# LAND COVER EFFECT ON DUNE EROSION AND OVERWASH

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In this study, a numerical morphodynamic model eXtreme Beach behaviour (XBeach) was used to simulate the effects of land cover on the shape of the post storm profile s at two test sites on barrier islands at Outer Banks, North Carolina. The simulations included dune erosion and overwash regimes and were carried out with and without the inclusion of land cover effects. The model results were assessed by comparing post storm profiles extracted from XBeach and Light Detection And Ranging (LiDAR) data. The simulations showed that the morphological response of the profiles was sensitive to land cover and inclusion of these effects improved the model results.

*Keywords: dune erosion; overwash; land cover; coastal morphological modeling*

## INTRODUCTION

Extreme events such as storms and hurricanes can cause rapid and far-reaching changes in coastal landforms. The combinatorial effect of storm surge, wave height, wave period and storm duration during these events together with the local topographic, geologic and land cover characteristics can result in beach and dune erosion, overwash and formation of new inlets through breaching. In order to be able to mitigate the damage and problems that can be caused by such processes successful coastal morphology models are essential. During the last several decades, the advancements in computational power and increase in availability of coastal data has shifted the focus from empirical models to process-based. These models are increasingly more 'realistic' and can successfully represent the complex topographic and hydrodynamic conditions in coastal areas (Roelvink and Reniers, 2012).

One effort to improve the 'realism' of these morphologic models is to consider the influence of land cover on the dissipation of wave energy and water flow and resulting erosion patterns. Intrinsically vegetation will reduce erosion on the coast by increasing resistance to flow and by providing soil stabilization effects due to root mass. Hard, surfaces such as roads can create channels for the water to flow changing the flow direction and characteristics, cause increased scour at the boundary of the pavement and natural sediments and resist erosion until the point at which the pavement is undermined and collapses. Therefore, insight into the interactions between the land cover and morphological response of coastal landforms during extreme events will improve the predictive capability of these models.

Kurum et al., 2012 introduced a methodology for incorporating land cover using a 2D implementation of XBeach (Roelvink et al., 2009) and showed significant improvements in the predictive capability of the model by comparing model results to post storm field data. However, profile based, 1D models are still widely used due to their simplicity and significantly lower computational requirement. Although they fail to capture the alongshore variability, 1D models have shown success in assessing the storm impact on coasts (Dean 1973, Vellinga 1986, Larson et al., 2004) and have provided valuable insight and direction for more complex models. Thus the effectiveness of including land cover in the 1D framework is of interest.

This paper presents the application of process-based morphological model XBeach in 1D to study dune erosion and overwash, and the effect of land cover on these processes. XBeach is a process-based numerical model developed to determine coastal morphological change including dune erosion, overwash and breaching in response to time-varying extreme conditions such as storms and hurricanes. The model resolves coupled short wave energy, flow and infragravity wave propogation equations, sediment transport and bed update. A more detailed description is given by Roelvink et al., 2009. In this study XBeach was used at two study sites, with and without the inclusion of land cover effects to simulate two different landform responses: dune erosion and overwash. The results of the model simulations were then compared to field measurements extracted from post hurricane lidar data.

## STUDY SITE A: DUNE EROSION

Study site A is located approximately 10 km south of Oregon Inlet on the Outer Banks of North Carolina, within the Pea Island Natural Wildlife Refuge (PINWR) (Figure 1).

This site was selected based on the dune face erosion that occurred during Hurricane Isabel in 2003. Dune erosion refers to incidences in which the dune remained intact post storm, a significant

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volume of sand was transported from the dune face and no overwash occurred. This corresponds to the collision regime as described in storm impact scale by Sallenger, 2000.

