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MORPHOLOGIC CLASSIFICATION OF COASTAL OVERWASH

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A set of pre- and post-storm beach profile data was assembled and the profiles classified into seven different cross-shore morphology change types resulting from overwash. These were crest accumulation, dune/berm translation, dune lowering, dune destruction, barrier accretion, short-term barrier rollover, and barrier destruction. Pre- and post-storm barrier profile sets from recent laboratory experiments also fell into the new classification system. Forcing mechanisms for the different categories are suggested. Understanding of the mechanisms leading to different types of cross-shore morphologic change is useful in developing cross-shore profile numerical modelling capabilities.

INTRODUCTION

Severe storms can cause large-scale morphology change, damage to infrastructure, and injury and loss of life. Two major phenomena accompanying large storms are overwash and breaching. Overwash is the flow of water and sediment over the crest of the beach that does not directly return to the water body from where it originated. On developed barrier islands, overwash can destroy existing infrastructure such as coastal roads and buildings, but the existence of overwash also maintains the integrity of barriers and is essential to the health of certain flora and fauna.

Overwash morphologies have typically been characterised based on the spatial extent and shape of washovers as viewed from the air (e.g., Price 1947, Morton 1979, Suter et al. 1982, Morton and Sallenger 2003). Such characterisations defined common washover morphology terms in use today, such as perched washover fans, washover terraces, sheet lineations, and sheet-wash. This study examines cross-shore morphology change. Introduction of a system to identify different types of cross-shore morphology change due to overwash helps to associate types of morphological change with the hydrodynamic forcing. Models of cross-shore beach profile change caused by overwash are currently under development (Larson et al. 2005, Donnelly et al. 2006). Comprehensive understanding of how the cross-shore beach profile can be changed by overwash will contribute to further improvement of such models.

More than 110 sets of pre- and post-storm cross-shore beach profiles showing overwash occurrence were assembled. The data were examined for patterns in the morphologic change, and relations between the forcing and

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morphology were sought. Additionally, new large-scale physical model experiments on overwash of a low-crested barrier and overwash of a low crested barrier with a prominent dune were conducted. The experiments are described and resulting morphology change compared with that observed in the field. The morphology change types are analyzed with reference to the laboratory hydrodynamics to understand the mechanisms controlling overwash, sediment transport, and associated morphological evolution.

FIELD DATA

Pre- and post-storm cross-shore beach profile survey data sets were assembled from locations where overwash occurred. Overwash profiles were compiled both from published literature and from city, state, and consulting engineers, and beach protection authorities. Most of the available overwash profile sets are from the United States Atlantic and Gulf coasts, with one data set from the south coast of Portugal. Overwash occurs in many locations around the world, but monitoring is more frequent in the U.S.A. Table 1 summarises locations, storms, and the sources of the newly compiled data sets.

Overwash was deemed to have occurred if the post-storm profile indicated morphologic change on and behind the beach crest. Both the spatial and temporal extents of the pre- and post-storm profiles vary considerably from region to region. For example, some profile surveys terminate directly seaward of the beach crest, whereas others extend across an entire barrier island. Often the landward extent of the pre-storm profile is limited to the beach crest, probably because overwash was not expected by those measuring the pre-storm profile. These factors are taken into account when analysing the data. The temporal extent of the profiles also varies, mainly the timing of the pre-storm survey. For most of the data sets, the post-storm survey was no later than one month after the overwash event. For the few cases where the post-storm survey occurred later than one month after the primary overwash event, the wave record was checked for subsequent storms within the survey period.

Profile surveys that were supplied as x,y,z coordinates were plotted in the horizontal (x-y) plane to check that the alignment of the pre- and post-storm surveys coincided. Some profile sets showed a large net gain of sand across the profile. For these profile sets, it was presumed that long-shore transport contributed to the sediment gain. Data sets with no overwash, a significant net sediment gain from longshore transport, insufficient pre-storm landward survey extent, or poor alignment of pre- and post-storm surveys were discarded.

