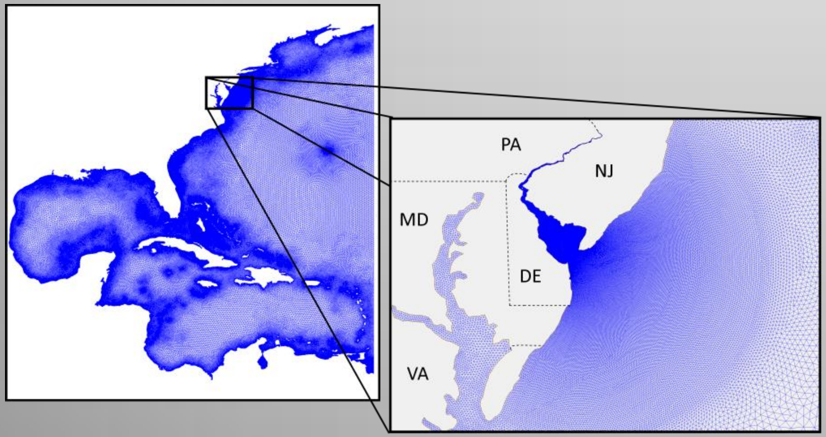
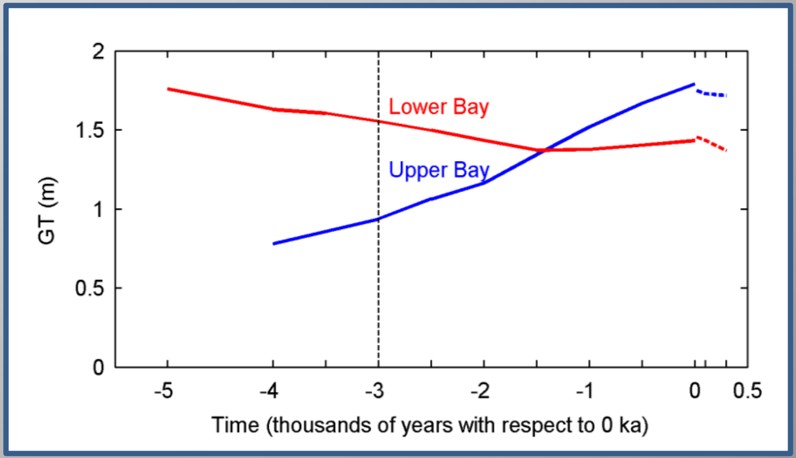
A high-resolution study of tidal range changes in the Delaware Bay: Past conditions and future scenarios





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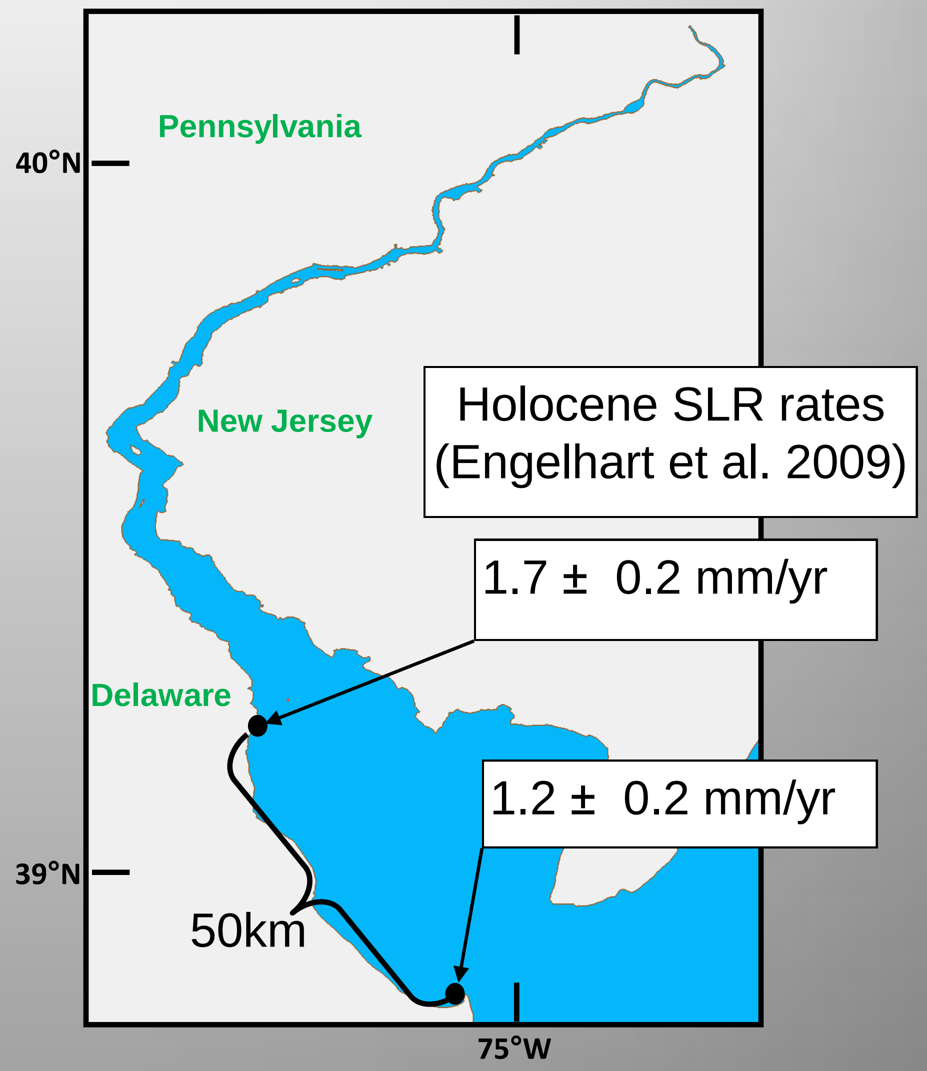
Tidal Range Change

- 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.**

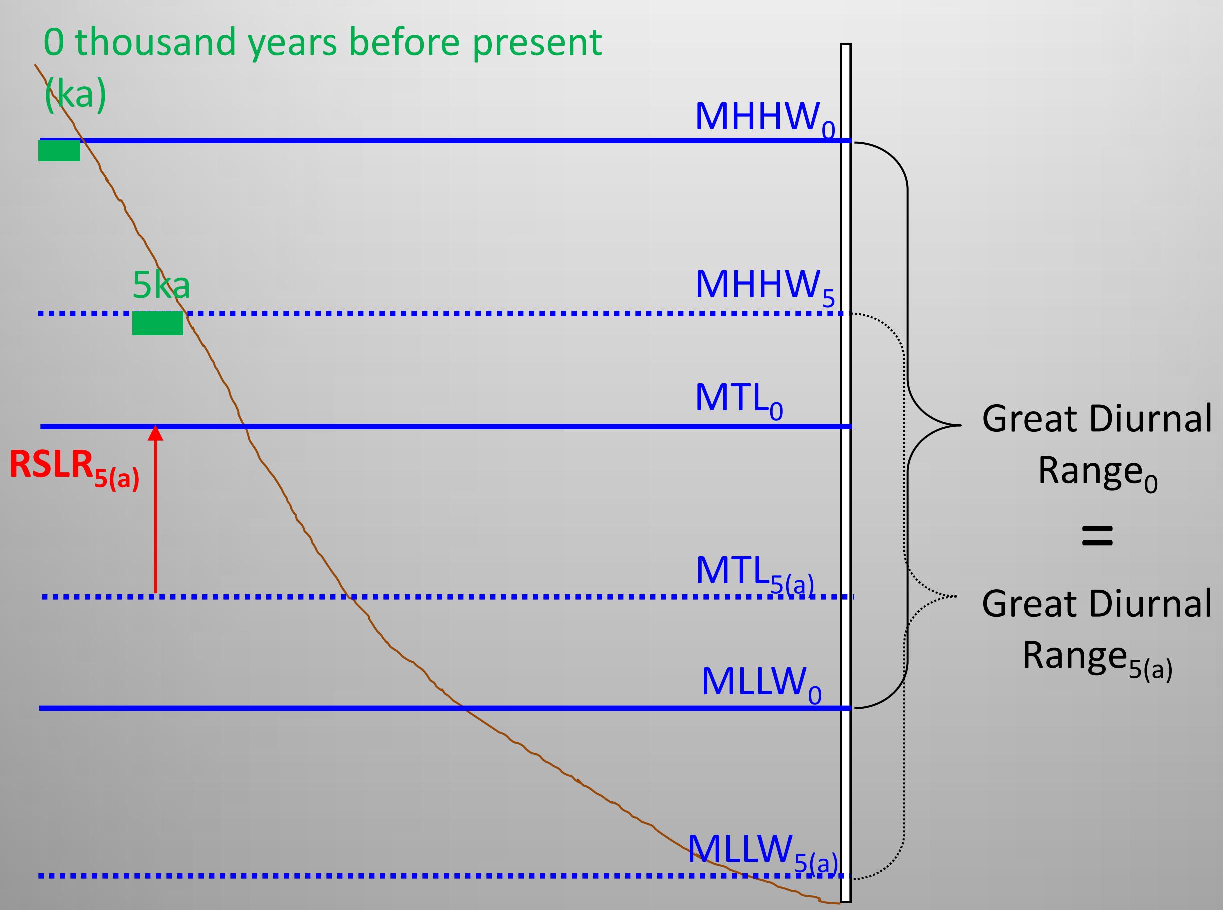
- Tidal range can be used as a measure of changing tides.

