Supporting Materials for

The Effects of Intra-Annual Variability of River Discharge on the Spatio-Temporal Dynamics of Saltmarsh Vegetation at River Mouth Bar: Insights from an Ecogeomorphological Model

S. Zhang[1, 2], W. Gao[1, 2, 3], D. Shao[1, 2, 4 *], W. Nardin[5], C. Gualtieri[6], and T. Sun[1, 2 *]

1. Normalized average velocity and relative sediment concentration

Vegetation that develops on river mouth bar are strongly influenced by continual process of geomorphology and hydrodynamics during river flood stage (Carle et al., 2015; Carle and Sasser, 2016). In this study, velocity and elevation are two factors controlling vegetation distribution (Equations 4 to 6, in manuscript). Therefore, we used normalized average velocity v^* and relative sediment concentration S^* at the river outlet as proxies of the "velocity" and "erosion" stresses of plant growth to evaluate the response of vegetation to unsteady river discharge during the high flow period. Higher v^* indicates that vegetation is more influenced by velocity. Higher S^* indicates mouth bar tends to accrete rather than be eroded.

$$v^* = \frac{v - v_{amin}}{v_{amax} - v_{amin}} \tag{1}$$

$$S^* = \frac{S}{S_e} \tag{2}$$

where v is cross section average velocity at river outlet during the period of high flow (m/s). v_{amax} is the maximum velocity threshold for local adult vegetation (m/s); v_{amin} is the minimum velocity threshold for local adult vegetation (m/s); S and S_e are sediment concentration (kg/m^3) and equilibrium sediment concentration (kg/m^3), respectively, during the period of high flow at the river outlet.

The equilibrium sediment concentration Se is calculated using following equations.

$$Q_s = \frac{0.05B}{D_{50}R^2\sqrt{g}} \cdot \frac{v^5}{C^3} \tag{3}$$

$$S_e = \frac{\rho_s Q_S}{Q_w} \tag{4}$$

where Q_s is sediment load (m^3/s); B is river outlet width (m); D_{50} is median grain size (μm); R (= 1.65) is submerged specific density of sediment; g (= 9.81) is the acceleration of gravity (m/s^2); v is cross section average velocity at river outlet during the period of high flow (m/s); C is Chezy coefficient (m$^{1/2}$/s). The values of Chezy coefficient are between 60 and 90. ρ_s (= 2650) is sediment density (kg/m^3); Q_w is cross section average discharge at river outlet.

Normalized average velocity and relative sediment concentration in three real cases were estimated as follows.

1.1. Yellow River Estuary

The sediment load and river discharge data come from Lijin Station. The water-sediment regulation scheme (WSRS) was conducted from July 6th to July 26th in 2018. Therefore, the data measured in July was used. As reported by Yellow River Sediment Bulletin 2018 (Yellow River Conservancy Commission, 2019), the discharge was measured at 6.723 × 10^9 m^3 and suspended sediment load was 14,000 × 10^4 t. The water depth and width at the river mouth are 4 m (Fan, 2019) and 800 m (measuring from the remote sensing image), respectively. The bed material of the lower Huanghe consists of silt and very fine sand, with a median grain diameter (D50) of ~70 mm (Ma et al., 2017). As such normalized average velocity v^* and relative sediment concentration S^* at Yellow River outlet was estimated as follows:

Cross section average velocity and sediment concentration at river outlet:

$v = 6.723 \times 10^9 / (24 \times 60 \times 60 \times 30) / 800 / 4 = 0.8105$ m/s

$S = (14{,}000 \times 10^4 \times 1000) / (67.23 \times 10^8) = 20.82$ kg/m^3

Hence, normalized average velocity v^* was calculated as follow:

$v^* = (0.8105 – 0.4) / (0.56 – 0.4) = 2.5656$

The sediment loads were calculated using maximum and minimum Chezy coefficient values.