Only for some data sets were complete hydrodynamic data (water level, wave height and wave period) available. Where available, such data was used to study the relationship between the forcing conditions and the resulting morphology. Overwash is most often generated by hurricanes and severe extra-tropical storms, and such storms often cause measurement equipment to fail. Hindcast wave data was also collected where available.

Table 1 - Summary of available overwash profile data sets							
Location	**Storm**	**Survey Periods**	**Peak WL**	**Max Deep Hs**	**Site Description**	**No. Profiles**	**Reference/Source**
Metompkin Island, VI	H. Gloria, 27/9/1985	11/83-5/86	2 m	4.7 m	Low, flat, barrier island	2	Byrnes and Gingerich 1987
Manasquan, NJ	N'easter, March 1984	3/84 – 4/84	2 m	7 m	Narrow, high beach with groins	2	Wise et al. 1996
Folly, Garden City and North Myrtle Beaches, SC	H. Hugo, 21/9/1989	10-/88 – 9/89	3 m	7 m	Foredunes, barrier island	20	Eiser and Birkemeier, 1991
Ocean City, MD	N'easters, Winter 91/92		2 m	4 m	Artificial dunes backed by development, barrier island	7	Wise et al. 1996
Santa Rosa Island, FL	H. Opal, 4/10/1995		2.5 m	8 m	Low, flat, barrier island, with dunes	1	Stone et al. 2004
Assateague Island, MD	N'easters, Jan 1998 (2)	9/97 – 2/98	2 m	4 m	Low, flat, barrier island	6	Larson et al. 2005, USGS
Santa Rosa Island, FL	H. Georges, 28/9/1998		1.5 m	8 m	Low, flat, barrier island, with dunes (vegetated)	1	Stone et al. 2004
Outer Banks, NC	H. Dennis, 9/1999		1.5 m	6.3 m	High dunes	1	Wetzell et al. 2003
St Lucie County, FL	H. Irene, 15/10/1999	7/99 – 11/00	na	na	Narrow dunes	3	CP&E
Chaland & Pelican Islands, LA	H. Isidore, 26/9/2002 & Lili 3/10/2002	9/02 -12/02	1.5 m	12 m	Low barriers, fine sediments	10	CP&E, LDNR
Captiva and Sanibel Islands, Lee County, FL	TS Gabrielle, 14/9/2001	5/01- 11/ 01	1 m	na	Narrow barrier, little or no dunes	8	CP&E
Lovers Key, Captiva and Sanibel Islands, Lee County, FL	H. Charley, 13/8/2004	Mar/Jun 04 - Nov 04	na	na	Narrow barrier, Dunes vary	7	CP&E and Lee County
Fort Pierce, St Lucie County and Martin County, FL	H. Frances 5/9/2004 & Jeanne 26/9/2004	Jul 04 - Nov 04	na	na	Generally high dunes, Nourished.	35	Taylor Engineering, FDEP, CP&E and Martin County Eng Dep.
Santa Rosa Island, FL	H. Ivan, 16/9/2004	May 04 - Sep 04	3 m	16 m	Low, flat, barrier, dunes	5	FDEP
Ria de Formosa, PORTUGAL	Small local storm 2001	Same day	1.7 m	1.4 m	Low, flat, barrier island	2	Matias et al. 2004

LABORATORY DATA

Laboratory experiments of overwash and breaching were conducted in a 3.3 m wide, 64 m long flume at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. A barrier island, composed of well-sorted quartz sand with a median grain size of 0.16 mm, was constructed in the flume. Two experiments were conducted on two different barrier profiles. In total, four cases were run on the two profiles (Table 2). Both monochromatic and irregular wave cases were run. The purpose of the experiments was to generate data sets to develop predictive numerical models for coastal barrier overwash and to further understanding of overwash processes.

