Sediment model manuscript

Christopher M. Tasich[a,1], Jonathan Gilligan[a,2], and Steven L. Goodbred[a,3]

[a]Vanderbilt University

This manuscript was compiled on November 3, 2020

Please provide an abstract of no more than 250 words in a single paragraph. Abstracts should explain to the general reader the major contributions of the article. References in the abstract must be cited in full within the abstract itself and cited in the text.

aggradation | sea level rise | tidal river management

This PNAS journal template is provided to help you write your work in the correct journal format. Instructions for use are provided below.

Note: please start your introduction without including the word "Introduction" as a section heading (except for math articles in the Physical Sciences section); this heading is implied in the first paragraphs.

Model design

Numerical model. We modeled tidal platform elevation (ζ) using a zero-dimensional mass balance model using the basic formulation provided by Krone (1) and further refined by Allen (2), French (3), and Temmerman et al. (4, 5). The rate of tidal platform elevation change is described as

$$\frac{d\zeta}{dt} = \frac{dS_M}{dt} + \frac{dS_O}{dt} + \frac{dP}{dt} + \frac{dM}{dt}, \quad [1]$$

where S_M is mineral sedimentation, S_O is organic matter sedimentation, P is compaction, and M is tectonic subsidence. Each term of equation 1 can be further expanded.

We approximate S_M as

$$S_M(t) = \int \frac{w_s C(t)}{\rho_b} dt, \quad [2]$$

where w_s is the characteristic settling velocity of a given grain size, $C(t)$ is the depth-averaged and time-varying sediment concentration in the water column, and ρ_b is the dry bulk density of the sediment. We assume there is no resuspension of mineral sediment which is consistent with Krone's (1) initial formulation.

w_s is calculated for a given grain size by using Stokes' law to determine the terminal velocity of a sphere falling through a fluid given by

$$w_s = \frac{2}{9}\frac{\rho_p - \rho_f}{\mu} g R^2 \quad [3]$$

where ρ_p is the mass density of the particle or grain, ρ_f is the mass density of the fluid, μ is the dynamic viscosity of the fluid, g is the acceleration due to gravity, and R is the radius of the grain. This is approximation for w_s is consistent with previous similar studies (2, 4, 5). We assume basic properties of water for ρ_f ($1000\,\mathrm{kg\,m^{-3}}$) and μ ($1 \times 10^{-3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$) for simplicity. Salinity does vary seasonally which will change these values, but had little affect on the model output.

We capture the temporal variation of $C(t)$ through the mass balance given as

$$\frac{d[h(t) - \zeta(t)]C(t)}{dt} = -w_s C(t) + C_{in}\frac{dh}{dt}, \quad [4]$$

where h is the height of the water column and C_{in} is the incoming suspended sediment concentration of the adjacent water column. We consider ζ to be a function of time and update it at every timestep which differs from previous studies (1–6) which only update ζ after every tidal cycle. The physical interpretation of equation 4 is that the first term is the mass flux above an area on the tidal platform, the second term is the mass flux extracted from the water column, and the third term is the mass flux from the adjacent water column. Further derivation of equation 4 results in

$$\frac{dC}{dt}[h(t) - \zeta(t)] = -w_s C(t) + [C_{in} - C(t)]\frac{dh}{dt} + C(t)\frac{d\zeta}{dt} \quad [5]$$

From equation 5, we can approximate the solution for concentration numerically.

Model inputs. We obtained model inputs from field measurements. We observed tidal height, grain size, suspended sediment concentration (SSC), and dry bulk density around Polder 32 over multiple field seasons from 2011 to 2016 (7–9).

For h, we extracted one year of contiguous tidal data from from a pressure sensor deployed within the tidal channel near Polder 32. We used the oce package in R (3.6.3) to create an idealized tidal curve from our data (10). The tidal curve was then shifted down so that mean higher high water would be 0.3 m above the Sundarban platform and 1.8 m above the polder surface (ζ). We replicated this tidal curve for each subsequent year for the length of the model run. Field observations confirm these benchmark elevation (7, 9, 11). In order to simulate sea level rise, the subsequent year tidal curves were increased at a linear rate of $2\,\mathrm{mm\,yr^{-1}}$ which is consistent with field observations.

