Hydrodynamic Controls on the Morphodynamic Evolution of Subaqueous Landforms

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Hydrodynamic Controls on the Morphodynamic Evolution of Subaqueous Landforms

A Thesis

Submitted to the Graduate Faculty of the University of New Orleans in partial fulfillment of the requirements for the degree of

Master of Science in Earth and Environmental Sciences

by

Timothy Lawrence Nelson

B.S. University of North Carolina at Chapel Hill, 2013

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Abstract

The southern Chandeleur Islands are an ideal setting to study shoal evolution given their history of submergence and re-emergence. Here, numerical models shed light on the attendant processes contributing to shoal recovery/reemergence following a destructive storm event. Simulations of a synthetic winter storm along a cross-shore profile using Xbeach shows that convergence of wave-induced sediment transport associated with repeated passage of cold-fronts initiates aggradation, but does not lead to reemergence. A Delft3d model of the entire island chain shows that as these landforms aggrade alongshore processes driven by incident wave refraction on the shoal platform, backbarrier circulation and resulting transport become increasingly important for continued aggradation and eventual emergence. Aggradation magnitudes are a function of depth ranging from 2 – 10 mm per event (onset to recovery to near mean sea level). In the absence of big storms, this modest aggradation can be more than one meter in a few years.

Keywords: sediment transport, numerical modeling, barrier islands, Delft3D, Xbeach, winter storms, subaqueous shoals, shoal recovery, shoal aggradation, Chandeleur Islands
Chapter 1

Introduction

The debate over the origins of barrier islands began with the emergence theory proposed by de Beaumont (1845). He suggested that sand bars aggrade and eventually emerge above sea level. A second theory by Gilbert (1885) advocates that barrier islands formed after spits, built by longshore transport, elongated and eventually separated from the mainland after a breaching event. A third theory proposed by McGee (1890) suggests that islands formed with the drowning of low-lying areas behind beach ridges and dunes as sea levels rose and mainlands subsided. After centuries of debate, with compelling evidence for each theory, Schwartz (1971) acknowledged that specific islands may support different theories of origin. He also noted that these three mechanisms may work together and that a combination of the theories could explain the origin of a particular island. Swift (1975) had a similar point of view, suggesting that the debate on barrier island genesis theories by observing present systems is not relevant because barriers formed well offshore at a lower sea level, and migrated to their present position through shoreface retreat. This lead to multiple regional genesis models with a focus on local conditions (Penland et al. 1988; Otvos and Giardino 2004; Simeoni et al. 2007; Otvos and Carter 2013). Penland et al.’s three stage model, for example, includes aspects of both spit detachment, and beach ridge drowning. The island itself is shaped by spit extension on both ends of a headland, but detachment from this mainland happens as a result of subsidence induced submergence following river avulsion and delta lobe abandonment.

While regional genesis models likely explain the origin of barrier island systems as a whole, there have been numerous observations of emergence of smaller barrier islands. Price (1963) observed storm induced nearshore bar development that lead to barrier island emergence with post-storm water level setdown. Since then, barrier emergence has been observed near Chesapeake Bay (Oertel and Overman 2004), North Carolina’s Outer Banks (McNinch and Wells 1999) and across the Gulf Coast (Otvos 1970, 1979, 1981, and 1984; Davis and Hine 1989; Gibbs and Davis 1991; Ritchie et al. 1992; Davis 1994; Davis et al 2003). While the necessary conditions have not been clearly defined, Otvos (1981) acknowledges that emergence requires available sand, characteristics of the hydrodynamic regime, and relatively shallow initial depths.

Otvos’ emergence requirements are met on subaqueous landforms in a variety of environments. Shallow subaqueous shoals aggrade when there is available sediment and a convergence of sediment transport. For cape-associated shoals, this occurs as the convergence of alongshore sediment transport between littoral cells on either side of the shoal (Pierce 1969, Swift et al. 1972, McNinch and Wells 1999). Ebb tidal deltas, on the other hand, experience a cross-shore convergence of sediment transport. On the seaward side of an inlet, residual tidal flow is ebb-dominant (Oertel 1988, Ridderinkhof 1988). This generates offshore directed transport that is opposed by the onshore directed transport due to wave asymmetry and residual currents. Numerical modelling suggests that residual wave currents are primarily responsible for aggradation, while wave asymmetry serves to
keep the shoal a coherent structure by opposing tidal currents (Ridderinkhof 2016). With both cape-associated shoals and ebb tidal deltas, once a shoal is established, wave refraction and shoaling around the landform will further transport convergence by focusing wave induced transport towards the shallowest locations of the shoal.

Submerged former barrier islands are a type of subaqueous shoal whose morphodynamic evolution has received little attention. Knowledge of hydrodynamic and geomorphic processes governing the evolution of these landforms is lacking, but they are expected to behave like other submerged shoals such as cape shoals and ebb tidal deltas. As with ebb tidal deltas, sediment transport due to wave asymmetry and residual currents contributes to landward migration and aggradation. Without an offshore component, it is possible that the shoals would lose their coherent structure as they migrate landward. The absence of a nearby shoreline landward of the shoal suggests that there is minimal offshore directed pressure gradient force due to wave setup against the coast. Potential offshore transport mechanisms include return flow following the passage of a storm with significant setup, or residual tidal currents if significant tidal exchange flow is present over the shoal crest. Additionally, offshore transport could potentially occur as a result of the wind and wave climate of the region. As with cape shoals, a convergence of transport across the shoal could be induced by episodic shifts in prevailing wind and wave directions. In addition to potential alongshore convergence of wave-driven transport, a convergence could also be set up by a periodic shift between onshore and offshore directed winds and waves.

One such shoal exists periodically in the ephemeral southern Chandeleur Islands. Gosier, Grand Gosier, and Curlew Islands have experienced repeated cycles of destruction and transgressed reemergence dating as far back as 1772 (Otvos 1981; Penland et al. 1985; Fearnley et al. 2009). Historic shorelines and island areas are shown in Figures 1 and 2, where a recent cycle of destruction and reemergence occurred for all four islands following Hurricanes Besty (1965) and Camille (1969). Gosier Island experienced an additional cycle of destruction and reemergence following Hurricane Fredrick in 1979 (Kahn 1986). Most recently, Hurricane Katrina (2005) reduced all three islands to submerged shoals. After several years with no major tropical storms since 2005, fair-weather processes contributed to the aggradation of the shoals, leading to their reemergence by early 2012 (Morgan 2013). This observed recovery indicates that in the absence of high intensity storms it is possible for available sand to be reworked to aggrade submerged shoals. Analysis of oblique aerial photos of the shoals during reemergence suggests that recovery occurs as a four-stage process (FitzGerald et al. 2015). In the first stage, sands reworked by breaking and shoaling waves are deposited on a shallow shoal. As the shoal aggrades, it transitions to an intertidal bar (stage 2). From here, migrating sand bars weld to the intertidal bar and it becomes an incipient barrier (stage 3). Following emergence, long-term beach accretion and dune building processes build the barrier into a robust barrier (stage 4). Figure 3 shows Curlew shoal’s transition from disorganized shoal to incipient barrier. Evidence of sand bars welding to the shoal is visible on both sides of the shoal. Figure 4 shows additional evidence of bar welding on the backbarrier side of Grand Gosier Island. Similar long, linear, widely spaced bars were observed in the shallow backbarrier on emergent cape shoal islands (Oertel and Overman 2004).
Figure 1: South Chandeleur shorelines 1855-1989 (adapted from Ritchie et al. 1992).
Figure 2: Average island area for the Grand Gosier and Curlew Islands 1869-2005 (adapted from Fearnley et al. 2009; 2014 data (0.2 km²) estimated from satellite images).

Figure 3: Satellite images of the observed bar development and emergence of Curlew Island (images courtesy, Google Earth).
A recent geophysical survey of the region indicates that despite the lack of significant sediment supply (e.g. from a fluvial source), a large volume of sand is still present in the area. Isopach maps of the barrier island lithosome indicate that $656 \times 10^6 \text{ m}^3$ of sand rich deposits are present over the 371 km$^2$ area of the southern Chandeleurs (Twichell et al. 2009). Recent seafloor change analysis of Grand Gosier Shoals shows that despite a net loss of sediment, the shoal has seen a significant increase in elevation due to reworking of immediately offshore sediment (Flocks and Terrano 2016), suggesting that available sediment is sufficient to allow reworking and reemergence.

The region’s frequent winter storms (20-40 events annual; Georgiou et al. 2005) represent one possible driver contributing to the islands observed recovery. The passage of a front causes rapid changes in wind speed, direction, barometric pressure, temperature, and humidity (Mossa and Roberts 1990). For the Chandeleurs, this means that strong southerly winds rapidly switch to northerly winds (Moeller et al. 1993; Keen 2002). The prefrontal southern winds and associated wind and wave setup, together with the low atmospheric pressure significantly elevate water levels during the passage of the front. Previous work indicates that winds are responsible for ~50% of the total setup, while waves and atmospheric pressure each account for ~25% (Li et al. 2011). As a cold front passes, wave, wind, and atmospheric pressure induced setup dies down, forcing flow offshore. This flow was suggested to be morphologically significant by Miner et al (2009) and was measured and found to be morphologically significant for the northern Chandeleur Islands (Sherwood et al. 2014). This setdown is also accompanied by a shift in

Figure 4: Oblique aerial photograph of Grand Gosier island after emergence showing evidence of bar welding (Morgan 2016).
wind directions to offshore (Li et al. 2011). Figure 5 shows this trend in wind and water levels in the nearby Atchafalaya-Vermilion Bays.