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

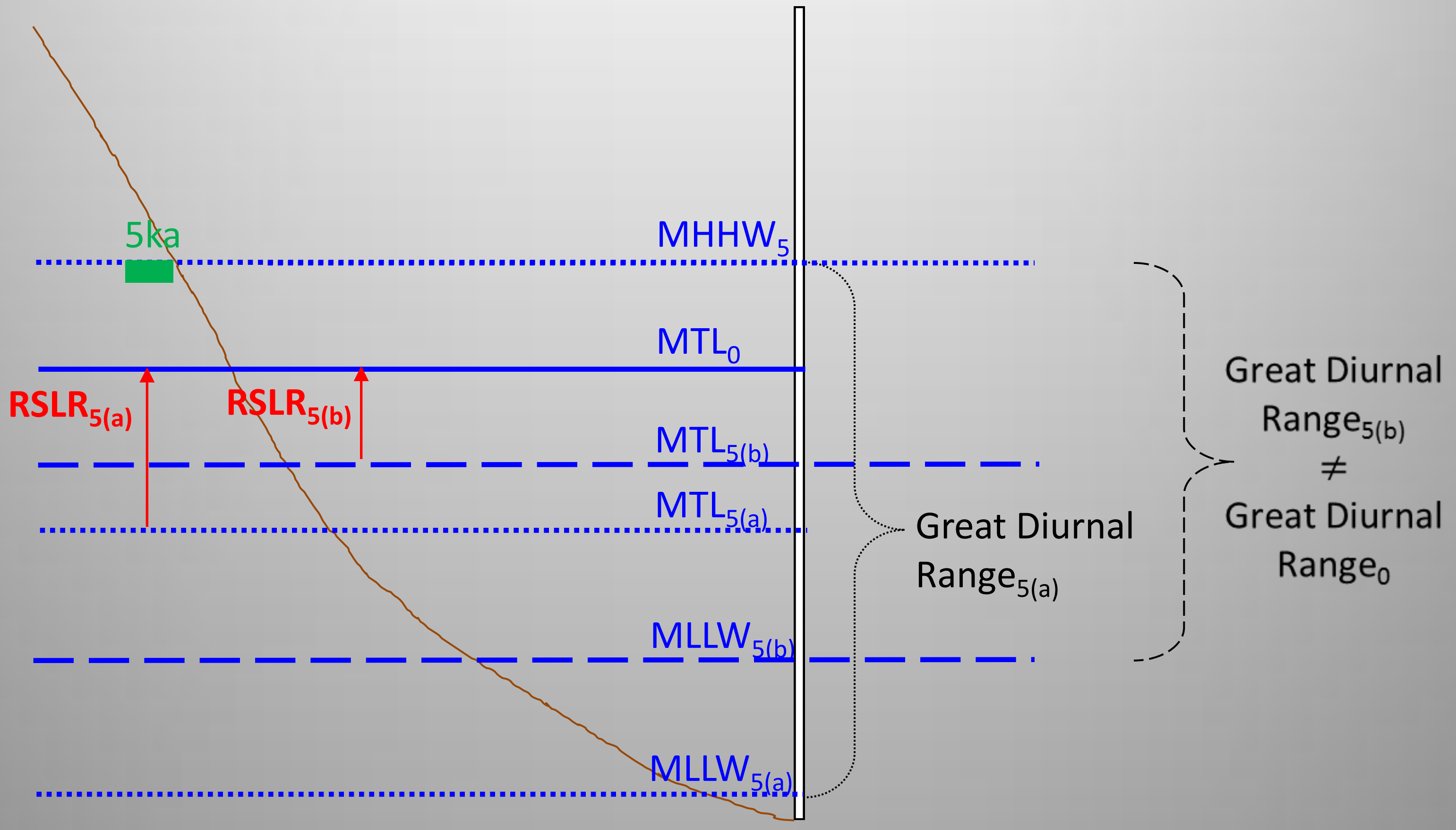
- Past conditions:
  - Factor into sea level rise estimates from Holocene index points.



Tidal Range Change



Tidal Range Change



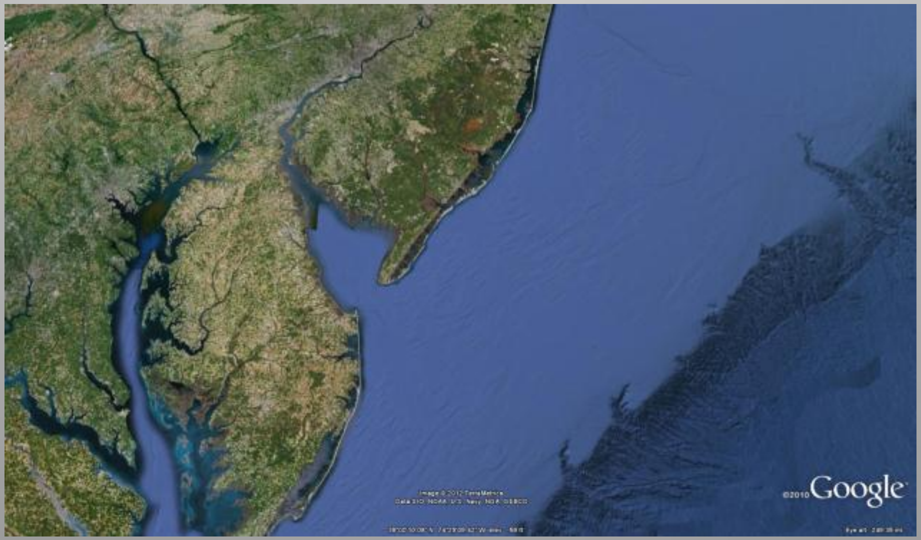
Project Goals

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.

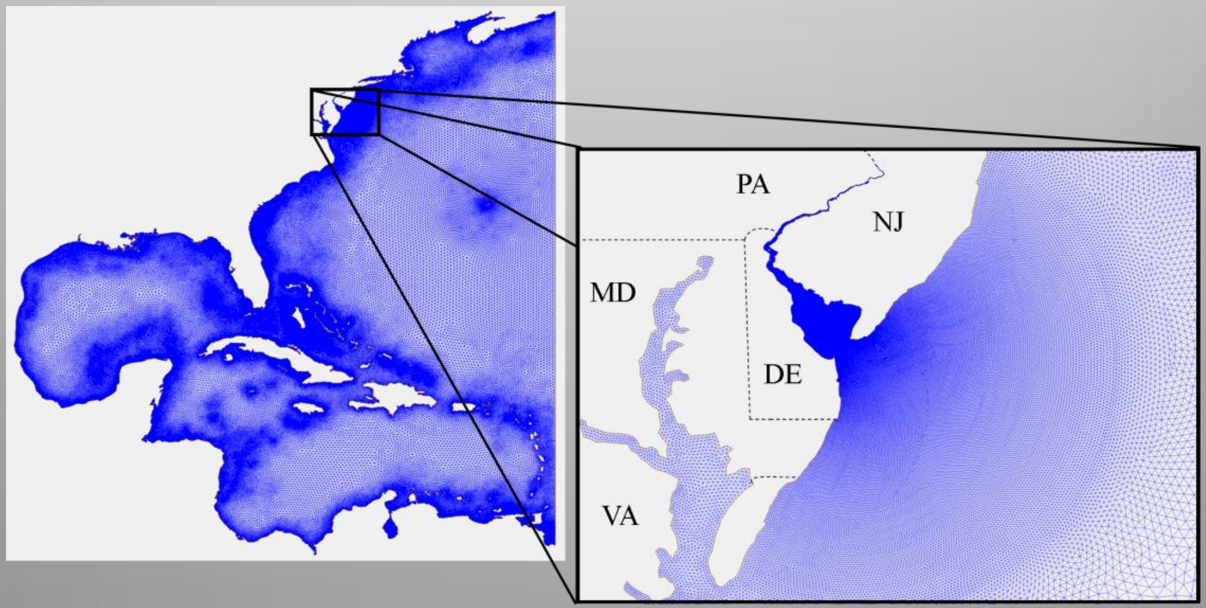
- Model **Future** tidal range change scenarios to explore effects of a global sea level rise.



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).

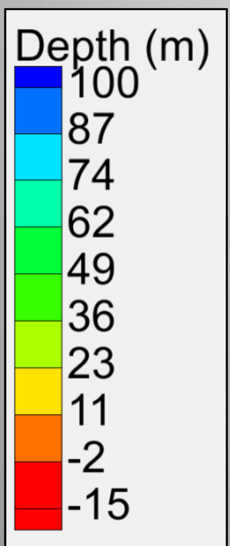
- Forcing: Present day constituents from TPXO model, along 60th meridian open boundary, **variable in space but constant in time** to focus on local bathymetry changes.

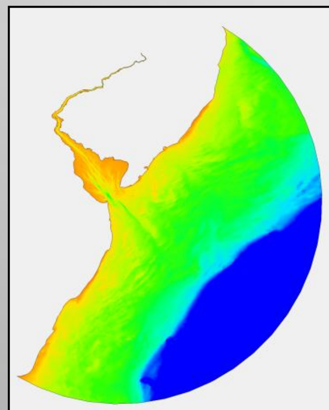


Methods: Grid Generation

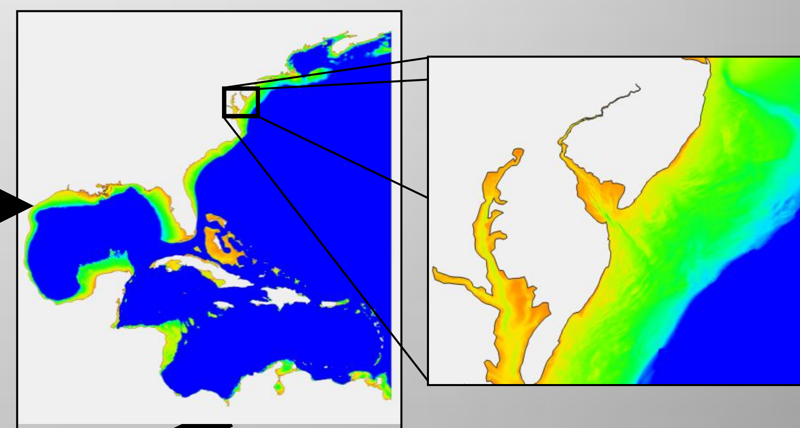
Delaware Bay Grid
101,075 nodes, 196,039 elements

