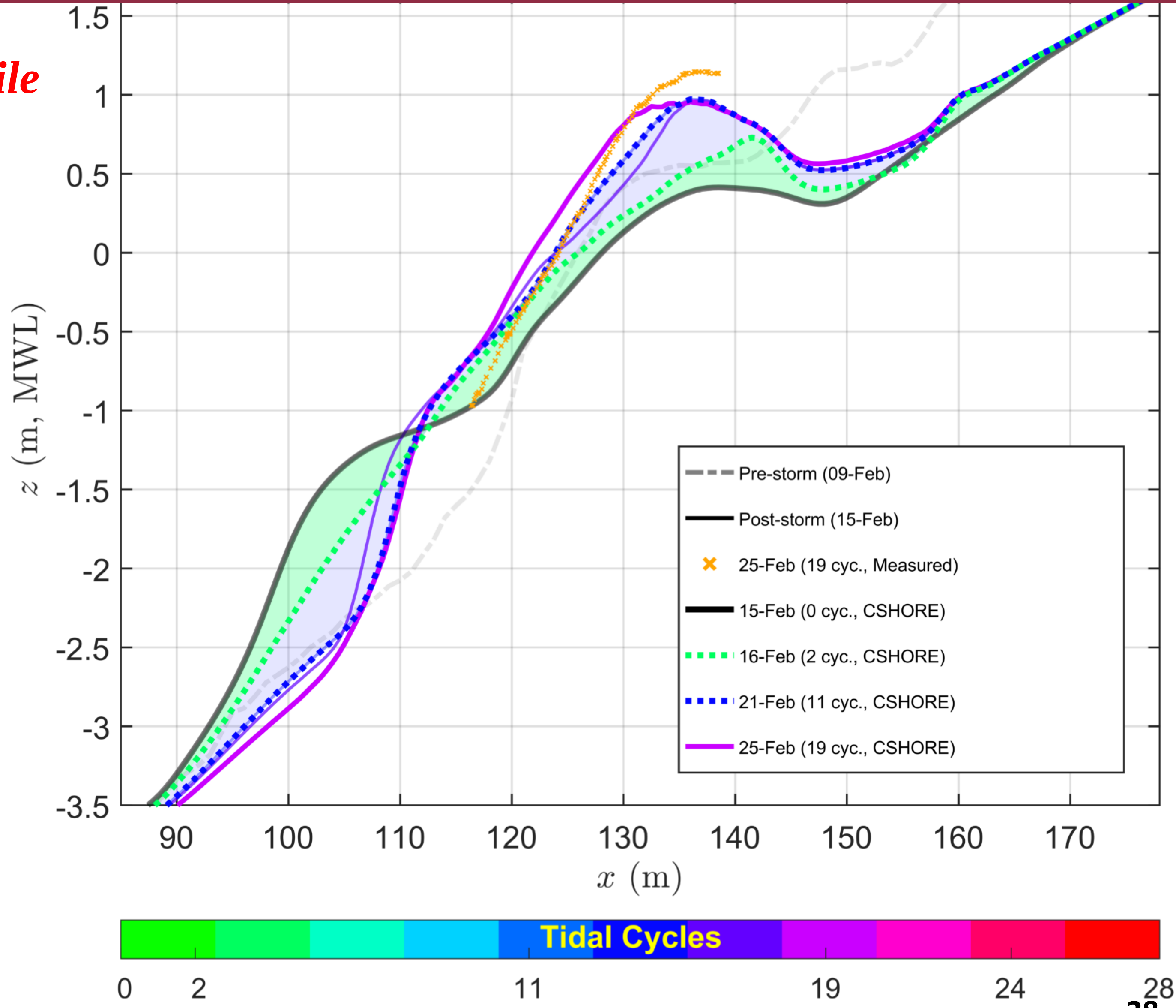


ζ_{MES} = 1.14 m, ζ_{CSH} **= 0.96 m (89 %)**

RMSE = 0.20 m (in swash zone)