Figure 5: Wind vectors, observed water levels, and flux during the passage of a cold front for several locations in Atchafalaya-Vermilion Bays. (from Feng 2009).

A balance between onshore prefrontal and offshore postfrontal conditions could set up a convergence of sediment transport over the shoal. This would be analogous to the balance between onshore directed transport due to waves and offshore directed transport due to residual tidal currents responsible for the aggradation and migration of ebb tidal deltas (Ridderinkhof 2016). Additionally, offshore directed transport associated with postfrontal setdown could induce seaward transport over the shoal. Despite their comparatively low intensity, winter storms are still significant drivers of morphodynamic change along the Chandeleurs. The region experiences at least 20-40 cold fronts per year on a 3 to 7 day cycle (Roberts et al. 1989; Chaney 1998; Georgiou et al. 2005). Because of this high frequency, it has been suggested that they can potentially cause more erosion than tropical storms (Mossa and Roberts 1990). Winter storms have proven to be important in regulating estuarine salinity gradients (Schindler 2010) and have been responsible for saltwater intrusion events because of significant sub-tidal water level variations (Feng and Li 2010; Li et al. 2011). Regional models suggest that they are important in reworking or re-shaping backbarrier and lagoon sediments (Georgiou and Schindler 2009, Pepper and Stone 2004, Stone et al. 2004). Locally, smaller storms can supply sand and promote dune and berm aggradation on barrier islands (Stone et al. 2004). Storms have the potential to promote constructive or destructive reworking based on the size of the storm and orientation of the barrier. Elsewhere in the Gulf, they are responsible for driving accretion on the Chenier Plain (Roberts et al. 1989) and on barrier islands in Texas (Price 1963; Davis and Fox 1975).
Figure 6 presents a conceptual diagram of a potential recovery and reemergence mechanism for an ephemeral barrier shoal. Following a major storm, the island is reduced to a subaqueous shoal (Figure 6, top). At these depths, alongshore transport processes are relatively dormant. Cross-shore processes associated with the frequent, cyclic convergence of onshore and offshore directed transport due to cold front passage initiate constructive shoal reworking. As these processes aggrade the shoal to shallower depths, the littoral zone becomes more active and alongshore processes become more important (Figure 6, middle). Constructive reworking accelerates due to increased convergence of transport from longshore transport and refractive focusing of wave energy over the shoal. With continued aggradation, the shoal emerges as an incipient barrier island (Figure 6, bottom). Bar welding and eventual dune building drive beach accretion on this barrier as it transitions to a robust barrier.
Figure 6: Conceptual model for the reemergence of an ephemeral barrier island following hurricane-induced reduction to subaqueous levels.
Recent advances in computer modeling coupled with increased computational capability could potentially shed light on the governing processes contributing to this recovery. A coupled hydrodynamic and morphodynamic numerical model, eXtreme Beach behavior (Xbeach), is capable of modeling nearshore processes on relatively short spatial and temporal scales (Roelvink et al. 2009), allowing for the exploration of controls governing the evolution of these landforms. Xbeach determines morphological change based on the sediment mass conservation equation, wave- and flow-driven sediment transport parameterizations, wave energy conservation, and momentum conservation. Waves are modeled using a short-wave averaged, wave-group resolving module. This phase resolving approach allows for modelling of complex surf and swash zone sediment transport using the Soulsby-Van Rijn equations (Soulsby 1997). Xbeach is capable of running two-dimensional vertically averaged (2D) and/or two-dimensional horizontally averaged (2DH) models. Typically, however, 1D transect models are still widely used because of their substantially lower computational requirements. This allows users to model significantly longer events in shorter amounts of time while maintaining most relevant nearshore wave processes and resulting morphology (Roelvink et al. 2009).

Previous 1D applications of Xbeach have shown success in prediction of erosion despite their inability to consider alongshore variability (van Santen et al. 2012; Pender and Karunaratna 2013; Karanci et al. 2014). One dimensional applications of Xbeach lose the ability to account for alongshore variability in transport, including differences from wave run-up to do wave directional spreading, and alongshore convergence due to depth induced shoaling around the shoal. Despite these limitations one can gain extensive insight into governing processes contributing to shoal aggradation.

A separate model can be utilized to determine the role of alongshore processes over longer time scales. Delft3d (Lesser et al. 2004) is a coupled hydrodynamic and morphodynamic model capable of modeling waves, flow, sediment transport, and bed evolution. Waves are modeled using the phase averaged spectral wave module, Simulating WAVes Nearhsore (SWAN; Booji et al. 1999; Holthuijsen 2007). This module considers shoaling, refraction, energy dissipation, wave-wave interactions, and wave-current interactions. The module considers energy losses due to depth-induced breaking (Battjes and Jannssen 1978), bottom friction (Hasselmann et al. 1973), and whitecapping (Komen et al. 1984). The flow module calculates currents based on the unsteady depth-averaged shallow water equations. Sediment transport for bed load and suspended sediment is computed using the van Rijn (1993,2007) equations. Because it resolves waves spectrally, it is possible to model morphologic change over larger spatial and temporal extents than Xbeach. Unlike a 1D application of Xbeach, a 2D Delft3d model could account for alongshore processes such as wave refraction, backbarrier circulation, and resulting longshore transport. It does, however, lack Xbeach’s ability to model nearshore processes. Delft3d has been used extensively to model morphological evolution and has been used locally to model hurricane induced change on North Chandeleur Island (Plant et al. 2011). It has also been used to model morphology of submerged sand bodies including estuarine channel shoals (Hibma 2004), cape associated shoals (Kline et al. 2013) and tidal deltas (Tung et al. 2009; Nienhius et al. 2016; Pluis 2016; Ridderinkhoff et al. 2016). It has not yet been applied to barrier shoals.
**Objective**

The key objective of this study is to use numerical models along with available wave, water level, and bathymetric data of a submerged shoal to investigate the role of storms, tidal, and subtidal water level variations in the morphodynamic evolution of subaqueous landforms, as observed in the reemergence and recovery of the southern Chandeleur Islands following Hurricanes Betsy and Camille (1960s), and more recently Hurricanes Ivan (2004) and Katrina (2005).

**Key Hypothesis**

We hypothesize that shoal aggradation, subsequent recovery and eventual reemergence are linked to constructive rather than destructive processes. We also hypothesize that constructive processes leading to net aggradation and reemergence are initially driven by primarily storm-induced cross-shore transport processes (when the shoal crest is low without an active littoral zone), but subsequently longshore transport can be a key factor for the continued aggradation and re-emergence as the shoal aggrades to shallower depths. Finally, we hypothesize that onshore transport alone cannot be a continuously constructive process without the additional reworking from offshore directed transport (e.g. during post-frontal conditions) aided further by tidal and sub-tidal water level variations.

H1: Cross-shore transport processes during winter storms are the chief agent of subaqueous shoal recovery following destruction caused by a large hurricane. Shoal aggradation, leading to the reemergence or near reemergence, is driven by frequent and cyclic mild to intermediate storm activity (e.g. winter storms).

We will use modeling to subject a bathymetric profile (extracted across a subaqueous shoal following hurricane Katrina) to winter storm activity over the duration of the event while incorporating both onshore and offshore transport pathways. We will repeat the storm impact over many events (20-30) to represent annual forcing.

H2: Both onshore and offshore transport processes must be present to facilitate aggradation, driven by combined effects of waves, tidal and subtidal water level variations associated with winter storm activity.

H3: At near-emergence, cross shore transport processes alone cannot promote continued aggradation.

H4: After cross-shore processes initiate aggradation, continued aggradation may occur due to longshore processes.

We will examine the role of longshore transport as a key driver of continued shoal aggradation when shoals approach shallow depths and the relative contribution from other nearshore processes aiding to alongshore transport.
**Research Questions**

Key research questions to supplement the hypotheses include the following:

(1) Can the passage of moderate-energy winter storms induce aggradation of a subaqueous shoal

(2) What is the effect of post-frontal reworking (winds, waves, and subtidal variations) on shoal aggradation, migration, and coherency

(3) How does this aggradation rate change as depth decreases

(4) To what extent do sub-tidal water level variations influence shoal aggradation

(5) To what extent do longshore transport processes influence aggradation

(6) Can these processes account for aggradation above fair weather mean sea level

**Regional Study Area**

The Chandeleur Islands of southeastern Louisiana began development following the abandonment of the Mississippi River’s St. Bernard Delta Complex about 2,000 BP (Frazier 1967; Penland et al. 1988; Tornqvist et al 1996; Otvos and Giardino 2004). The deltaic headlands evolved into barrier islands following the conceptual model of Penland et al. (1988). In the absence of a sediment supply, headlands were reworked by marine processes into elongated spits. As the mainland subsided in the absence of a supply of sediment, these spits detached to form barrier islands. With continued subsidence and sea level rise, these islands migrated landward to their current position 5-15km west of the original delta coast (Frazier 1967).