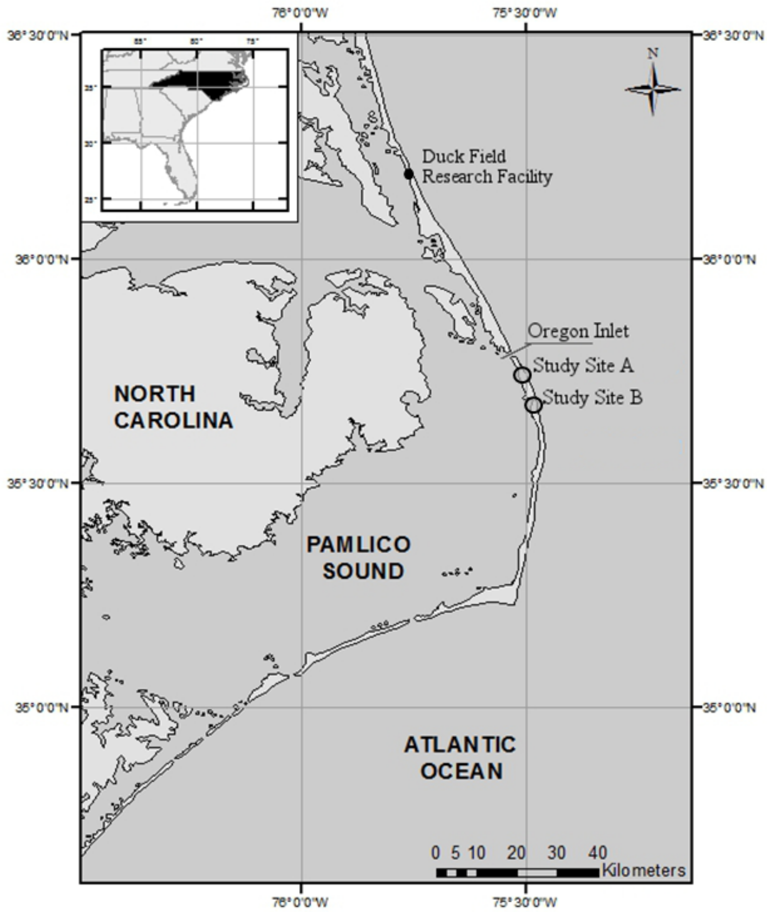


**Figure 1. Study area location on the Outer Banks of North Carolina.**

## Hydrodynamic Conditions

On September 18th, Hurricane Isabel made landfall in eastern North Carolina. It battered Outer Banks; eroded dunes, caused overwash and opened inlets. The hydrodynamic condition data for Hurricane Isabel was taken from the Datawell Directional Waverider, ID 630, located approximately at 17 m depth from the US Army Corps of Engineers Field Research Facility (FRF) pier, Duck NC (Figure 2). Hurricane Isabel had a maximum $H_{mo}$ of 8.1 m, a storm period of 15.4 seconds and storm duration of 79 hours. The maximum observed surge was approximately 1.8 meters. In XBeach, the hurricane offshore wave boundary conditions were represented with 72 hourly Jonswap spectrums, covering three days with the peak of the hurricane centered in the hydrograph.

## Model Domain

Pre and post Hurricane Isabel lidar elevation data was gathered on September 18th and September 21st of 2003, by the National Aeronautics and Space Administration (NASA)/U.S. Geological Survey (USGS) Experimental Advanced Airborne Research Lidar (EAARL) system. These data have a point density of 1 point per 3 meters and a vertical accuracy of 15 cm.

Pre Isabel lidar elevation data were merged with the 10m resolution bathymetric DEM created as part of the State of North Carolina Department of Emergency Management Flood Plain Modernization Program. Pre lidar elevation data and bathymetric data were projected into same coordinate system. Then merged and interpolated into 1m resolution DEM using regularized spline interpolation method (Mitasova et al., 2005).

