Simulating Dune Evolution on Managed Coastlines: Exploring Policy Options with the Coastal Recovery from Storms Tool

Motivation and Community Need

Coastal foredunes provide critical ecosystem services; they are the first line of defense against flooding, provide conservation value for native species, and are a major draw for recreation and tourism. However, dunes remain highly vulnerable to both climatic (e.g., sea level rise, changes in storminess) and anthropogenic (e.g., reduced sediment supply, trampling of vegetation) pressures. Despite the importance of dunes to many low lying coastal communities, our understanding of how these pressures affect the viability of foredunes on time scales of relevance is particularly poor. Only recent advances in numerical modeling have enabled predictions of both progradational and erosional morphodynamics, including the growth of dune systems during calm periods and their erosion during storms.

Here we introduce the **C**oastal **R**ecovery from **S**torms **T**ool (**CReST**). **CReST** is a graphical user interface which aims to expand the capabilities and usability of **Windsurf,** a process-based numerical modeling system which simulates the evolution of dune-backed sandy coastal systems in response to both wave and wind forcings, to better account for the complex dynamics of managed coastlines. The ability to incorporate dune grass planting scenarios, beach nourishment and dune construction, beach scraping, dune grass removal, and the presence of hard engineering structures into **CReST/Windsurf** provides a new research tool to explore the implications of management decisions on coastal vulnerability (Fig. 1).

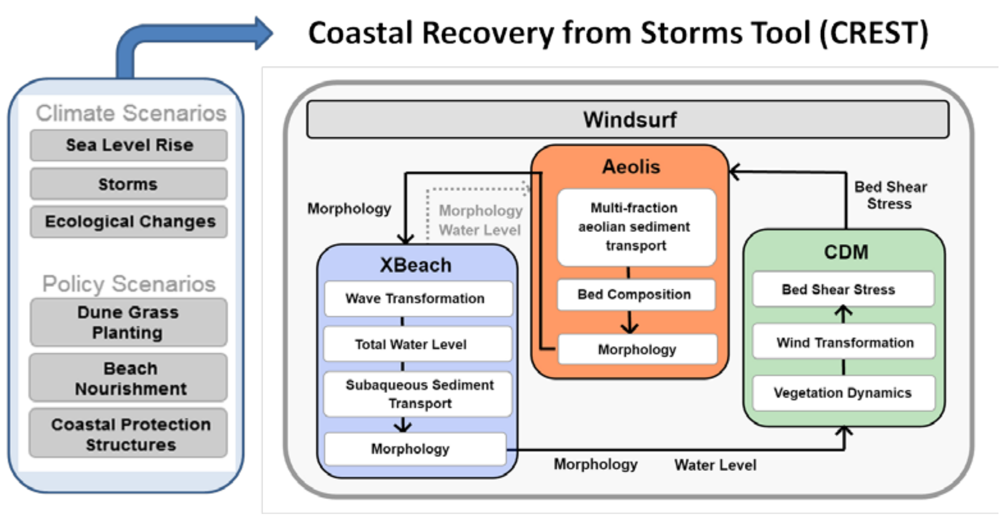

Figure 1. Schematic representing the general **CReST** framework which includes the coupled model **Windsurf** at its core with three standalone numerical models (XBeach, Coastal Dune Model, Aeolis).

Approach

Using the **Windsurf/CReST** modeling system we are exploring optimum beach nourishment strategies which (1) promote the natural development of dunes and (2) have the longest project lifecycles (Figure 2). Additional targeted modeling questions are being developed in conjunction with local stakeholders at study sites in Bogue Banks, NC and in the US Pacific Northwest in order to help guide effective and economic management strategies for beach/dune nourishment and vegetation planting campaigns.

Figure 2. Examples of (a) grass planting, (b) grass removal, (c) beach nourishment, (d) beach scraping, and (e) coastal protection structures incorporated into **CReST.**

Findings/ Benefits

Windsurf is a new open-source coupled numerical modeling framework capable of simulating the co-evolution of the nearshore, beach, and dunes. Consistent with field measurements, recent **Windsurf** applications have shown skill at simulating coastal change by winds and waves at time scales of hours to years. **CReST** extends the **Windsurf** model capabilities to explore implications of management decisions on coastal evolution. This in-development tool will provide a valuable asset for scientists and managers struggling to synthesize coastal evolution in response to environmental, ecological, and anthropogenic factors.