Table 2. Forcing conditions for overwash experiments

Case	WL above Structure Toe (m)	Wave Height (m)	Wave Period (sec)	Wave Type
OWB1 – Low Flat barrier	0.46	0.25	7	Regular
OWB2 – Low Flat Barrier	0.46	0.23	5	Irregular
OWB3 – Low Flat Barrier	0.46	0.25	7	Regular
OWD2 – Barrier with Dune	0.58	0.54	7	Regular

The first barrier profile was designed to replicate a low, flat barrier island with no dune feature. The seaward slope was 1:17, and the landward slope was 1:100. Similar landward slopes are seen at Assateague Island, MD, and Metompkin Island, VA.

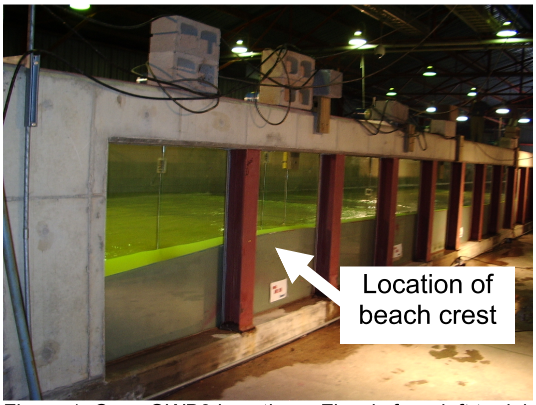


Figure 1. Case OWB3 in action – Flow is from left to right.

Figure 1 shows case OWB3, inundation overwash of a low flat barrier, underway. The landward slope steepened at a distance of approximately 3 m from the end of the flume, to a slope of 1:4. This was primarily done to fit the profile within the flume's length.

A second experiment was conducted on the low profile barrier island, this time with a prominent dune built on the barrier crest. The beach slope and back barrier slopes were retained from the previous cases, but a dune with front and rear slopes of 1:3.3 was built on top of the barrier crest. The dune was notched to model the channelling of overwash through an overwash throat and lateral spreading of the confined overwash when it reaches the back barrier. The profile was subject to a water level such that runup overwash occurred through the overwash throat. The two pre-storm barrier profiles are depicted in Figure 2. In the following profile figures, the ocean is to the right and bay is to the left, such that overwash occurs from right to left.

Capacitance wave gauges and acoustic Doppler velocimeters (ADVs) were deployed to monitor wave height and period, water level, and current velocity. Profile development and water level were monitored with six digital video cameras. Additionally, the final barrier topography was surveyed by total station. This paper focuses on the profile change measurements.

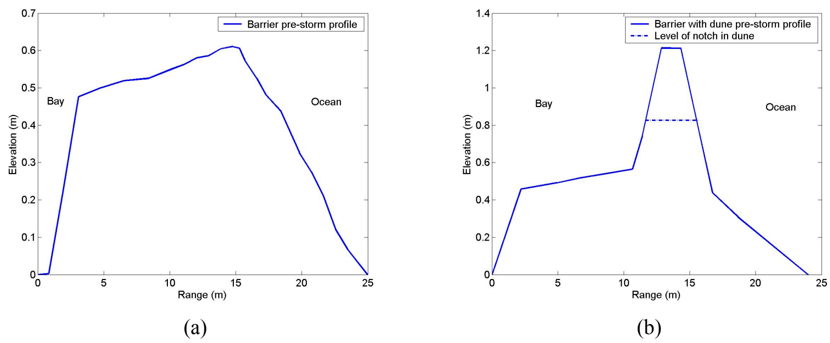


Figure 2. Initial laboratory barrier profiles, (a) low flat barrier, and (b) prominent dune.