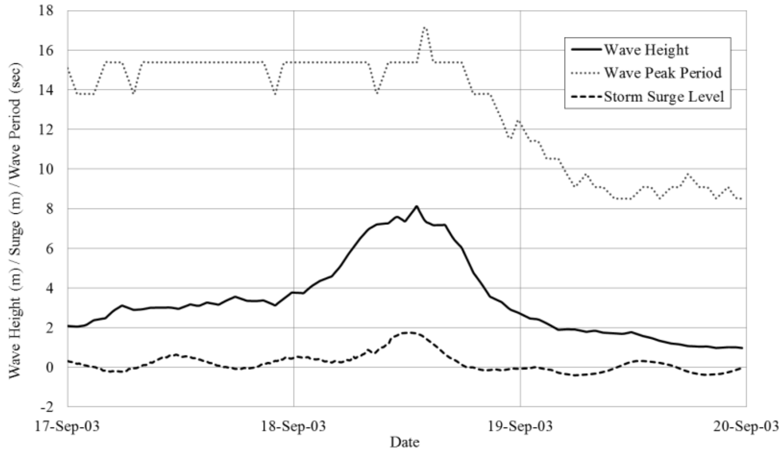


**Figure 2. Measured wave heights, peak periods and surge level during Hurricane Isabel at FRF Buoy 630.**

At study site A, profiles were established 50 meters apart. Transects, coinciding with washover fans and maintenance buildings were excluded. The selected 33 profiles over the area showed a lot of variability in dune heights; crest heights changing between 4.8 to 9.3 meters. In XBeach profiles had a spatially varying grid resolution that ranged from 20 meters spacing offshore to 1 meters nearshore and over the land. The offshore extent of the profiles was limited to reach 17 meters depth (corresponding the depth of the buoy where the hydrographic data were extracted for both storms).

## STUDY SITE B: OVERWASH

To investigate overwash phenomenon study site B, also located in PINWR, was chosen 7 km north of study site A. This site was chosen because of the historically observed washover fans. Both Hurricane Isabel 2003 (Overton et. al, 2006) and Hurricane Sandy 2012 (Figure 3A, 3B) created washover fans in the area. During Hurricane Sandy washover fans reached 130 meters landward of the road. Further analysis of the area by differencing pre and post Hurricane Sandy lidar data show 0.15-0.35m elevation change at washover areas (Figure 3C).

During overwash, the combination of water and sediment passes across beach or dune crest due to storm induced conditions and does not return directly to its originating waterbody (Donnelly et al. 2006). Thus land cover can play a very important part in shaping post storm morphology. At site B land cover features include substantial vegetation landward of the dune crest.

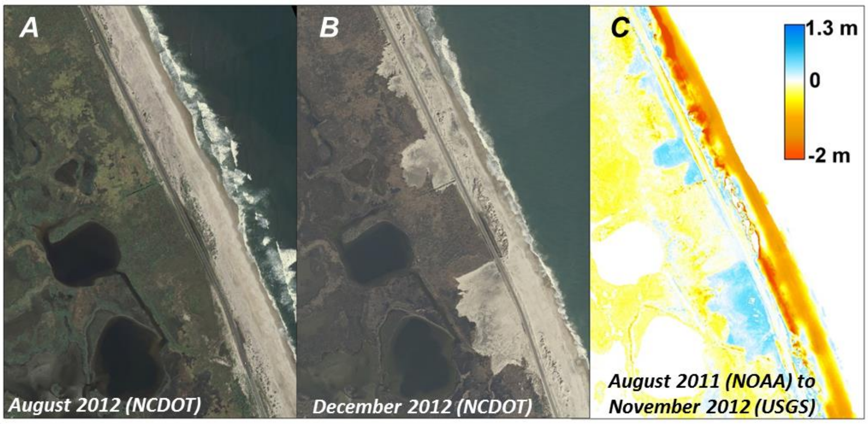


**Figure 3. Pre and post-storm orthophotos and elevation difference maps displaying overwash fans at study area 2 (Positive values indicate accretion and negative values indicate erosion).**

**Hydrodynamic Conditions**

Powerful winds and waves caused by Hurricane Sandy reached the Outer Banks coasts on October 28 and caused considerable dune erosion and overwash. The hydrodynamic condition data for Hurricane Sandy was also gathered from the Datawell Directional Waverider, ID 630, located approximately at 17 m depth from the FRF pier, Duck NC. Hurricane Sandy had a 7.5 m $H_{mo}$, a storm period of 14.3 and storm duration of 152 hours (Figure 4). Eight days were covered by 192 hourly Jonswap spectrums for Hurricane Sandy simulations.