The Chandeleurs are a physically and ecologically important feature for southeast Louisiana. They serve to regulate salinity for Breton sound (Reyes et al. 2005; Schindler 2010). They provide a unique habitat for several threatened and endangered species (Poirrier et al. 2007), and serve as nesting grounds, nurseries, and spawning grounds (Reyes et al. 2005; van Heerden and DeRouen 1997). The chain also serves as the first line of defense for wetlands and the mainland against tropical storms (Stone and McBride, 1998; Stone et al. 2005). Numerical modeling suggests these islands significantly reduce wave heights in Breton Sound and lessen storm surge (Wamsley et al. 2009; Grzegorzewski et al. 2011). During an experiment where the islands were degraded, wave heights during tropical storms appear to increase by up to 50%, while in a scenario where the islands were restored to a high dune elevation, wave heights decreased by up to 90% and peak storm surge lagged by 1-2 hours (Grzegorzewski et al. 2009). This response alone suggests that the islands will become increasingly important as sea level continues to rise and tropical storms become more frequent and severe (Goldenberg et al. 2001; Emanuel 2005; Marm et al. 2006; Knutseon et al. 2010).
A recent period (1996-2005) of concentrated tropical storms accelerated island subaerial land erosion (Fearnley et al. 2009). Since then, the islands have seen limited recovery, despite the fact that there have been relatively few intense storms. Seafloor change analysis revealed a net loss of sand from the entire system (Miner et al. 2009; Georgiou et al. 2009, Flocks and Terrano 2016). This sand deficit, along with the islands recent inability to migrate landward due to expansive seagrass beds and backbarrier marsh (Fearnley et al. 2009) suggests that the system is approaching a transition to inner-shelf shoal. If fact, Fearnley et al. (2009) suggested if the trend continued the islands would lose their subaerial footprint by 2013, a result that was corroborated further by Moore et al. (2014) using a morphological behavior model, who reported that the islands have less than 10% of their lifetime remaining. Even Fearnley et al. (2009) however, noted that under quiescent (storm) conditions, the islands would maintain subaerial exposure through 2039.

Response and recovery from storm events has been highly variable across the island chain (Penland et al. 1988, Fearnley et al. 2009). In the southern section, Breton, Grand Gosier, and Curlew Islands have proven to be a more dynamic and geomorphically complex subsystem. In addition to their cycles of destruction and reemergence, they have seen significantly more erosion and landward migration compared to the northern section of the island. Collectively, the southern islands lost $4.0514 \times 10^6$ m$^3$ of sediment and up to 8.89m of elevation from 1870 to 2004, with shoreline retreat rates as high as 17m/yr (Miner et al. 2009).

As transgressive barriers, the key factors driving shoreline evolution in the Chandeleurs are the supply of sediment, the rate of sea level rise, and the frequency and intensity of storms (Georgiou et al. 2005; Georgiou et al. 2010). The islands are impacted by both frequent winter storms, and less frequent but more severe tropical storms. The only modern supply of sand to the system comes from reworking of the underlying St. Bernard distributary deposits through shoreface retreat (Miner et al. 2009). This includes fine sands from the muddy prodelta, delta front, and lagoonal deposits, channel fill, and relict strand plain deposits (Otvos 1981; Rogers et al. 2009; Miner et al. 2009). As the islands migrate onshore, these deposits are reworked from the retreating shoreface, releasing sand that is brought onshore via cross-shore transport mechanisms. This supply of sand however, is insufficient to match the volume of sand lost to storms and longshore transport and a net loss of sand has been estimated at 2.3-6 m$^3$/m/yr (Moore et al. 2014). Recent morphodynamic models show that a sufficient sediment supply from the shoreface is required to prevent an island from drowning (Lorenzo-Trueba and Ashton 2014), suggesting that degradation will continue for this system. Miner et a. (2009) also reported that sand is lost laterally to the island flanks due to the presence of a bi-directional longshore transport (Ellis and Stone, 2006; Georgiou and Schindler, 2009). This sand, and sand that is lost to deepwater sinks during storms cannot be reworked back into the littoral system under fair-weather conditions (Georgiou and Schindler 2009).

The Mississippi River Delta Plain (MRDF) and the Chandeleur Island chain also experiences regional and local subsidence due to compaction of deltaic sediments (Penland and Ramsey 1990), tectonics (Dokka et al 2006), and oil and gas extraction (Morton et al. 2002). Estimates for the region range from 1.7 mm/yr (Zervas 2001) to 10 mm/yr.
(Penland and Ramsey 1990). More recent estimates of 4.3mm/yr (Twichell et al. 2013) and 6.4 mm/yr (Moore 2014) fall somewhere between the two.

Tropical storms are the primary driver of geomorphic change for the islands. It has been estimated that hurricanes are responsible for up to 90% of shoreline retreat in Louisiana (Kahn 1986). The Chandeleurs have been impacted by about 42 hurricanes since the early 1900s (Fearnley et al. 2009), and previous work has shown that these storms are responsible for a large percentage of annual sediment transport (Hayes 1967; Ellis and Stone 2006; Georgiou and Schindler 2009). Numerical modeling indicates that storm induced transport is over 2 orders of magnitude greater than transport during calmer periods (Grzegorzewski and Georgiou 2011), and evidence of this process was reported following the passage of Hurricane Katrina, where the barrier chain lost 86% of their subaerial exposure (Sallenger et al. 2009).

The island system has been extensively studied. Previous work has focused on geomorphic response (Penland et al. 1988), historic shoreline change (Penland et al. 1988; McBride et al 1992; Jaffe et al. 1997; Penland et al. 2005, Miner et al. 2009, Martinez et al. 2009; Terrano et al. 2016), framework geology (Penland et al. 1988; Twichell et al. 2009), storm erosion and recovery (Kahn and Roberts 1982; Kahn 1986; Fearnley et al. 2009; Sallenger et al. 2009; Lindermer et al. 2010; Sherwood et al. 2014), ecology (Poirrier and Handley 2007; O’Connell et al. 2009), longshore transport (Georgiou et al. 2005; Ellis and Stone 2006; Georgiou and Schindler 2009; Miner et al. 2009; Miselis et al. 2015), sand resources (Twichell et al. 2009), and morphological behavior (Moore et al. 2014). Quantified, physics-based process modeling is limited and has not been applied to the more dynamic southern islands (Ellis and Stone 2006; Georgiou and Schindler 2009; Lindermer et al. 2010; Grzegorzewski and Georgiou 2011, Sherwood et al. 2014). Xbeach and Delft3d have been used to model the short-term destructive effects of storms in the area (Lindemer et al. 2010; Plant et al. 2011; Sherwood et al. 2014), but have yet to be used to simulate aggradation caused by multiple fair weather and moderate energy events.
Chapter 2

Xbeach Methods

Initial Conditions

To test the cross-shore component of our hypotheses, we used Xbeach to model sediment transport over the shoal and resulting aggradation in the southern Chandeleurs using available bathymetric and sediment data. We drove the model with time-varying water levels, and synthetic time-dependent wave data derived from a combination of observations and model derived data meant to represent a typical cold front passage.

A 9.6km bathymetric transect of Curlew Shoal was obtained from a DEM of the Chandeleur Islands with a 3m resolution (Miner et al., 2009; Twitchel et al. 2009). This transect spans from the 10m isobath seaward of the shoal to the 5m isobath landward of the shoal (Figure 7). The model resolution along the transect was ~20m, except over the shoal, where a finer resolution of ~3m was utilized where water depths are less than 2m.

![Figure 7: Shoal transect used for Xbeach simulations (Sea is left, backbarrier is right).](image)

Sediment characteristics for the model were determined from data from Louisiana’s Barrier Island Comprehensive Monitoring (BICM) program (Kindinger et al. 2013). Data from 5 sediment samples taken near the transect during the summer of 2008 were averaged to determine D$_{50}$ and D$_{90}$ values of 153 and 221 μm. Porosity was assumed to be 0.4 and sediment density was assumed to be 2,650 kg/m$^3$. We assume no mud content along the profile, consistent with results of Twitchell et al. (2009) and sediment samples in Kindinger et al (2013). Although offshore areas do have finer sands and perhaps some mud
present, the assumption of sandy substrate is appropriate, as Twitchel et al. (2009; 2013) showed that the sandy isopach thickness extends along the entire subaqueous shoal.

**Model Setup and Forcing**

Wave conditions were supplied to Xbeach as a table of time dependent conditions. The wave boundary condition parameter “instat = 41” allows the user to input wave conditions by supplying a time series of significant wave height, representative period, mean wave direction, peak enhancement factor and spreading coefficient (representing directional spreading of wave energy). A peak enhancement factor of 1 and spreading coefficient of 20 (degrees) were assumed. Time dependent wind inputs were not possible in this scenario since the model is used in 1D. Waves were applied to weakly reflective 1D boundaries at the ends of the transect, while the lateral boundaries were set as a no gradient (Neumann) boundary also known as zero flux boundary with respect to sediment transport – ie no alongshore flux.

The default 1D configuration of XBeach version 1.21.3667 was used for this model application. Infragravity waves were modeled using phase resolving, non-linear shallow water equations. Short wave propagation was modeled with a spectral wave model, and sediment transport was calculated with the Thiel-Van Rijn formulation (Van Rijn 1984). The vegetation, quasi 3d effects, ships, short-wave runup, groundwater, non-hydrostatic flow, and bed level time series functions were not used in this model.

**Simulations**

We modeled the potential for shoal aggradation by running repeated cycles of onshore and offshore conditions to simulate the passage of multiple cold fronts. The simulated frontal passage is shown in figure 8. Onshore events were forced from the seaward end of the transect, while offshore conditions were applied to the seaward end of the transect. The 5 day onshore event begins with 1m waves that gradually ramp up to 4m waves over the course of 3 days. Over the next 2 days, the waves gradually ramp back down to 1m. After running an onshore winter storm event, a 2 day representative offshore condition was applied to the bay side of the transect to simulate postfrontal conditions. Offshore conditions were determined with the Amry Corps of Engineer’s shore protection manual using available wind data, lagoonal depths, and fetch distance. Waves remain constant at 1m while water levels drop 1m to simulate post-frontal setdown. Sequences of storm and offshore conditions were repeated up to 40 times to simulate the passage of a year’s worth of cold front passages.
Figure 8: Wave height and water level for the passage of the simulated cold front. The solid black line represents a shift from offshore to onshore directed waves.