Status/Steps Moving Forward

While additional effort is required to further test the model in other settings and with other environmental cases, **CReST/Windsurf** provides a new platform to explore complex interactions between the subaqueous and subaerial zones of the coastal profile for a variety of exploratory and applied applications.

Support and Points of Contact

Development of **CReST/Windsurf** has been primarily supported by NOAA via the EESLR program under Grant NA15NOS4780172 with additional support via an USCRP challenge grant and the National Science Foundation under grant EAR-1561847. For more information please contact:

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US Coastal Research Program (USCRP) DUNE R&D

Wave runup on a constructed berm: Implications for dune design

Motivation and Community Need

Although many prior studies have examined wave runup on coastal structures and beaches, few studies have focused on the effect of runup on a nourished beach with a designed berm. Design guidance is not widely available for construction of relatively small, termed “starter” dunes in areas like the Town of Kitty Hawk, North Carolina, where the distance between the active shoreline and infrastructure (roads, houses) constrains the potential dune size considering the width of the design berm and the beach slope. The purpose of this research is to develop a method to assess runup on a constructed beach berm in order to evaluate the potential overtopping of small “starter” dunes.

Erosion mitigation on NC 12 in Kitty Hawk, NC, Oct. 2015. Photo: County of Dare.

This project came directly out of the needs of coastal managers in the Town of Kitty Hawk and practitioners working to design a beach and dune nourishment project for the Town. It was hypothesized that an extended berm would provide some resistance to runup and decrease the runup elevation that would reach the toe of the dune. Work by de Waal and van der Meer (1992) conducted with structures containing a berm established an “equivalent slope” based on the structure berm geometry and wave conditions. This work was used in the design of the Kitty Hawk project to enable consideration of the berm, however, it had not been field tested for sandy beaches until the present study.

Approach

The locally-funded beach and dune nourishment project in Kitty Hawk that took place during the summer and fall of 2017 served as a full-scale laboratory for investigation of constructed beach berm effects on runup. High water marks were surveyed along the study area using Real Time Kinematic (RTK) GPS techniques four times, including dates prior to the project, during a high-wave event, and post-project. In addition to the field surveys, XBeach, a numerical model, was employed to assess runup using pre- and post-construction beach profile surveys provided by the consulting firm who designed the nourishment project. The XBeach model results and field survey data were compared with empirical equations used to predict runup [e.g. Stockdon (2006), de Waal and van der Meer (1992)].

Post-nourishment field survey.

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Findings/Benefits

Findings from this project indicate that estimating runup elevation on a beach nourishment project using an equivalent slope approach (de Waal and van der Meer (1992) is sufficient for design of starter dunes. Estimates of runup using this approach were slightly conservative compared with XBeach results and field observations, which is considered reasonable for design purposes. This approach allows consulting firms to quickly evaluate project designs considering berm with effects on potential dune overtopping. Researchers presented these findings along with a description of the project to the Town of Kitty Hawk and interested public in February 2018.

Status/Steps Moving Forward

In addition to the primary aim of the project, an ancillary collaboration was initiated with the USACE Field Research Facility (FRF) and the N.C. State Institute for Transportation Research and Education (ITRE). As a part of this collaboration, teams from the FRF and ITRE traveled to the site and conducted Unmanned Aerial Vehicle (UAV) and terrestrial lidar surveys, which were compared with Real-Time Kinematic Global Positioning System (RTK-GPS) data. Video time series captured by the UAV were processed using techniques developed by the Coastal Imaging Research Network to extract runup time series (Sciaudone et al. 2017). Further data were collected and will be analyzed in the future to compare with the results from the field surveys.