For C_{in}, we use observed values of SSC from Hale et al. (8) that are characteristic of the tidal channels in the region. Similar to Temmerman et al. (4, 5), we scaled the observed tidal channel SSC by a factor as the flood waters are expected to have a lower SSC than the tidal channel due to lower flow velocities. For our preliminary study, we use a k-factor of

Significance Statement

Authors must submit a 1201-word maximum statement about the significance of their research paper written at a level understandable to an undergraduate educated scientist outside their field of speciality. The primary goal of the significance statement is to explain the relevance of the work in broad context to a broad readership. The significance statement appears in the paper itself and is required for all research papers.

Please provide details of author contributions here.

The authors declare no conflict of interest.

[1]To whom correspondence should be addressed. E-mail: chris.tasichvanderbilt.edu

0.7. In future model iterations, we will better explore this relationship and determine an appropriate k-factor.

For ρ, we used values derived from conversations with Steven Goodbred and Carol Wilson.

Materials and Methods

Please describe your materials and methods here. This can be more than one paragraph, and may contain subsections and equations as required.

Subsection for Method. Example text for subsection.

ACKNOWLEDGMENTS. Please include your acknowledgments here, set in a single paragraph. Please do not include any acknowledgments in the Supporting Information, or anywhere else in the manuscript.

1. R Krone, A Method for Simulating Marsh Elevations in *Coastal Sediments*. (American Society of Civil Engineers, New Orleans, Louisiana), pp. 316–323 (1987).
2. JRL Allen, Salt-marsh growth and stratification: A numerical model with special reference to the Severn Estuary, southwest Britain. *Mar. Geol.* **95**, 77–96 (1990).
3. JR French, Numerical simulation of vertical marsh growth and adjustment to accelerated sea-level rise, North Norfolk, U.K. *Earth Surf. Process. Landforms* **18**, 63–81 (1993).
4. S Temmerman, G Govers, P Meire, S Wartel, Modelling long-term tidal marsh growth under changing tidal conditions and suspended sediment concentrations, Scheldt estuary, Belgium. *Mar. Geol.* **193**, 151–169 (2003).
5. S Temmerman, G Govers, S Wartel, P Meire, Modelling estuarine variations in tidal marsh sedimentation: Response to changing sea level and suspended sediment concentrations. *Mar. Geol.* **212**, 1–19 (2004).
6. J French, Tidal marsh sedimentation and resilience to environmental change: Exploratory modelling of tidal, sea-level and sediment supply forcing in predominantly allochthonous systems. *Mar. Geol.* **235**, 119–136 (2006).
7. LW Auerbach, et al., Flood risk of natural and embanked landscapes on the Ganges–Brahmaputra tidal delta plain. *Nat. Clim. Chang.* **5**, 153–157 (2015).
8. R Hale, R Bain, S Goodbred Jr., J Best, Observations and scaling of tidal mass transport across the lower Ganges–Brahmaputra delta plain: Implications for delta management and sustainability. *Earth Surf. Dyn.* **7**, 231–245 (2019).
9. RP Hale, CA Wilson, EJ Bomer, Seasonal Variability of Forces Controlling Sedimentation in the Sundarbans National Forest, Bangladesh. *Front. Earth Sci.* **7**, 211 (2019).
10. D Kelley, C Richards, Oce: Analysis of Oceanographic Data (2020).
11. EJ Bomer, CA Wilson, RP Hale, ANM Hossain, FMA Rahman, Surface elevation and sedimentation dynamics in the Ganges-Brahmaputra tidal delta plain, Bangladesh: Evidence for mangrove adaptation to human-induced tidal amplification. *CATENA* **187**, 104312 (2020).