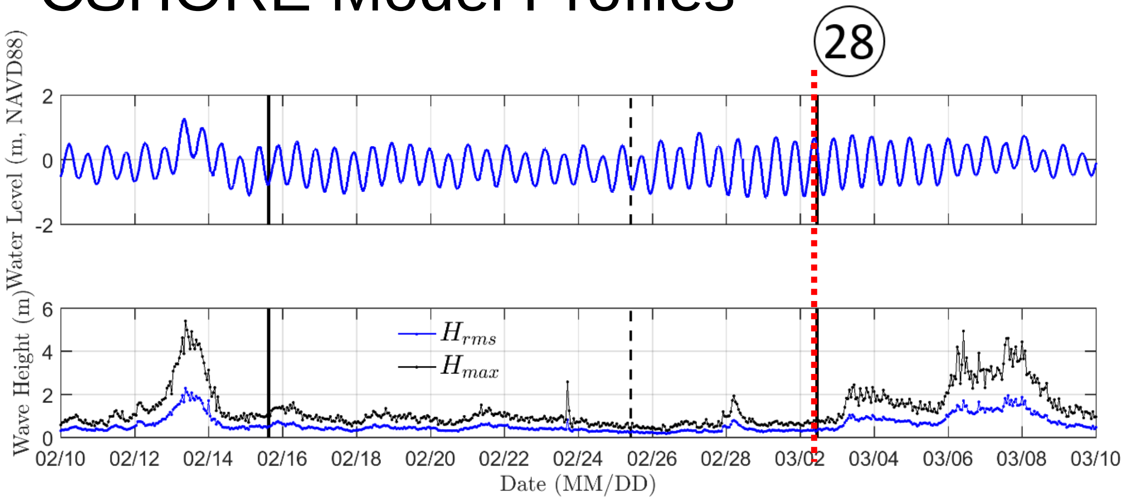
V_{CSH} = 27.2 m^3/m (**85% Recovery**)