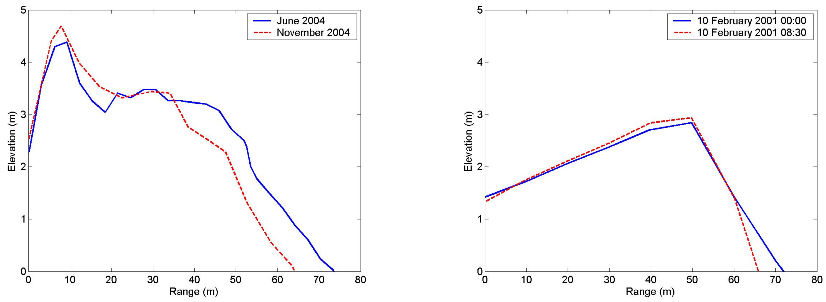
METHODS

The profile sets were grouped according to similarities in morphologic change landward of the beach crest and as to whether or not a dune existed on the pre-storm beach profile. They were plotted in the same scale so that the relative slopes of the profiles could be compared. An additional plot of each data set was made at a larger scale so that the details of the morphologic change could be observed. Spatial and temporal resolution of the profile sets was highly varied, and this was taken into account in comparing profiles. A dune was loosely defined as a prominent feature on the profile, with slope on the rear of the dune exceeding 1:20 and a height exceeding 0.5 m above the back barrier. It was possible to classify the data sets into seven groups.

ANALYSIS AND DISCUSSION

Seven morphology change types in response to overwash were observed: The morphologies and hydrodynamic conditions for their formation are discussed below:

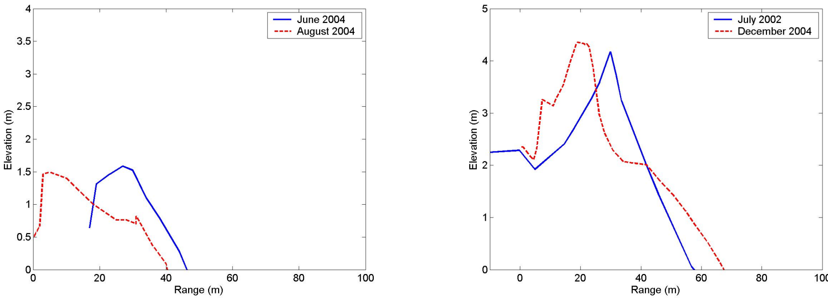
1. Crest Accumulation: This is the accumulation of sediment on the beach crest. The phenomenon was first described in terms of overwash by Fisher et al. (1974) and by Leatherman (1976), and was observed on shingle beaches by Carter and Orford (1981). It is thought to occur when the wave runup height only slightly exceeds the beach crest. As the runup decelerates up to the beach crest, sediment is deposited. It should be noted, however, that the overtopping flow continues over the crest. Examples of crest accumulation, on both a dune and on a low flat barrier, are shown in Figures 3(a) and 3(b) respectively.



(a) (b)

Figure 3. Crest Accumulation, (a) Fort Pierce R-44, FL, following Hurricanes Frances and Jeanne 2004, and (b) Ria de Formosa, Portugal, following 8.5 hr field experiment (Matias 2003).

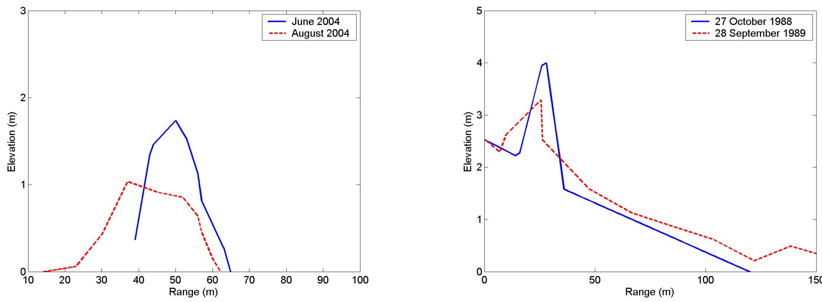
2. Landward translation of dunes/berms: In many field profile sets, the landward translation of an intact dune was observed both for prominent foredunes and for less prominent beach berms. One suggestion is that an erosive overwash regime first causes dune lowering. This may then be followed by a period of accumulation overwash restoring the dune to its original height translated landward; however, hydrodynamic evidence of this is required. The dunes usually maintained their height above sea level, but cases where the dunes increased or decreased in height were also observed. This is thought to be controlled by the relative period of accumulation overwash on the waning stages of the storm. Figure 4 shows two examples of landward dune translation by overwash.



(a) (b)

Figure 4. Landward dune translation, (a) Lovers Key R-217, FL, following Hurricane Charley 2004, and (b) St Lucie county R-109, FL, following Hurricanes Frances and Jeanne 2004.