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

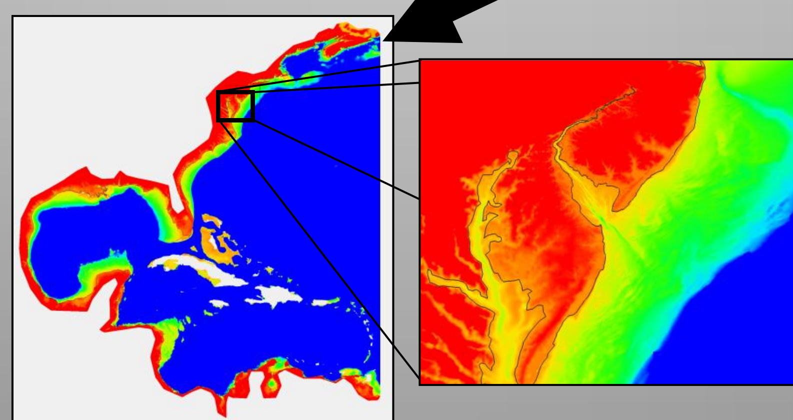




Stitched to Mukai et al. (2002) grid



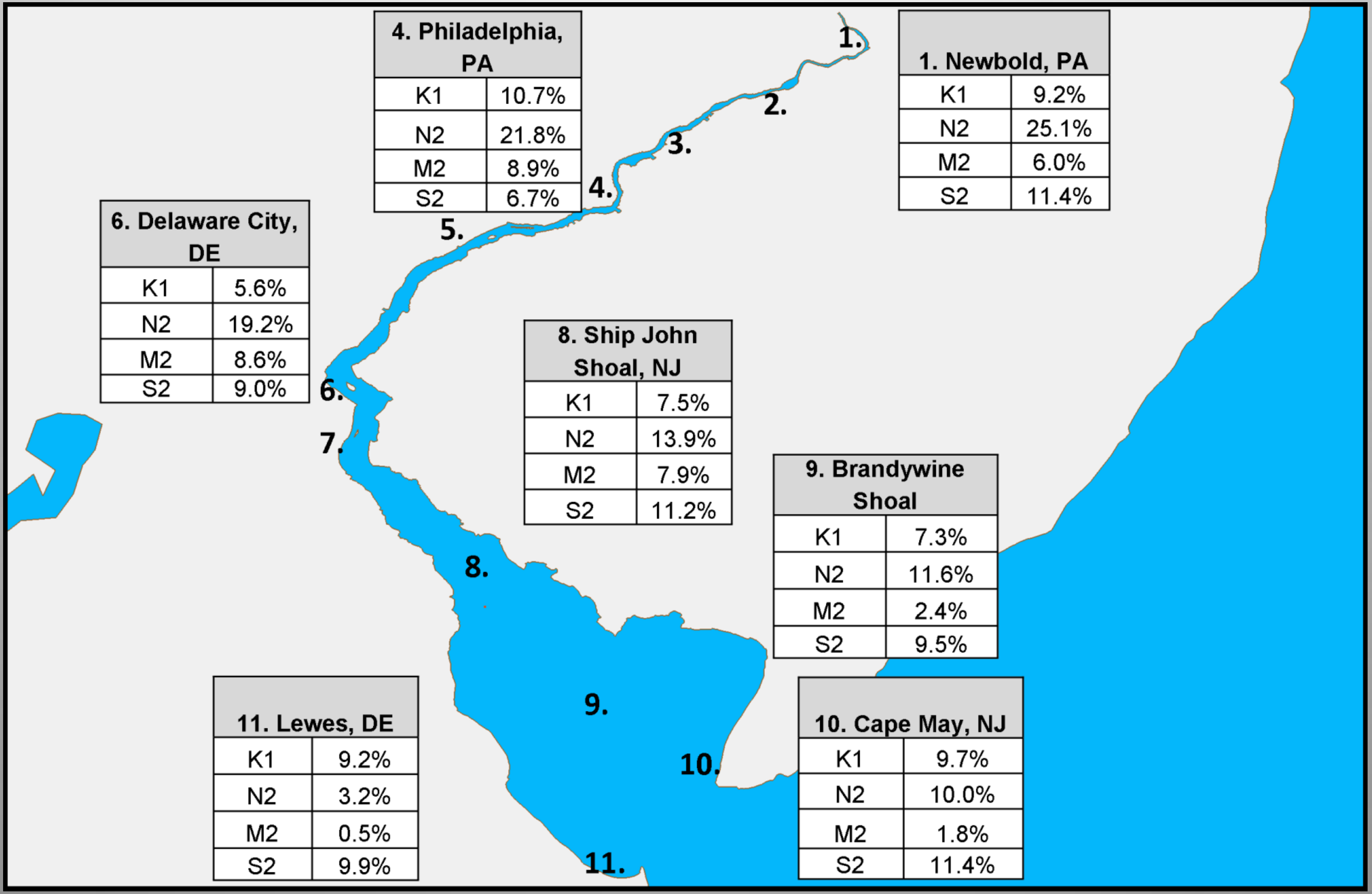
Added topographic data



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

Present day baseline conditions

Methods: Grid Verification



1. Newbold, PA	
K1	9.2%
N2	25.1%
M2	6.0%
S2	11.4%

4. Philadelphia, PA	
K1	10.7%
N2	21.8%
M2	8.9%
S2	6.7%

6. Delaware City, DE	
K1	5.6%
N2	19.2%
M2	8.6%
S2	9.0%

8. Ship John Shoal, NJ	
K1	7.5%
N2	13.9%
M2	7.9%
S2	11.2%

9. Brandywine Shoal	
K1	7.3%
N2	11.6%
M2	2.4%
S2	9.5%

10. Cape May, NJ	
K1	9.7%
N2	10.0%
M2	1.8%
S2	11.4%

11. Lewes, DE	
K1	9.2%
N2	3.2%
M2	0.5%
S2	9.9%

Constituent Amplitude, % Difference from NOAA Gauge

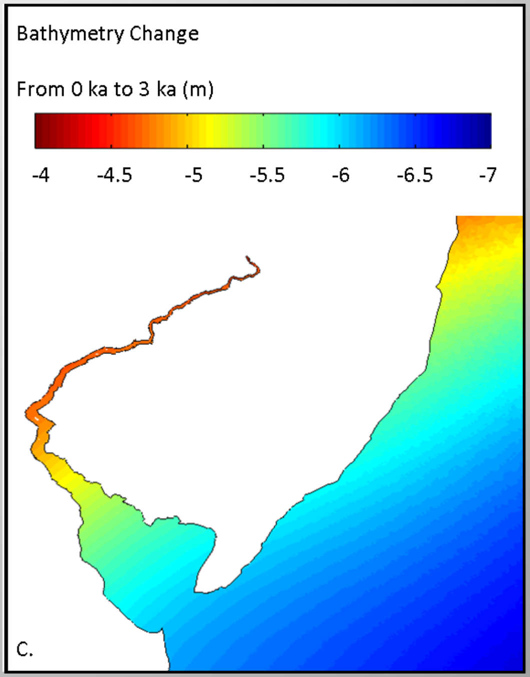
Methods: Grid Transformations

- 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).

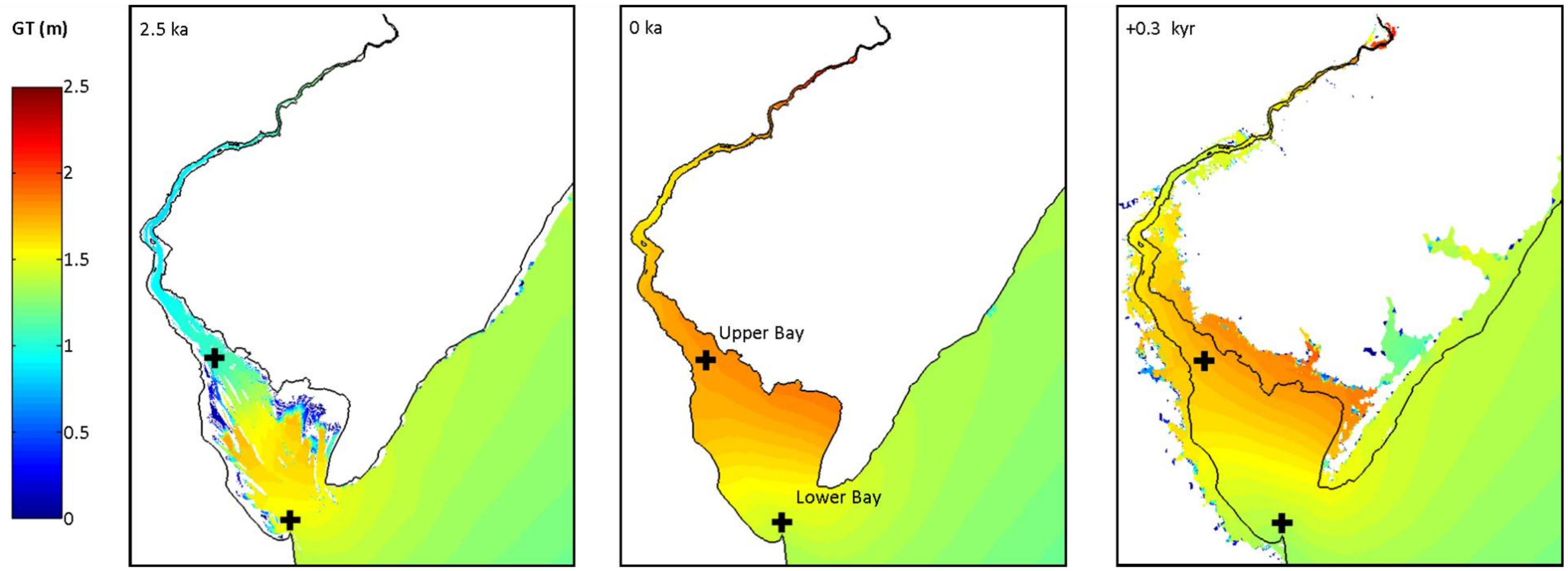
- Does not model changes to the basin shape due to smaller time-scale estuarine morphology.