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



RESULTS: BEACH PROFILE EVOLUTION

CSHORE Model Profiles

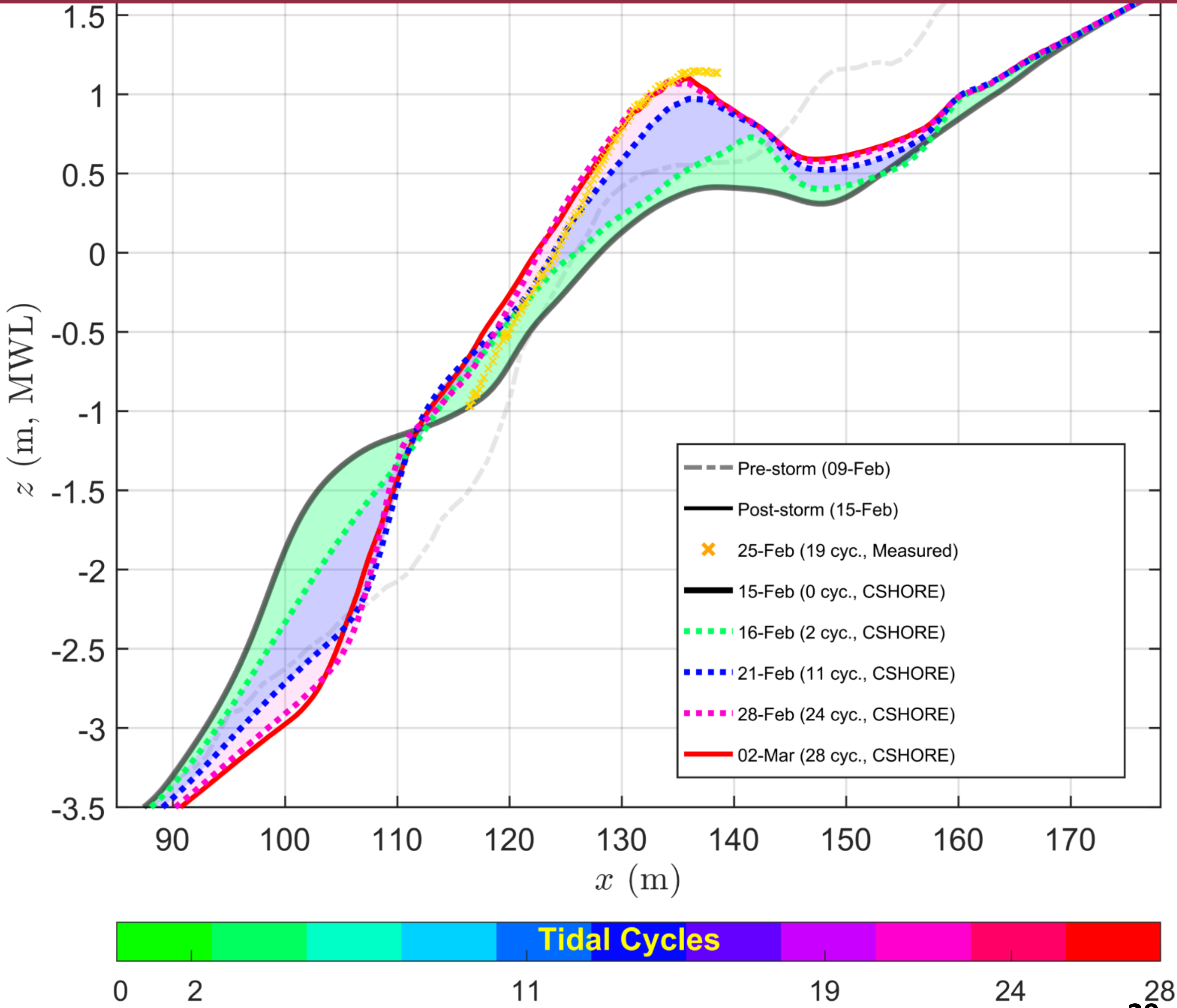


ζ_{MES} = 1.14 m, ζ_{CSH} **= 1.10 m (97 %)**

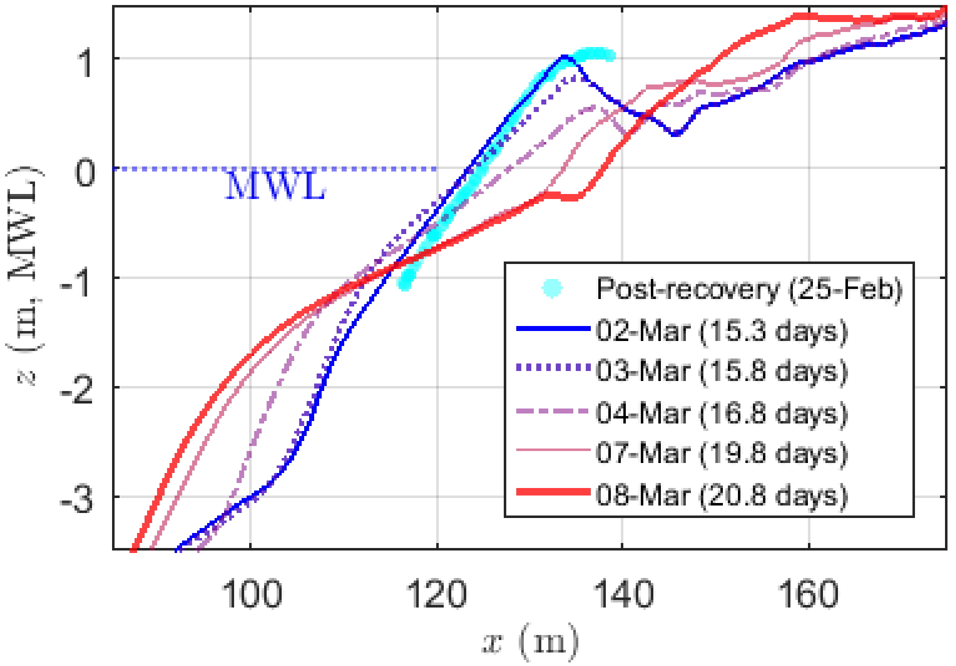
$RMSE$ = 0.16 m (in swash zone)

