Seasonal to Interannual Storm Controls on Coastal Morphology at NASA-Kennedy Space Center

Matthew Conlin[1], Peter Adams[1], and John Jaeger[1]

[1]Department of Geological Sciences, University of Florida

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Abstract

Large storms are considered to be influential drivers of morphologic change on open sandy coasts. Whereas storm-driven morphologic changes and the recovery processes that typically follow have been robustly documented, less well understood is the concept of storm-driven coastal behavior over seasonal to annual timescales, which integrates multiple storm response and recovery cycles. In this study, storm controls on coastal evolution are evaluated using a topographic dataset containing monthly measurements of the intertidal and subaerial beach for 5 years (2009-2014) along a 10 km reach of open sandy coast fronting NASA-Kennedy Space Center near Cape Canaveral, Florida. In addition to shoreline and volume change analyses, a novel Empirical Orthogonal Function (EOF) analysis has been applied to these data to extract dominant spatial and temporal patterns of morphologic change over the full beach surface, as opposed to being applied over individual cross-shore transects or alongshore contours as previously practiced. Results indicate that the most dominant pattern of morphologic evolution within these data describes an isolated change of state to this system initiated by the impact of Hurricane Sandy (2012). This is exhibited physically as a southward migration of a previously stable cuspate foreland beginning immediately after the storm, resulting in nearly 600 m of propagation over the following 1.5 yr observation interval. Additionally, remaining dominant patterns describe a seasonal erosion cycle linked to storm driven seasonality in nearshore water levels, and a spatially variable berm formation cycle on inter-storm timescales likely driven by storm-induced variations in sediment storage locations and associated availability to non-storm hydrodynamics. These results illustrate that coastal response to an individual storm may control the recovery processes that follow by shifting morphologic equilibria such that processes of recovery drive the beach toward a configuration unlike its pre-storm state. Because these post- event processes influence morphologic response to the next event, the results presented here highlight a largely unexplored coupling between storm response and recovery that may be considered a dominant control on interannual-scale coastal evolution in storm-prone regions.

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Matthew P. Conlin[1], Peter N. Adams[1], John M. Jaeger[1], and Richard MacKenzie[1]

conlinm@ufl.edu

[1]Department of Geological Sciences, University of Florida, Gainesville FL, 32611

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1. Introduction

- Short-term storm response/recovery cycle understood
- Decadal variability driven by variable storminess studied
- Storm controls on coastal morphology over seasonal-interannual timescales not well documented
- How do storms influence the seasonal-interannual morphologic evolution of NASA-KSC?

2. Methods

2.1 Study Site, data

- 65 ~monthly ATV-based RTK GPS surveys between dune toe and water line (2009-2014) at NASA-KSC