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



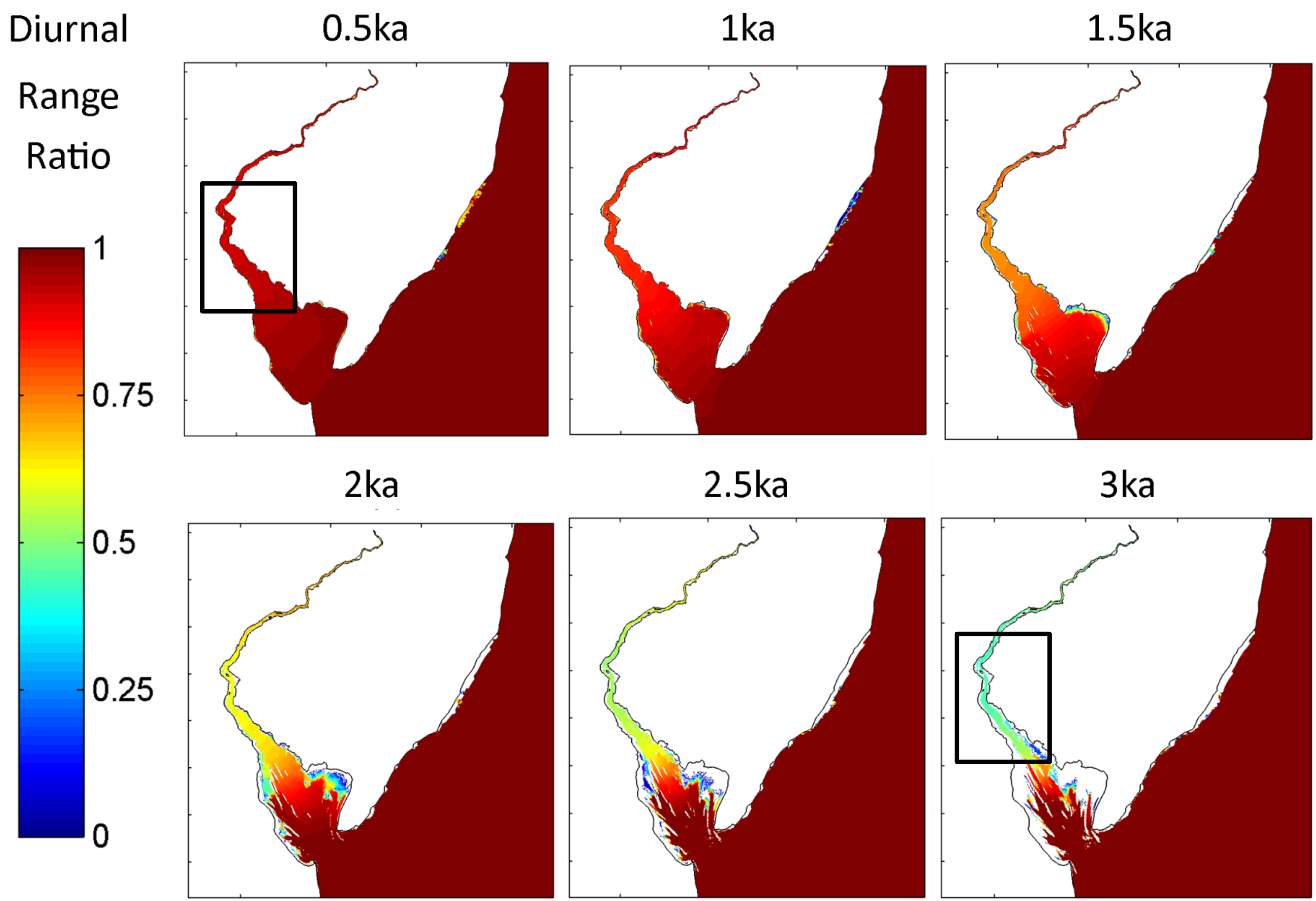
(Hall et al., in press)

Results: Local

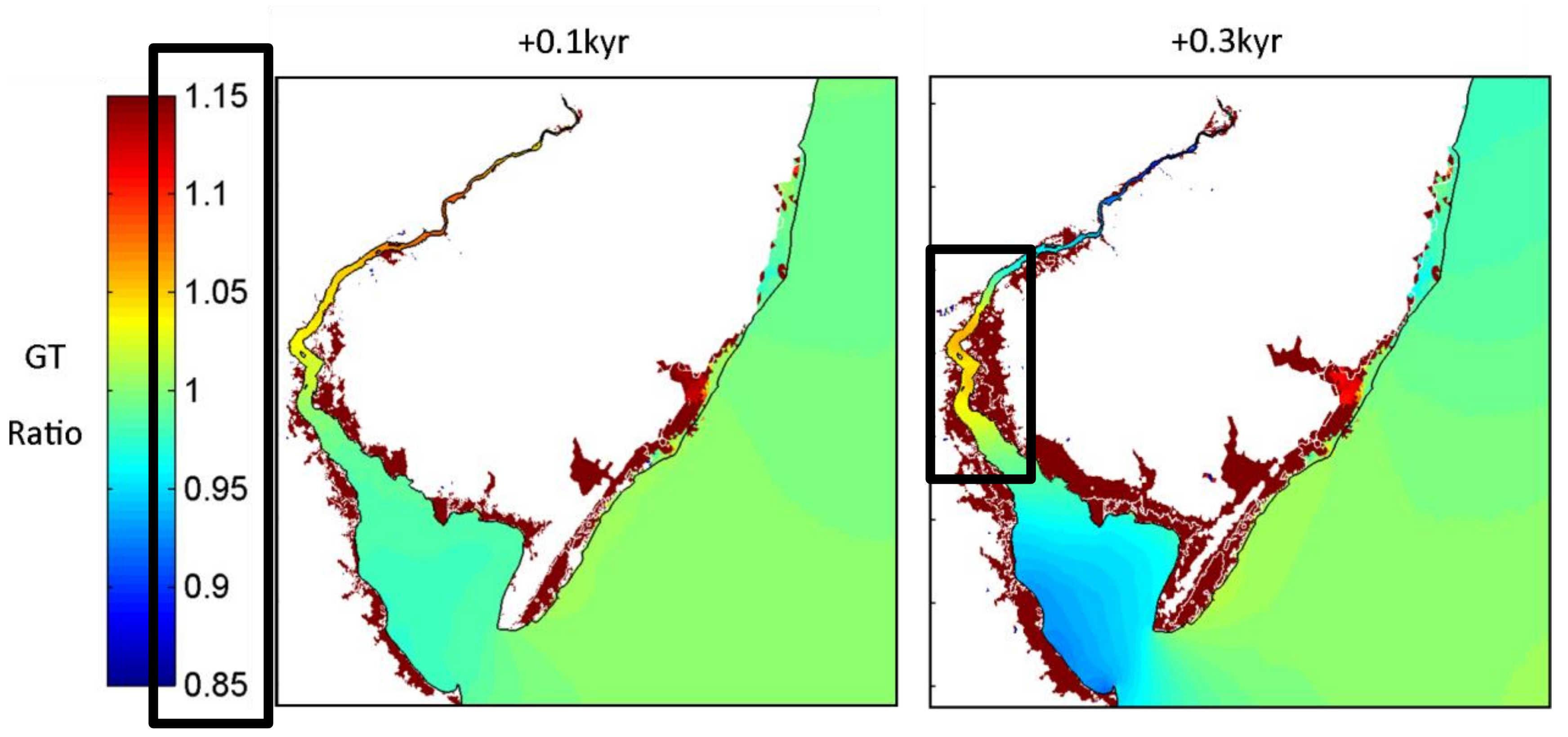


(Hall et al., in press)

Results: Local



Results: Local



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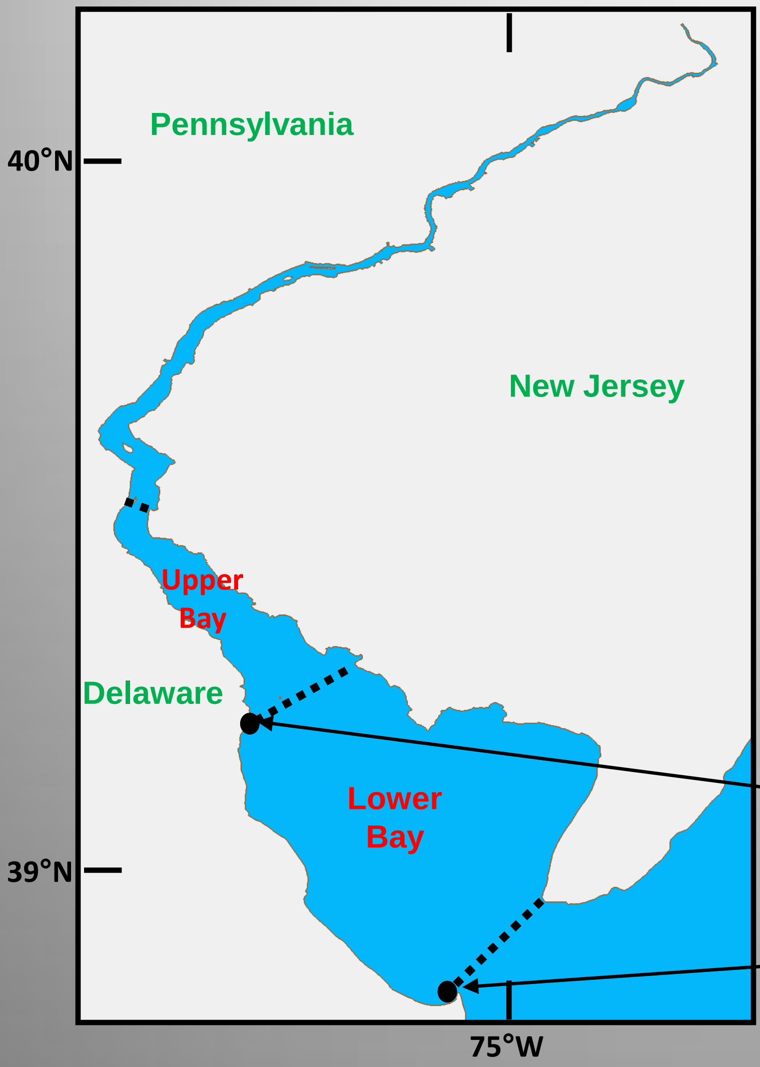
Comparison

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)

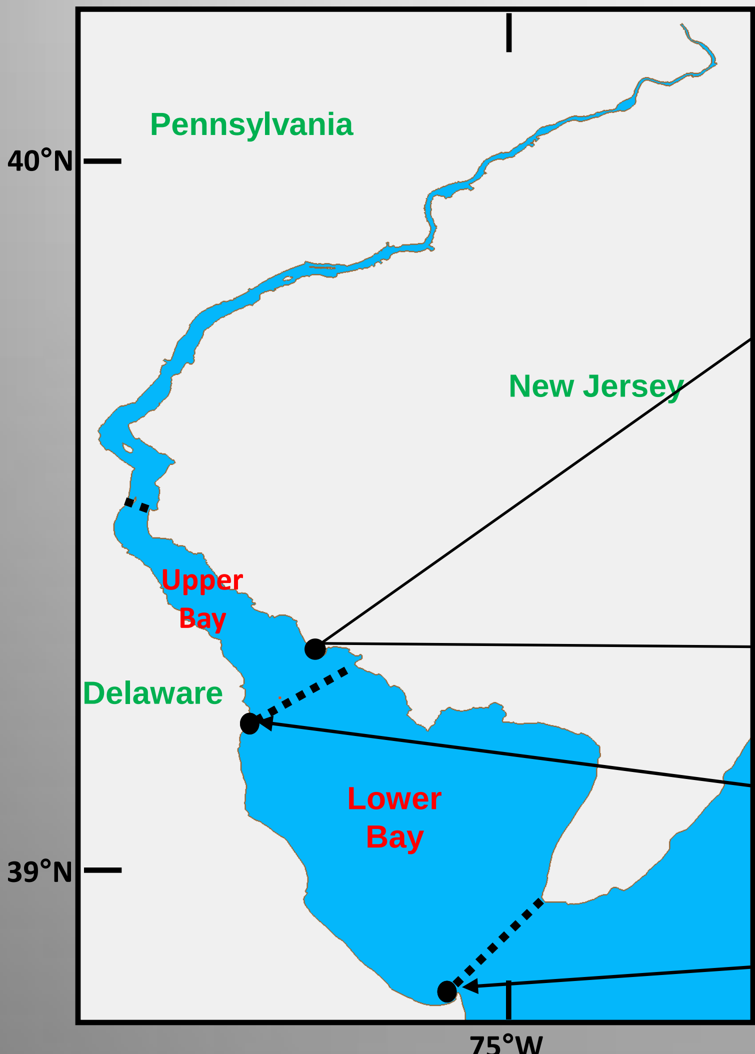
MHHW-MLLW Change Rate		
Location	Measured (Flick et al. 2003)	Modeled 0.5-0ka
10 Cape May, NJ		
(mm/100yr)	-51	8
(%/100yr)	-3	0.5
11 Lewes, DE		
(mm/100yr)	-33	5
(%/100yr)	-2	0.4