A set of model runs was performed to determine the ideal morphodynamic upscaling coefficient (morfac) setting for the models. Morphologically upscaling is a method to increase modeled timescales for sediment transport by increasing bed level changes from each hydrodynamic time step by an acceleration factor (Lesser et al. 2004). Morphodynamically upscaling the model significantly reduces the computational time for each run, and can increase the total length of time simulated. 10 cycles of storm and offshore events were applied to a profile with morfac values of 1, 2, 4, and 10.

To test the hypothesis that at near-emergence, cross-shore transport processes alone cannot promote continued aggradation, we artificially raised the profile by 1m and subjected it to the same conditions. We used the output profile from the 10th run to ensure that the profile had adjusted to these storm conditions before being raised.

Two additional sets of Xbeach simulations were performed to determine the role of tidal water level variations in driving morphological change over the shoal. A 6-day time series of water level data from NOAA tide station 8760721 (Pilottown, LA) was added to onshore events. The record spans from 1/22/17 to 1/28/17 and includes a 0.41m spring tide. This time series was applied so that the peak storm coincided with both high tide and low tide. Both simulations were subjected to 5 cold front events. Final shoal crest elevations were compared to investigate the impact of tides on shoal reworking.

An additional set of Xbeach simulations was performed to determine the importance of offshore events in reorganizing the shoal after the storm. In addition to limiting landward migration, it is possible offshore event induced reworking of the shoal allows for increased aggradation during onshore events. Georgiou and Schindler (2009) reported significant surf-dissipation in the backbarrier resulting from post-frontal offshore directed winter storms and evidence of backbarrier morphologies reflecting this process such as
linear berms. To investigate this possibility, the same transect was subjected to 10 onshore events without offshore events.

**Delft3d Methods**

**Initial Conditions**

A second model (Delft3d) was used to determine the role of alongshore processes and their contribution to shoal aggradation, and to observe how this role changes as the shoal rises. The model was driven with observed winds, waves, and water level data for a one month period to model winter storm induced morphologic change. The data were collected by the University of New Orleans (UNO) Pontchartrain Institute for Environmental Sciences (PIES). The observed record was modified to develop four base scenarios and two “residuals scenarios” of varying water level and wave magnitudes to simulate change on the initial shoal bathymetry, and subsequently assess change on the same profile but with bathymetry raised by 0.5m and 1m, producing 32 simulations.

The model utilized 110km by 50km grid as the model domain of the entire Chandeleur chain. Alongshore resolution is 500m across the domain. In the cross-shore direction, grid resolution is 500m offshore and in the backbarrier; and ~167m in the vicinity of the islands and shoals. Wave and water level conditions are supplied to the offshore boundary as a time series. Time-dependent spatially constant winds are applied across the domain. Bathymetry (Figures 9 and 10) was derived from the same DEM used for Xbeach simulations (Miner et al., 2009 and Twitchel et al. 2009). Sediment characteristics were the same as those used in the Xbeach model (Kidinger et al., 2013).
Figure 9: Delft3d model domain and initial bed level. The area between the horizontal black lines represents the region with a finer cross-shore grid resolution. The dashed box shows the section of southern shoals shown in Figure 10.
Figure 10: Initial bed level in the vicinity of the southern shoals.
Model Setup and Forcing

The default configuration of Delft3d version 4.02.03 was used for these simulations. The SWAN module utilized 3rd generation mode for physics. Depth-induced breaking based on the Battjes and Jannsen model. Spectral wave shape at the boundary followed a JONSWAP formulation using a peak enhancement factor of 3.3, with a directional spreading of 20 degrees was utilized. Bottom friction was determined using a JONSWAP formulation with a coefficient of 0.067m^2/s^3. Wind growth, whitecapping, refraction, and frequency shift processes were active. Non-linear triad interactions and wave diffraction were not considered. Accuracy criteria were set to require convergence over 95% percentage of wet grid points with relative change of 0.02m. For the flow module, bottom roughness calculations utilized a uniform Chezy formulation and a constant value of 67 was used representing sandy bottom. A 720 minute spin-up interval was employed to gradually bring the model to dynamic equilibrium before applying any morphological changes on the bed. Salinity, temperature, pollutant, secondary flow, dredging processes were not utilized.

Simulations

Wave and wind conditions were based on hourly measurements of wave height, wave period, wave direction, wind speed, and wind direction from NOAA buoy 42040. Hourly water levels were determined from local data collected by the University of New Orleans (UNO Pontchartrain Institute for Environmental Sciences (PIES). Subtidal and tidal water level signatures were separated using a low pass filter of a moving average. Data for this one-month period (12/17/10 to 1/17/11) is shown in Figure 11.

![Figure 11: Unaltered wave (top), wind (middle), and water level (bottom) data for Delft3d modeling of the period of 12/17/10 to 1/17/11.](image-url)
To test the hypothesis that the effects of waves, tidal water level variations, and subtidal water level variations facilitate shoal aggradation during the passage of a winter storm, the Delft3d model considered four different wave and water level scenarios (Figure 12), and two additional scenarios meant to determine sediment transport due to waves and water level variations. The first, “as is” scenario used unaltered wave and water level data for the period of interest. The second scenario was meant to determine the relative contribution of setup. Here, we used the same data as scenario 1, but wave heights were reduced by 50%, and all subtidal water level variations, except the surge associated with the peak storm, were removed. The third scenario was meant to determine the role of peak storm conditions. It used the same data as scenario 1, however, the waves and water levels associated with the strongest storm were removed. The fourth scenario was meant to investigate the role of tides. Wave heights were reduced by 50% and all subtidal water level variations were removed.
Figure 12: Altered wave and water level conditions for the four base scenarios considered in Delft3d.
To test the hypothesis that after cross-shore processes initiate aggradation, and that continued aggradation occurs due to longshore processes, each scenario was run with original and elevated bed levels. To make results comparable, this was achieved by lowering water levels rather than raising bed levels (Figure 13). Each scenario was run with original bed levels, bed levels elevated 0.5m (water levels lowered by 0.5m), and bed levels elevated 1m (water levels lowered by 1m). Additionally, each scenario was run with morfac values of 1 and 20 to determine the short and long-term effect resulting from these conditions.

![Cross-shore Distance (m)](image)

**Figure 13:** Illustration of bed raising technique for a cross-shore profile of the shallowest location of Curlew Shoal. Water levels are lowered to decrease shoal depths and simulate a raised profile. Vertical distance represents depth for the unraised scenario.

Eight additional simulations were selected to distinguish between wave induced transport and transport due to residual tidal and subtidal currents. A set of simulations with no water level forcing was run at initial and 1m raised bed levels with morfac values of 1 and 20 to determine wave induced transport. A second set of simulations was run without the waves module to determine transport due to water level induced flow and circulation alone. A summary of all model runs is presented in table 1.
<table>
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<th>Run Number</th>
<th>Water Levels</th>
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<th>Morfac</th>
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<td>Unaltered (Fig 9)</td>
<td>Unaltered (Fig 7)</td>
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<td>Unaltered (Fig 9)</td>
<td>Unaltered (Fig 7)</td>
<td>20</td>
</tr>
<tr>
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<td>Unaltered (Fig 9)</td>
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</tbody>
</table>

Table 1: Summary of wave and water level conditions used to force all 32 runs in Delft3d.
Chapter 3

Xbeach Results

Ideal Morfac Setting

Figure 14 shows the evolution of the crest of a shoal as it is subjected to 10 cycles of repeated sequences of onshore and offshore conditions using morfac values of 1, 2, 4, and 10. Values of 1, 2, and 4 yield comparable results. The crest aggrades and widens following each storm event. Offshore events widen and rework the shoals. Aggradation or degradation during storm events is on the order of millimeters. This results in a general trend of steady aggradation. This behavior is not seen with the highest morfac. Offshore events cause excessive degradation, and ultimately, a seaward translation is observed. The excessive degradation during offshore events also causes significant shoal crest lowering. This results in an unnatural shift back and forth between profiles following onshore events and profiles following offshore events. A morfac value of 4 was chosen for future runs in order to decrease computation time while continuing to produce realistic results.

Figure 14: Evolution of the crest of a shoal subjected to repeated storm and offshore events with morfac values of 1, 2, 4, and 10.
<table>
<thead>
<tr>
<th>Morfac</th>
<th>Translation (m)</th>
<th>Aggradation (mm)</th>
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<td>1</td>
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<td>32.97</td>
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<tr>
<td>10</td>
<td>-22.57</td>
<td>4.67</td>
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</table>

Table 2: Total translation and aggradation at the end of the 10th set of runs with morfac values of 1, 2, 4, and 10.

**Extended Simulation**

Figure 15 shows the evolution of the crest of a shoal as it is subjected to 40 cycles of repeated sequences of onshore and offshore conditions. Aggradation and translation rates from an extended run (40 cycles) are plotted in Figure 16. The shoal experiences a general trend of net aggradation and landward translation. Aggradation is observed following each onshore event. After the first onshore event, storm induced aggradation is ~3.5mm per event. This rate slowly increases to just less than 5mm per event. Degradation from offshore events weakens until the 20th cycle, and then strengthens until the 40th cycle. The resulting total aggradation rate reaches its peak around the 25th cycle, and declines until the 40th. Onshore event induced landward translation increases with subsequent cycles; however, seaward translation during offshore increases faster. This causes a net decrease in landward translation rates over the complete set of runs.