$Q_{s1} = 0.05 \times 800 / (0.00007 \times 1.65^2 \times 9.81^{0.5}) \times 0.8105^5 / 60^3 = 0.1085$ m^3/s

$Q_{s2} = 0.05 \times 800 / (0.00007 \times 1.65^2 \times 9.81^{0.5}) \times 0.8105^5 / 90^3 = 0.0322$ m^3/s

The equilibrium sediment concentration was calculated as follow:

$S_{e1} = 2650 \times 0.1085 / (67.2 \times 10^8 / 24 / 60 / 60 / 30) = 0.1109$ kg/m^3

$S_{e2} = 2650 \times 0.0322 / (67.2 \times 10^8 / 24 / 60 / 60 / 30) = 0.0329$ kg/m^3

Relative sediment concentration S^* at Yellow River outlet was estimated as follows:

$S^*_1 = 20.82 / 0.1109 = 187.7367$

$S^*_2 = 20.82 / 0.0329 = 632.8267$

1.2. Wax Lake Delta

In May 2011, high rainfall in the upper Mississippi River basin combined with spring snowmelt generated a record flood on the lower Mississippi River (Carle et al., 2015). The flood lasted almost two months. The monthly river discharge at upstream outlet of the Wax Lake Delta in May and June were 6,935 m^3/s and 6,309 m^3/s, respectively (USGS Water Data for the Nation, 2023). The suspended sediment concentration was estimated using the empirical flow-sediment relationship (Olliver et al., 2020).

$S = 0.0003 Q_w^{0.8618}$

The water depth and width at the river mouth are 15 m (Xing et al., 2017) and 350 m (measuring from the remote sensing image), respectively. The median grain diameter (D50) was 105 *um* (Shaw et al., 2013). As such normalized average velocity v^* and relative sediment concentration S^* at Wax Lake Delta outlet was estimated as follows:

Cross section average velocity and sediment concentration at river outlet:

$v_1 = 6935 / 350 / 12.5 = 1.5851$ m/s

$v_2 = 6309 / 350 / 12.5 = 1.4421$ m/s

$S_1 = 0.0003 \times 6935^{0.8618} = 0.6128$ kg/m^3

$S_2 = 0.0003 \times 6309^{0.8618} = 0.5648$ kg/m^3

Hence, normalized average velocity v^* was calculated as follow:

$v^*_1 = (1.5851 – 0.4) / (0.56 – 0.4) = 7.407$

$v^*_2 = (1.4421 – 0.4) / (0.56 – 0.4) = 6.513$

The sediment loads were calculated using maximum and minimum Chezy coefficient values.

$Q_{s1} = 0.05 \times 350 / (0.000105 \times 1.65^2 \times 9.81^{0.5}) \times 1.5851^5 / 60^3 = 0.9055$ m^3/s

$Q_{s2} = 0.05 \times 350 / (0.000105 \times 1.65^2 \times 9.81^{0.5}) \times 1.5851^5 / 90^3 = 0.2683$ m^3/s

$Q_{s3} = 0.05 \times 350 / (0.000105 \times 1.65^2 \times 9.81^{0.5}) \times 1.4421^5 / 60^3 = 0.5644$ m^3/s

$Q_{s4} = 0.05 \times 350 / (0.000105 \times 1.65^2 \times 9.81^{0.5}) \times 1.4421^5 / 90^3 = 0.1672$ m^3/s

The equilibrium sediment concentration was calculated as follow:

$S_{e1} = 2650 \times 0.9055 / 6935 = 0.3460$ kg/m^3

$S_{e2} = 2650 \times 0.2683 / 6935 = 0.1025$ kg/m^3

$S_{e3} = 2650 \times 0.5644 / 6309 = 0.2371$ kg/m^3

$S_{e4} = 2650 \times 0.1672 / 6309 = 0.0702$ kg/m^3

Relative sediment concentration S^* at Wax Lake Delta outlet was estimated as follows:

