Appendix A. Dune Response Modeling

Introduction

In this appendix CSHORE (Johnson et al., 2012; Kobayashi 2013) numerical modeling results of beach and dune profile evolution under various hydrodynamic forcing conditions are presented. Table A-1 gives an overview of the presented cases. Many more combinations of dune geometry, core structure geometry and type, and storm impact scenarios have been simulated. The cases presented here are intended to give the reader a better feel for the land barrier profile response to storm impacts but are by no means an exhaustive compilation of all possible scenarios. The presented CSHORE results have to be understood as a first approximation only.

Table A-1. Dune response modeling results presented in this Appendix

Dune Design	Hydrodynamic Forcing	Core-Enhancement
Single 14 ft	10-year return value proxy storm	No core
Single 17 ft	Hurricane Ike (30-year return value)	Single core
Dual 12/14 ft	10-year return value proxy storm	No core
Dual 12/14 ft	Hurricane Ike	Dual core
Dual 15/17 ft	10-year return value proxy storm and Hurricane Ike	No core
Dual 15/17 ft	Hurricane Ike	Dual core
Dual 12/14 ft with widened crest widths	Hurricane Ike	Single seaward core
Dual 15/17 ft with widened crest widths	Hurricane Ike and 100-year return value proxy storm (with and without 2.1-ft sea level increase)	No core, single seaward core, single landward core

All core-enhancements are simulated as sloping solid impermeable structures 1 m below the sand cover surface for this assessment.

CSHORE Overview

The brief CSHORE overview here has been adapted from Harter and Figlus (2017). CSHORE is a very efficient process-based 1D cross-shore coastal response model. The model includes a time-averaged and depth-averaged combined wave and cross-shore current model, a time-averaged sediment transport model, a probabilistic model for the intermittently wet and dry zone, as well as empirical formulas for irregular wave runup. The model employs a linear wave theory based model with an assumed Gaussian distribution of the free-surface elevation below mean sea level (MSL) and a model based on the time-averaged continuity and momentum equations derived from nonlinear shallow-water equations above still water level (SWL) to provide hydrodynamic forcing for sediment transport and morphology changes. Outputs from both models are averaged in the zone between SWL and MSL to provide smooth results over the entire computation domain. The actual location of SWL and MSL at each time step dictates where along the profile the two models are applied. CSHORE predicts cross-shore variations of the mean and standard deviation of the free surface elevation, the depth-averaged cross-shore current, the cross-shore velocity standard deviation, the cross-shore bed-load transport rate, and the cross-shore suspended sediment transport rate. The root-mean-square wave height, spectral peak period and setup/setdown with respect to SWL are used as input at the offshore boundary of the computation domain. Only the initial bottom profile elevation is specified for the computation of the entire model run. Since CSHORE is a 1D cross-shore time-averaged model, it is most effective when applied to representative shore locations where bathymetric contours are approximately parallel. Computational efficiency, robustness, and relatively good accuracy are some of the major advantages of using CSHORE as a tool to predict beach profile changes. CSHORE parameter values used in this study follow Harter and Figlus (2017).

Hydrodynamic Forcing Conditions

The hydrodynamic forcing conditions used for most model simulations are adapted from Ebersole et al. (2018). Locations of data output from their modeling efforts are shown in Figure A-1. Since shown CSHORE model tests were mainly based on Galveston Island profiles, Stations 11 and 17 are used primarily. The time series of hydrodynamic forcing conditions at Stations 11 and 17 are shown in Figures A-2 and A-3, respectively. Parameters include water level, root-mean-square wave height, peak wave period, and mean wave angle of approach relative to shore normal.