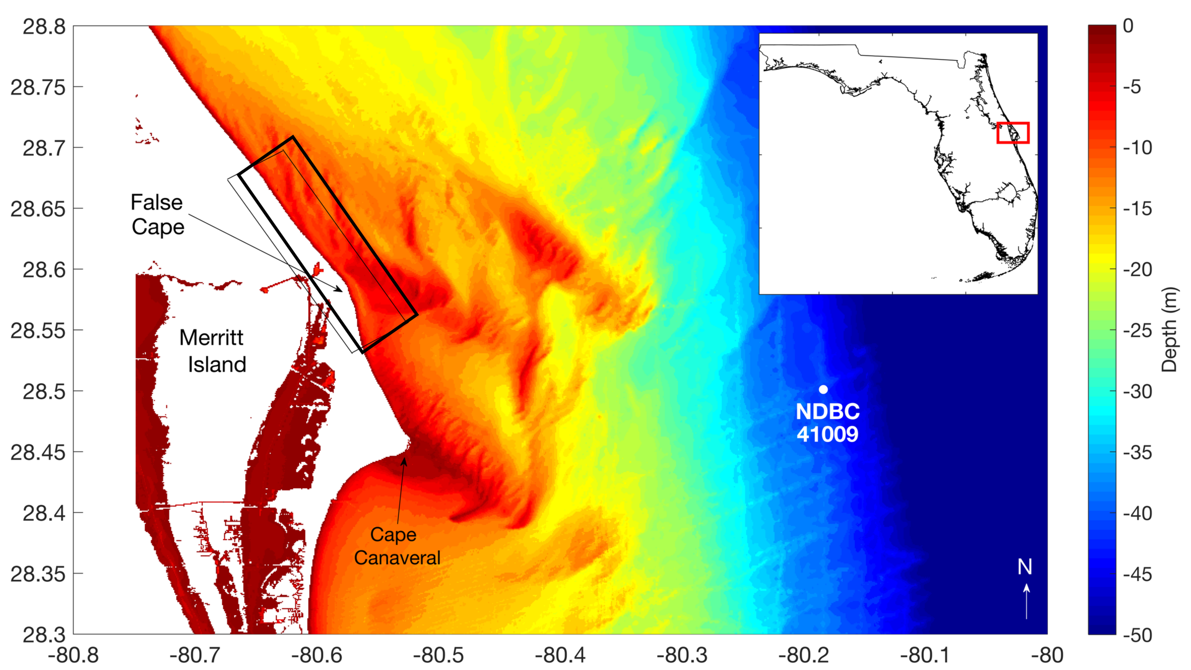


Fig. 1. Study site on east coast of Florida

2.2 Morphologic variability analyses

- Data from each survey interpolated onto grid which is oriented everywhere with the local cross/alongshore
  - ❖ We have 65 DEMs of this location, one for each survey. Each grid point, then, contains an elevation time-series
- Morphologic change rates are found by taking linear regression elevation change rates at each grid point = Linear Regression of DEMs (LRoD)
- EOF analysis of elevation over entire beach surface through time completed = Surface EOF (SEOF)

2.3 Storm identification and analysis

- Peaks-Over-Threshold method used to ID coastal storms
- Integrated Wave Energy Density of each storm calculated

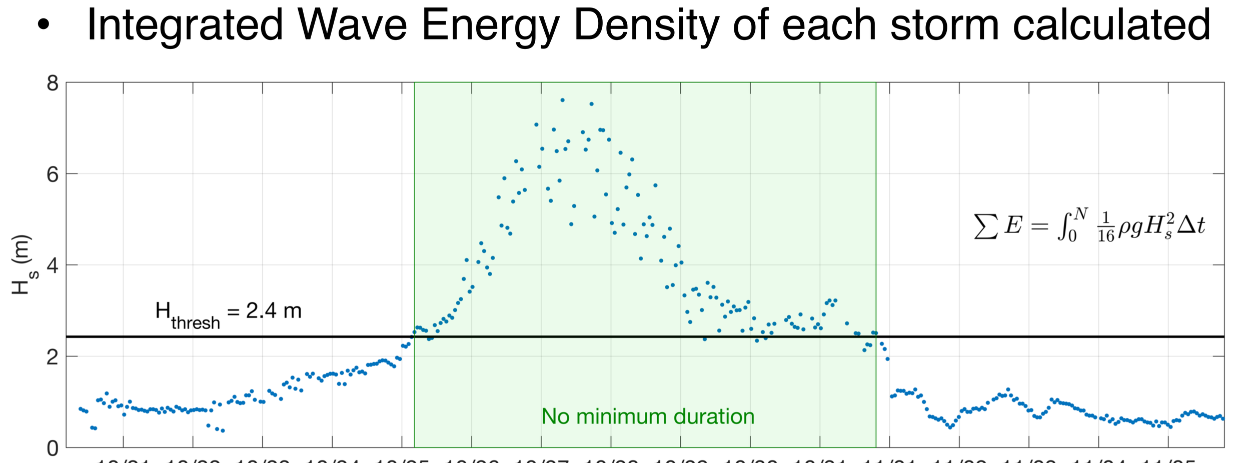


Fig. 2. Definition plot for the POT technique. A storm is identified from a record of H_s as a series of measurements (no minimum duration) exceeding a threshold H_s (H_{thresh}) .