More Information

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Wind Tunnel Analyses of Vegetation Species: Differences in Sand Capture Efficiency for Natural & Nature-Based Dune Accretion & Management

Motivation & Community Need

Coastal dunes buffer inherently geologically unstable coastal areas, thereby reducing the risk of storm damage to inland habitats and infrastructure. Dunes grow over time with plants as ecosystem engineers that both build the habitat and stabilize it to combat erosive forces during high tides and storm events. Management efforts to build or recover dunes generally include planting dune stabilizing plants like Ammophila breviligulata to trap sand and build dunes over time. Recent studies suggest that species may differ in their efficiency at trapping sand and may build dunes of varying morphologies, potentially similar to their own stature (i.e. a taller plant builds a taller dune). The plant trapping characteristics have direct implications for storm recovery time, accretion efficiency, and how we approach planting efforts. Maintaining shorelines buffered by dunes must involve consideration of how plants differ in their ability to capture sand and stabilize dunes. However, species-specific data of this nature remains largely unknown. To examine this, a unilateral flow wind tunnel was constructed to examine sand accumulation morphology around the base of A. breviligulata, Carex kobomugi, and Panicum amarum, using at the baseline of zero accumulation as a function of the morphology of these plant species.

Approach

The wind tunnel can achieve a maximum speed of 27 mph (12.1 m/s) and was designed for adaptability beyond the scope of this research. Plants were pre-established in monocultures at one of three non-staggered planting densities, 18-, 12-, and 6-inches on center, in boxes designed to be inserted into the wind tunnel maintaining a continuous chamber length (n=4 replicated per species per density). The plants were subjected to 30 minute trials at 18.5 mph (8.25 m/s). Prior to trials, we measured the morphology of each plant. Post-trial we used a 3D sensor with sub-mm accuracy to scan the resulting topography, i.e. the bedforms around the individual plants. By knowing the morphology of each plant in a box, we were able to attribute bedform morphology to plant morphology and biomass.

Left: The wind tunnel which has a 1m x 1m moveable bed test area where boxes established with plants can be inserted. **Right**: *A. breviligulata* plants at 6-inch spacing and the resulting bedforms built around their base post-experimental trial.

Findings

The plant species varied in morphology, and biomass was most closely coupled with all of the morphology parameters. Bedforms did not form in the absence of plants in our null trials that contained only sand filled boxes. Bedforms formed in all of our experimental trials (trials with plants at one of three densities) and accumulation differed as a function of species and biomass. Bedform height varied by plant biomass, which varied by species. Bedform volume and area varied by plant biomass and bedforms varied in shape as a function of species. Density between 18- or 12-in spacing did not affect bedform accumulation. The 6-in density trials, in which the spacing mimics natural density, are still being analyzed. The 12- and 18-in spacing densities are commonly used in plantings. This research is ongoing and the researchers intend to field validate the results as well as further explore the relationships between the different morphological measures and the significant effects.

Benefits

Information about how plants shape dunes will become more important with time as storms continue to grow more frequent, severe, and unpredictable, while the use of coastal regions continues to also increase. Coastal dunes are unique systems and information needed to inform management spans a variety of disciplines. Many studies and management strategies simplify the system and approach it from one dimension. This work approaches the topic with a multifaceted perspective spanning ecology, sedimentology, geology, and conservation management. Local high school students and students from 8 institutions were involved throughout the research and logged over 150 volunteer research hours across 10 days. The findings have direct applications for management planting efforts and involving high schoolers may inspire future scientists.

Status/Steps Moving Forward

We are currently in the process of repeating the experiments carried out in 2017 with the potential changes in wind speed, plants, and duration, but will alter the planting design to be staggered, as is more traditional in management. We have been approved for a second round of funding to further expand the capabilities of the wind tunnel for future research use, as well as to carry out this aforementioned research. The wind tunnel is available for outside use for research, outreach, and teaching. We have an upcoming collaboration to examine the effects of lift and drag on plants experiencing wind stress, and expect more collaborations. We will continue to involve high school students in all research. We hope to have students use the wind tunnel for science fair projects as well as to have classes visit as a hands-on learning lab resource. We hope to design lesson plans around using the wind tunnel for local high schools and colleges.