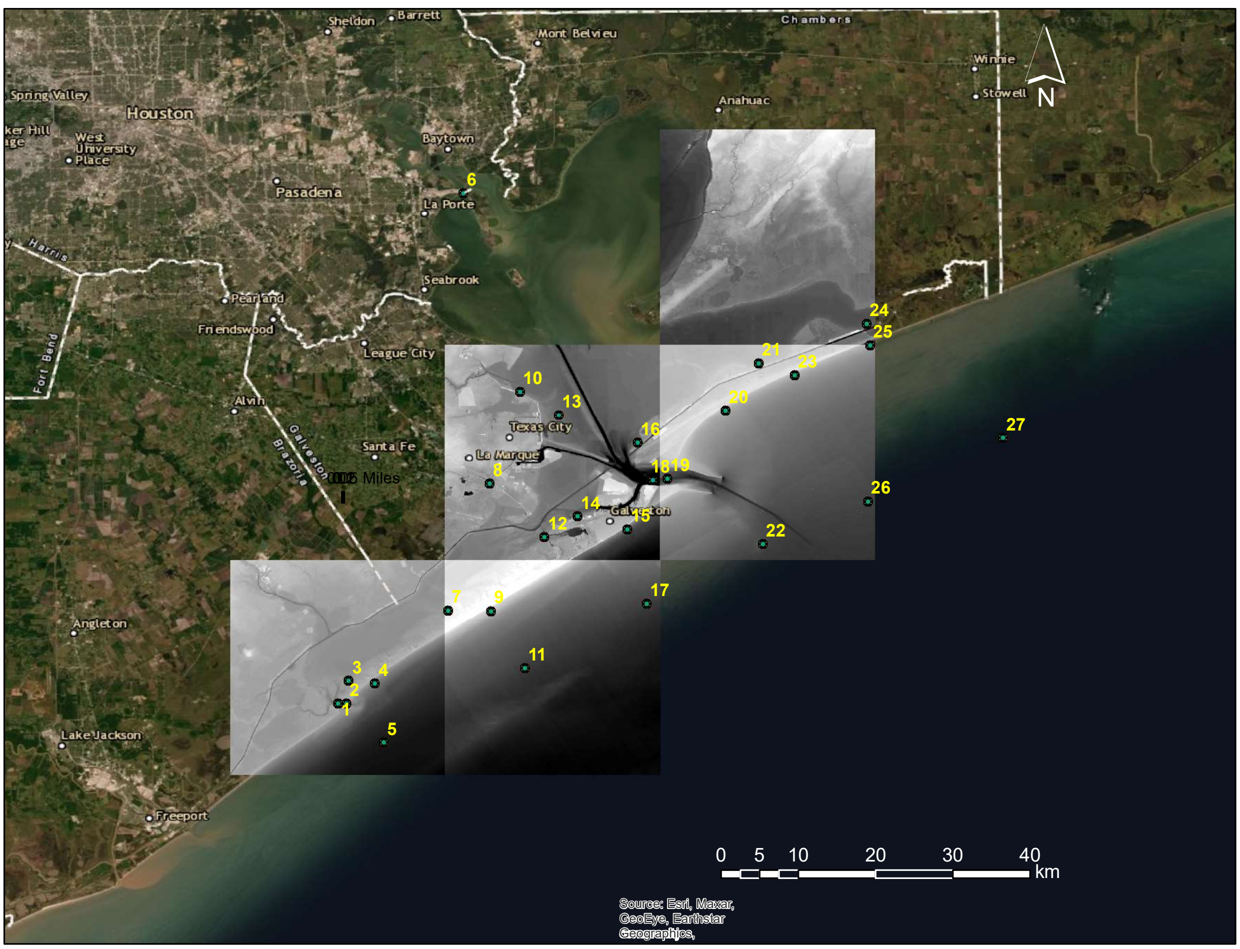

Figure A-1. ADCIRC output station numbers (Ebersole et al., 2018)

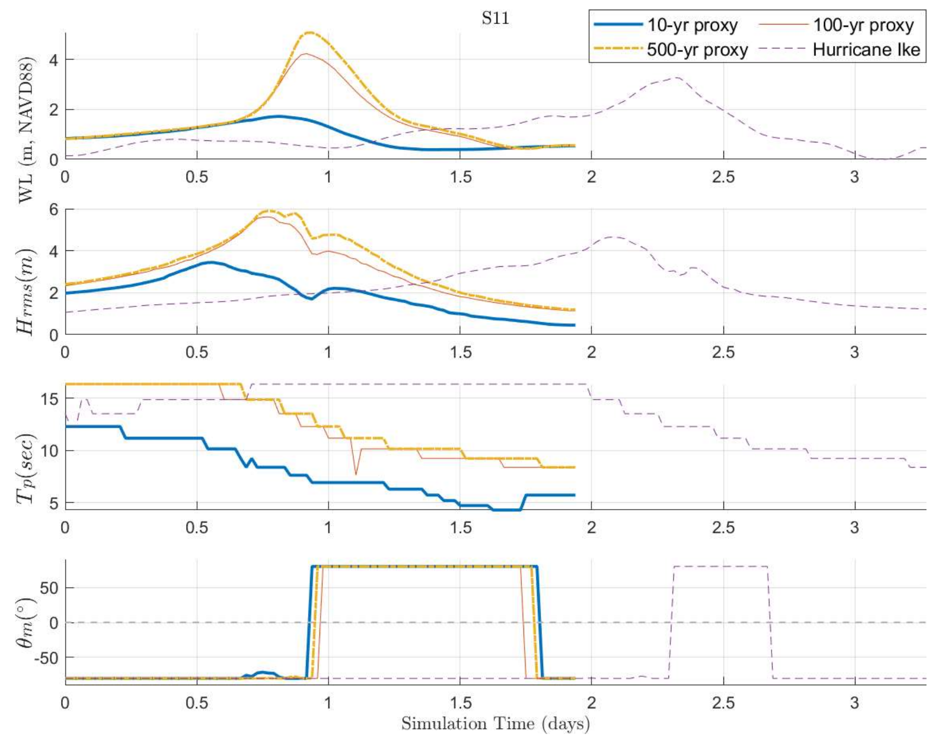

Figure A-2. Hydrodynamic forcing conditions used as CSHORE input. The time series are based on Ebersole et al. (2018) and are associated with location S11 (Figure A-1) at a water depth of 14 m.