$S^*_1 = 0.6128 / 0.3460 = 1.7711$

$S^*_2 = 0.6128 / 0.1025 = 5.9785$

$S^*_3 = 0.5648 / 0.2371 = 2.3832$

$S^*_4 = 0.5648 / 0.0702 = 8.0446$

1.3. Jiuduansha of the Yangtze River Estuary

The river discharge and sediment load are measured at the Datong Station upstream of the Yangtze River Estuary. The flood occurred in July, 2016. As reported by Changjiang Sediment Bulletin 2016 (Changjiang Water Resources Commission, 2017), the river discharge and sediment load in July of 2016 were 177.5×10^9 m^3 and 36.78×10^6 t, respectively. The water depth and width at the river mouth are 15 m (Bao, 2017; Zhou et al., 2019) and 4500 m (measuring from the remote sensing image), respectively. The median grain diameter (D50) was 76 *um* (Zhang et al., 2018). As reported by Guo (2013), Jiuduasha was located in turbidity maximum zone of Yangtze River Estuary. The sediment concentration in Jiuduansha was much higher than that in other parts of Yangtze River Estuary (1.32 ~ 1.73 kg/m^3 vs 0.207 kg/m^3). The range of observed velocity was between 0.96 to 1.41 m/s. Therefore, the observed sediment concentration and velocity was used to calculate relative sediment concentration S^* normalized average velocity v^*. As such normalized average velocity v^* and relative sediment concentration S^* at Jiuduansha of Yangtze River Estuary was estimated as follows:

Normalized average velocity v^* was calculated as follow:

$v^*_1 = (0.96 – 0.4) / (0.56 – 0.4) = 3.5$

$v^*_2 = (1.41 – 0.4) / (0.56 – 0.4) = 6.3125$

The sediment loads were calculated using maximum and minimum Chezy coefficient values.

$Q_{s1} = 0.05 \times 4500 / (0.000076 \times 1.65^2 \times 9.81^{0.5}) \times 0.96^5 / 60^3 = 1.3106$ m^3/s

$Q_{s2} = 0.05 \times 4500 / (0.000076 \times 1.65^2 \times 9.81^{0.5}) \times 0.96^5 / 90^3 = 0.3883$ m^3/s

$Q_{s3} = 0.05\times4500/(0.000076\times1.65^2\times9.81^{0.5})\times1.41^5/60^3=8.9579$ m^3/s

$Q_{s4} = 0.05\times4500/(0.000076\times1.65^2\times9.81^{0.5})\times1.41^5/90^3=2.6542$ m^3/s

The equilibrium sediment concentration was calculated as follow:

$S_{e1} = 2650 \times 1.3106 / (4500 \times 15 \times 0.96) = 0.0536$ kg/m^3

$S_{e2} = 2650 \times 0.3883 / (4500 \times 15 \times 0.96) = 0.0159$ kg/m^3

$S_{e3} = 2650 \times 8.9579 / (4500 \times 15 \times 1.41) = 0.2494$ kg/m^3

$S_{e4} = 2650 \times 2.6542 / (4500 \times 15 \times 1.41) = 0.0739$ kg/m^3

Relative sediment concentration S^* at Jiuduansha was estimated as follows:

$S^*_1 = 1.32 / 0.0536 = 24.6269$

$S^*_2 = 1.32 / 0.0159 = 83.0189$

$S^*_3 = 1.73 / 0.2494 = 6.9367$

$S^*_4 = 1.73 / 0.0739 = 23.41$

Table S1. Scenarios of Unsteady River Discharges in Delft3D Model

	Scenario	High Flow (m^3/s)	The Onset of High Flow (Julian day)	Duration of High Flow (d)	Sediment Concentration (kg/m^3)
Group I	R1S1T1D1	2000	226	20	2
	R2S2T1D1	3000	226	20	0.5
	R2S1T1D1	3000	226	20	2
	R1S1T1D2	2000	226	40	2
	R2S2T1D2	3000	226	40	0.5
	R2S1T1D2	3000	226	40	2
Group II	R1S1T2D1	2000	76	20	2
	R2S2T2D1	3000	76	20	0.5
	R2S1T2D1	3000	76	20	2
	R1S1T2D2	2000	76	40	2
	R2S2T2D2	3000	76	40	0.5
	R2S1T2D2	3000	76	40	2