Implementation



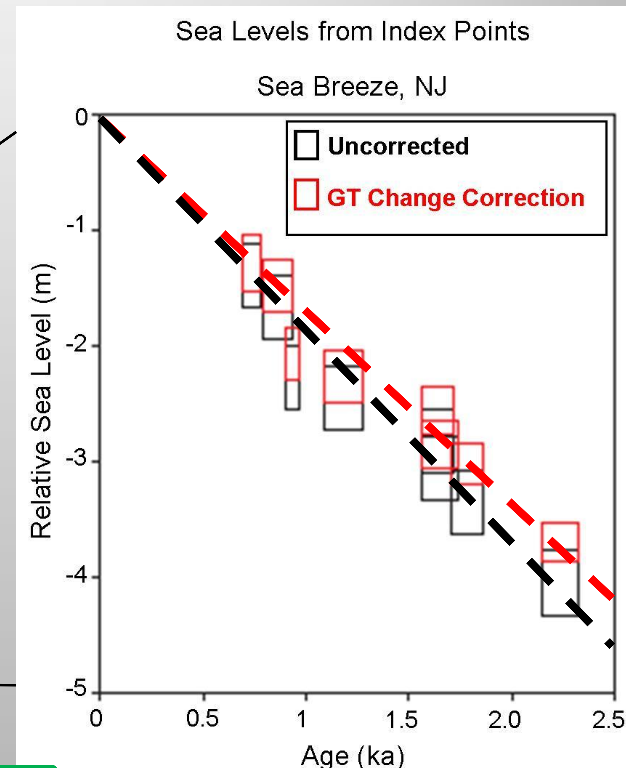
Holocene SLR rate (Engelhart et al. 2009)	Tidal Range Change (this study)
1.7 ± 0.2 mm/yr	Large GT Increase
1.2 ± 0.2 mm/yr	Small GT Decrease

Implementation



1.7 ± 0.2 mm/yr

1.2 ± 0.2 mm/yr



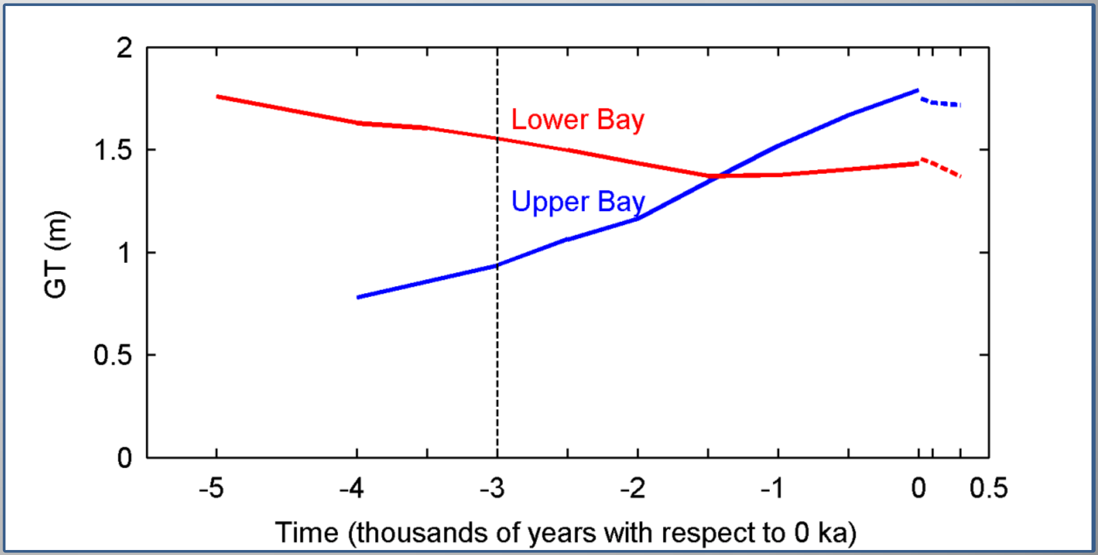
Nikitina et al. (in press)

Conclusions

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

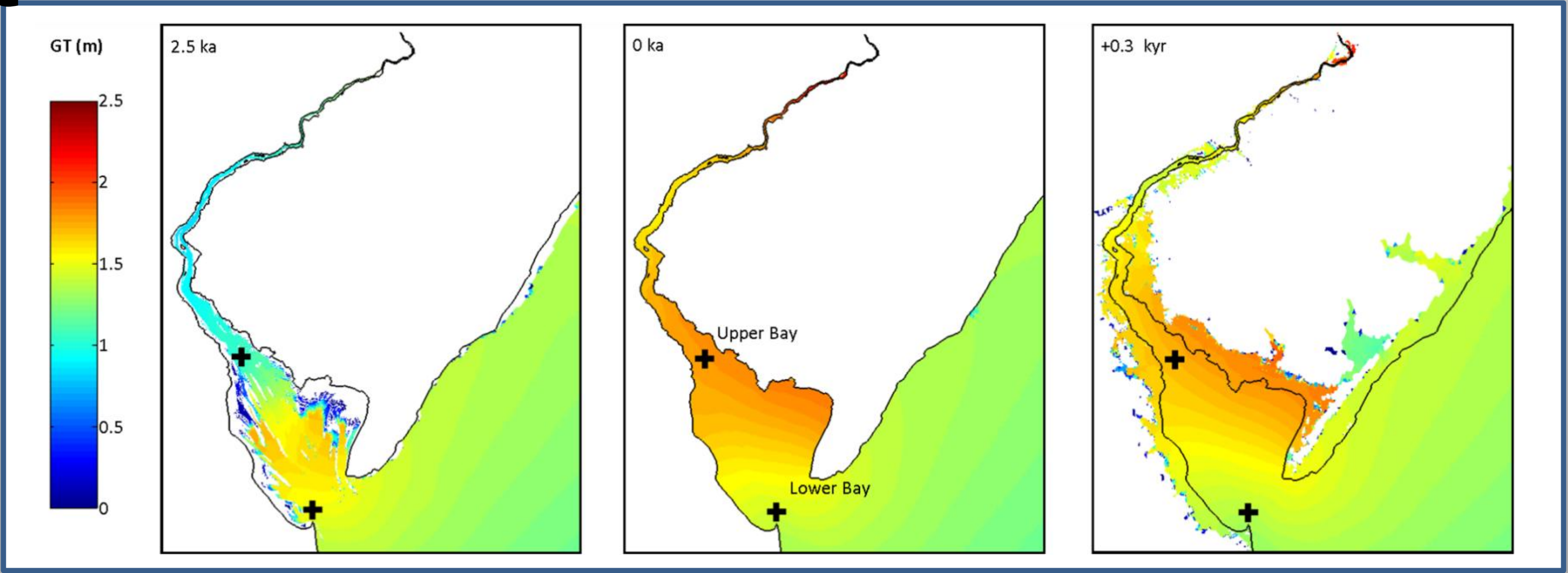
- GT in the upper bay has increased 80% since 3ka. GT in the lower bay has remained relatively constant. This difference may help account for differences in past SLR estimates in these locations.

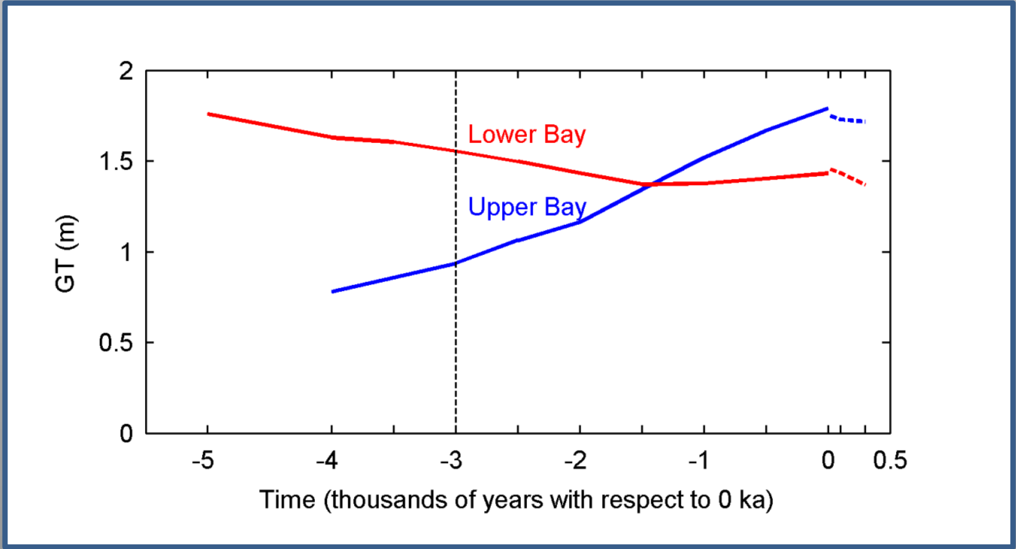
- Future GT decrease agrees with tidal gauge data trend. Changes are small relative to SLR.