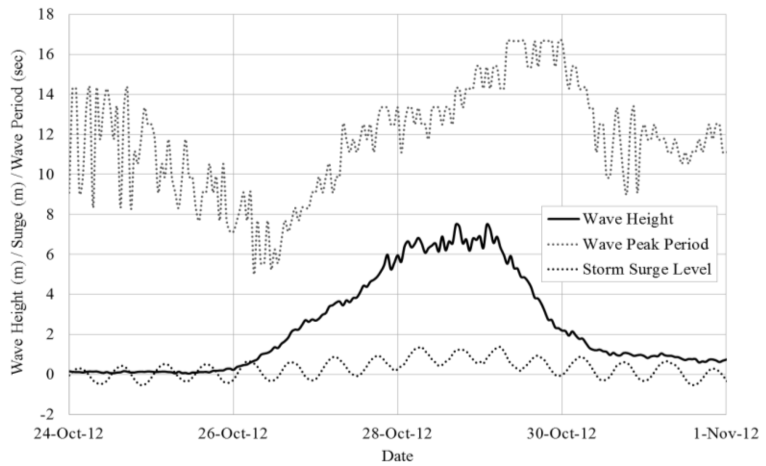


**Figure 4. Measured wave heights, peak periods and surge level during Hurricane Sandy at FRF Buoy 630**

**Model Domain**

Pre-storm data for Hurricane Sandy was collected on October $11^{th}$ of 2012 by the North Carolina Department of Transportation (NCDOT) Photogrammetry Unit. The vertical precision of data is 5 cm and has a point density of 1 point per 1 meter. The post-storm data was obtained on November 4th of 2012 by the USGS. Data were provided as a raster file with 1m resolution and a vertical accuracy of 15 cm. 10m resolution bathymetric DEM that was used for study site A was also used at this location. Pre-storm data and bathymetric data were converted into the same coordinate system and interpolated into 1m resolution DEM using regularized spline interpolation method.

At study site B, 28 profiles passing over the washover fans with 5m spacing were selected to simulate overwash process (Figure 5). Cross shore profiles selected were represented with spatially varied grid resolution that started from 25 meter resolution offshore to 1 meter at nearshore and land. Compared to the dune crest heights at study area 1, dune profiles taken at this location are lower with crest heights varying between 2.2 to 4.1 meters. In this research one-dimensional XBeach model was used to simulate hurricanes profiles taken over the study sites. The offshore extent of the profiles was limited to reach 17 meters depth to match the depth of the FRF buoy where hydrodynamic conditions were taken.

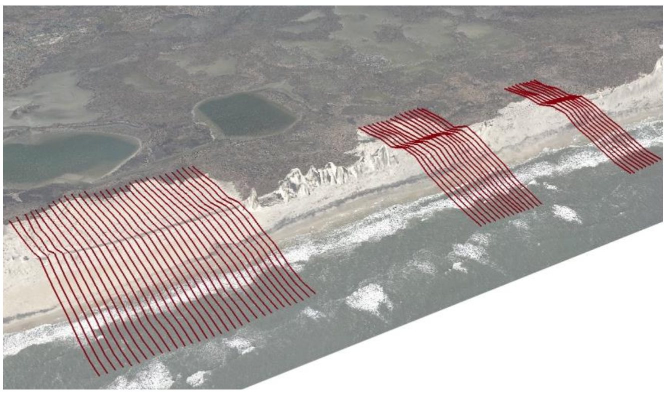

**Figure 5. Profiles selected for 1D XBeach application at Study site B.**

### LAND COVER IMPLEMENTATION

XBeach simulations were carried out in two stages to examine the effect of land cover on morphological processes during storms. First, all of the nodes along the profiles were represented as sand. The results of these cases, which were classified as "sand" cases, were than compared to the results of "land cover" cases. In the land cover cases, nodes in the model are classified into land cover types and then attributed their corresponding land cover properties by utilizing the land cover implementation framework defined by Kurum and Overton, 2012.