3. Dune Lowering: This case is the predecessor of dune destruction. Sediment is removed from the seaward side and crest of the dune and deposited behind the crest in a wedge decreasing landward. Thus, the dune crest height is reduced, while the back barrier height increases.

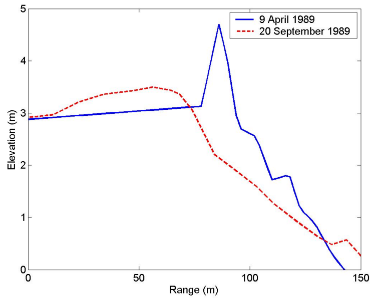


(a) (b)

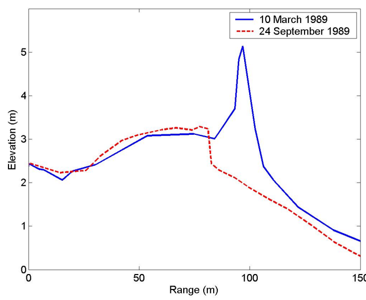
Figure 5. Dune Lowering, (a) Lovers Key R-216, FL, following Hurricane Charley 2004, and (b) Folly Beach 2801, SC, following Hurricane Hugo 1989.

4. Dune destruction: Destruction of an entire foredune occurs. A proportion of this sediment is usually deposited behind the original crest position in a landward-decreasing wedge. The proportion of sediment deposited on the barrier depends on the amount of dune erosion that occurred prior to overwash. For example, Figure 6 (a) shows a situation where most of the eroded dune sediment was deposited on the back barrier, and Figure 6 (b) shows an example where dune erosion occurred first, with a small amount of overwash assumed to have occurred after dune destruction

Both dune lowering and dune destruction are thought to be caused by runup overwash; the latter being the result of runup overwash over a longer period, which may or may not be followed by a period of inundation overwash as the beach crest lowers.



(a)

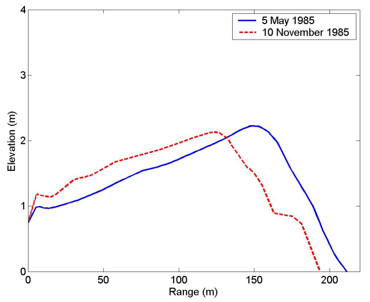


(b)

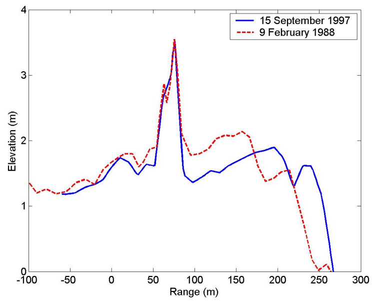
Figure 6. Dune destruction, (a) Garden City Beach 4930, SC, following Hurricane Hugo 1989, and (b) North Myrtle Beach 5820, SC, following Hurricane Hugo 1989.

5. Barrier Accretion: This type of morphologic change occurs on barrier islands, spits, or low lying mainland beaches. Sediment is eroded from the foreshore and deposited in a landward decreasing wedge on the back barrier. For barrier islands and spits, the landward extent of washover does not reach the back barrier bay. The barrier becomes narrower and higher, and the rear slope becomes steeper.

Several occurrences of barrier accretion with an offset dune some distance behind the beach crest were observed, with washover deposited landwards of the rear dune crest, and little erosion of the dune occurring (Fig. 7 (b)). The washover behind the offset dune is probably deposited by lateral spreading.