(Hall et al., in press)

Questions


GT (m)
2.5
2
1.5
1
0.5
0
2.5 ka
0 ka
Upper Bay
Lower Bay
+0.3 kyr


Lower Bay
Upper Bay
GT (m)
2
1.5
1
0.5
0
-5
-4
-3
-2
-1
0
0.5
Time (thousands of years with respect to 0 ka)

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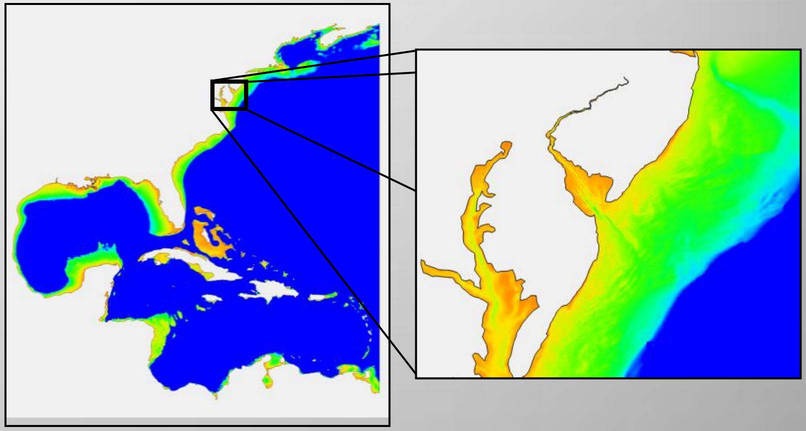
Additional Material

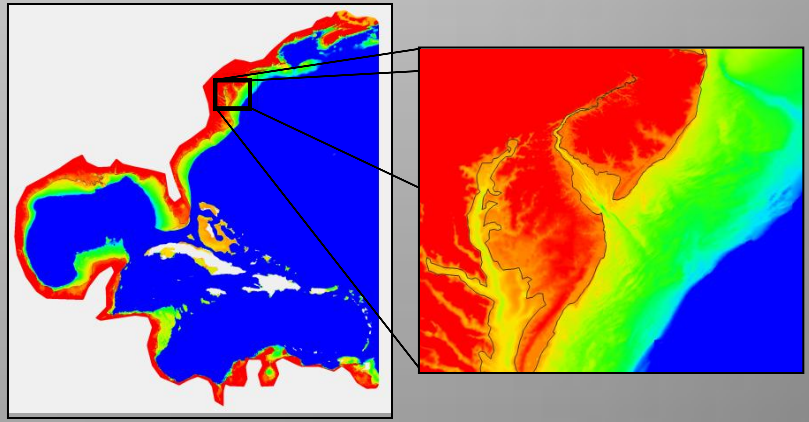
Accuracy

- 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

Holocene Run Grid



Future Run Grid



Accuracy

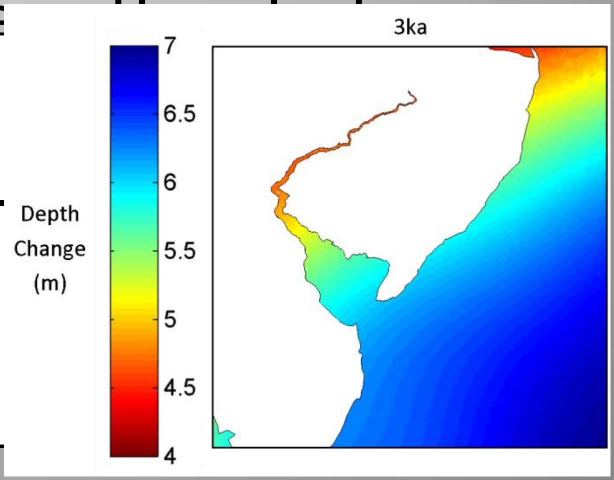
- Potentially significant processes not modeled:
  - River inflow
  - Estuarine evolution
  - Smaller temporal scale geomorphology (i.e. shoreline change)
  - Other human induced changes (dredging, coastal protection, etc.)
  - Baroclinic effects (i.e. changes in salinity)
- Use of GIA represents greater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

M_2 Amplitude Ratio

	Leorri et al. (2011)	This Study
% of Present Day	4 to 0ka	3 to 0ka
Upper Bay	0.50	0.51
Lower Bay	1.20	1.09



Comparison

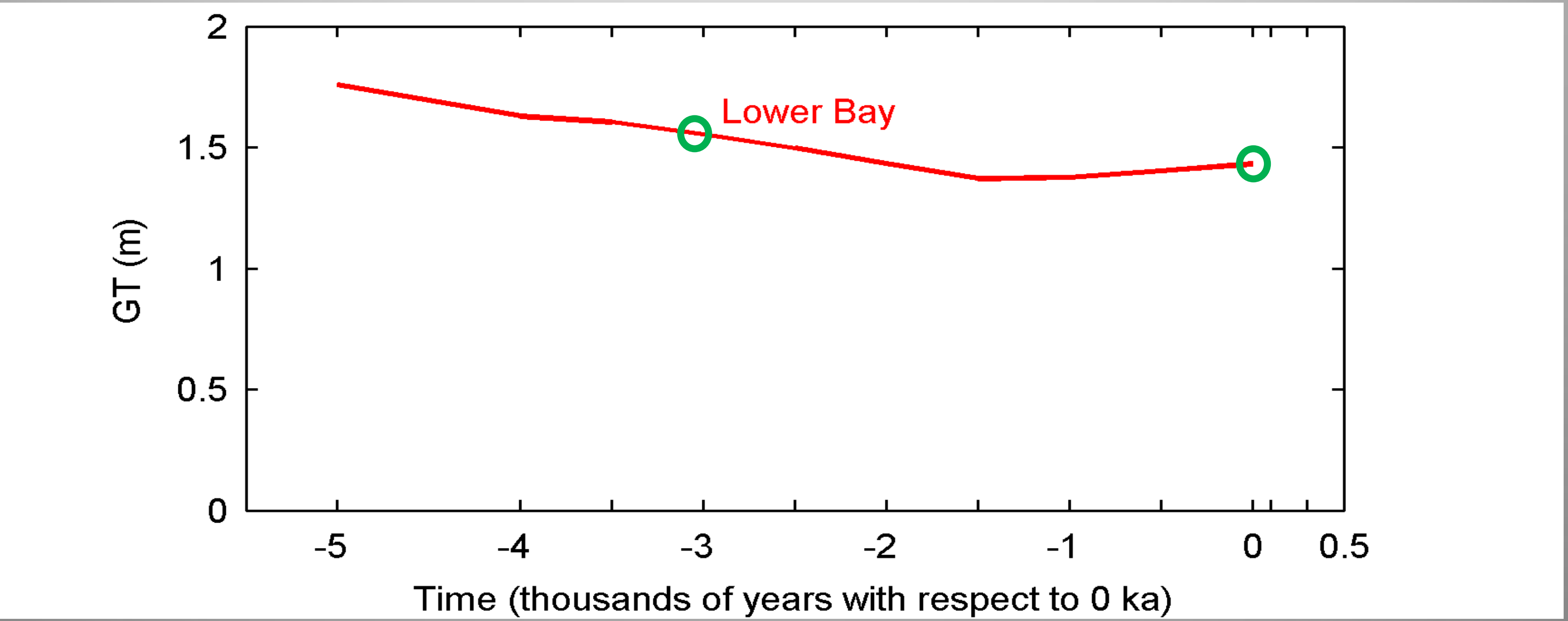
- Leorri et al. (2011) model of Delaware Bay
  - Their 4ka = 3ka in this study based on avg. depth change
  - Results similar for same depth changes
  - Spatially variable sea level change in this study vs.

	M_2 Amplitude Ratio		GT Ratio
	Leorri et al. (2011)	This Study	This Study
% of Present Day	4 to 0ka	3 to 0ka	3 to 0ka
Upper Bay	0.50	0.51	0.53
Lower Bay	1.20	1.09	1.09

Resonance

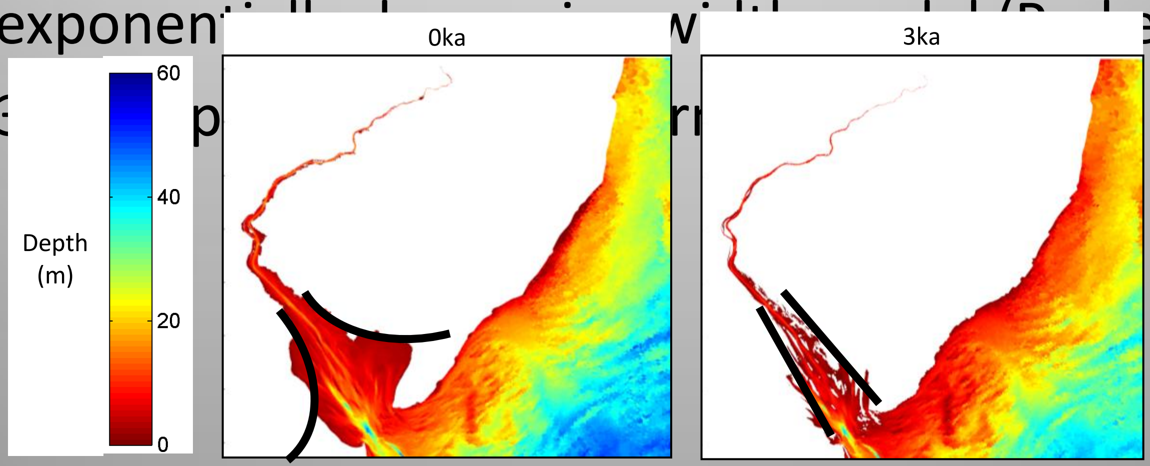
- Decreased GT in lower bay 3ka to 0ka
  - Resonance when $T_{tide}=T_{bay}$

T_{M2}; 12.5 hrs > $T_{bay\ 0ka}$↑; 9 hrs (Walters 1997)