3. Results

3.1 Storm variability

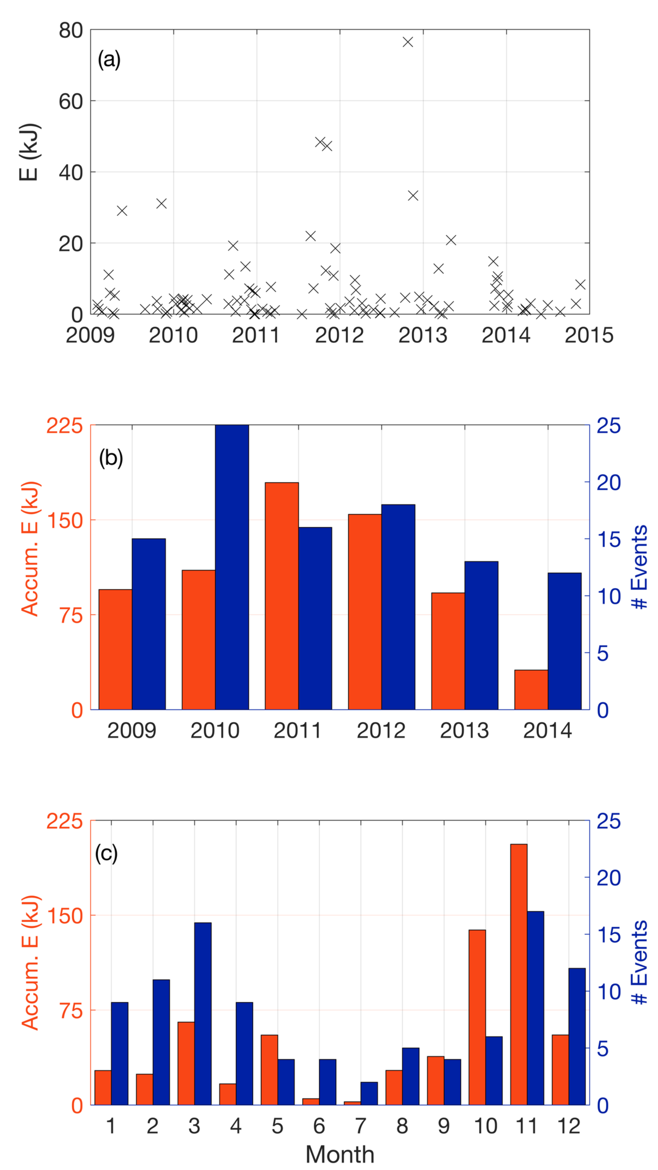


Fig. 3. Summary of identified storms. (a) Integrated wave energy density of each event. (b,c) Breakdown of storms by year (b) and month (c)

- Largest storm in October 2012 represents Hurricane Sandy (Fig. 3a)
- 4 largest storms in record hit as two clusters of two events (Fig. 3a)
- Most accumulated energy in 2011/ 2012, despite fewer storms than 2010 (Fig. 3b)
- October-January were months which saw the most storm energy (Fig. 3c)
- Nearly zero storm energy in Jun/Jul (Fig. 3c), illustrating seasonal cycle in storm activity