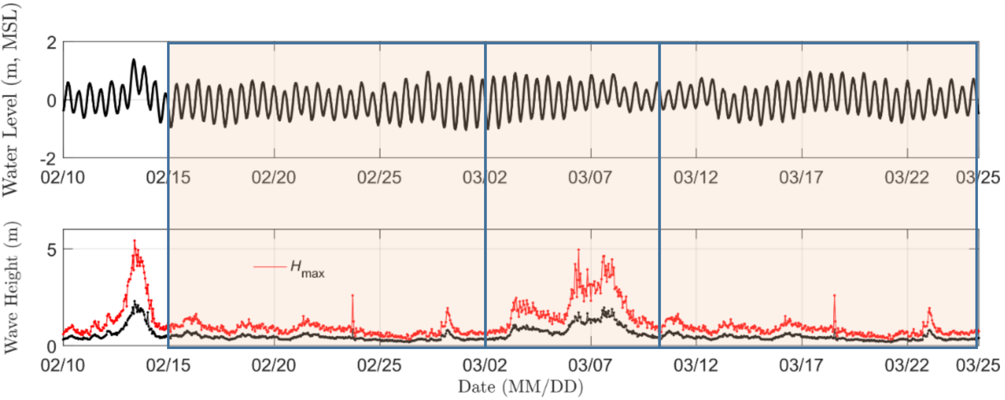
V_{CSH} = 27.8 m^3/m (**87% Recovery**)

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



Profile Evolution: Ridge-Runnel Formation & Stabilization





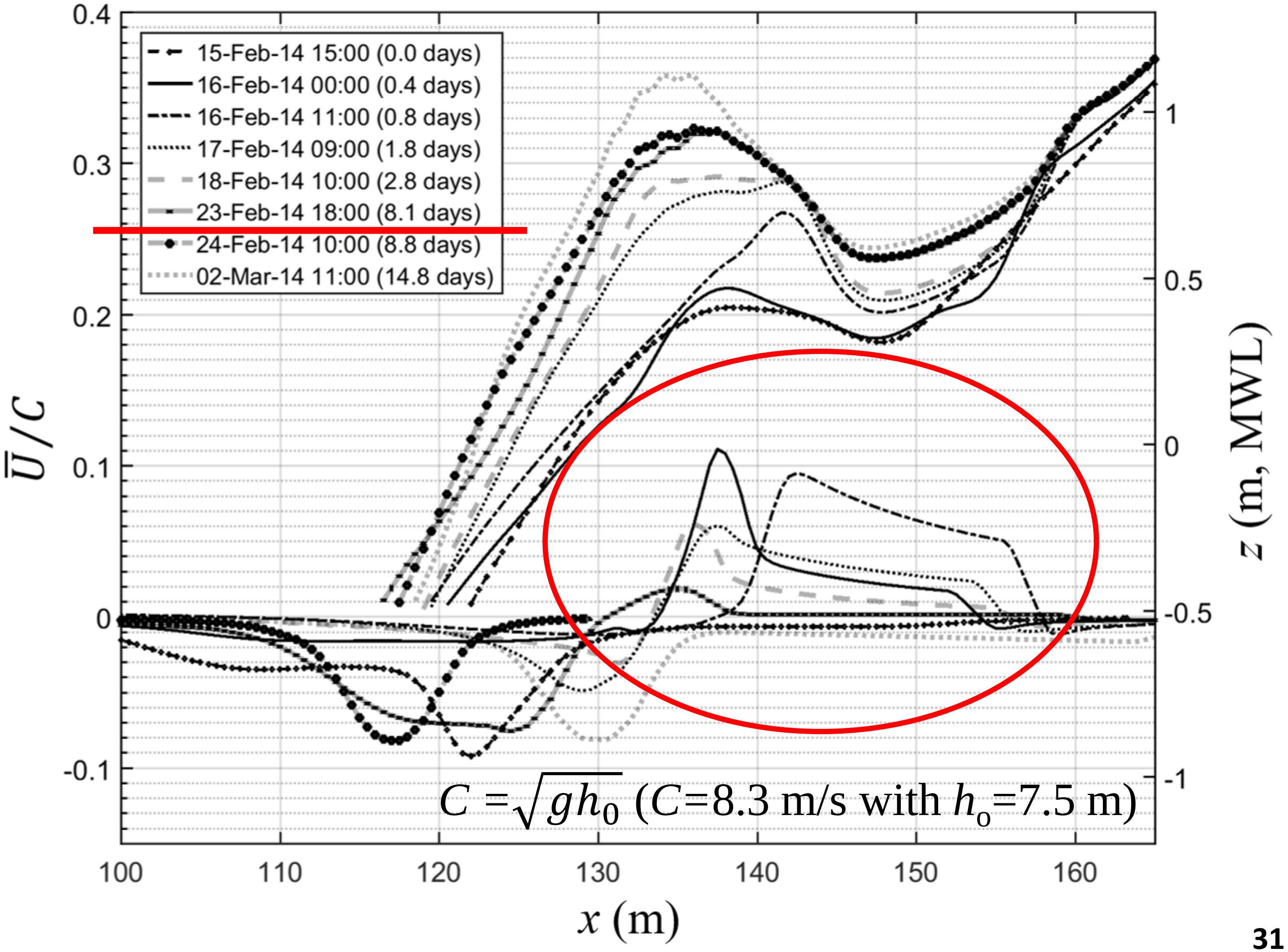
CSHORE Profiles vs. Swash Velocities (*Figlus et al., 2017, IJOPE*)