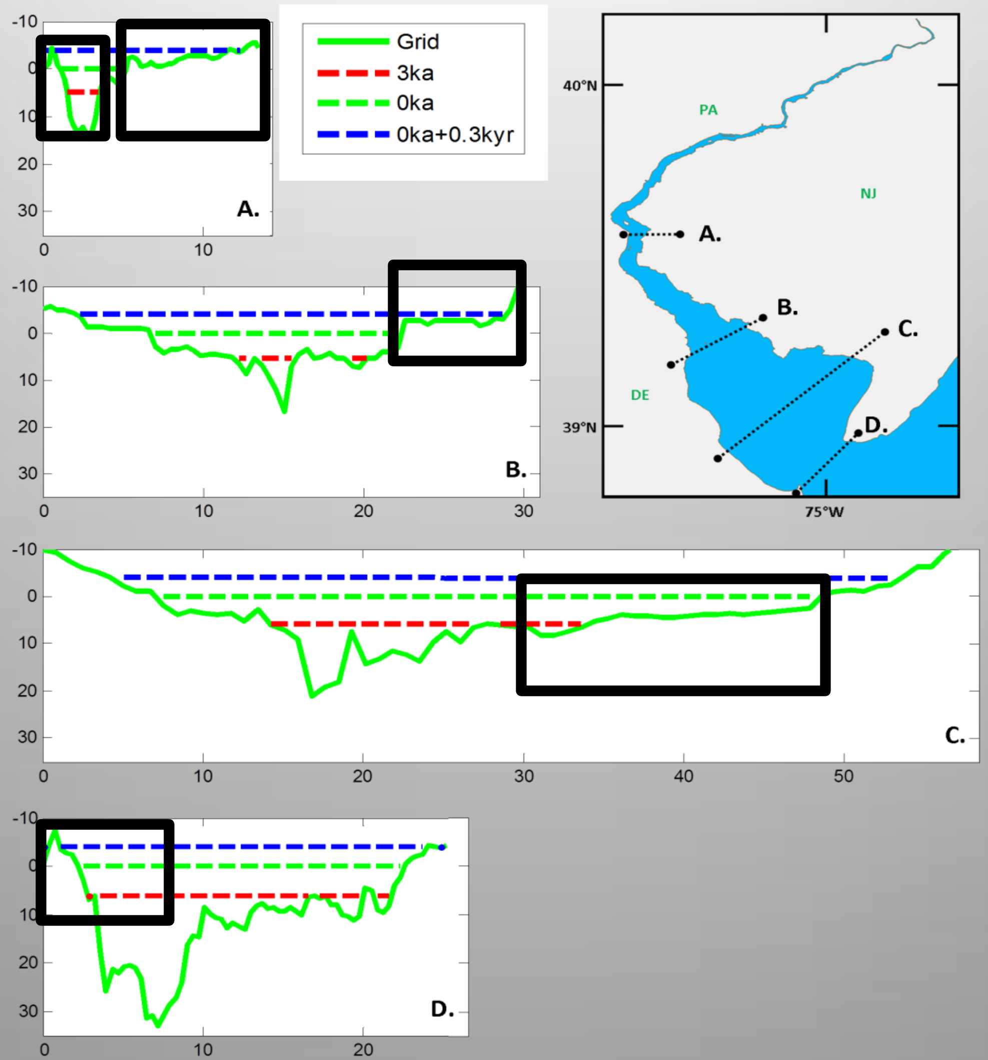


Bay Shape

- Rise in upper bay GT 3 to 0ka
  - Funnel shape
    - Higher tides in the narrow region
    - Delaware Bay 0ka tidal behavior estimated using exponent[illegible]w[illegible]er 1991)
    - 3[illegible]p[illegible]rr[illegible]



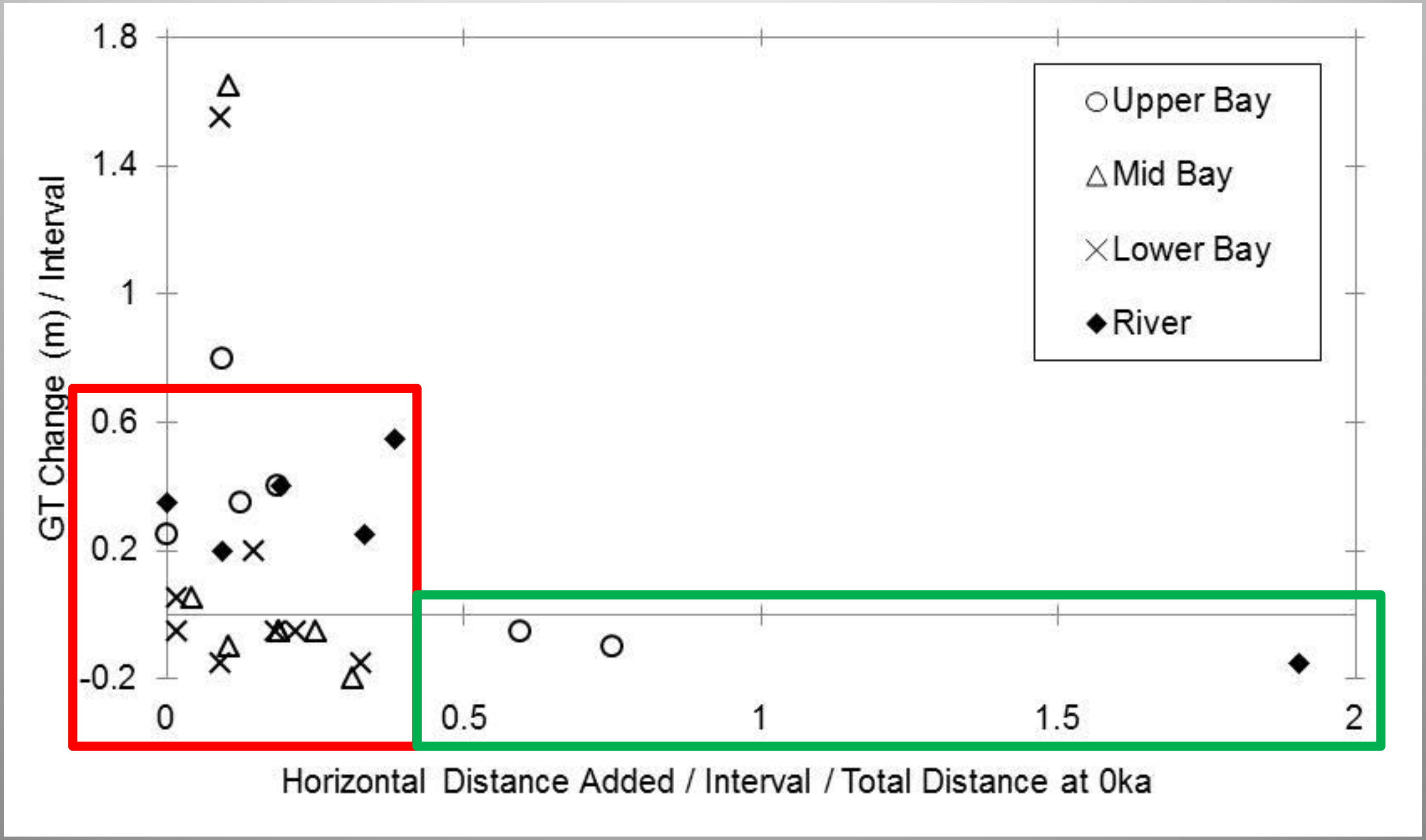
Shallow Water Damping



Bathy change with respect to 0ka condition (m)

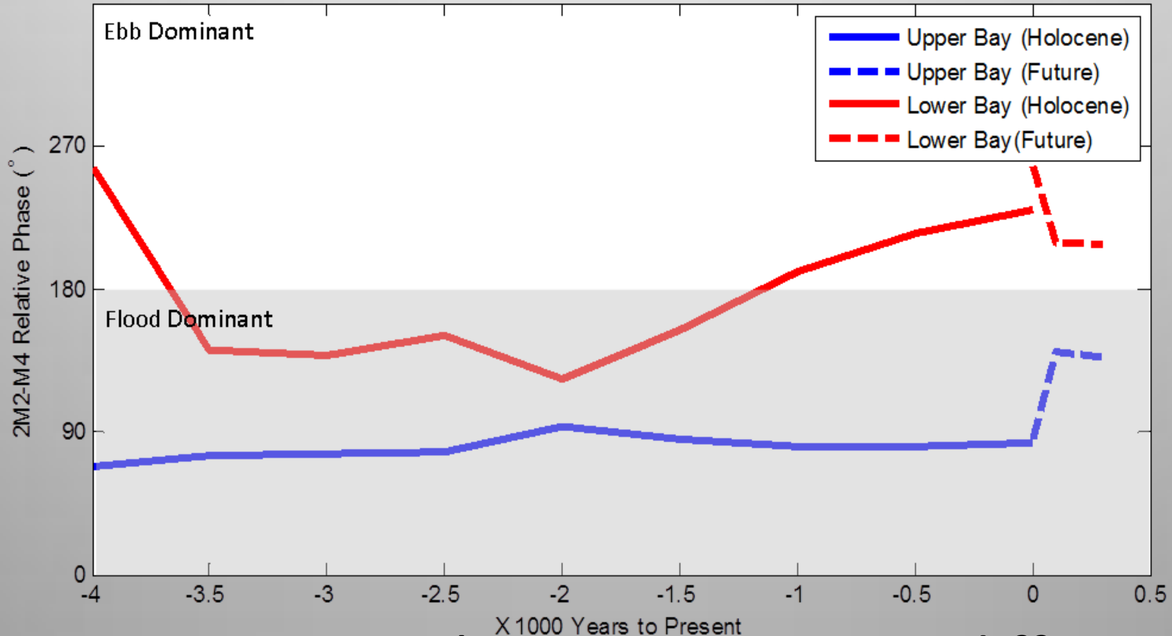
Horizontal Distance Across Section (km)