Using this framework the land cover cases nodes in the model were first classified into their respective land cover classes extracted from pre storm orthoimagery. In this study land cover over the study areas were represented as concrete/pavement, vegetation and sand. Using supervised radiometric classification the pre storm orthoimagery was processed to produce a land cover raster defining these three land cover features (Figure 6). The nodes along the profiles are then attributed grain sizes ($D_{50}$, $D_{90}$) and sediment calibration factor (parameter which controls ease of movement of a sediment particle) according to their corresponding land cover class from land cover raster. Values suggested in Kurum and Overton 2012 were used for these parameters.

XBeach also allows defining multiple sediment layers in its model setup. Using this feature each land cover class in the model domain was represented in 3 layers of 0.3 m thickness. Layer properties for each land cover class is define differently. For a sand node all three layers were classified as sand. To imitate roots two top layers of vegetation node was assigned as vegetation and the bottom layer was classified as sand. Pavement was assumed to be sitting on sand so only the top layer was given pavement properties.

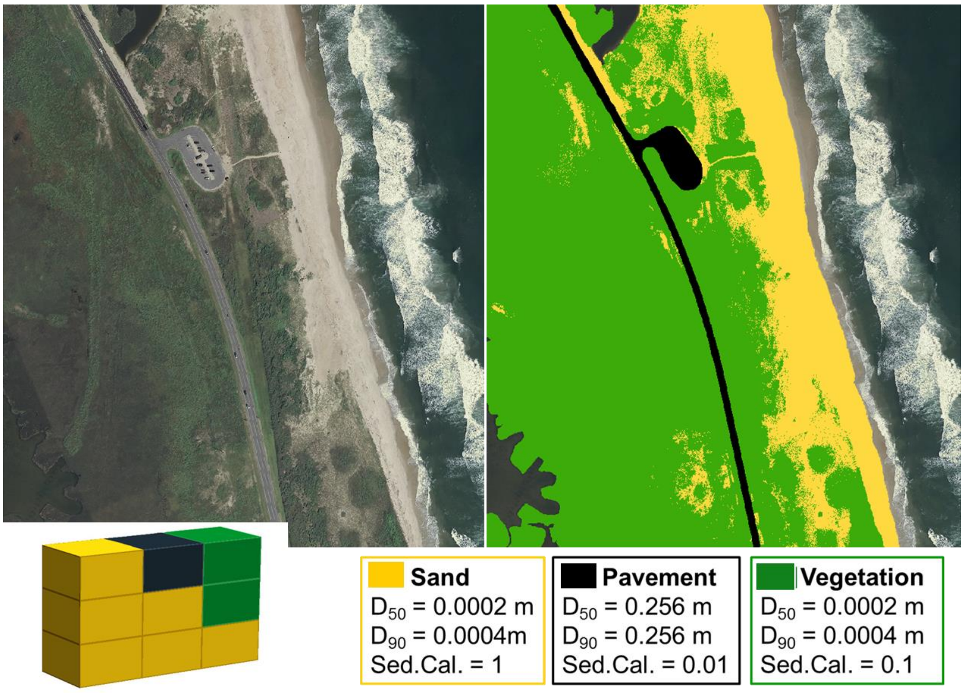


**Figure 6. Land cover classification raster, land cover layer configuration and; sediment characteristics**

### RESULTS

#### Dune Erosion

To investigate dune erosion XBeach was used to simulate hurricane Isabel over 33 profiles selected from study site A. The results of the model runs were then compared based on the measured eroded areas from pre and post hurricane lidar observations and the simulated eroded areas per profile. The vertical extent of the eroded area calculation for the profiles were limited by the still water flood level (SWFL) associated with the storm (Figure 2, SWFL = 1.74 meters for Hurricane Isabel). The horizontal extent was limited by the intersection point of all pre, post and simulated profiles (Figure 7).