CSHORE prediction

- Time-, depth-averaged velocities
- Max. onshore current of 0.11C
- Max. undertow up to 0.10*C*

Initial formation/growth associated with pronounced onshore swash overtopping

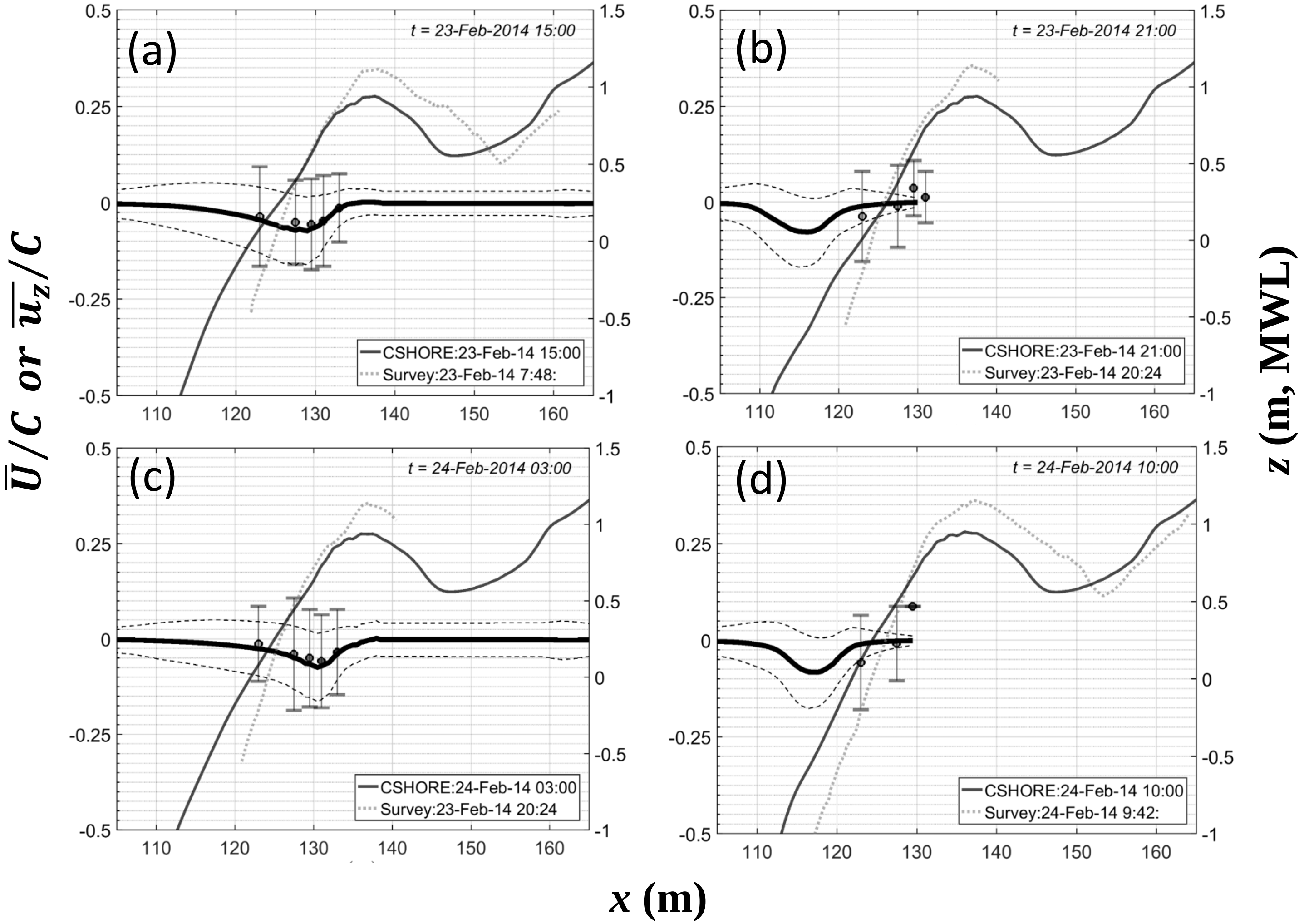
Later accretion/stabilization by steady swash-backwash actions