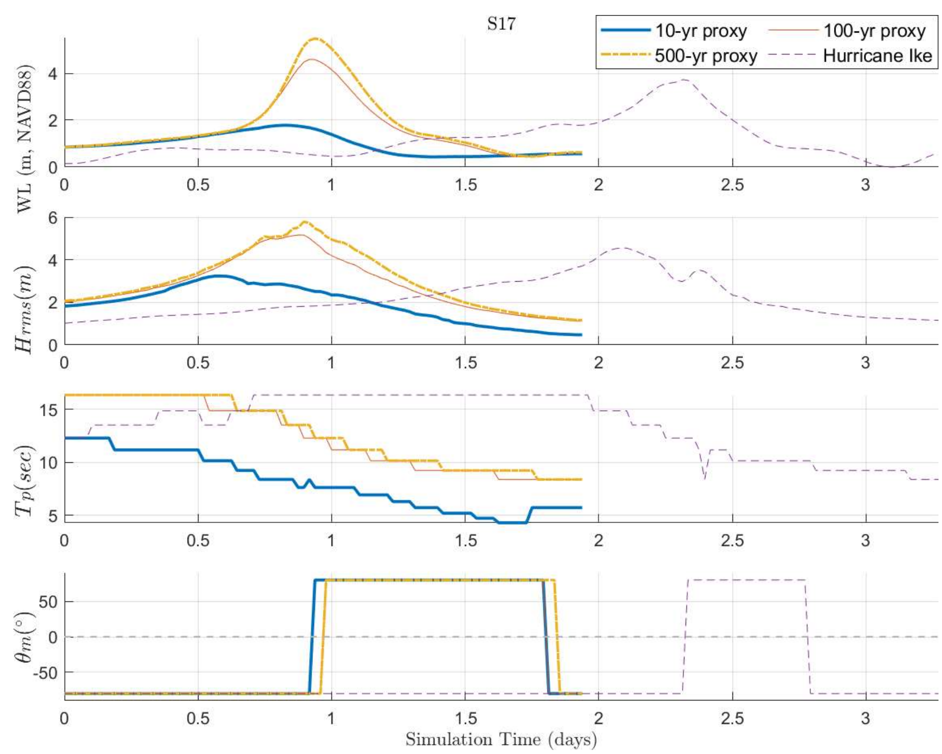

Figure A-3. Hydrodynamic forcing conditions used as CSHORE input. The time series are based on Ebersole et al. (2018) and are associated with location S17 (Figure A-1) at a water depth of 14 m.

Some CSHORE model simulations using hydrodynamic forcing conditions based on NOAA NDBC buoy 42035 measurements during Hurricane Ike (17 m water depth) were run as well since these have been used by the USACE for some of their SBEACH modeling (see Figure A-4).

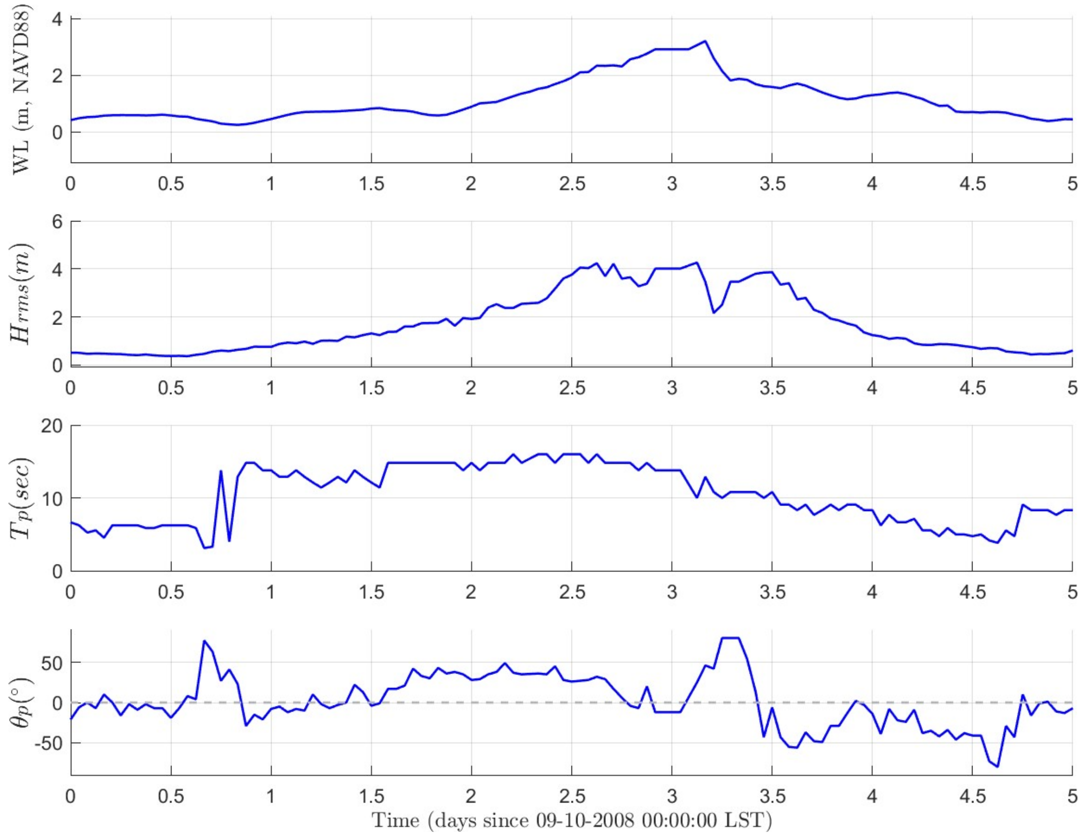

Figure A-4. Hydrodynamic conditions during Hurricane Ike measured by NOAA NDBC buoy 42035 in 17 m water depth offshore of Galveston Island.

Single-Dune Performance

In this section profile evolution of a single dune under storm forcing conditions are shown. While a 14-ft high dune with otherwise similar geometry to the USACE dune design can withstand the 10-year proxy storm (Figure A-5), it is eroded completely under Hurricane Ike conditions (30-year return value). Even a 17-ft high single dune is eroded completely by Hurricane Ike conditions. Adding a solid core inside the 17-foot high dune allows the dune to remain functional under Hurricane Ike conditions but with complete exposure of the seaward slope of the core structure (Figure A-6).

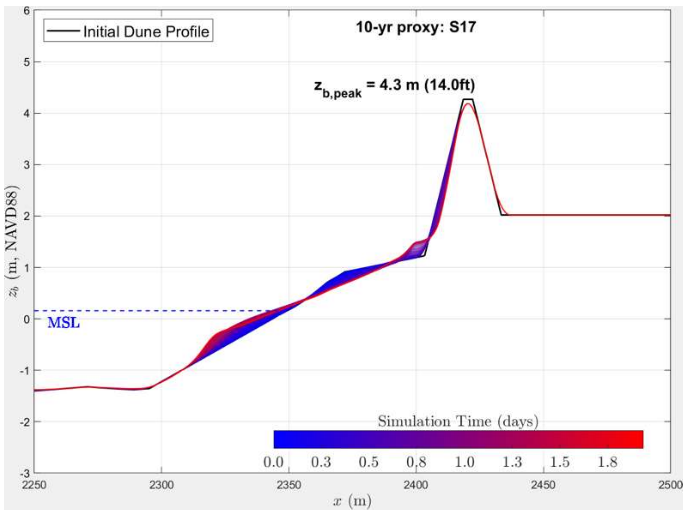

Figure A-5. Modeled beach and dune profile evolution of single dune (14-ft crest elevation) with 10-year proxy storm forcing shown in Figure A-3.