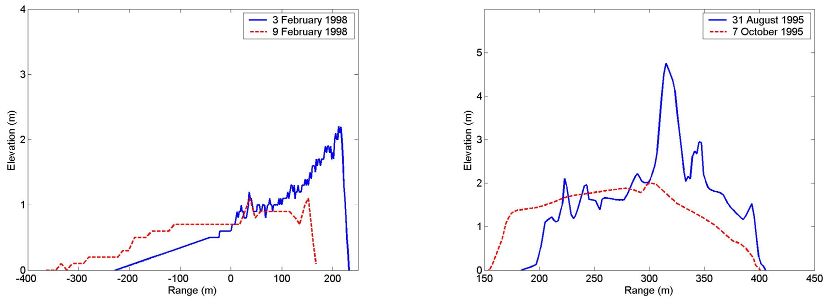
(a)



(b)

Figure 7. Barrier accretion (a) Metompkin Island R-26, VA, following Hurricane Gloria 1985, and (b) Assateague Island GPS1, MD, following Northeasters 1998.

6. Barrier Rollover (short-term): This is the landward translation of an entire barrier island or spit. It refers to the short-term rollover caused by a single overwash event. (Barrier rollover is often discussed at geological time-scales.) During an overwash event, sediment is transported from the foreshore and deposited both on the rear barrier slope and in the back barrier bay (Fig 8). It is thought to only occur during inundation overwash, but rollover was observed also for experiment OWB3 (Fig. 12), where the barrier was inundated by wave setup rather than mean water level. Where foredunes exist, these are destroyed prior to inundation, such as seen in Figure 8(b), indicating some cross-over between the responses. The mechanism for barrier rollover is thought to be different than that for dune translation because the slopes on which rollover occurs are often hydraulically mild slopes.



(a) (b)

Figure 8. Barrier Rollover (short-term), (a) Assateague Island GPS4, MD, following 1998 Northeasters, and (b) Santa Rosa Island, FL, following Hurricane Opal 1995.

7. Barrier Disintegration: This occurs when low-lying barriers become completely inundated. Sediment is removed from the entire barrier island surface in high-energy overwash conditions and either deposited subaqueously near the rear side of the barrier or lost offshore. If this continues for a sufficient length of time, the barrier may breach, that is the post-storm profile lies below mean sea level (Figure 9).

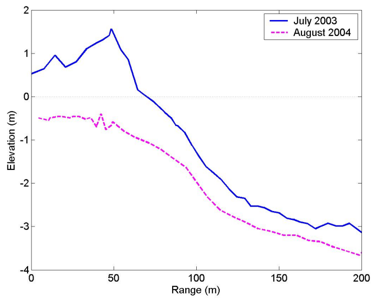


Figure 9. Barrier Disintegration - North Captiva Island breach following Hurricane Charley 2004.

Analysis of the laboratory profile set data allowed the hydrodynamics to be related to the observed morphology change. Cases, OWB1 and OWB2, fall into the category of crest accumulation overwash (profile sets shown in Fig. 10 and 11). The accumulation is more dispersed for OWB2, which was carried out with irregular waves. During the experiments, overwashing flow penetrated the entire modelled barrier length, but no morphologic change occurred on the less steep, main barrier slope. Observations through the side flume window revealed suspended sediment and bedload in the uprush bores, but relatively clear flow both landward of the barrier crest and in the downrush flow. On the barrier crest, sediment was deposited by the decelerating uprush flow indicating that relatively low energy overwash results in crest accumulation.

In the field, accumulation overwash was observed on both dunes and barriers. The morphologic change that occurred during a small storm on a low barrier island in the Ria Formosa barrier system Portugal (Matias 2003, Fig. 3(b)) is similar to that observed in run OWB1, shown in Figure 10.

At the downstream end of the flume, where the barrier slope steepened, the flow accelerated, entraining sediment and initiating channel formation. Antidunes were observed to form and migrate upstream, indicating the effect of barrier slope behind the beach crest. Whether or not the slope causes sub- or supercritical flow is of importance. It is not believed that such steep bay beach slopes are realistic for the back barrier bay shore.

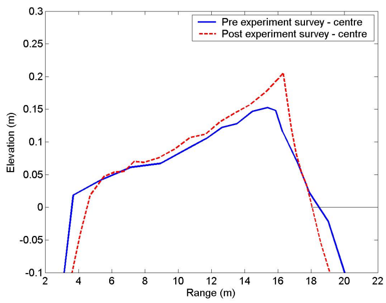


Figure 10. Profile change, Case OWB1.