3.2 Morphologic variability

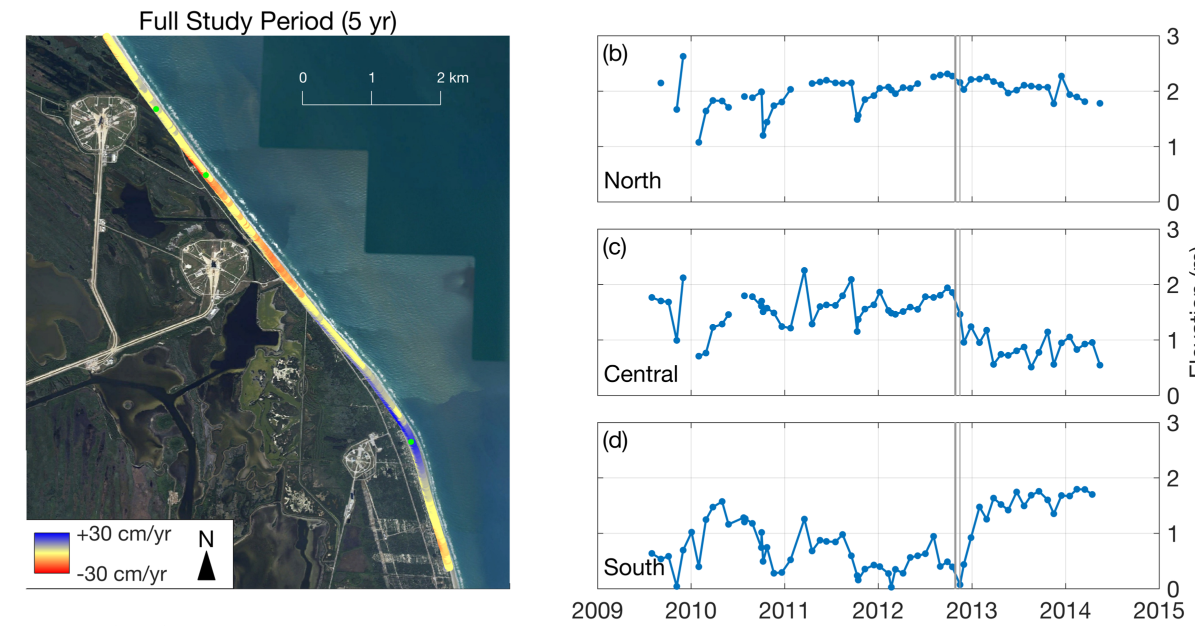


Fig. 4. (Left) LRoD calculated over full study period, with elevation time-series at three example grid poins (b-d). Grey bars indicate timing of Sandy and a following winter storm

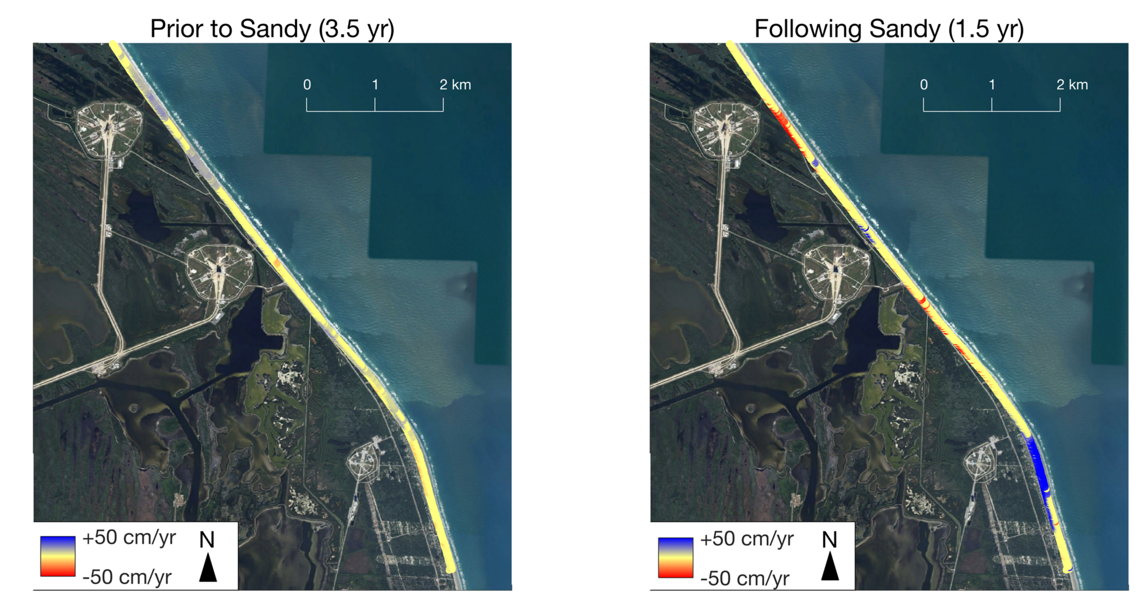


Fig. 5. LRoDs calculated prior to and following Sandy

- Overall: False Cape accretional, isolated erosion, most of site stable (Fig. 4, left)
- Non-stationary variability at central and southern grid points; shift in behavior immediately following Sandy and a following storm (Fig. 4c,d). This results in 4-month accretion at southern point, erosion at central, followed by stability for remaining 1.5 yr of measurements
- After the storms: southern False Cape highly accretional, some northern reach erosional. These trends not apparent before (Fig. 5)