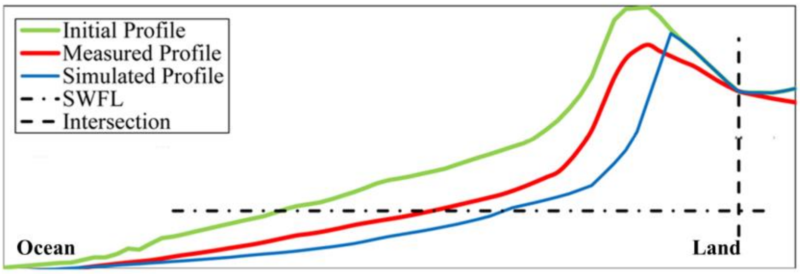


**Figure 7. The extents of eroded area calculations for pre, post and simulated profiles (adapted from Kurum, 2013)**

The measured eroded areas were plotted against the simulated eroded areas for each model run (sand, land cover) where the trends for each can be observed relative to the perfect prediction line indicating where the simulated erosion would be equal to the observed erosion (Figure 8).

From Figure 8, we can observe that both XBeach simulations are on the over estimating side of the perfect prediction line. However introduction of the land cover greatly improves the prediction capacity of simulation results. The scatter and its trend line for the XBeach land cover case is more concentrated and parallel to the perfect prediction line. The median error in prediction over all profiles for XBeach (sand) was calculated as 7.87% over prediction, XBeach (land cover) 3% over prediction.

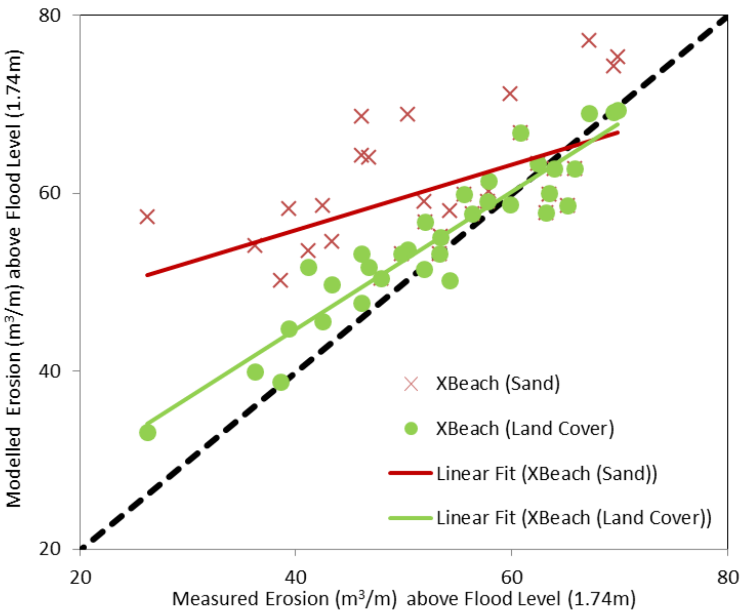


**Figure 8. Erosion above SWFL for XBeach sand, XBeach landcover and field observations (adapted from Kurum, 2013)**

**Overwash**

XBeach was simulated over 28 profiles selected at Study site B for Hurricane Sandy to study overwash phenomenon. The model results were than assessed by comparing the measured sand deposition areas with the simulated sand deposition areas per profile. Post storm lidar images were gathered after the road was cleared and sand deposited over the road was transferred ocean side. Therefore post storm elevation data between the road and the backside of the dune gathered from lidar were considered to be misleading and this area was excluded during comparison analysis. The horizontal extend of sand deposition area used for comparison of results starts from the road passing through the PINWR and moves landward until the intersection of pre, post and simulated profiles. In this horizontal extend sand deposition areas was defined as the area between pre and post storm profiles (Figure 9).