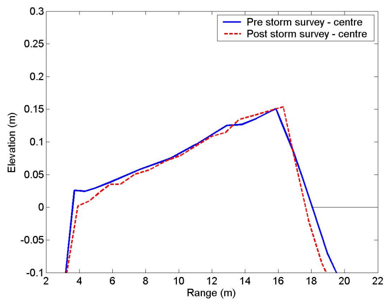


Figure 11. Profile change, Case OWB2.

The third laboratory case, OWB3, caused barrier rollover. The resulting morphology change was largely controlled by the existence of the steeper rear barrier slope, although the morphology observed on and directly landward of the beach crest is thought to be representative of field conditions. Overwashing bores in this run were significantly larger and more energetic than those observed in OWB1 and OWB2. Suspended sediment and bed load was observed in the uprush and overwashing flow, in particular directly behind the broken bore front. The landward translation of the barrier crest and thinning wedge of deposition are typical for barrier rollover and were observed for several of the field profiles sets, for example Assateague Island GPS 4 shown in Figure 8(a). The change observed on the steeper rear slope was not observed in any of the field cases, and again it is doubted that such slopes exist.

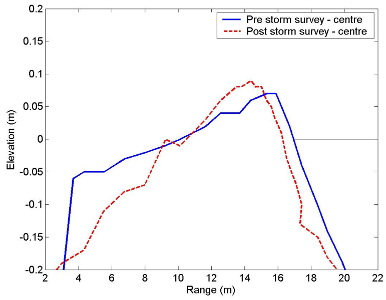


Figure 12. Profile change, Case OWB3.

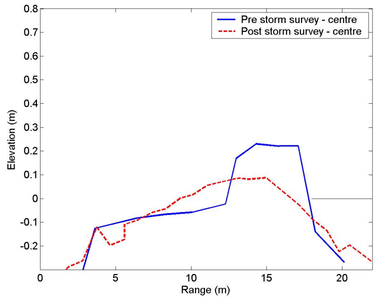


Figure 13. Profile change, Case OWD2, Throat centre.

The fourth laboratory case, OWD2, was conducted on a barrier with a prominent dune. Overwash was allowed to occur through a gap (throat) in the centre of the dune. Post-storm profiles were measured through the centre of the throat, and over the dunes either side of the throat. Profile change through the throat centre (Fig. 13) was similar to that observed for dune destruction, with sediment deposited in a landward thinning wedge on the back barrier. There was a net loss of sediment across this profile because some of the eroded dune sediment was deposited towards the sides of the flume by lateral spreading.

The profile sets either side of the throat (Fig. 14) showed erosion of the dune front, little change on the crest and rear slope, and deposition behind the dune. Rather than being deposited over the dune crest, this sediment was deposited behind the dune crest by lateral spreading. Similar morphologic change was observed at Ocean City, MD, profile 52, following the January 4, 1992 northeaster (Fig. 15). Both profile sets indicate the importance of knowing the 3-D nature of pre-storm morphology when analysing profiles.

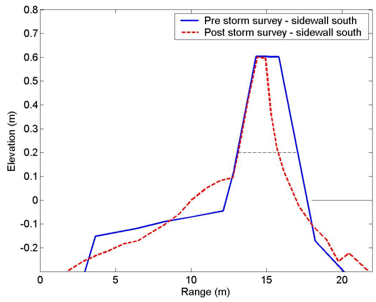


Figure 14. Profile change, Case OWD2, sidewall south.

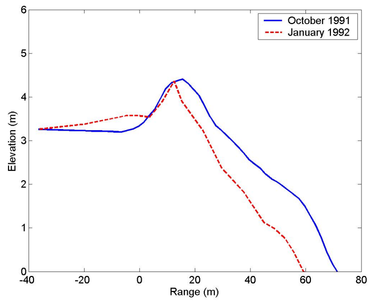


Figure 15. Ocean City, MD. Profile 52, Northeaster 1992.

