Exploring the morphodynamic response of coastal barriers to sea-level rise along the Texas Gulf Coast

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Big question:

What is the **long-term (10^2 yr) trajectory** of Texas’ coastal barrier system?

Reasonable response:

Apply a **suitability complex** model to estimate **barrier response** to relative sea-level rise (RSLR).
### Texas Coast: VITAL STATISTICS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal range</td>
<td>&lt; 1m</td>
</tr>
<tr>
<td>Sig. Wave</td>
<td>0.9 to 2.1 m @ SE direction</td>
</tr>
<tr>
<td>Closure Depth(^1)</td>
<td>4.2 to 11 m @ 500 yr</td>
</tr>
<tr>
<td>Shoreline disp.(^2)</td>
<td>(p_{10}, p_{50}, p_{90}): -4.6, -0.9, 1.6 m yr(^{-1})</td>
</tr>
<tr>
<td>RSLR</td>
<td>2 to 6 mm yr(^{-1})</td>
</tr>
<tr>
<td>Shelf slope</td>
<td>(10^{-3}) to (10^{-4.2})</td>
</tr>
<tr>
<td>Barrier Height</td>
<td>&lt;1 m to &gt;5 m</td>
</tr>
<tr>
<td>Barrier Width</td>
<td>&lt;300 m to &gt;8000 m</td>
</tr>
</tbody>
</table>

\(^1\)Ortiz and Ashton (2016), \(^2\)Paine et al (2016)
Three key regions of interest:

**Follets Island (sensitive canary)**
- Flanks a *major deltaic headland*
- Retreating landward > 2m yr\(^{-1}\)
- Low, narrow

**Mustang Island (stable and stout)**
- updrift of “*longshore convergence zone*”
- Retreating landward < 1m yr\(^{-1}\)
- Tall, wide

**North Padre Island (modestly prograding)**
- Within “*longshore convergence zone*”
- Slightly prograding 0.03 m yr\(^{-1}\)
- Very tall and wide
Task: simplify Texas’ coastal barrier morphology into characteristic scales and morphodynamics into parameterized expressions which resolve fundamental geomorphic responses to external forcing.
Reducing a barrier to characteristic scales

Conceptual figure: not to scale

Lorenzo-Trubea and Ashton (2014)
Reduced complexity process representation in *Barrier Sections*:

1) Cross-shore sediment flux

\[ Q = K_i(\alpha_{Equilibrium} - \alpha_i) \]

2) Passive flooding during RLSR

3) Overwash sediment fluxes

Critical width = 300 m
Critical height = 2 m

4) Net longshore sediment flux

Connectorg the coastal barrier model

Individual barrier sections have **local morphodynamic parameters**. Sections communicate via longshore sediment flux.

Boundary conditions set by long-term rates.
Individual barrier sections have local morphodynamic parameters. Sections communicate via longshore sediment flux.

Ashton and Lorenzo-Trubea (2015) state that boundary conditions are set by long-term rates.

**Big assumptions:**
1. Barrier sediment composition is sand
2. Inlets/jetties allow longshore bypass
3. Seawalls prevent shoreline displacement
4. Wave climate is unchanging
5. Fluvial contributions are steady
6. Human activities are minimal
7. No geomorphic clearing events
Data sources & methods

**Local** relative sea-level rise
(NOAA tide gauges)

**Simplified regional** barrier morphology:
- Barrier height and width (*NOAA survey*)
- Shoreline shape (*Paine et al. 2016*)
- Shoreface, shelf slope (*NOAA survey*)

**Parameterized** morphodynamic processes:
- Single local *morphodynamically significant wave* (*ACoE, Ortiz and Ashton, 2015*)
- Longshore sediment transport (*theoretical + calibration*, inhomogeneous diffusion)
- Cross-shore sediment transport (*theoretical*, Lorenzo-Trubea and Ashton, 2014)
- Morphodynamic depth of closure (*theoretical*, Ortiz and Ashton, 2015)
**Data sources & methods**

- **Local relative sea-level rise** *(NOAA tide gauges)*
- **Parameterized morphodynamic processes:**
  - Single local morphodynamically significant wave *(ACoE, Ortiz and Ashton, 2015)*
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**Model execution:**
1. Initial condition: modern coast
2. Timestep: 1 day
3. Run time: 500 yr
4. Model output
   1. Shoreline position
   2. Barrier scales
   3. Sediment fluxes
Post-processing: Monitor three key regions

**Follets Island**
- A sensitive canary of the coast
- Updrift of major deltaic headland
- Elevation (MHHW)
  - $H = 1.3 \text{ m}$
  - $W = 412 \text{ m}$

**Mustang Island**
- A stout, stable barrier
- Updrift of "longshore convergence zone"
- Elevation (MHHW)
  - $H = 3.0 \text{ m}$
  - $W = 751 \text{ m}$

**North Padre Island**
- Modestly prograding
- Within "longshore convergence zone"
- Elevation (MHHW)
  - $H = 3.4 \text{ m}$
  - $W = 1736 \text{ m}$
Follets Island: A sensitive canary of the coast

- Net shoreline displacement (m)
  - seaward
  - landward
  - median
  - min
  - max

- Subaerial Vol. % diff
  - growing
  - shrinking

- Overwash: Height deficit
  - seaward
  - landward

- Overwash: Width deficit
  - seaward
  - landward

- Critical barrier ratio
  - no overwash
  - overwash

- Barrier height
- Critical height
- Barrier Width
- Critical Width

- Cross-shore flux
- Overwash: Height deficit
- Overwash: Width deficit
- Cumulative sediment flux (m² yr⁻¹)
  - Longshore flux
  - Overwash: Height deficit
  - Overwash: Width deficit
**Mustang Island: A stout, stable barrier**

![Graphs showing net shoreline displacement, subaerial volume difference, and cumulative sediment flux over time for Mustang Island.](Image)
N. Padre Island: *Modestly prograding*

- **Median**
- **Max**
- **Min**

### Figures:

1. **Net shoreline displacement m**
   - **Seaward**
   - **Shrinking**

2. **Critical barrier ratio**
   - No overwash
   - Overwash

3. **Cumulative sed. flux m² yr⁻¹**
   - **Seaward**
   - **Landward**

### Graphs:

- **Barrier height**
- **Critical height**
- **Barrier Width**
- **Critical Width**

- **Overwash: Width deficit**
- **Overwash: Height deficit**
- **Cross-shore flux**
- **Longshore flux**
Conceptual summary:

1. Sea-level increases

2. Barrier scale diminishes, overwash begins

3. Overwash is sourced from shoreface
   1) retreat rates *increase*
   2) progradation rates *decrease*
   3) Barrier volume *stabilizes*

4. Longshore transport system is *modified*

**Retreating barriers**

- Longshore flux
- shoreline
- Overwash

**Prograding barriers**

- Longshore flux
- shoreline
- Overwash
Conclusions

- Texas’ long-term barrier trajectory is set by initial scales and location within Texas’ longshore transport system.
- Barrier responses to sea-level rise modify longshore transport patterns.
- Dependence on barrier scales highlights needs:
  - Barrier topography
  - Barrier bayline motion
  - Barrier sediment composition
Thank you!

A special thanks to Dr. Hongbo Ma! (Rice U.)