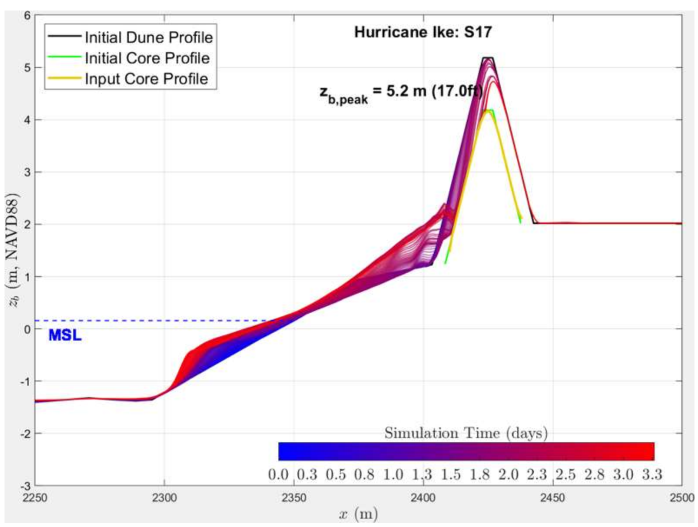

Figure A-6. Modeled beach and dune profile evolution of single dune (17-ft crest elevation) including core-enhancement with Hurricane Ike forcing shown in Figure A-3. Note that without the core-enhancement, the same dune was severely overtopped and eroded around the peak of the storm. The exposed seaward slope of the core structure helped prevent that in the result plot shown here.

Dual-Dune Performance (12/14-ft crest elevation)

The USACE proposed dual-dune design with 12- and 14-ft crest elevations, respectively, can withstand the 10-year proxy storm conditions with only minor erosion of the seaward dune face (Figure A-7). The dunes do not survive Hurricane Ike conditions and severe erosion and overtopping commence even before the peak of the storm. Hardened core structures included in both dunes are exposed during Ike conditions (Figure A-8).

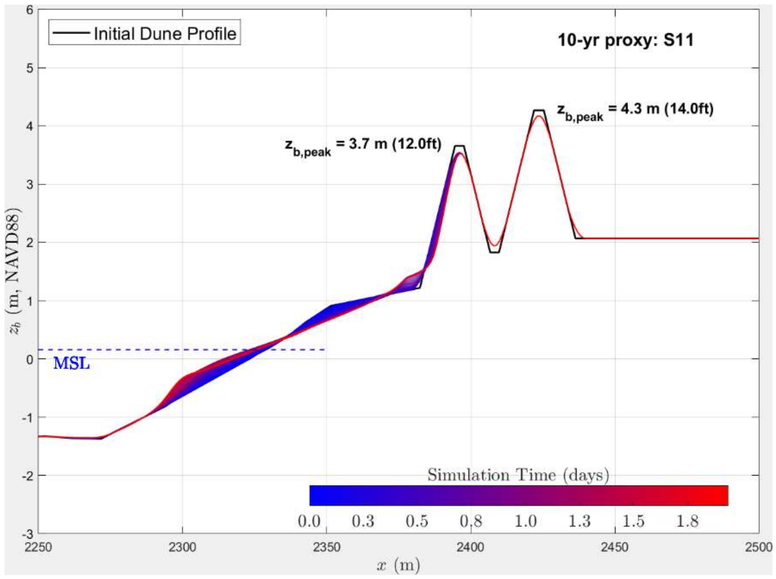

Figure A-7. Modeled beach and dune profile evolution of a dual-dune design (12/14-ft crest elevations) for 10-yr proxy storm forcing shown in Figure A-2.

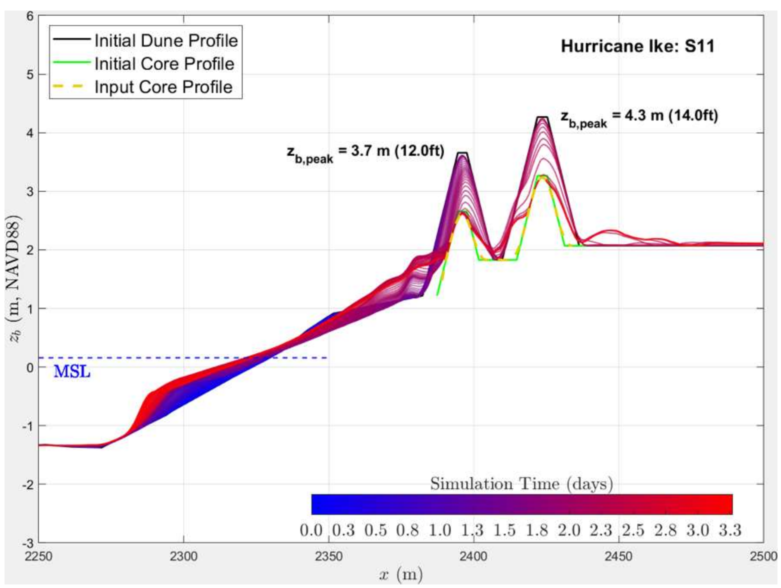

Figure A-8. Modeled beach and dune profile evolution of dual-dune design (12/14-ft crest elevations) including core-enhancements with Hurricane Ike forcing shown in Figure A-2. Note that without the core-enhancement, the same dune system was severely overtopped and eroded even before the peak of the storm.