CONCLUSIONS

More than 110 pre- and post-storm overwash profiles were assembled. The collation of a sufficiently large set of cross-shore overwashed profile data allowed the identification of seven different morphology change types caused by overwash: crest accumulation, dune/berm translation, dune lowering, dune destruction, barrier accretion, short-term barrier rollover, and barrier disintegration. These classifications further understanding of short-term beach profile change caused by overwash and are expected to contribute to continued development of numerical modelling capability for simulating morphology change by overwash.

Additionally, laboratory experiments on overwashing of low flat barrier islands and of barrier islands with prominent dunes were conducted. The morphology change resulting from these experiments fell within the new classification system and allowed the hydrodynamics to be related to the classifications. The profile changes caused by lateral spreading behind a prominent dune were identified both in the laboratory and the field data sets, emphasising the importance of three-dimensional processes in overwash.

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REFERENCES

Byrnes, M. R., and Gingerich, K.J. 1987. Cross-island profile response to Hurricane Gloria, *Proceedings Coastal Sediments '87*, ASCE, 1486-1502.

Carter, R. W. G., and Orford, J. D. 1981. Overwash processes along a gravel beach in South-East Ireland, *Earth Surface Processes and Landforms*, 6(5), 413-426.

Donnelly, C., Ranasinghe, R., and Larson, M., 2006. Numerical modeling of beach profile change caused by overwash, *Proceedings Coastal Dynamics '05*, CD-ROM, ASCE, 14 pp.

Eiser, W. C., and Birkemeier, M. 1991. Beach profile response to Hurricane Hugo, *Proceedings Coastal Sediments'91*, ASCE, 1681-1696.

Fisher J. S., Leatherman, S. P., and Perry, Capt. F. C. (1974). "Overwash processes on Assateague Island," *Proceedings 14th Coastal Engineering Conference*, ASCE, 1194-1211.

Larson, M., Wise, R. A., and Kraus, N. C. 2005. Modeling dune response due to overwash transport, *Proceedings 29th Coastal Engineering Conference*, World Scientific Press, 2133-2145.

Leatherman, S. P. 1976. *Quantification of overwash processes,* Ph.D. Dissertation, Department of Environmental Sciences, University of Virginia, Charlottesville, VA, 245 pp.

Matias, A., Vila-Concejo, A., Ferreira, Ó., Dias, J.A. 2003. Field measurements of morphologic variations during an overwash event, Thalassas*, Special issue for the 4th Symposium on the Iberian Continental Margin*, 19 (2b), 164-165.

Morton, R. A. 1979. Subaerial storm deposits formed on barrier flats by wind-driven currents, *Sedimentary Geology*, 24, 105-122.

Morton, R. A., and Sallenger, A. H., Jr. 2003. Morphological impacts of extreme storms on sandy beaches and barriers, *Journal of Coastal Research* 19(3), 560-573.

Price, W.A. 1947. Equilibrium of form and forces in tidal basins of coast of Texas and Louisiana, *Bulletin of the American Association of Petroleum Geologists*, 31 (9), 1619-1663.

Stone, G.W., Liu, B., Pepper, D.A. and Wang, P. 2004. The importance of extratropical and tropical cyclones on the short-term evolution of barrier islands along the northern Gulf of Mexico, USA, *Marine Geology,* 210, 63-78.

Suter, J. R., Nummedal, D., Maynard, A. K., and Kemp, P. 1982. A process-response model for hurricane washovers, *Proceedings 18th Coastal Engineering Conference,* ASCE, 1459-1789

Wetzell, L. M., Howd, P. A., and Sallenger, A. H. 2003. Simple models for predicting dune erosion hazards along the Outer Banks of North Carolina, *Proceedings Coastal Sediments '03*, CD-ROM, East Meets West Productions, Corpus Christi, TX ISBN-981-238-422-7, 10 pp.

Wise, R. A., Smith, S.J., and Larson, M. 1996. SBEACH: Numerical model for simulating storm-induced beach change. Report 4. Cross-shore transport under random waves and model validation with SUPERTANK and field data, *Technical Report CERC-89-9*, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.