![Figure 15: Shoal crest evolution for a transect subjected to 40 cycles of onshore and offshore events (Sea is left, backbarrier lagoon is right).](image-url)
Figure 16: Aggradation and translation trends for a transect subjected to 40 cycles of onshore and offshore events.
Raised Shoal

After 10 cycles of onshore and offshore runs, the final profile was raised 1m and subjected to the same conditions to determine if aggradation would continue in a shallower environment. Results suggest that storms of that magnitude would have a destructive impact on the shoal (Figure 17). The shoal crest lowers 43.6mm over the course of 7 sets of events. Landward translation continues, and the shoal widens. Offshore conditions cause minimal degradation, and do not change the location of the crest.

Figure 17: Transect evolution after raising bed levels by 1m following repeated cycles of onshore (ns) and offshore (no) events.

Tides

Data for model runs utilizing a spring tide water level time series is summarized in table 3. After 5 sets of onshore and offshore events, simulations where storm peak conditions coincided with high tide experienced 4.49mm less aggradation and 53.56m more landward migration than scenarios without tides. Scenarios where peak storm conditions coincided with low tides experienced 2.01mm more aggradation and 5.7m more landward migration.
<table>
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<th>Change in Translation (m)</th>
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<td>Low tide at storm peak</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td>2.01</td>
</tr>
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<td>0.20</td>
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<tr>
<td><strong>Offshore Average</strong></td>
<td>-0.38</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>Net Average</strong></td>
<td>-0.45</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 3: Change in aggradation and translation rates for scenarios where the storm peak coincides with high tide and low tide.

**Offshore Events**

Results indicate that the inclusion of offshore events in simulations serves to increase net aggradation (Figure 18). After 10 runs, the onshore-only transect was wider, shorter, and farther landward than the profile subjected to storm and offshore conditions. Net aggradation for the 10 runs was 15% (4.9mm) less than the 32.9mm observed with offshore events included. Landward translation was 25.4m more.

**Delft3d Results**

**Sediment Transport**

Significant sediment transport occurs along the island chain over the course of the Delft3d simulation. Mean total transport magnitudes appear to be a function of depth, and are highest at the shallowest locations (Figure 19). The highest magnitudes of transport are observed along of Chandeleur Island, but significant transport also occurs near Breton Island as well as Curlew, Grand Gosier, and Gosier Shoals. Transport near these southern shoals increases with both shoal size and proximity to Chandeleur Island. Curlew experiences the most transport, followed by Grand Gosier, and then Gosier Shoals. As the profile is raised, transport magnitudes decrease near Chandeleur Island and increase near the southern shoals. Higher morfac runs experience decreased transport near Chandeleur Island and the southern shoals.
Figure 19: Mean total transport magnitudes for the entire island chain for initial and raised bed levels. Previous work suggests that a seasonally fluctuating nodal point in sediment transport direction exists near the middle of Chandeleur Island (Ellis and Stone, 2006; Georgiou and Schindler, 2009). During the cold front season, this point shifts slightly north of the center of the island. Our results confirm the existence of this point, and, as expected for a winter storm, place it near the cold front season location. Figure 18 shows normalized mean sediment transport for the entire chain.
North of the nodal point the dominant longshore transport direction is north, while sediment south of the nodal point moves south.

A previous energy balance for the system determined that energy input into the sound is strongest to the north of the chain. The southern end experienced equal energy gain and loss, while inlets experienced energy loss (Hart and Murray 1978). Our storm produces this same general flow pattern, and it is evident in plots of mean total transport vectors along the chain (Figure 20). There is a noticeable flood dominant transport over the spit platform to the north of Chandeleur Island. Over most of the southern shoals, transport is generally cross-shore balanced and primarily southward. Transport is ebb dominant in southern inlets. Additionally, since water is predominantly entering the basin to the north of the chain and exiting to the south, there is consistent southward transport behind the barrier.

Figure 20: Normalized mean total transport vectors showing divergence of longshore transport opposite nodal point (blue line) for the unraised base-case scenario.
These sediment transport patterns due to longshore transport and backbarrier circulation induce significant sedimentation and erosion for the southern shoals. Results are presented in figures 21-23. Higher morfac runs exhibit similar sedimentation and erosion patterns; however, the magnitudes of both sedimentation and erosion are amplified. Curlew Shoal exhibits patterns typical of landward migration. The seaward sides of the shallowest depths of the shoal experience erosion, while the central and landward sides experience sedimentation. Gosier and Grand Gosier experience patterns typical of spit growth and elongation. The center of each shoal experiences erosion, while the northern and southern edges experience aggradation. Raising bed levels increases magnitudes and changes sedimentation and erosion patterns for Curlew Shoal. Raised scenarios experience increased landward migration. Raising bed levels for Gosier and Grand Gosier Shoals increases magnitudes of change, but does not appear to have a significant impact on sedimentation and erosion patterns. All scenarios experience erosion in inlets and deposition in ebb tidal deltas. Scenario 1 has the largest spatial extent of erosion and the smallest magnitudes of sedimentation. Scenario 3 has the largest magnitudes of both sedimentation and erosion.
Figure 21: Sedimentation and erosion patterns for the unaltered scenario at initial and raised bed levels.
Figure 22: Sedimentation and erosion patterns for each of the four base scenarios with unraised bed levels.
Figure 23: Sedimentation and erosion patterns for each of the four base scenarios with bed levels raised by 1m.
**Shoal Aggradation**

Since aggradation and degradation also depend on initial depths, plan views of sedimentation and erosion do not accurately depict aggradation or degradation of the shoal. Shoal aggradation can be masked by shoal widening and landward migration of the entire shoal. Figures 24 and 25 depict aggradation and degradation of the shoal crest using an alongshore transect of the shoal crest elevation from south to north. Aggradation and degradation trends indicate southern movement of sediment along the chain. This is evident in the downdrift movement of shoals and inlets, in agreement with previous observations of sediment transport in this region (Georgiou and Schindler 2009), and is also apparent in our mean total sediment transport results. Slight degradation is seen along most of the transect; Gosier experiences significant destructive reworking, and shoal crests lower approximately 1m in every scenario. Grand Gosier experiences slight aggradation in morfac 1 simulations, and degradation in morfac 20 simulations. This degradation weakens as the transect is raised. Curlew Shoal, on the other hand, experiences significant aggradation in raised scenarios. Unraised scenarios experience minimal aggradation or degradation. Scenario 1 experiences slight degradation, while scenarios 2-4 experience slight aggradation. As the bathymetry is raised, aggradation increases, and the differences between scenarios becomes more apparent. Scenario 4 experiences the most aggradation, while scenario 1 experiences the least.
Figure 24: Alongshore crest elevations for unraised and raised base scenario simulations using morfac values of 1 (left) and 20 (right). The top plot shows results for all unraised and raised scenarios with bed levels normalized to the unraised state. The lower plots show initial and final shoal depth for each initial bed level. The transect starts near the MRGO channel (left) and extends to north of Curlew Shoal (right). “GG” represents Grand Gosier and “G” represents Gosier. Scenarios are named $xyp$, where $x$ is the base scenario, and $y$ is the amount that bed levels have been raised.
Figure 25: Alongshore crest elevations for unraised (top) and raised scenarios 1-4 using morfac values of 1 (left) and 20 (right). Mean sea level is plotted as a horizontal blue line. The transect starts near the MRGO channel (left) and extends to north of Curlew Shoal (right). Results from raised scenarios have been normalized to initial bed levels. Scenarios are named $x_y$, where $x$ is the base scenario, and $y$ is the amount that bed levels have been raised.
Chapter 4

Discussion

Cross-shore Processes

The lack of aggradation in unraised Delft3d scenarios suggests that immediately following a large hurricane event, these shoals are unable to aggrade by alongshore processes alone. All four scenarios with morfac values of both 1 and 20 exhibit either destructive or negligible reworking of the shoals (Figure 25). Low sediment transport volumes suggest a relatively inactive littoral zone (Figure 19). Xbeach runs, on the other hand, show potential for constructive reworking and aggradation through cross-shore processes, likely because the phase resolving waves better represent nearshore processes. As the profile is subjected to repeated simulated cold front passages, available sand is reworked onto the crest of the shoal, and the shoal migrates landward. Over the course of 40 events, the profile experienced an average of 3.24mm of net aggradation per cold front passage. Net aggradation steadily increased to a maximum of 3.71mm per event on the 22\textsuperscript{nd} event. For events 22-40, net aggradation steadily decreased, indicating that the profile crossed a threshold where reworking became less and less constructive. This suggests that eventually there may be a point where this storm induces destructive reworking of the shoal. During this period, the aggradational contribution from onshore events continues to increase; however, rapidly increasing degradation associated with post-frontal, offshore events results in this observed decrease in net aggradation rates (Figure 16). Water level data used in Delft3d runs indicates that subtidal water level variations are about half of our initial estimate. It is possible that aggradation could continue to accelerate if these runs were repeated with a more realistic setdown of 0.5m.

If the seabed profile were to continue to aggrade at the average rate of 3.24mm per event, it would take over 15 years with 30 cold fronts per year for this shoal to aggrade above mean sea level. In reality, the intensity and duration of cold front passages would vary, so this is a rough estimate. Additionally, if the trend in decreasing aggradation rates continues, emergence forced solely by cross-shore processes would take even longer, or not occur at all, making the 15 year window a best case scenario. The observed reemergence of these shoals took approximately 7 years; suggesting that additional processes become important as the profile rises, and that these additional processes accelerate aggradation. This hypothesis is strengthened by the fact that aggradation does not continue when the profile is raised 1m. The same storm becomes destructive, whereby shoal crest elevation lowers, and landward migration accelerates, hindering overall aggradation. While this technique does not consider changes in shoal geometry as the shoal rises, this was a necessary simplification as it is not computationally feasible to run enough simulations to aggrade to near emergence.