3.3 SEOF analysis

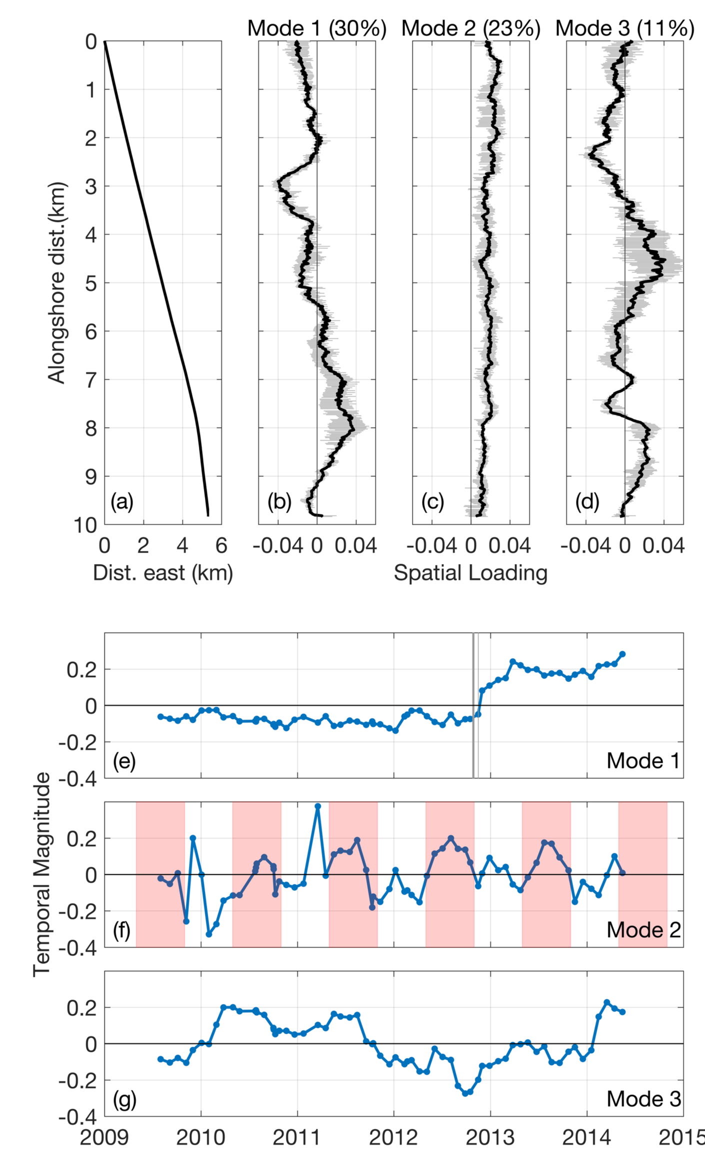


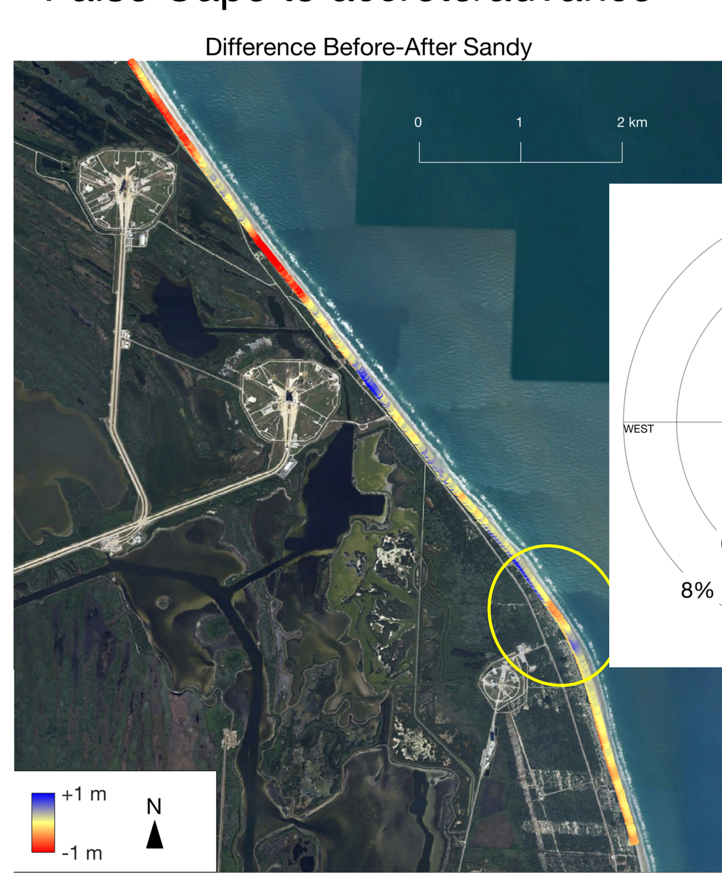
Fig. 6. Results of the SEOF analysis. (a) Planview representation of the study site. (b-d) Plots of the cross-shore averaged spatial loading for Modes 1-3, where grey bars indicate cross-shore variability. (e-f) Time-series of temporal magnitudes for Modes 1-3. Gray bars in (e) represent the timing of Hurricane Sandy and a following winter storm. Red bars in (f) represent May 1 - October 31 of each year.

