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Monitoring overwash using water-level loggers resolves frequent inundation and run-up events

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ABSTRACT

Long-term (months to years) data on barrier-island overwash are lacking, but necessary for the proper parameterization of models addressing island response to rising sea levels, increased storminess and anthropogenic changes. Here, we present a method for recording overwash events that requires little maintenance and can endure storms. This technique uses water-level data loggers suspended in shallow wells that are anchored deeply into the ground. The loggers are placed close to the highest elevation of the barrier island along a cross-shore transect and record high-resolution (±1 cm) and high-frequency (2 minute) water-level measurements. We developed a schema for differentiating between tidal fluctuations in groundwater, run-up overwash and inundation overwash based on the pattern of water-level changes. Interpretations were validated using trail cameras aimed at the well and programmed to take a photograph every 5 min during daylight hours. There were some data gaps in the record caused by siltation of the logger in the well, repairing a corroded severed cable that was suspending the logger, and limited logger data storage. We constructed a year-long record of overwash frequency and magnitude from October 2012–2013 that included 43 distinct overwash events at a washover fan that initially formed in August of 2011 on Onslow Beach, NC, USA. The record revealed a shift in overwash intensity at the study site, reflecting both changing water levels and changing barrier morphology. The high number of overwash events that occurred at the washover fan 14 months after its initial formation is likely not unique to this site; however, overwash frequency needs to be measured along other shorelines using this method.

1. Introduction

The morphology and evolution of barrier islands is largely driven by aeolian and hydrodynamic processes, including wind-, wave- and current-driven erosion and transport of sand along and across the shoreline. Barrier-island studies commonly use contemporaneous observations of wind, current, wave and/or water level conditions and the morphologic response of the shoreface, beach, and/or dunes to improve conceptual and numerical models of morphologic change (e.g., King, 1951; Orford and Carter, 1982; Sallenger, 2000; Anderson and Walker, 2006; Callaghan et al., 2008; Theuerkauf et al., 2014). Ocean overwash, which occurs when the water level of the ocean exceeds the height of the beach berm or dune crest resulting in the flow of water and sediment landward across a barrier island (Donnelly et al., 2006), is an important process driving island evolution; however, it is difficult and oftentimes dangerous to collect measurements of overwash frequency, duration and height on a barrier island.

The occurrence of ocean overwash depends on ocean conditions (waves and water levels) and the morphology of the shoreline. Obtaining measurements of overwash processes from numerous morphologically distinct barrier islands would provide better constraints on overwash-threshold conditions, resulting in improved predictions of barrier-island response to rising sea level and increased anthropogenic influences. Overwash is the main process for increasing barrier-island width during transgression because it counterbalances island narrowing in response to oceanfront and back-barrier erosion by transporting sediment across the island (Leatherman, 1979, 1983; Kochel and Dolan, 1986; Timmons et al., 2010). Human development on barrier islands tends to restrict cross-shore sediment exchange, contributing to island narrowing and ultimately resulting in increased vulnerability to storms (Riggs and Ames, 2003; Nordstrom, 2014). Additionally, sand transported by overwash processes into the back-barrier lagoon or tidal creeks can create new substrate for back-barrier environments, such as salt-marshes, grass fields, and maritime shrub and scrub (Godfrey and Godfrey, 1974), which provide essential ecosystem services like fish and bird habitat, carbon sequestration, and protection from waves (Redfield, 1972; Peterson and Turner, 1994; Pendleton et al., 2012).

Barrier-island overwash varies in response to a suite of morphodynamic factors, producing different morphologies of the

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resulting deposit (washover fan). The controls on overwash and washover-fan morphology include the magnitude and duration of increased ocean-water level, wave height, wind speed and direction, berm and dune elevations, dune morphology (e.g., breaks in the dune), sediment type, resident vegetation, and accommodation space (Reading and Collinson, 1996; Sallenger, 2000; Donnelly et al., 2006; Matias et al., 2008; Carruthers et al., 2013; Masselink and van Heteren, 2014). Donnelly et al. (2006) differentiate run-up overwash from inundation overwash by the level of the ocean water relative to the elevation of the dune crest. Run-up overwash occurs when storm-surge elevation is less than dune-crest elevation but storm-surge elevation plus wave run-up exceeds dune elevation (Donnelly et al., 2006). Inundation overwash occurs when storm-surge elevation, measured independently from run-up, is greater than dune-crest elevation, resulting in water consistently flowing over the barrier. Water level measurements on a barrier island are useful for distinguishing inundation overwash from run-up overwash, in addition to determining the direction of flow across the island (Sherwood et al., 2014). The type, duration, and height of overwash define the landward extent and morphology of the washover fan, ultimately influencing the sand budget and geomorphic evolution of the island.