Tidal water level variations showed potential for both constructive and destructive reworking. Aggradation potential depended on the phase relationship between tides and the peak of the storm. While both scenarios still experienced aggradation, simulations
where high tide coincided with peak storm conditions experienced less aggradation. When low tide coincided with the peak in storm intensity, aggradation increased. Aggradation decreases associated with high tide runs were greater than increases during low tide runs; suggesting that, overall, tides serve to decrease aggradation potential. It should be noted that these simulations only consider spring tides where maximum water levels coincide with peak storm intensity. Rising and falling tides coinciding with peak storm intensity were not investigated. Tides were not assessed over a range of water levels or storm intensities, and it is possible that they could have a completely different impact on the shoal under different circumstances. Because tides had both constructive and destructive potential, and because of the complexity associated with determining a representative tide on an event scale simulation, tidal water level variations were not added to long-term simulations.

Results from model runs that do not include offshore events indicate that, despite being destructive, offshore events have an indirect contribution to the aggradation potential of this shoal. While every offshore event causes shoal crest lowering, it sets the profile up for increased aggradation in the next onshore event; resulting in net aggradation. Additionally, offshore events appear to retain the shoal’s coherency as it aggrades. Simulations that do not include offshore events have final profiles that are wider and farther landward. While aggradation is still observed, aggradation rates decrease as more events are simulated (Figure 26). Simulations that include offshore events experience increasing rates of aggradation for the first 22 events. In the absence of a sediment input, constructive reworking requires profiles to narrow in order to rise. The widening associated with onshore only simulations implies that aggradation will not continue. This suggests that constructive cross-shore reworking is exclusive to cold front passage. While noncold-front storms of similar magnitude may cause aggradation, this aggradation will not continue without offshore reworking from the setdown and wave direction shift associated with cold front passage. This is analogous to offshore directed processes observed controlling growth and retaining coherency on ebb tidal deltas (Ridderinkhof 2016).
Figure 26: Aggradation rates for complete cycles of cold front passage (red) and cycles that do not include offshore events (blue). Aggradation rates begin to decline immediately in runs that do not consider offshore events.

Across all scenarios, results suggest that a balance exists between landward migration and aggradation rates. Significant increases in landward migration tends to be related to decreased aggradation or even degradation. Results from the onshore only and low tide at peak storm simulations show increased landward migration and decreased aggradation. Raised scenarios experience extreme migration and significant degradation. In the extended set of simulations, maximum aggradation rates coincide with a decrease in translation rates. As with ebb tidal deltas, this suggests that if onshore directed forces aren’t balanced by offshore directed forces, aggradation will not continue. On the other hand, extended simulations suggest that some degree of net onshore migration increases aggradation. While aggradation rates initially increase as translation slows, the system reaches a point where translation stops for several consecutive cycles. This marks the threshold where aggradation rates begin to decline. If these trends continue, the shoal may reach a point where it is unable to aggrade or migrate landward. This is analogous to in-place drowning observed on barrier island systems (Kumar 1975, Nummedal et al. 1984, Lorenzo-Truba and Ashton 2014), but occurs on time scales short enough for sea level rise to be insignificant. This form of drowning is driven by destructive lowering of bed levels and sediment loss rather than rising sea levels.

While results indicate that cross-shore processes are capable of inducing constructive reworking and aggradation of a shoal, it is important to note that this is merely a proof of concept. It is not an attempt to quantify how many cold front passages are necessary to cause emergence, and it is not a comprehensive attempt to constrain magnitudes of forces capable of inducing constructive reworking. This is an event scale model repeatedly forced with one simplified synthetic cold front passage. Actual conditions will vary and will be much more complicated than this example. Potential combinations of bed levels, shoal geometries, prefrontal durations, postfrontal durations, wave intensities,
setups, setdowns, and tidal water level variations are too numerous to be tested with this model. We attempt to determine the contribution of a particular variable (or process) towards aggradation potential, but it is important to remember that this variable (process) has not been tested in every possible scenario. Interactions between forces have not been comprehensively tested. For example, applying our synthetic cold front to a raised profile results in destructive reworking. However, it is possible that constructive reworking could be observed if setup magnitudes were greater or if wave heights were smaller. Additionally, any attempt to determine what magnitudes of each of these forces induces constructive reworking would need to consider sequences of events, not just individual events. For example, results from simulations that do not include offshore events indicate that these destructive events actually set up the profile for net aggradation during future events. Similarly, an event with destructive wave heights could potentially set up a shoal geometry that is more conducive to aggradation during future, less intense events. It is important to not over-interpret these results as limitations in computational power and available data make it impossible to fully constrain each potential variable. Results indicate this shoal can aggrade when subjected to one simplified, repeated, representative event, and give limited insight into how this behavior changes with reasonable deviations in forcing mechanisms.

**Littoral Activation**

Results for each scenario indicate that as bathymetry is raised, the littoral zone becomes more active (Figure 19). The largest increases in transport occur at shallower initial depths. This results in increased littoral transport south of the nodal point on Chandeleur Island, and increased transport along the southern shoals. These trends in littoral activation contribute to the constructive reworking and aggradation on Curlew Shoal. Because Curlew Shoal is closest to the areas of highest sediment transport on Chandeleur Island, it would be the first shoal to receive any sediment travelling south due to longshore transport. Additionally, the inlet between Curlew Shoal and Chandeleur Island is significantly shallower and narrower than the inlet between Curlew and Grand Gosier Shoals. This is indicative of less energy in the inlet and a greater chance of sediment bypassing. A sediment input to Curlew Shoal would serve to amplify constructive reworking. Magnitudes of transport decrease in the downdrift direction, resulting in a decreased sediment supply to Gosier and Grand Gosier Shoals. This could be responsible for the lack of significant aggradation in this region of the shoals. An increase in activity of the littoral zone would also serve to amplify transport patterns over the shoals themselves; increasing magnitudes of both constructive and destructive reworking. Because Curlew Shoal has the largest footprint, this activation occurs over a larger spatial extent, and morphological change accelerates as the profile rises. Gosier and Grand Gosier Shoals have a smaller spatial extent. While the littoral zone still becomes more active, it does so over a smaller area and the increase in morphologic change as the profile rises is less apparent. This applies to both constructive reworking over Grand Gosier, and destructive reworking over Gosier.

Observed backbarrier circulation patterns present another mechanism to increase transport to shoals closest to Chandeleur Island. Persistent southbound backbarrier currents increase sediment transport on the backbarrier side of both Chandeleur Island
and the southern shoals. This would serve to rework any overwash deposits that occur during high energy events. This transport decreases with distance from Chandeleur Island because of significant offshore flow through inlets between shoals. As with longshore transport, this would serve to increase sediment supply and reworking, particularly around Curlew Shoal.

**Sediment Transport Patterns**

In addition to increasing the magnitude of transport, raising the bathymetry significantly changes transport patterns near the southern shoals. As the region rises, offshore transport through inlets slowly increases while transport over the shoal switches from alongshore to strongly onshore (Figure 27). In the unraised scenario, sediment behind and over the shoal is transported alongshore towards the south, and offshore through inlets. Results are similar with morfac values of both 1 and 20. When the bathymetry is raised 0.5m, transport over the shallowest parts of Curlew and Grand Gosier Shoals changes from alongshore to onshore. The magnitude of this transport is comparable to transport volumes offshore through inlets. When bathymetry is raised by 1m, landward transport over the shoals begins to dominate. This onshore transport appears to drive the constructive reworking observed on both shoals. Curlew has the strongest onshore transport and experiences the greatest amounts of constructive reworking. Gosier, on the other hand, retains downdrift dominant transport as the profile rises. Gosier has no onshore transport, and experiences destructive reworking.