More Information

This project was funded through a USCRP challenge grant. For more information please contact the point of contact, Bianca Reo Charbonneau at Binoink@gmail.com. Please visit https://thewindtunnel.weebly.com for more specific information on the wind tunnel's specifications, those involved in this research, and or getting involved, such as by helping with lesson plans or using the wind tunnel. For more information on the additional coastal dune research and outreach being carried out by Bianca, please visit https://thedunegoon.weebly.com.

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Calibration of Coastal Dune Models using Structure-from-Motion Photogrammetry and a Genetic Algorithm

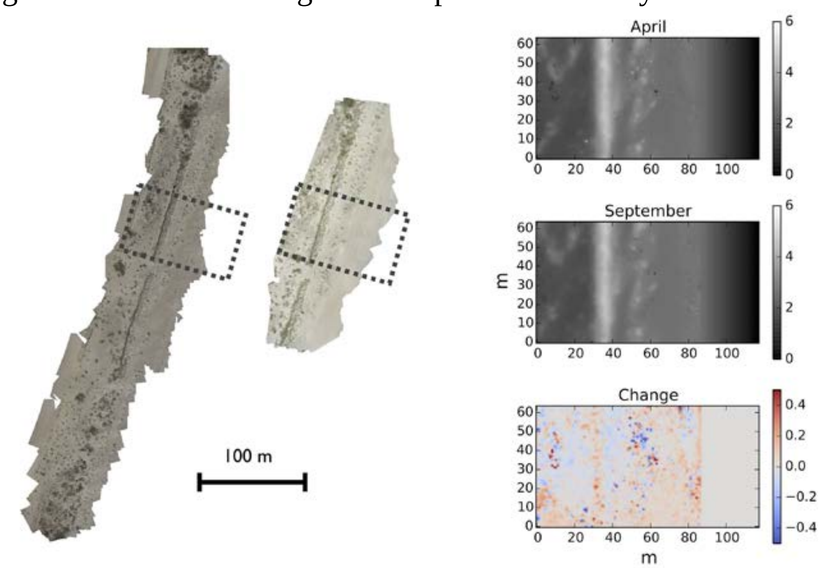
Motivation and Community Need

Coastal foredunes can reduce impacts from elevated water levels during storms and high water. Storm forecasting tools use dune parameters (i.e., height, volume) to predict storm impact, however dune topography is often not up-to-date because acquiring high-resolution topographic data before every potential storm is impractical and/or infeasible. As a result, dune growth between storms is often unaccounted for in storm impact forecasts, limiting the accuracy of storm impact predictions.

Given that regional measurements of dune topography are made only periodically, an alternative approach to predicting dune height at any given time is to use quantitative models to simulate foredune growth. Accurate numerical modeling of dune growth requires calibration of free parameters in the model. But how do we optimally tune free models when many free parameters must be adjusted?

Approach

We developed an approach for setting model parameter values using the machine learning technique of genetic algorithms. There are 3 component steps in this approach. First, we collected spatially extensive topographic and vegetation data using kite-based structure from motion photogrammetry. After processing this data we used this data in a coastal dune model (Duran and Moore, 2013; Goldstein et al., 2017) that used a genetic algorithm to find optimal free parameter values to model this dataset. Within several iterations, the genetic algorithm routine converges on the parameters that yield the lowest error.



Example of photogrammetry data used to calibrate coastal dune model.

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Findings/Benefits This approach allows users to input actual topographic data into coastal dune models as an initial condition and to use observed initial topography, in combination with observed topography at a later time, to set free parameters. Beyond its utility in calibrating coastal dune models, the calibration workflow we developed is flexible, and can be used with other coastal morphodynamic models.

Status/Steps Moving Forward

We identified the need to continue to collect synchronous topographic and vegetation data in coastal dunes, and further test the ability of this calibration routine to help parameterize coastal models.

More Information

This work was funded through a USCRP Challenge Grant with additional leveraged funding from the NOAA Ecological Effects of Sea Level Rise Program. See also: Goldstein, E.B., and Moore, L.J., *in press.* A calibration workflow for coastal dune models. *Shore and Beach.*

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