Dual-Dune Performance (15/17-ft crest elevation)

Increasing the dual-dune elevations to 15 and 17 ft, respectively, for the seaward and landward dune, improves the system's resistance against erosion somewhat. The profile evolution for 10-year proxy storm forcing is shown in Figure A-9 where only minor erosion on the seaward dune slope is noted. Hurricane Ike forcing leads to complete erosion of the seaward dune and some erosion (1-ft crest reduction) and overtopping of the landward dune (Figure A-10). This means a 15/17-ft dual-dune system may barely survive a 30-year return value storm but require major renourishment afterwards.

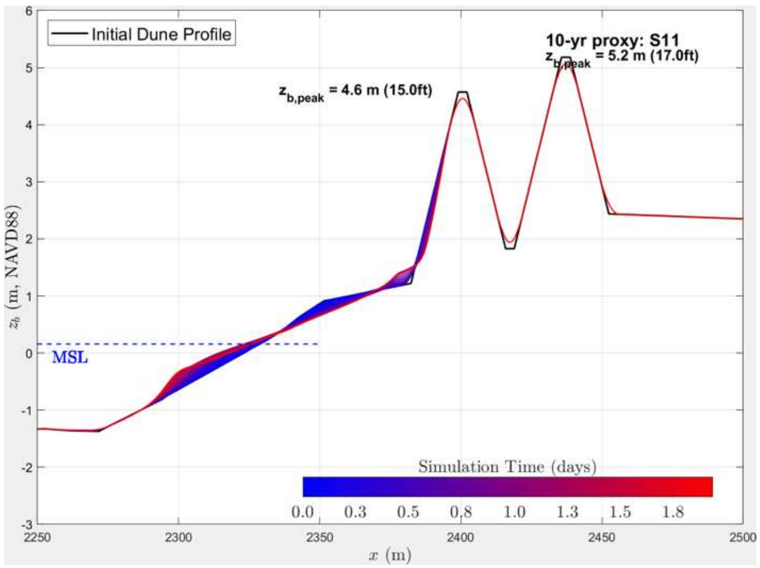

Figure A-9. Modeled beach and dune profile evolution of a dual-dune (15/17-ft crest elevations) for 10-yr proxy storm forcing shown in Figure A-2.

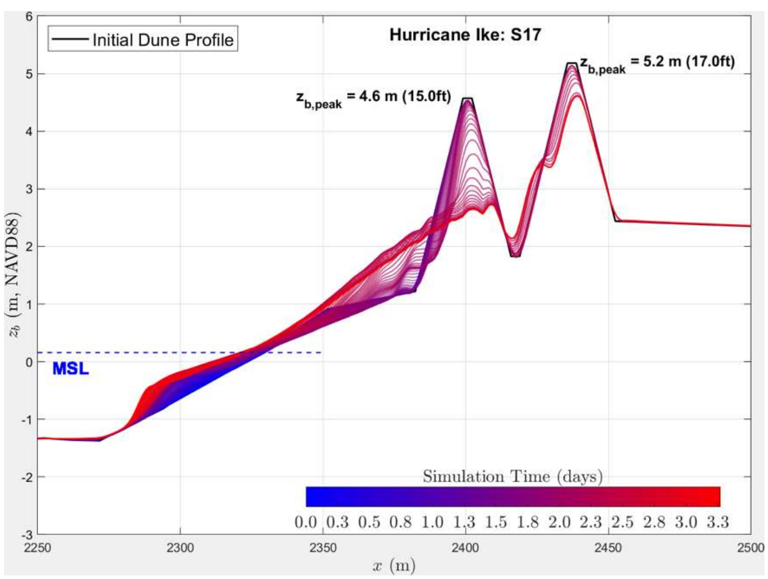

Figure A-10. Modeled beach and dune profile evolution of a dual-dune (15/17-ft crest elevations) for Hurricane Ike forcing shown in Figure A-3. The seaward dune helps protect the landward dune somewhat from eroding but crest elevation reduction over 1 ft is still apparent in the landward dune.

If dual cores are implemented, the landward dune erosion is mostly prevented due to the fact that the core of the seaward dune remains intact (Figure A-11).

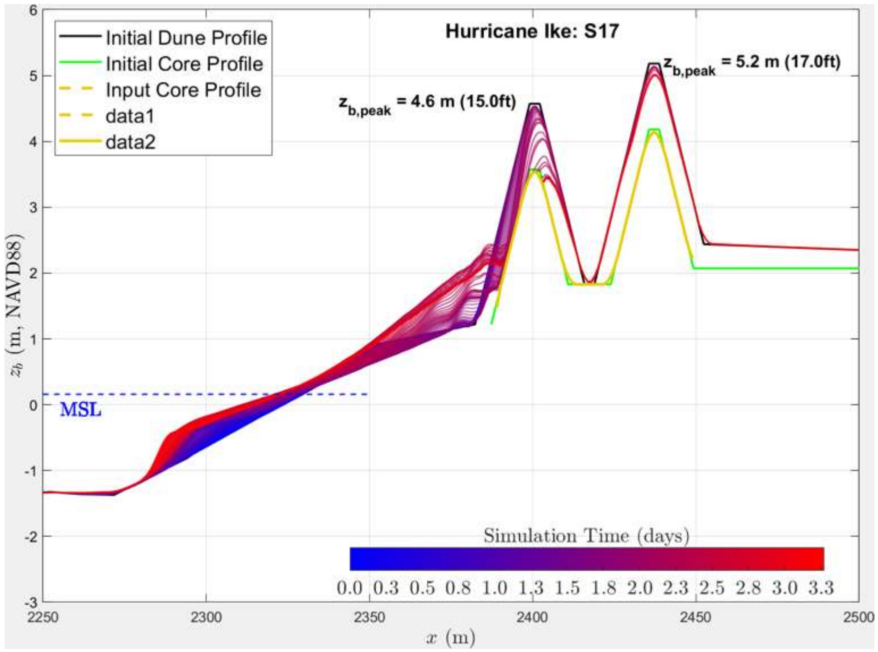

Figure A-11. Modeled beach and dune profile evolution of dual-dune design (15/17-ft crest elevations) including core-enhancements with Hurricane Ike forcing shown in Figure A-3. Note that without the core-enhancement, the seaward dune was completely eroded.