- Mode 1 (Fig. 6b,e) shows rapid sign change following 2012 storms, False Cape out of phase with rest of site. This mode therefore captures the change-of-state observed in the morphology (Fig. 4)
- Mode 2 (Fig 6c,f) is in phase over entire beach surface and shows a seasonal oscillation
- Mode 3 (Fig 6d,g) complex in space with a multi-year oscillation

4. Discussion (Mode 1)

- Morphologic state change (Mode 1) occurs immediately following storms = events caused the change
- Explanation:

Storms caused southern portion of False Cape to accrete/advance + Waves are typically from the northeast = Protrusion smeared itself along southern reach over next 4 months, return to equilibrium



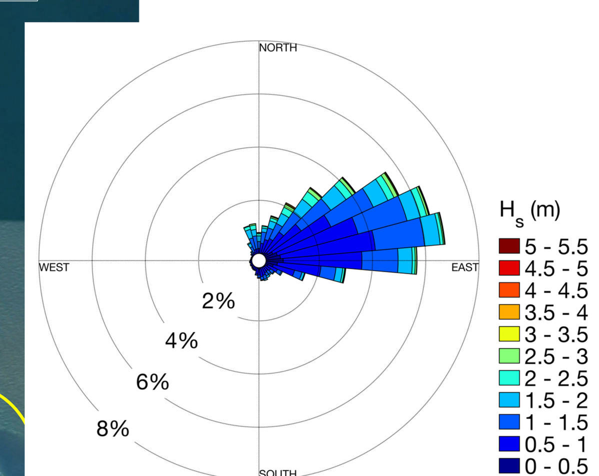


Fig. 7. (Left) Difference of DEMs for before-after 2012 storms. (Top) Wave rose for nearshore waves during the 1.5 years of morphologic data following the 2012 storms

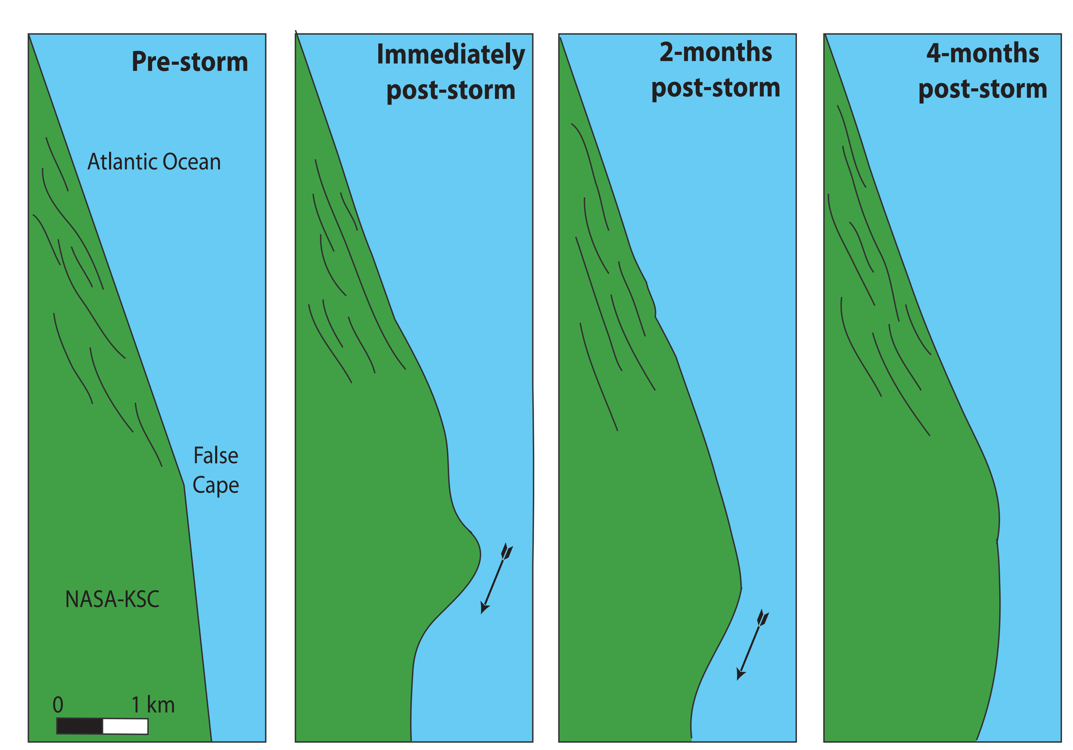


Fig. 8. Hypothesized multi-month evolution of the site following 2012 storms (exaggerated)