RESULTS: CROSS-SHORE VELOCITIES

OCEAN ENGINEERING TEXAS A&M UNIVERSITY
UNIVERSITY OF DELAWARE

CSHORE vs. Observed Swash Velocities (*Figlus et al., 2017*)`

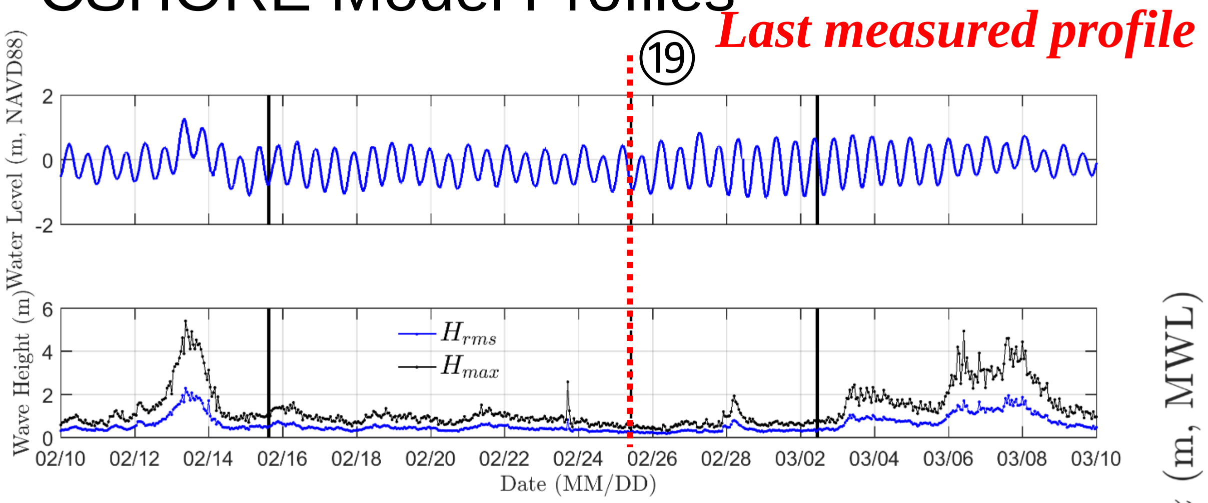


- Max. mean flow of 0.11*C and -0.10C*
  ($C = \sqrt{gh_0}$ =8.3 m/s with h_o=7.5 m)