Dual-Dune Performance (modified crest widths and sea level rise scenario)

The following examples of CSHORE simulations investigate a limited range of geometric and core-enhancement modifications to the USACE proposed dual-dune design. Simulations include performance under Hurricane Ike forcing using the NOAA NDBC buoy data as input as well as increases in crest width and crest height of the dual-dune system (e.g., Figures A-12, A-14). Both single seaward and landward dune core-enhancements are tested (e.g. Figures A-13, A-15, A-17). Finally, the effects of a 2.1-ft sea level increase for enlarged dual-dunes with single landward and seaward dune core-enhancement, respectively, are shown (e.g., Figures A-16, A-17).

The modification to the dual-dune system shown in Figure A-12 is a doubling of the crest width in both the seaward and landward dune.

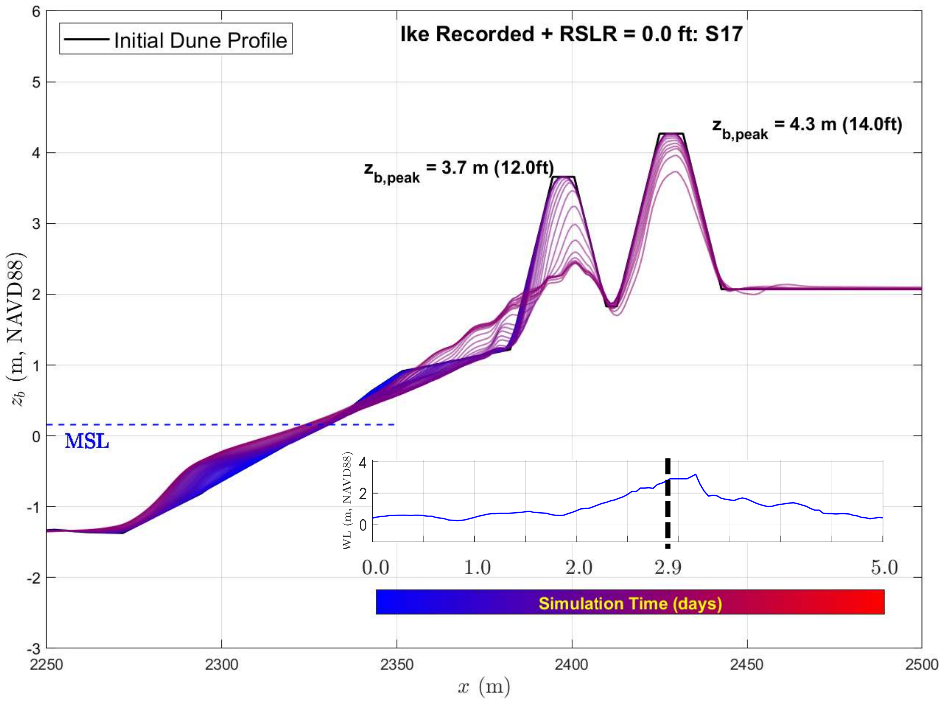

Figure A-12. Modeled beach and dune profile evolution of dual-dune design (12/14-ft crest elevations, double crest widths) with Hurricane Ike forcing shown in Figure A-4 and no sea level increase. Note that both dunes are severely overwashed well before the peak of the storm and water would continue to overtop the system for at least 10 hours. The simulation results are only shown up until the vertical black dashed line in the inset figure because past that point the dunes are destroyed and the simulation results become unrealistic.

Figure A-13 shows the same setup and forcing as Figure A-12 except that the seaward dune includes the core-enhancement. This leads to exposure of the core in the seaward dune under Hurricane Ike conditions, as well as delayed and reduced erosion of the landward dune.

Increasing both the width and height of the dual dunes helps increase erosion and flooding resistance. In Figure A-14 the dune profile evolution for a dual-dune system with 15/17-ft elevations and doubled dune crest widths is shown. The seaward dune is still completely eroded but its buffer function allows the landward dune to survive albeit with significant dune crest erosion.

