Quantifying estuarine bathymetric changes under sea-level cycles: Insights from a moving boundary framework

Md Nurul Kadir[1], Jorge Lorenzo-Trueba[1]

1. Department of Earth and Environmental Studies, Montclair State University, Montclair, NJ

INTRODUCTION

☞Estuaries provide ecosystem services, support industry, food production, and recreation, and provide habitats for animal species.

☞Estuaries are highly dynamic, and their communities are vulnerable to natural hazards like sea-level rise, storms, and high river water discharge.

☞**Bathymetry is critical for determining flood risk in estuaries.**

☞**The interplay between bathymetric changes and sea level cycles during storm conditions is poorly quantified.**

OBJECTIVES

➢ To understand the interplay between bathymetric changes and the sea level cycle during a single storm event.

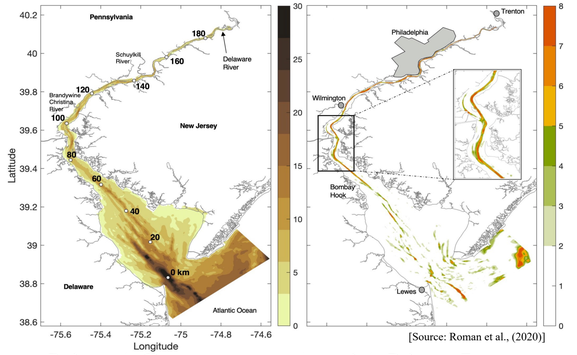
➢ To provide insights into the quantitative relationship between estuarine bathymetry and sea-level cycles.

MOTIVATION

Flooding of an Estuary depends on:

- River Discharge, Storm Surge
- Bathymetric change (Natural and anthropogenic)

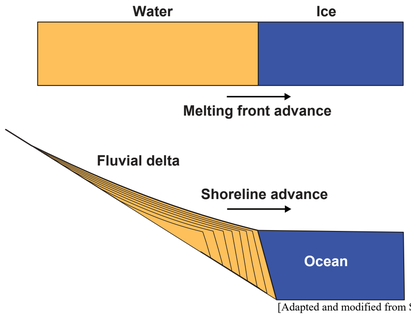
These changes can be complex and computationally expensive.



Bathymetric Changes over a centurion scale in Delaware Estuary

CONCEPTUAL FRAMEWORK

The Swenson Analogy: Melting vs. Shoreline Movement



[Adapted and modified from Swenson et al., (2000)]

$$\frac{\partial h}{\partial t} = -\frac{\partial q}{\partial x}, \quad r(t) \le x \le s(t)$$

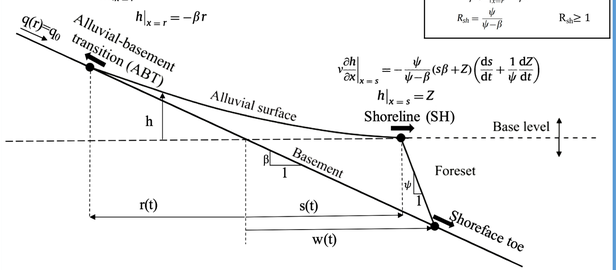
$$v\left.\frac{\partial h}{\partial x}\right|_{x=r} = -q_0$$

$$h|_{x=r} = -\beta r$$

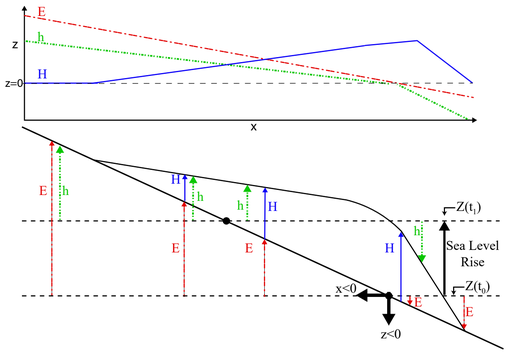
$$v\left.\frac{\partial h}{\partial x}\right|_{x=s} = -\frac{\psi}{\psi-\beta}(s\beta+Z)\left(\frac{ds}{dt}+\frac{1}{\psi}\frac{dZ}{dt}\right)$$

$$h|_{x=s} = Z$$

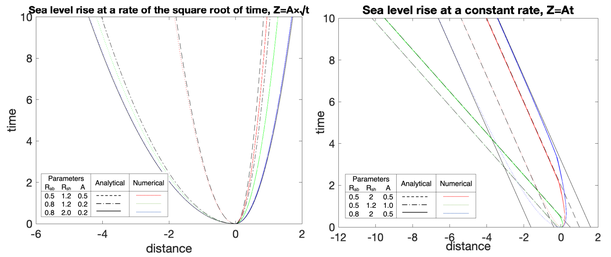
Dimensionless Parameters	Physical constrain
$R_{ab} = -\frac{1}{\beta}\frac{\partial h}{\partial x}\Big\|_{x=r} = \frac{q_0}{\beta v}$	$0<R_{ab}<1$
$R_{sh} = \frac{\psi}{\psi-\beta}$	$R_{sh}\ge 1$