Improving models that predict the occurrence of overwash should be of interest to coastal managers, as well as researchers in a variety of disciplines, including paleoclimatology, barrier-island geology and ecology, and coastal engineering. Numerical models have been developed (e.g., Sallenger, 2000; Larson et al., 2005; Stolper et al., 2005; Tuan et al., 2007; Roelvink et al., 2009; Lorenzo-Trueba and Ashton, 2014) with the goal of pinpointing stretches of coastline vulnerable to overwash and simulating the evolution of barrier islands with respect to sea-level rise; however, there is a scarcity of field data on overwash processes for use in model parameterization and validation. Those data that do exist span short time periods (i.e. storm events) and are localized (e.g., Fisher et al., 1974; Fisher and Stauble, 1977; Leatherman and Zaremba, 1987; Guillen et al., 1994; Matias et al., 2010; Sherwood et al., 2014) because overwash events are difficult to predict, challenging to conduct field work around, and are associated with high-energy processes that can damage or remove equipment. Sedimentological methods, such as analyzing the stratigraphy of washover deposits or examining washover sediment texture and grading, have been employed to understand overwash processes (Hayes, 1967; Schwartz, 1975; Kochel and Dolan, 1986; Sedgwick and Davis, 2003; Nielsen and Nielsen, 2006; Phantuwongraj et al., 2013; Shaw et al., 2015) and those methods would be enhanced if paired with independent measurements of island inundation during sediment deposition.

A robust technique for collecting remotely-sensed measurements of overwash during a long period (years) is needed to increase the number of data-sets that can be used to improve model parameterization, validation, and applicability over a wide range of barrier-island morphologies. To address this need, we present an automated method for monitoring the frequency, duration, and height of island overwash resulting from both storm and tidal events, and a framework for interpreting those data. The method detects overwash using pressure sensors housed inside anchored shallow wells. Over the course of a year these sensors collected high-resolution water-level data capable of detecting events ranging from run-up overwash to hurricane-induced, high-inundation overwash. This manuscript describes well design, discusses deployment on a frequently overwashing barrier island, explains the schema for interpreting overwash in the data-set, presents a year-long record of overwash, and discusses limitations and considerations for applying the technique elsewhere.

2. Materials and methods

The method involves installing one or more anchored shallow wells with water-level loggers suspended inside on a barrier island. Overwash type, duration, and height can be determined from the water-level record and periodic measurements of the ground surface elevation adjacent to the well. To measure overwash at any cross-shore transect position along a shoreline, the well should be located at the highest elevation landward of the dune crest, or berm crest if dunes do not exist on that part of the barrier island. The well is only measuring the occurrence of overwash at that point, thus multiple wells should be installed to resolve spatial differences in overwash. For example, wells can be deployed parallel to the shoreline to resolve along-beach variation in overwash or in a line perpendicular to the shoreline to resolve cross-shore gradients in water level. Two wells were installed in this study in order to present the well design, data-collection methodology and overwash-interpretation schema.

2.1. Well construction

Our well design consisted of a slotted polyvinyl chloride (PVC) well screen (2 m long, 5 cm internal diameter and 0.25 mm slotted screen), capped at the bottom with a conical PVC well point and at the top with a PVC test plug (Fig. 1). The well screen was buried vertically, leaving the top 50–90 cm exposed above ground to provide easy access to the well and allow for changes in surface elevation around the well due to erosion or deposition, which would otherwise expose the water-level logger or bury the top of the well, respectively. The base of the well was about 50 cm below the water table and the above-ground portion of the screen was wrapped with plastic to prevent wind-blown sand from filling the well. To prevent horizontal and vertical movement of the wells after installation, we used a fence post driver to set a 3 m length of 1.5 cm diameter steel rebar in the ground to the point of refusal and attached the well to the rebar using two metal worm-gear hose clamps. Inside each well we suspended an Onset HOBO® U20 water-level logger from the PVC test plug using a plastic-coated, 0.635 cm-diameter stainless steel cable. Initially, the water-level logger was positioned below the water table, approximately 10–20 cm above the bottom of the well. The offset between the depth of the sensor on the logger and the top of the well was measured to the nearest mm. The depth of the water-level logger in the well had to be periodically adjusted during the observation period to account for sediment accumulating in the bottom of the well and corrosion of the cable. The new offset was recorded so that water levels could be referenced to the same position. The water-level logger was submerged around 85% of the time and was always below the ground surface, a position that must be maintained for the entire observation period in order to obtain a complete record.

2.2. Data collection and processing

We set the water-level logger to a 2-minute recording interval, which, given memory constraints, required data to be downloaded once each month. During initial deployment and when data were downloaded from the logger, we collected elevation measurements on the ground surface about 1 m away from the well and at the top of the well using a Trimble RTK-GPS ($\pm$0.5 cm horizontal and $\pm$2.0 cm vertical). In addition, we determined a reference water level by measuring the distance from the top of the well to the water surface. We used these measurements to: 1) convert observed water levels to the North American Vertical Datum of 1988 (NAVD88) by referencing the well top; 2) evaluate the vertical stability of the well (our wells moved up and down an average of 4.4 ± 2.3 cm (SD) during month-long observation periods); 3) estimate overwash duration and height based on the recorded water level and the elevation of the ground surface next to the well; and 4) account for drift in the sensor using the reference water level.

Water-level logger data were processed using HOBOware Pro software. Water-level measurements from the sensor were corrected for variations in barometric pressure, which were measured simultaneously by an above-ground pressure sensor located 500 m