A high-resolution study of tidal range changes in the Delaware Bay: Past conditions and future scenarios

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Tidal Range Change

- Astronomical ocean tides change with cyclic changes in constituent forcing. These tides are also influenced by changing bathymetry and therefore should change on longer temporal scales.

- Tidal range can be used as a measure of changing tides.

- Future scenarios:
  - Inundation levels (high tide)
  - Harbor depths (low tide)
  - Currents

- Past conditions:
  - Factor into sea level rise estimates from Holocene index points.
Tidal Range Change

0 thousand years before present (ka)

MHHW

MLLW

MTL

RSLR

Great Diurnal Range

Great Diurnal Range

=

MHHW

MTL

MLLW

MLLW
Tidal Range Change

Great Diurnal Range $_{5(b)}$ ≠ Great Diurnal Range $_{0}$
Project Goals

Delaware Bay

– Create bathymetric grids for time slices before and after present.

– Model **Holocene** tidal range changes to factor into SLR estimates and explore behavior.

– Model **Future** tidal range change scenarios to explore effects of a global sea level rise.
Methods

- Model: ADCIRC 2D-DI model, fully nonlinear, ‘wetting and drying’ enabled. Conducted harmonic analysis to extract tidal constituents which were used to calculate datums and GT (MHHW-MLLW).

- Forcing: Present day constituents from TPXO model, along 60th meridian open boundary, variable in space but constant in time to focus on local bathymetry changes.
Methods: Grid Generation

Delaware Bay Grid
101,075 nodes, 196,039 elements

Holocene Run Grid
383,972 nodes, 745,137 elements

Stitched to Mukai et al. (2002) grid

Future Run Grid
517,237 nodes, 1,027,746 elements

Present day baseline conditions

Added topographic data
Methods: Grid Verification

Constituent Amplitude, % Difference from NOAA Gauge
Methods: Grid Transformations

- Applied a spatially variable GIA factor to depth values based on ICE-6G VM5b model; 10ka to present (Engelhart et al. 2009).

- Future runs at +0.1 and +0.3 kyr were also given a eustatic rise component (1.01m and 3.5m, respectively from Rhamstorf et al. 2011).

- Does not model changes to the basin shape due to smaller time-scale estuarine morphology.

- Delaware Bay:
  - Subsidence forward in time. Spatially variable changes.
  - Dry prior to 7ka. Focused on 3ka to 0ka+0.3kyr.
Results: Local

(Hall et al., in press)
Results: Local

Diurnal Range Ratio

0.5ka 1ka 1.5ka

2ka 2.5ka 3ka
Results: Local
Comparison

Flick et al. (2003) tide gauge observation GT change rates
- 2 gauges analyzed in Delaware Bay; decreasing GT
  - Trends agree with Future case rates, magnitudes similar
  - Trends disagree with Holocene rate (500 years ago to present)

<table>
<thead>
<tr>
<th>Location</th>
<th>Measured (Flick et al. 2003)</th>
<th>Modeled 0.5-0ka</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape May, NJ (mm/100yr)</td>
<td>-51</td>
<td>8</td>
</tr>
<tr>
<td>Cape May, NJ (%/100yr)</td>
<td>-3</td>
<td>0.5</td>
</tr>
<tr>
<td>Lewes, DE (mm/100yr)</td>
<td>-33</td>
<td>5</td>
</tr>
<tr>
<td>Lewes, DE (%/100yr)</td>
<td>-2</td>
<td>0.4</td>
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</tbody>
</table>
Implementation

Holocene SLR rate (Engelhart et al. 2009)

- Upper Bay: 1.2 ± 0.2 mm/yr (Small GT Decrease)
- Lower Bay: 1.7 ± 0.2 mm/yr (Large GT Increase)

Tidal Range Change (this study)

- Delaware
- New Jersey
- Pennsylvania
Implementation

Nikitina et al. (in press)

Upper Bay

Lower Bay

New Jersey

Pennsylvania

75°W

39°N

40°N

1.2 ± 0.2 mm/yr

1.7 ± 0.2 mm/yr

Sea Levels from Index Points

Sea Breeze, NJ

Uncorrected
GT Change Correction

Relative Sea Level (m)

Age (ka)
Conclusions

Modeled tidal ranges (GT) change in the Delaware Bay.

• GT in the upper bay has increased 80% since 3 ka. GT in the lower bay has remained relatively constant. This difference may help account for differences in past SLR estimates in these locations.

• Future GT decrease agrees with tidal gauge data trend. Changes are small relative to SLR.

(Hall et al., in press)
Questions
References
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Additional Material
Accuracy

• Grid verifications
  – Verified constituents with gauge locations
  – Future Run Grid showed higher error
    • Gauge locations in/out of grid coverage
    • Parameters tuned to Holocene grid
    • USGS topo vs. NGDC bathy
Accuracy

• Potentially significant processes not modeled:
  – River inflow
  – Estuarine evolution
  – Smaller temporal scale geomorphology (i.e. shoreline change)
  – Other human induced changes (dredging, coastal protection, etc.)
  – Baroclinic effects (i.e. changes in salinity)

• Use of GIA represents greater sophistication than models of estuaries using uniform changes in depth

• Highest temporal and spatial resolution
Comparison

- Leorri et al. (2011) model of Delaware Bay
  - Their 4ka = 3ka in this study based on avg. depth change
  - Results similar for same depth changes
  - Spatially variable sea level change in this study vs. constant in theirs; different depth changes = different rates at same time

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<tr>
<td>Upper Bay</td>
<td>4 to 0ka</td>
<td>3 to 0ka</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.51</td>
</tr>
<tr>
<td>Lower Bay</td>
<td>1.20</td>
<td>1.09</td>
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$M_2$ Amplitude Ratio

Depth Change (m)

3ka
Comparison

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M$_2$ Amplitude Ratio  

GT Ratio
Resonance

- Decreased GT in lower bay 3ka to 0ka
- Resonance when $T_{\text{tide}} = T_{\text{bay}}$

$T_{M2}; \boxed{12.5 \text{ hrs}} > T_{\text{bay}} \rightarrow 9 \text{ hrs}$ (Walters 1997)
Bay Shape

• Rise in upper bay GT 3 to 0ka
  – Funnel shape
    • Higher tides in the narrow region
    • Delaware Bay 0ka tidal behavior estimated using exponentially decreasing width model (Parker 1991)

![Bay Shape Diagram]
Shallow Water Damping

Bathy change with respect to 0ka condition (m)

Horizontal Distance Across Section (km)
Shallow Water Damping

[Graph showing data points and legend for different regions: Upper Bay, Mid Bay, Lower Bay, River]
Discussion: Future Impacts

- Tidally driven sediment transport

- Two SLR scenarios, nonlinear response to different levels
Discussion: Non-Linear Response
Discussion: Non-Linear Response