Shallow Water Damping



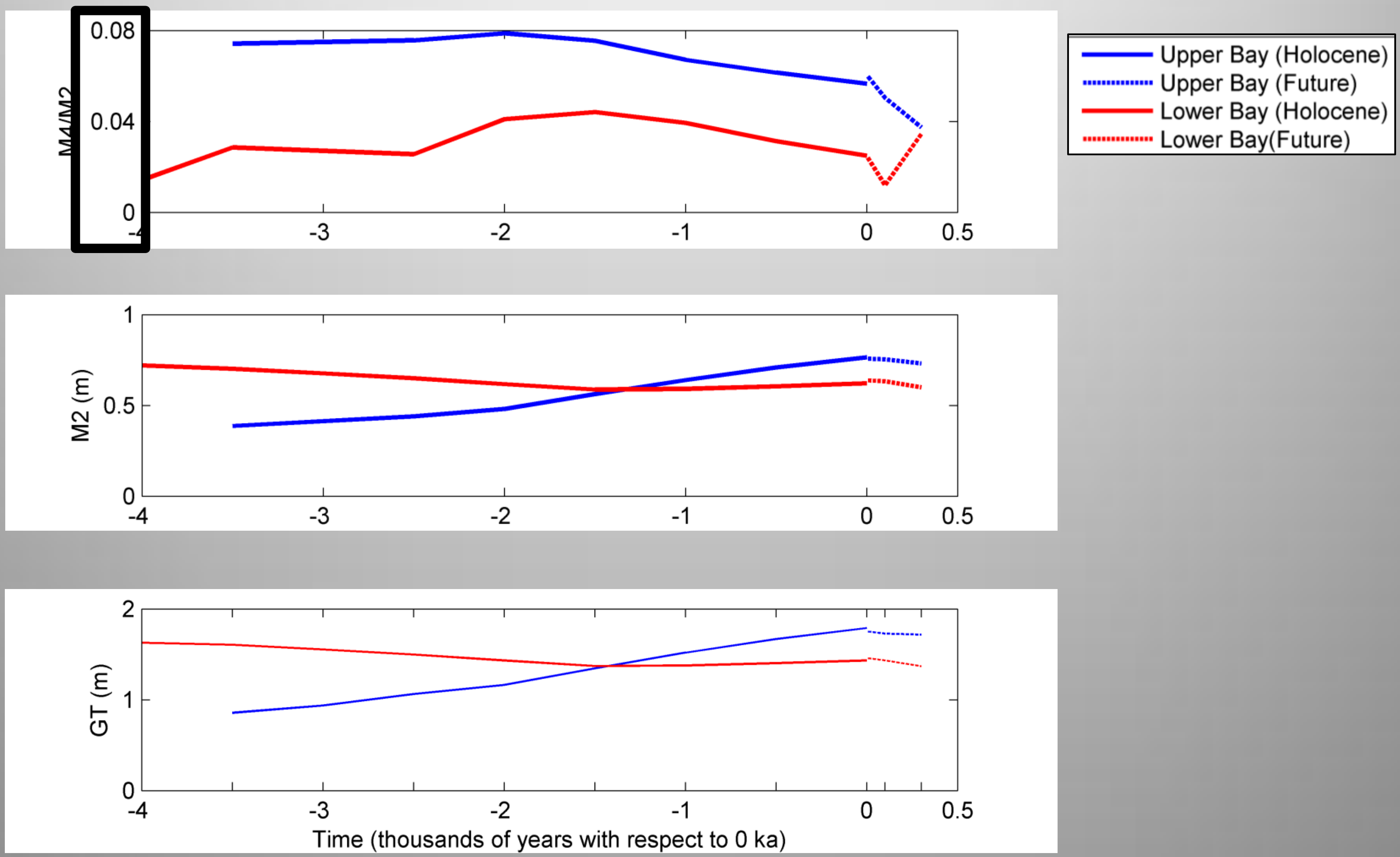
Discussion: Future Impacts

- Tidally driven sediment transport

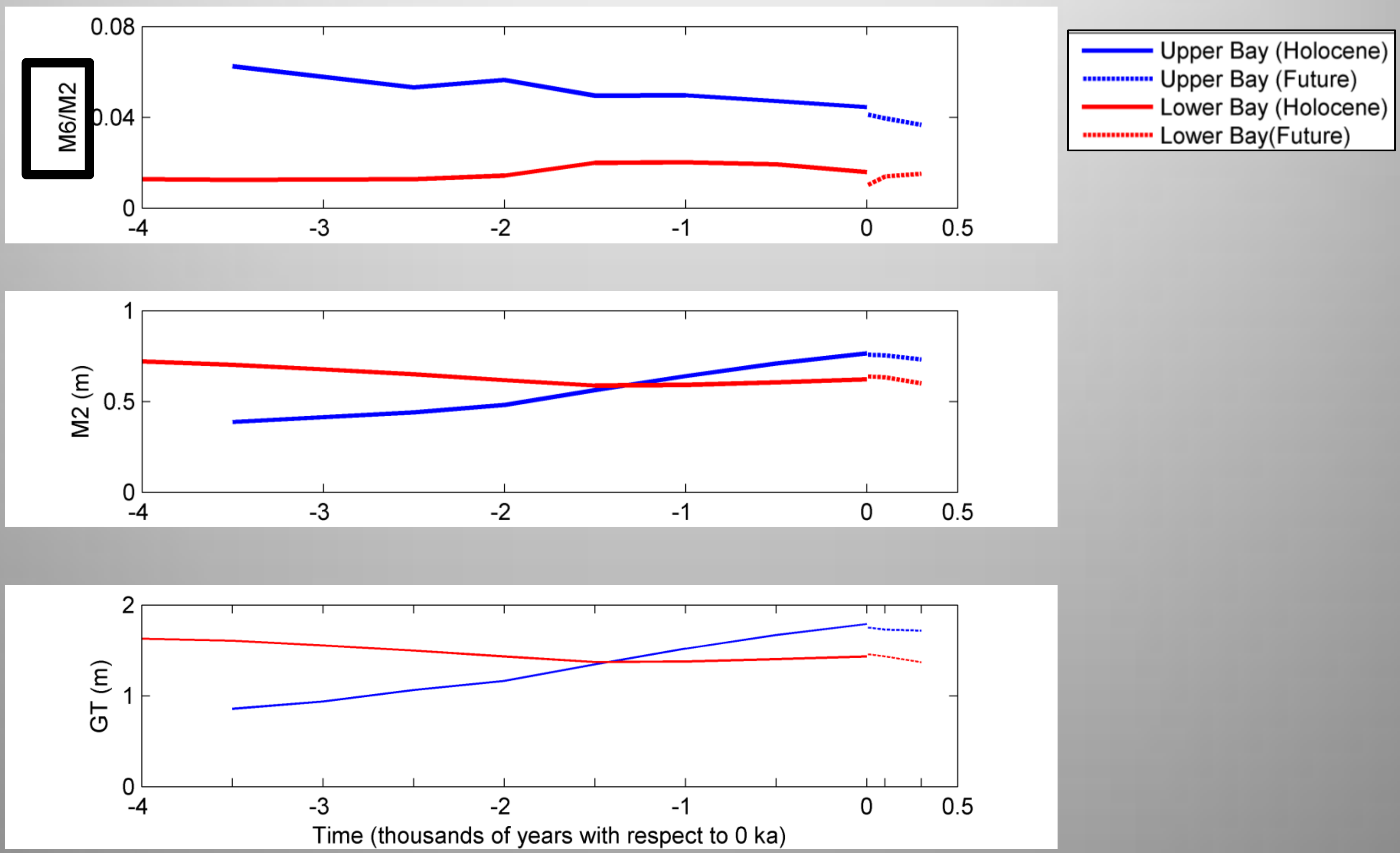


- Two SLR scenarios, nonlinear response to different levels

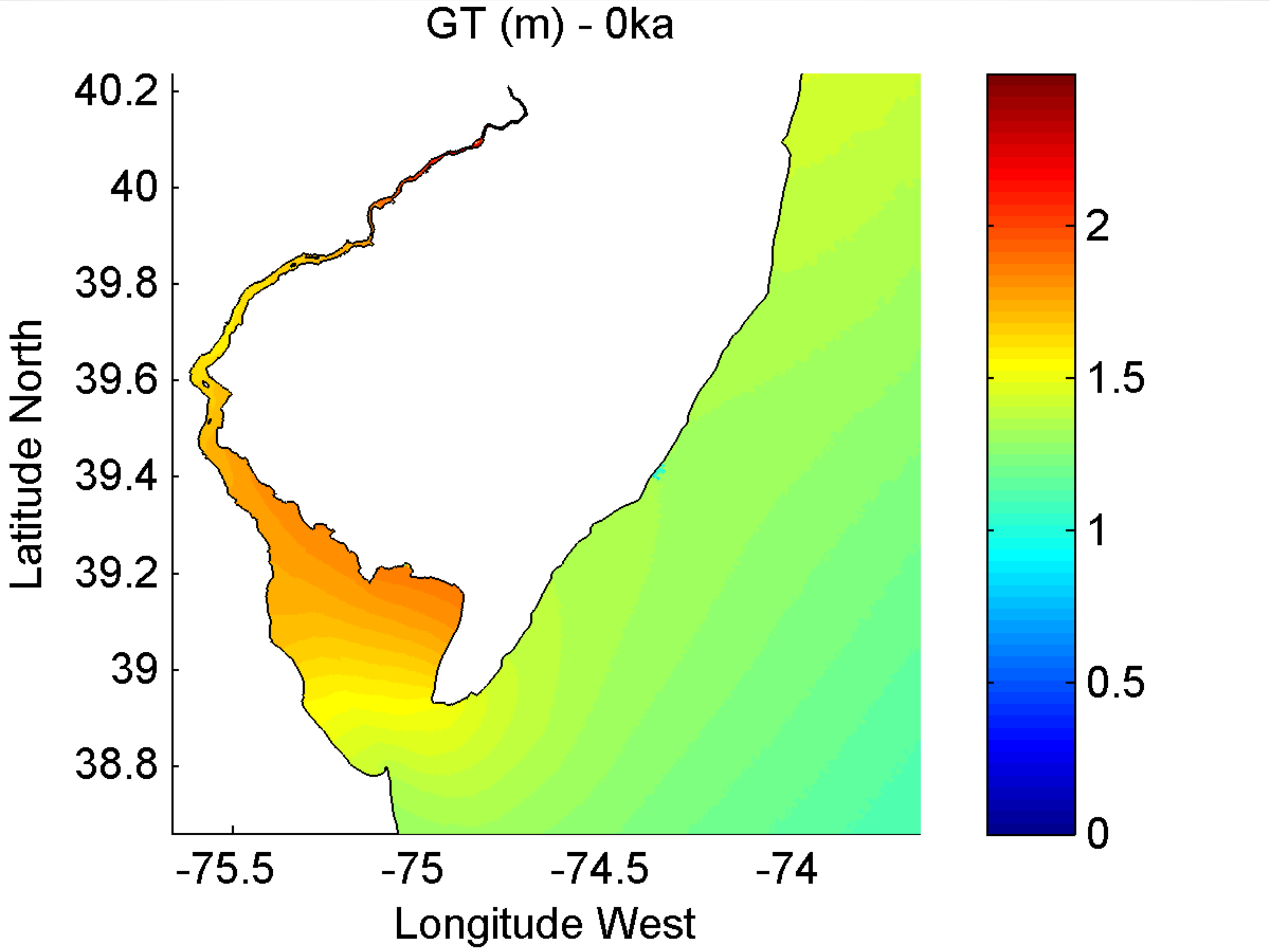
Discussion: Non-Linear Response



Discussion: Non-Linear Response



Local, Past



GT (m) - 0ka
Latitude North
Longitude West
40.2
40
39.8
39.6
39.4
39.2
39
38.8
-75.5
-75
-74.5
-74
2
1.5
1
0.5
0