- Underestimates rush-over flows
  → validation with runup extent

RESULTS: BEACH PROFILE EVOLUTION

CSHORE Model Profiles

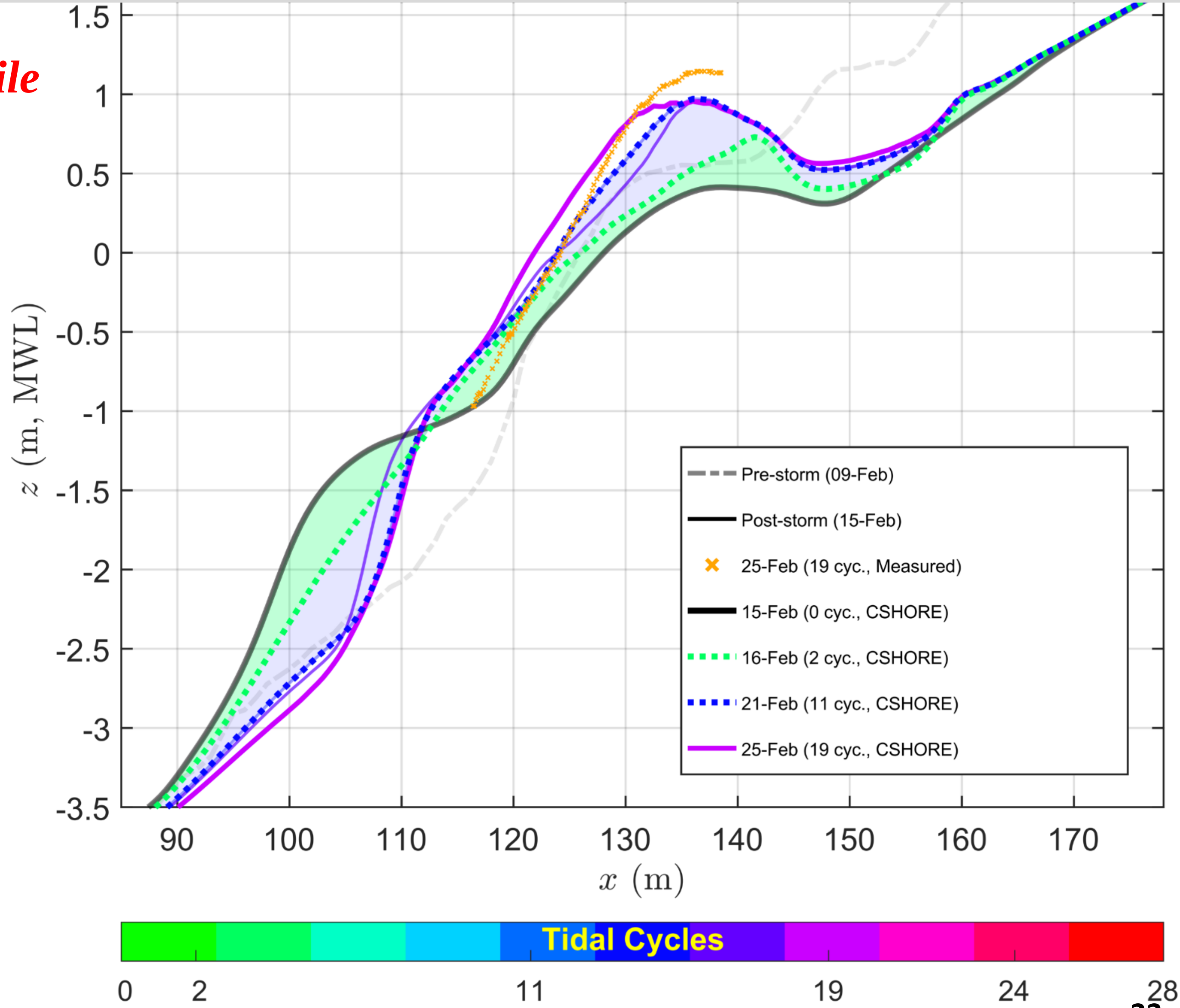


ζ_{MES} = 1.14 m, ζ_{CSH} **= 0.96 m (89 %)**

RMSE = 0.20 m (in swash zone)

V_{CSH} = 27.2 m^3/m (**85% Recovery**)

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



BACKGROUND: INTERTIDAL BARS

CSHORE: A process-based, 1D, morphodynamics model (Kobayashi, 2009)

A simple and robust model suited for engineering applications

- Routinely and reliably **predictable hydrodynamics input**
- **Transparent formulas** based on sediment dynamics on various scales
- **Easy calibration** and verification → computationally efficient

$$q_b = \frac{b P_b G_s \sigma_U^3}{g(s-1)} \qquad q_s = \left(a\overline{U} + a_o U_a\right) V_s \qquad V_s = P_s \left(\frac{e_b D_r + e_f D_f}{\rho g (s-1) w_f} \right) (1 + S_b^2)^{0.5}$$

bed load *b*, suspended load *a*, suspension efficiency (wave breaking e_b, bottom friction e_f), wave overwash a_o,