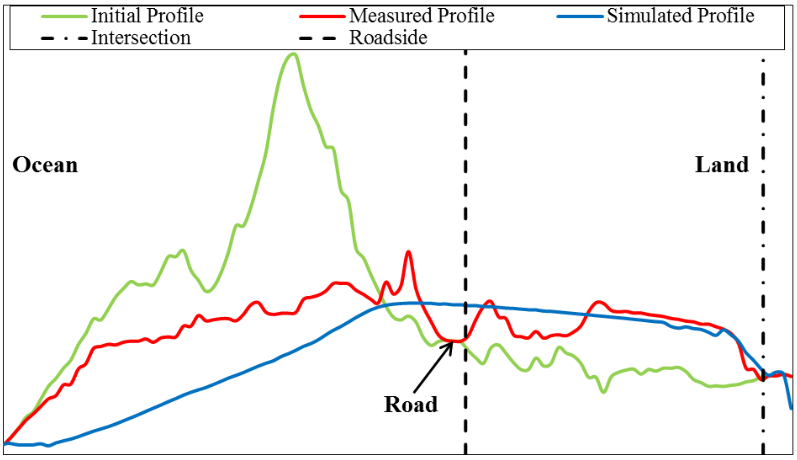


**Figure 9. The extents of sand deposition area calculations for pre, post and simulated profiles**

The measured sand deposition areas were plotted against the simulation results for both sand and land cover cases (Figure 10) and compared with the measured results. At figure 10 we can observe that both XBeach simulations under predict the sand deposition amounts. For both cases deviation from the observed results increased as magnitude of the observed sand deposition increased. As observed in the dune erosion case inclusion of land cover effects into the model improves model results. Median error in prediction over all profiles for XBeach (sand) was 12.1% whereas for XBeach (land cover) was 3.4% under prediction.

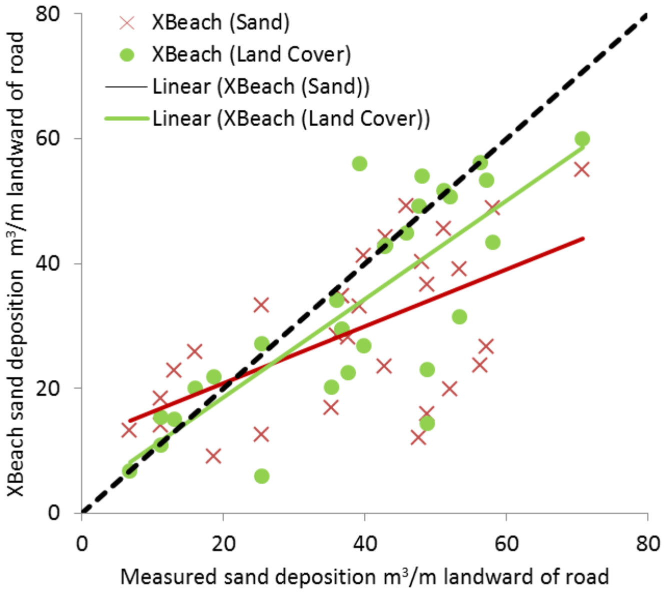


**Figure 10. Sand deposition amounts for XBeach sand, XBeach landcover and measured observations**

## CONCLUSIONS and FUTURE WORK

Extreme events can put tremendous pressure on coastal communities on barrier islands. Understanding of morphological processes take place during these events and improving models predictive capabilities can help coastal managers to develop more successful mitigation plans and increase resilience of coastal communities. Especially in cases like overwash where water flow due to hurricane interacts with the features landward of the dune, incorporation of land cover effect into the morphological change simulation is essential.

In this study, XBeach was used to simulate Hurricane Isabel and Hurricane Sandy in 1D to examine effects of land cover on overwash and dune erosion processes. XBeach exhibited an over estimating behavior when determining dune erosion amounts. On the other hand simulation of overwash process lead to under estimation of sand deposition amounts. For both overwash and dune erosion processes XBeach results improved for when land cover effect was incorporated.

It should be noted that the model assessments in this study were based only on area comparisons. The resulting shapes of overwash deposits and eroded profiles, extracted from model simulations were not analyzed. However, post storm profile may take various shapes while displaying the same amount of area for erosion or sand deposition. Especially in the overwash case, where the landward distribution of sand may be important for post storm recovery, investigation of the extent and shape of the washover can provide valuable insight and guidance for further modeling studies.

Future work will include simulation of overwash with land cover implementation in 2D, modeling at new locations, exploration of friction factor in XBeach to improve land cover implementation and introducing new land cover types (different vegetation types, buildings). In this study it was demonstrated that inclusion of land cover can increase the predictive capabilities of morphological models.

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