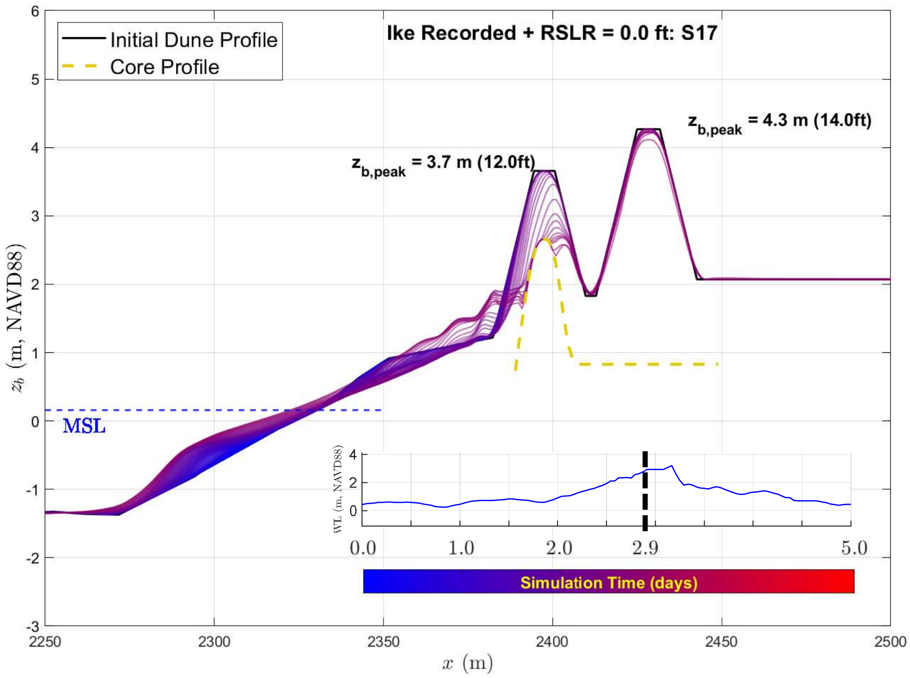

Figure A-13. Modeled beach and dune profile evolution of dual-dune design (12/14-ft crest elevations, double crest widths) and seaward dune core enhancement with Hurricane Ike forcing shown in Figure A-4 and no sea level increase. Note that the core structure delays and reduces erosion of the landward dune. The simulation results are only shown up until the vertical black dashed line in the inset figure to simplify comparison with the results in the previous figure.

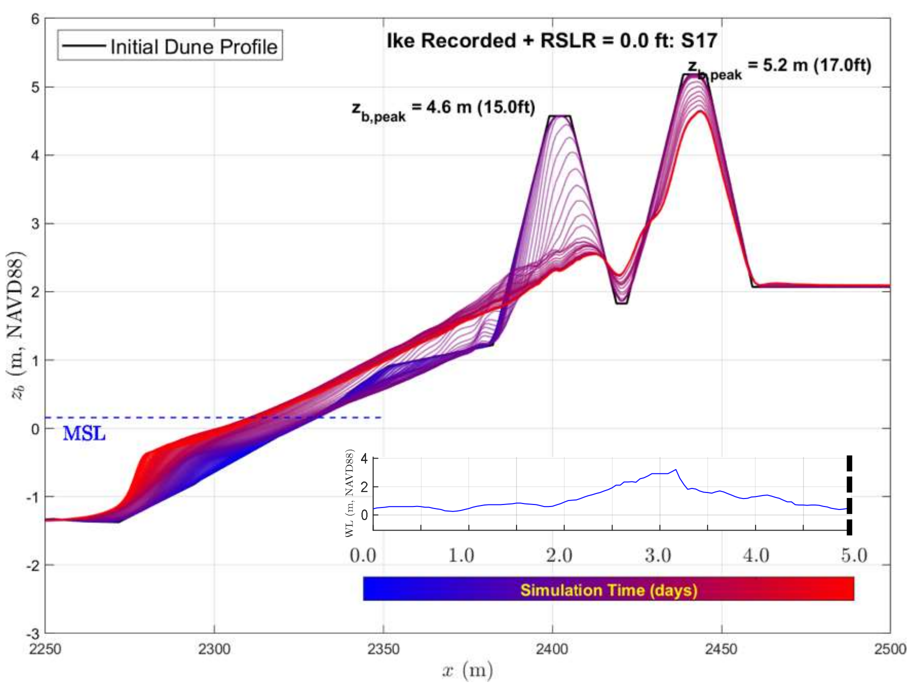

Figure A-14. Modeled beach and dune profile evolution of dual-dune design (15/17-ft crest elevations, double crest widths) with Hurricane Ike forcing shown in Figure A-4 and no sea level increase. The seaward dune is completely destroyed. The landward dune crest elevation is eroded by about 2 ft but the dune remains.

Figure A-15 shows the same scenario as Figure A-14 but now with a core-enhanced seaward dune. The core-enhancement is exposed during Hurricane Ike conditions and its sand covered crest is mostly eroded. The landward dune remains intact without major erosion.

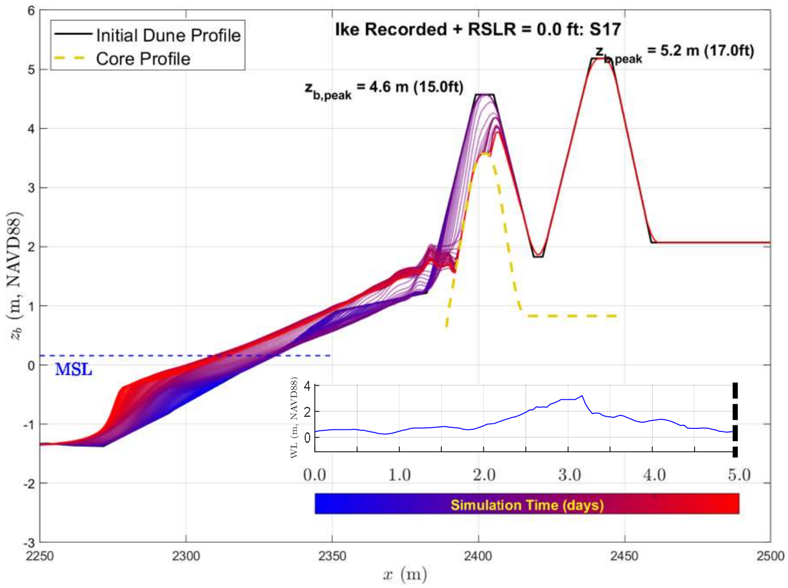

Figure A-15. Modeled beach and dune profile evolution of dual-dune design (15/17-ft crest elevations, double crest widths) and seaward dune core enhancement with Hurricane Ike forcing shown in Figure A-4 and no sea level increase. The enhanced core in the seaward dune is exposed and the dune crest erodes but the landward dune survives and remains intact.