Figure 27: Mean total transport vectors for the southern shoals for unraised (left) and raised scenarios.
Splitting wave and water level contributions to mean total transport indicates that, while mean total transport over the shoals is onshore, onshore wave induced transport is countered by a weaker offshore transport due to tidal and subtidal residual currents (Figure 28). This sets up a cross-shore convergence of sediment transport similar to the convergence that drove aggradation in Xbeach runs. This is analogous to the balance of offshore and onshore transport that drives accretion and promotes aggradation on ebb tidal deltas (Ridderinkhoff et al. 2016). This convergence of transport is strong over Curlew Shoal (Figure 29) and Grand Gosier Shoal (Figure 30). This likely accounts for the aggradation seen at these two locations. Grand Gosier, on the other hand, experiences downdrift wave, water level, and mean transport that drives destructive reworking of this shoal (Figure 30). As expected given the energy balance for the system, (Hart and Murray 1978), the offshore directed tidal and subtidal residual current induced transport is strongest in inlets between shoals. It should be noted that this vector splitting approach does not consider interactions between waves and water levels in determining sediment transport. Running the simulation without water level variations is meant to determine sediment transport due to waves only; however, wave induced transport is dependent on water levels. Water levels modify wave energy transmission and determine wave base. This is particularly important in the shallow and intertidal areas that are the focus of this study. These split vectors should be considered a first order estimate of transport due to waves and tidal and subtidal currents. Because of the interactions between waves and water levels, they may not sum up to the mean total transport determined in simulations that consider both waves and water levels.
Figure 28: Normalized mean total transport for the southern shoals showing wave induced transport (blue), tidal and subtidal current induced transport (red), and resulting mean total transport (black).
Figure 29: Convergence of onshore directed wave induced transport (blue) and offshore directed tidal and subtidal current induced transport (red) over Curlew Shoal induces aggradation in the direction of mean total transport (black) for scenario 1 raised 1m.
Figure 30: Mean total transport, sedimentation, and erosion patterns around Gosier (bottom) and Grand Gosier (top) Shoals. Wave induced mean total transport is shown in blue. Tidal and subtidal current induced transport is shown in red. Net transport is shown in black. Water level induced transport values are tripled to improve visibility.
In addition to the general downdrift orientation, mean total transport vectors at the edges of both Gosier and Grand Gosier Shoals have a significant offshore component on the northern end and onshore component on the southern end (Figure 30). On the southern end, mean total transport appears to be driven by onshore wave-induced sediment transport. Offshore transport due to residual currents is minimal, and mean total transport most resembles the wave induced transport vector. On the northern end, mean total transport appears to be driven by offshore tidal and subtidal current induced transport through inlets. Wave induced transport is minimal, and mean total transport most resembles the subtidal and tidal current induced transport vector. The cross-shore components of this transport become more pronounced as the shoal is raised. These transport patterns are reflected in the sedimentation patterns around the shoals. In each raised scenario, both shoals experience aggradation on the northeast and southwest edges of each shoal. Sedimentation on the northern, offshore pointing spit is most pronounced in scenario 3, where subtidal water level variations are present, but storm surge is removed. It is least pronounced in scenario 1, where both storm surge and subtidal water level variations are present. This suggests that this progradation is enhanced by subtidal water level variations, but not more intense storm surges. These patterns shed light on historic evolution for the system. The island has experienced multiple transitions from a “collar” to a circular shape (Figure 31). Following emergence or destructive events, the island takes the “collar” shape typical of emergent barriers described by Oertel and Overman (2004). A typical, onshore pointing recurved spit develops on the southern end of the island, while an offshore pointing spit develops on the northern end. The island takes on an “S” shape. These recurved spits become more pronounced until the island folds in on itself and it takes on a circular shape. Our results suggest that this evolution is driven by preferential pathways for wave and current induced transport around the shoal during cold front passage.
Figure 31: Observed evolution of Gosier island. Following a destructive event, the island transitions from a collar shape, to an “S” shape, to a circular shape. The island takes on a collar shape in 2001 following a destructive event.

**Shoal Aggradation**

Since crest elevation change is less apparent in simulations using a morfac value 1, this discussion focuses on morfac 20 simulations. However, it should be noted that Grand Gosier Shoal experiences slight aggradation in morfac 1 simulations. Degradation observed in morfac 20 runs is due to the intense storm later in the simulation. Storms of this magnitude are not typical in a representative month during cold front season, so a morfac of 20 may apply unrealistic weight to change induced by this storm. Grand Gosier Shoal appears to support aggradation when subjected to this storm once, but unrealistically repeated events induce degradation. This implies that Grand Gosier Shoal would experience aggradation over the course of a representative cold front season. Because Curlew Shoal experiences a rapid recovery following the storm, it is still able to experience net constructive reworking.

Sediment transport patterns are reflected in morphologic change evident in alongshore plots of crest elevations. While most of the shoal experiences degradation, Curlew Shoal experiences significant aggradation in raised scenarios. This aggradation is greatest in 1m raised simulations. This is due to the sediment supply, increased littoral activation, and convergence of transport unique to Curlew Shoal. Crest elevation change is more consistent between raised and unraised simulations on Gosier and Grand Gosier Shoals because littoral activation is occurring over a smaller area.

Across all scenarios raised by 0.5m, aggradation over Curlew Shoal appears to be related to wave height and subtidal water level variations. Scenario 4 experiences the most aggradation. It uses reduced waves and does not include storm surge or setup. Scenario 3
does include storm surge and experiences the second most aggradation. Scenarios 1 and 3 both include unaltered waves. Because scenario 1 includes storm surge, it experiences the least aggradation.

In all scenarios raised by 1m, aggradation over Curlew Shoal appears to be controlled by peak subtidal water level variations. Scenario 4 does not include storm surge or setup, and experiences the most aggradation. Scenario 3 includes setup, but not storm surge. It experiences the second most aggradation. Scenario 2 uses storm surge, but not setup. It experiences the 3rd most aggradation. Scenario 1 includes all subtidal water level variations and experiences the least aggradation. Despite having reduced waves, scenario 2 experiences more aggradation than scenario 3 at these depths, suggesting that as a shoal approaches emergence, subtidal water levels, and not waves, control aggradation.

In scenarios where Curlew Shoal is raised by 1m with a morfac value of 20, enough aggradation occurs to cause emergence above MSL for a 500m long section of the shoal. Figure 32 shows initial and final cross-shore profiles for the shallowest cross-section. Constructive reworking of this shallow profile causes between 0.33 and 0.47m of aggradation, and induces emergence above mean sea level. Scenarios that include storm surge or setup experience increased landward migration. Scenarios that do not include storm surge experience the most aggradation (scenarios 3 and 4). Scenario 1 experiences the least aggradation and includes both storm surge and setup. This seems to suggest that aggradation is controlled by subtidal water level variations; however, there can be no definitive conclusions without a closer look at individual events within the simulation period. The highest observed aggradation (0.96m) occurs over Curlew Shoal during the 4th scenario. This aggradation occurs over a 31 day period with a morfac value of 20. In order to compare this aggradation to rates observed during a single cold front passage in unraised Xbeach simulations (2mm per front), this value was adjusted to reflect aggradation over a 7 day period at lower morfac values. The adjusted value is 10.8mm per 7 day period. This suggests that in the absence of major storms, aggradation rates of shoals near emergence can be up to 5 times higher than shoals that have recently experienced significant destructive reworking (e.g. a hurricane).
Evolution of this profile with time gives insight to the relative importance of waves, setup, and storm surge in driving aggradation over Curlew Shoal. This month-long period can be characterized by 4 distinct events; a calm period, a short storm, a long storm, and an intense storm with a calm period (Figure 33). This discussion focuses on simulations that utilize morfac values of 20, as bed level changes are more pronounced and apparent.
Figure 33: Crest elevation change for the shallowest location on Curlew Shoal over the course of all morfac 20 simulations. Unaltered wave and water level conditions are plotted (bottom) for reference. The four events that are discussed are marked with vertical black lines. Scenarios are named $xyp$, where $x$ is the base scenario, and $y$ is the amount that bed levels have been raised.

The first eight days of the simulation are relatively calm with waves on the order of 1m. This period experiences minimal subtidal water level variations, but coincides with relatively high tidal ranges, so water levels are similar across all four scenarios. Tides reach their maximum range of 0.75 m about half way through this period. During this period, unraised scenarios remain relatively constant, but do experience slight degradation. All raised scenarios experience steady aggradation (Figure 33). Aggradation increases as the profile is raised and 1m raised simulations aggrade above mean sea level by the end of this
event. Aggradation is comparable across all four base scenarios. Because water levels are similar in each scenario, nothing can be inferred about the role of subtidal water level variations. The comparable aggradation suggests that fair-weather waves (~1m) are not significant in driving change, as a 50% reduction in wave heights produces negligible change in the profile.

The first storm event occurs 8 days into the simulation and has characteristically high waves, low water level variations, and a short duration. Wave heights increase from around 1m to a maximum of 3.36m over the course of just a few hours, and return to normal 3 days later. Because of this fast passage, subtidal water level variations are negligible. Additionally, this event coincides with neap tides, so total water level variations are minimal. Again, water levels are comparable for all four scenarios, so the major difference between scenarios with subtidal water level variations (1 and 3) and without (2 and 4) is the 50% reduction in wave heights. Unraised and 0.5m raised simulations experience degradation during peak storm conditions. Simulations raised by 1 experience a stall in aggradation. Aggradation resumes as waves decrease and approach background levels. Simulations raised by 1m take longer to resume aggradation, but still end up aggrading more than simulations raised by 0.5m. Unraised scenarios experience slight aggradation, and crest elevations approach pre-storm levels. Aggradation is highest in scenarios that include unaltered waves (1 and 3), but this difference isn’t observed until after wave heights drop. This suggests that while background waves are not significant in driving accretion during calm periods, they contribute to constructive reworking during post-frontal conditions. This occurs in the absence of significant tidal and subtidal water level variations.

The second storm event has smaller wave heights, a greater tidal range, greater setup, and a longer duration. Wave heights do not exceed 3m, however, wave heights of approximately 2m persist for three days. Unraised simulations experience initial aggradation followed by degradation, resulting in a negligible change in elevation. Simulations raised by 0.5m experience slight degradation. Aggradation during 1m raised scenarios stalls during peak wave conditions and resumes as waves return to background levels. Scenarios that include full waves and subtidal water level variations experience increased aggradation in 1m raised runs and decreased aggradation in 0.5m raised simulations. They also experience more landward translation and have steeper shorefaces (Figure 34). Since scenarios 1 and 3 have both full waves and subtidal water level variations, it is not yet apparent if this difference is due to waves or subtidal water level variations.
Figure 34: Shoal crests at the end of the second storm event showing increased landward migration in scenarios with subtidal water level variations. Mean sea level is plotted as a horizontal blue line.