- Response to storm dictated recovery through morphologic equilibrium shifts driven by storm conditions
- We know that recovery influences response to the next storm by setting the baseline upon which it acts
- Therefore, response from one storm can influence response to the next storm, illustrating a coupling between response and recovery which was the dominant control on the interannual evolution of this site

4. Discussion (Modes 2+3)

- Mode 2 indicative of seasonal morphologic changes due to seasonal water level variations
- Temporal variability matches storm variability

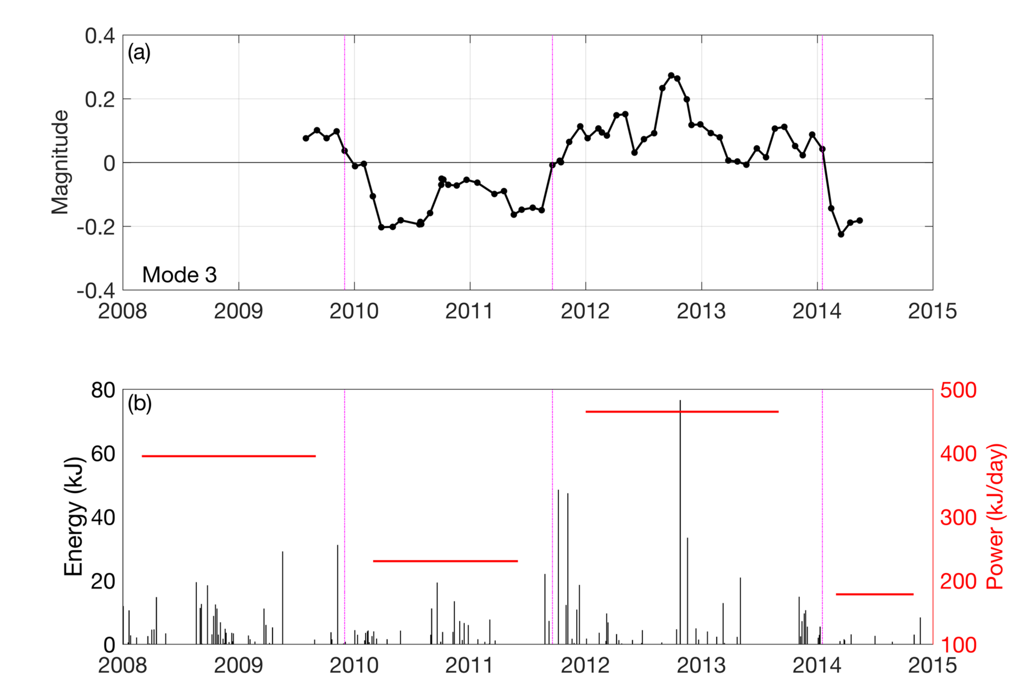


Fig. 9. Correlation of Mode 3 with periods of storminess. (a) Time-series of Mode 3 temporal magnitudes. (b) The integrated wave energy density of each storm (black bars) and storm power over time periods between magenta vertical lines

- Mode 3 positive during periods of intense storminess, negative during low storminess
- This suggests an underlying morphologic response to interannual storminess cycles
- Could correspond to variations in sediment storage location and accessibility from variable storminess

5. Summary: key points

- We use a dataset containing monthly topographic observations for 5-years to document the influence of storms on the seasonal-interannual evolution of a 10-km stretch of beach in Florida
- We find that Sandy's impact (2012) caused a morphologic change of state, dictating an evolution following the event which was unlike that of before
- We show that storm response dictated recovery, and it is known that recovery influences response to the next storm, so these results highlight a complex coupling between response and recovery which was the dominant control on interannual evolution here
- Morphology at this site also seems to respond to seasonal variations in storm activity and interannual storminess cycles