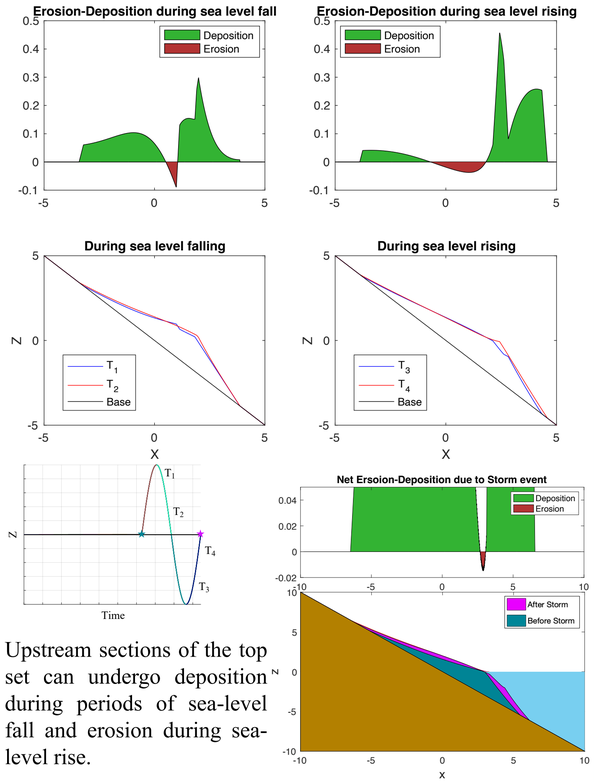
Moving boundary framework can be used to quantify the system: h = H+E-Z



MODEL VALIDATION



RESULTS



Upstream sections of the top set can undergo deposition during periods of sea-level fall and erosion during sea-level rise.

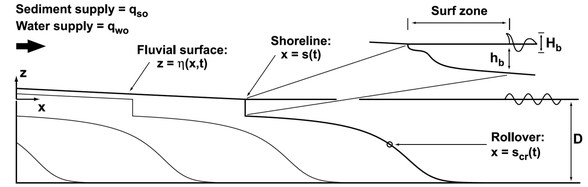
CONCLUSION

❑ We have applied a moving boundary framework to model estuarine evolution under sea-level cycles.

❑ We found counterintuitive bathymetric changes during sea-level rise and fall.

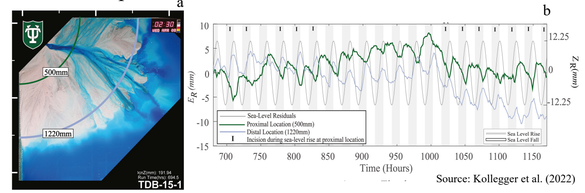
FUTURE WORK

- Incorporating Waves



A schematic diagram shows how the effect of the wave can change the shape of the estuary, taken from Swenson et al. (2005).

- Flume Experiment



Source: Kollegger et al. (2022)

a) Plan view of experiment b) Results from the experiment shows the relation between sea level cycle and elevation at different positions of the estuary

REFERENCES

- Anderson, W., Lorenzo-Trueba, J., & Voller, V. (2019). A geomorphic enthalpy method: Description and application to the evolution of fluvial-deltas under sea-level cycles. *Computers & geosciences*, *130*, 1-10.
- Kollegger, M., Lorenzo-Trueba, J., Fernandes, A. M., Singh, A., & Abeyta, A. (2022). Upstream Propagation of Sea-Level Signals in Fluvio-Deltaic Environments: Time-Lags and the Dynamics of the Fluvial Surface. *Geophysical Research Letters*, *49*(8), e2022GL097956.
- Pareja-Roman, L. F., Chant, R. J., & Sommerfield, C. K. (2020). Impact of historical channel deepening on tidal hydraulics in the Delaware Estuary. *Journal of Geophysical Research: Oceans*, *125*(12), e2020JC016256.
- Swenson, J. B., Paola, C., Pratson, L., Voller, V. R., & Murray, A. B. (2005). Fluvial and marine controls on combined subaerial and subaqueous delta progradation: Morphodynamic modeling of compound-clinoform development. *Journal of Geophysical Research: Earth Surface*, *110*(F2).
- Swenson, J. B., Voller, V. R., Paola, C., Parker, G., & Marr, J. G. (2000). Fluvio-deltaic sedimentation: A generalized Stefan problem. *European Journal of Applied Mathematics*, *11*(5), 433-452.