The third storm event gives insight into the profiles behavior when subjected to high waves, setup, and storm surge. This event experiences the largest waves (~5m) and highest water level (~1.5m). This storm coincides with a relatively low tidal range, so total water level variations are mostly a result of setup and storm surge. However, tidal range does increase during the calm period following the storm. In unraised and 0.5m raised simulations, scenarios 2-4 experience slight aggradation. Crest elevations in scenarios 2 and 4 are identical, suggesting that without setup, storm surge has no impact on crest elevations. Scenario 3 experiences comparable aggradation, suggesting that setup alone has no significant impact on crest elevation. Scenario 1, on the other hand, includes both setup and storm surge. This profile experiences significant degradation, suggesting that it is the combined effect of setup and surge that drives degradation at these depths. In the calm period following the storm, all four scenarios experience similar rates of recovery.

Simulations raised by 1m experience degradation in all scenarios with setup or storm surge. Scenarios with the highest water levels experience the most degradation. The storm surge included in scenario 2 causes more degradation than the setup included in scenario 3. Despite having significantly larger waves, scenario 3 experiences less degradation than scenario 2, suggesting that degradation is primarily driven by subtidal water levels, not waves. Scenario 4 includes only tides and experiences no degradation. Degradation in scenarios 1-3 is followed by a period of rapid recovery. Crest elevations rise at the fastest rates observed in the entire simulation. Recovery appears to be related to degradation, as the scenarios that experienced the most degradation experience the fastest recovery. By the end of the simulation, crest elevations appear to be converging. Because the scenario with no storm surge (4) experienced no degradation, it can be inferred that
this destructive event is induced by subtidal water level variations and not large waves. Additionally, rapid degradation coincides with peak storm surge. This occurs before peak wave conditions. Landward migration is comparable in all scenarios that experience degradation and does not appear to be dependent on magnitudes of subtidal water level variations. Landward migration does not appear to be reversible, as shoals in scenarios 1-3 do not migrate seaward during the recovery period (Figure 32).

Despite observed constructive reworking and aggradation, these shoals experience a net loss of sediment during the simulation in every scenario. Table 4 summarizes volume loss of the shoals for elevations (normalized to unraised state) less than 2m and 4m below mean sea level. Losses on the upper portion of the shoal are significantly higher than losses on the entire shoal. Losses over the entire shoal are comparable across base scenarios at both high and low starting elevations (Figure 35, Table 4). Upper shoal losses vary between base scenarios with no observable pattern. (Figure 36). There is no discernable trend in volume losses as the bathymetry is raised. Spatially, the greatest volume losses coincide with high initial elevations (Figures 35-37). Isolated volume gains are experienced downdrift from bathymetric highs. This observation of consistent sediment loss is in agreement with other studies that acknowledge a net loss for the entire Chandeleur system, and supports claims that the system is in the process of transitioning to an inner-shelf shoal (Miner et al. 2009; Georgiou and Schindler. 2009, Moore et al. 2014; Flocks and Terrano 2016). It also implies that future shoal recovery will become less effective over time.

<table>
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<tr>
<th>Shoal Region</th>
<th>Raised</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
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</thead>
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<td>+0m</td>
<td>27%</td>
<td>16%</td>
<td>23%</td>
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<td>+0m</td>
<td>2.2%</td>
<td>0.4%</td>
<td>0.3%</td>
<td>0.4%</td>
</tr>
<tr>
<td></td>
<td>+0.5m</td>
<td>1.9%</td>
<td>0.1%</td>
<td>0.2%</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>+1m</td>
<td>1.5%</td>
<td>0.5%</td>
<td>0.1%</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

Table 4: Volume of sediment lost above unraised 2m and 4m isobaths for the south Chandeleur shoals for each scenario considered.
Figure 35: Volume of sediment lost from shoal (above unraised 4m isobath) and upper shoal (above unraised 2m isobath) for the unaltered scenario with unraised, 0.5m raised, and 1m raised bed levels at a morfac of 20. Scenarios are named $xyp$, where $x$ is the base scenario, and $y$ is the amount that bed levels have been raised.

Figure 36: Volume of sediment lost from shoal (above 4m isobath) and upper shoal (above 2m isobath) for the all scenarios with unraised bed levels at a morfac of 20. Scenarios are named $xyp$, where $x$ is the base scenario, and $y$ is the amount that bed levels have been raised.
Figure 37: Volume of sediment lost from shoal (above unraised 4m isobath) and upper shoal (above unraised 2m isobath) for the all scenarios with 1m raised bed levels at a morfac of 20. Scenarios are named xpy, where x is the base scenario, and y is the amount that bed levels have been raised.
Chapter 5

Concluding Statements

Results show that following a destructive hurricane, where a barrier island or a shallow shoal becomes submerged, alongshore processes alone are not capable of initiating shoal growth as transport magnitudes are small. Unraised Delft3d scenarios experience minimal sediment transport. Transport that does occur is purely alongshore. With no convergence of transport on the shoal, any reworking that occurs at these depths is destructive, and does not contribute to shoal growth. Xbeach runs, on the other hand, show that shoal growth is initiated by cross-shore processes associated with frequent cyclic winter storm activity. The wave phase-resolving capabilities of the Xbeach runs induce constructive reworking of a shoal profile even at relatively deep, post-hurricane depths. Therefore, Hypothesis 1 is accepted.

Results from Xbeach runs that exclude the post-frontal, offshore component of the simulation suggest that Hypothesis 2 is also true. While individual offshore events reduce shoal height, they rework the shoal and set up a geometry that results increased aggradation during subsequent onshore events. This increase is large enough to cause a net increase in aggradation for the profile. This reworking also serves to limit landward migration and keep the shoal a coherent structure.

Results from extended Xbeach runs and Xbeach runs of a raised profile suggest that Hypothesis 3 is also true. While cross-shore transport processes are capable of constructive reworking at relatively deep depths, aggradation rates decrease as the shoal rises to shallower depths. Model runs of a raised profile reveal that at near emergence, the same processes that initiated aggradation cause destructive reworking of the shoal. Results from raised Delft3d simulations show that as bathymetry rises due to cross-shore processes, continued aggradation can occur due to alongshore processes; therefore, Hypothesis 4 is also accepted. As the profile is raised, sediment transport converges over the shallower locations of the shoal. Despite shoal volume losses, constructive reworking is evident on Curlew shoal following 0.5m raised scenarios. This aggradation increases during scenarios raised by 1m; resulting in reemergence above mean sea level, and the creation of an incipient barrier.

Results from Delft3d simulations show that constructive reworking around Curlew Shoal is due to increased littoral activation and convergence of sediment transport over this shoal. Because of its proximity to Chandeleur Island, Curlew Shoal receives more sediment from longshore transport and backbarrier circulation. Because of its larger footprint, it experiences the greatest increase in reworking as the littoral zone becomes active. Onshore sediment transport due to wave action is countered by weaker offshore transport due to residual circulation. This causes landward migration and constructive reworking. Gosier and Grand Gosier Shoals are farther from areas of high transport on Chandeleur Island, and have a deeper inlet separating them. They receive less sediment and do not experience significant constructive reworking. Gosier does not have a convergence
of wave and water level induced sediment transport and significant destructive reworking is observed.

Curlew Shoal’s response to individual events during the simulation leads to conclusions about the relative importance of waves, setup, and storm surge. While waves are insignificant in driving aggradation during calm periods, they serve to increase constructive reworking during post-frontal events. Degradation associated with more intense storms is controlled by large subtidal water level variations at shallower depths. Where degradation is observed, increased aggradation following the storm ensures that the only long-term effect is an increase in landward migration.

**Conclusions**

Following a destructive storm event, a cross-shore convergence of nearshore processes due to the frequent, cyclic passage of cold fronts initiates recovery for a submerged shoal. As the shoal aggrades to shallower depths, aggradation accelerates as a result of increased alongshore sediment transport due to wave refraction, longshore transport, and backbarrier circulation. While aggradation during each cold front passage is only on the order of millimeters, several years’ worth of repeated cold front passage are capable of inducing emergence of a shallow shoal.

**Future Recommendations**

Along the southern Chandeleurs, we observe sufficient variability in initial shoal crest heights, shoal crest widths, and slopes landward and seaward of the shoal. Xbeach simulations that did not include offshore events showed that shoal geometry plays a significant role in determining a profile’s response to a cold front passage. Future cross-shore models could utilize a wide range of initial profile dimensions. A range of backbarrier slopes, shoreface slopes, initial crest elevations, and shoal widths could be utilized to determine which shoal geometries are most conducive to aggradation.

Our ability to model morphodynamic evolution of submerged shoals is currently limited by computational power. Assuming processing capabilities continue to increase, future models could potentially take advantage of this.

Onshore Xbeach results highlight the importance of shoal geometry. By manually raising profiles, we disrupt the geometric evolution of the shoal. It is possible that as the shoal aggrades to near emergence, a gradual change in shoal geometry could change how the profile responds to cold front passage at shallower depths. If processing power allows, future applications could model aggradation from initial levels to near emergence without manually raising the profile.

If processing capabilities increase, future models could attempt to better constrain what conditions are capable of inducing constructive reworking. This is not currently feasible due to the many potential combinations of variables that would need to be tested. We tested a relatively narrow range of water levels with the same storm on one initial profile. Future models could investigate wider ranges of durations, wave heights, and water
levels on multiple profiles. Decreasing the time required to run models would make this a more reasonable task.

If future computational power allows, it would be beneficial to model shoal aggradation entirely in Xbeach. Because of computational limitations, we had to model cross-shore and alongshore processes separately. Future models could potentially apply Xbeach’s wave phase resolving capabilities at a regional scale. This would allow for simultaneous computation of both nearshore and alongshore processes.
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Vita

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