For the 100-year proxy storm conditions and a sea level increase of 2.1 ft, the dual-dune system with increased crest heights and crest widths including a seaward dune core-enhancement performs as shown in Figure A-16. Under those conditions, the seaward core is completely exposed, the seaward dune crest cover eroded, and even the landward dune is substantially eroded and overtopped leading to a 4-ft crest reduction (Figure A-16).

In Figure A-17, the single core-enhancement has been placed in the landward dune instead of the seaward dune and the seaward dune crest width has not been increased, only the landward dune crest has been widened by a factor of two compared to the original USACE dune crest widths. The forcing conditions remain the same as for the Figure A-16 results (100-year proxy storm, 2.1-ft sea level increase). Under those conditions the seaward dune erodes completely and the landward dune core is exposed, leaving the 14-ft solid core as the maximum crest elevation against storm surge and wave overtopping impact.

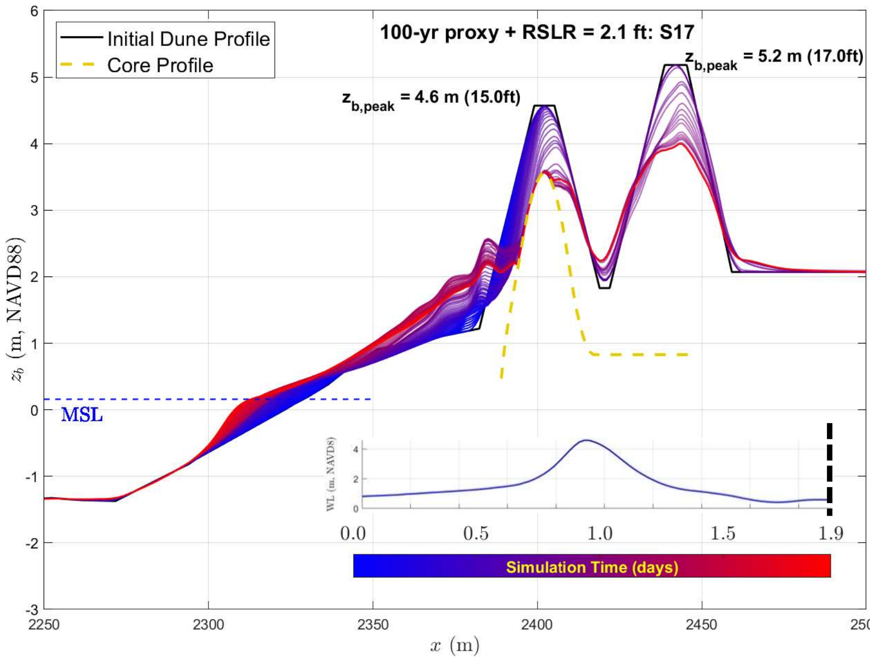

Figure A-16. Modeled beach and dune profile evolution of dual-dune design (15/17-ft crest elevations, double crest widths) and seaward dune core enhancement with 100-year proxy storm forcing shown in Figure A-3 and 2.1 ft sea level increase. The more energetic hydrodynamic forcing conditions coupled with the sea level increase reduces the landward dune crest by about 4 ft. Without the core protection both dunes are wiped out.

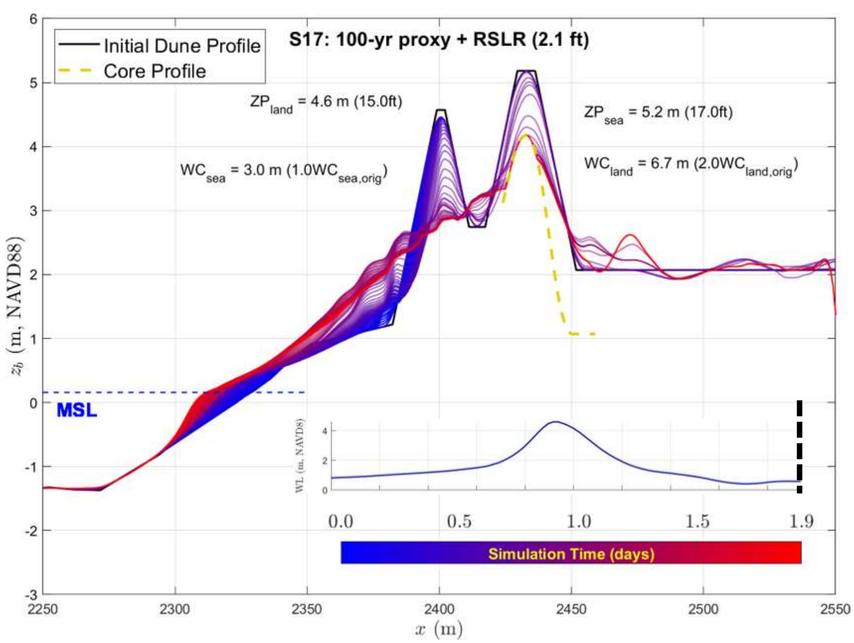

Figure A-17. Modeled beach and dune profile evolution of dual-dune design (15/17-ft crest elevations, double landward dune crest width) and landward dune core enhancement with 100-year proxy storm forcing shown in Figure A-3 and 2.1 ft sea level increase. The seaward dune is completely eroded and the core structure in the landward dune exposed. The solid core protection at 14 ft crest elevation remains intact to limit flooding.

References

Harter, C., & Figlus, J. (2017). Numerical modeling of the morphodynamic response of a low-lying barrier island beach and foredune system inundated during Hurricane Ike using XBeach and CSHORE. Coastal Engineering, 120, 64–74. https://doi.org/10.1016/j.coastaleng.2016.11.005

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