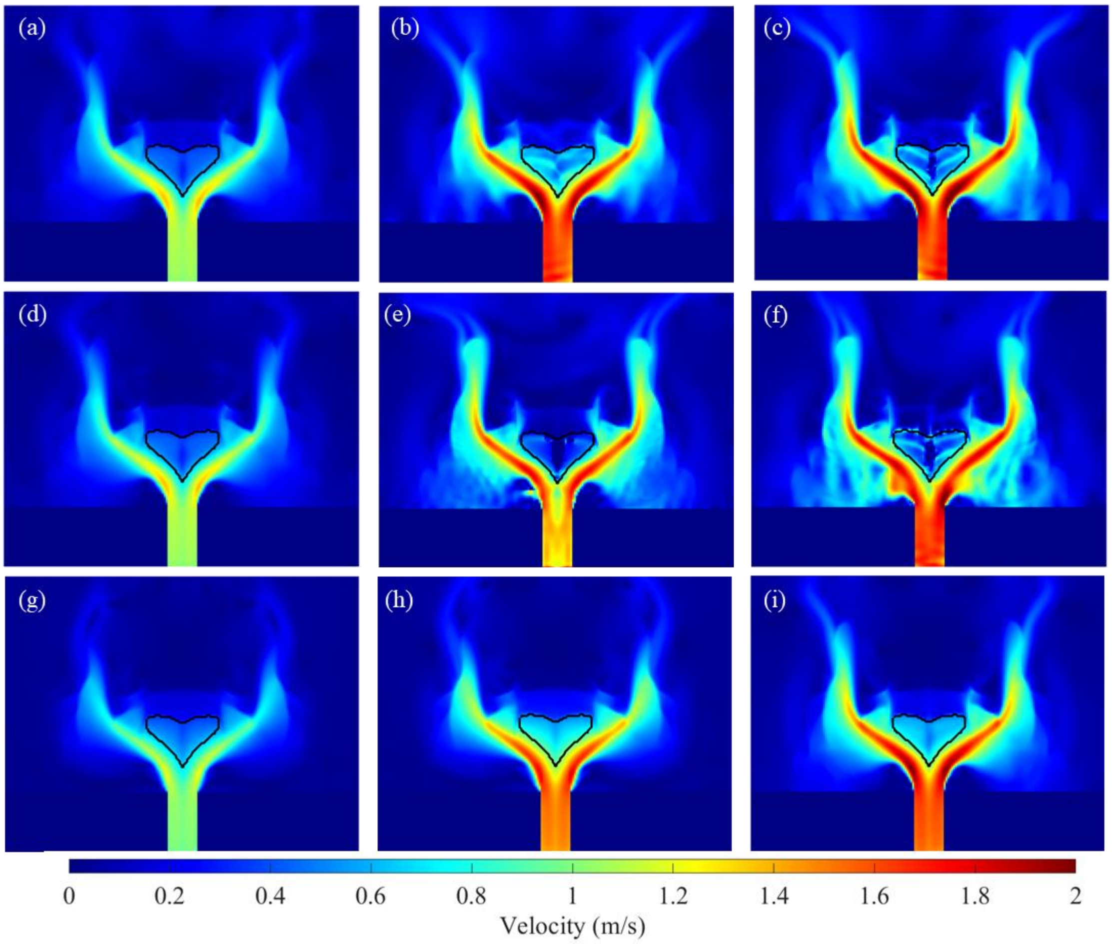

Figure S1. The comparison of velocity during high flow period for different scenarios: (a) R1S1T2D1; (b) R2S1T2D1; (c) R2S2T2D1; (d) R1S1T2D2; (e) R2S1T2D2; (f) R2S2T2D2; (g) R1S1T1D1; (g) R1S1T1D1; (h) R2S1T1D1; (i) R2S2T1D1. The black line is mouth bar outline before high flow stage. For (a) ~ (f), the velocity on 80th Julian Day was chosen. For (g) ~ (i), the velocity on 230th Julian Day was chosen.

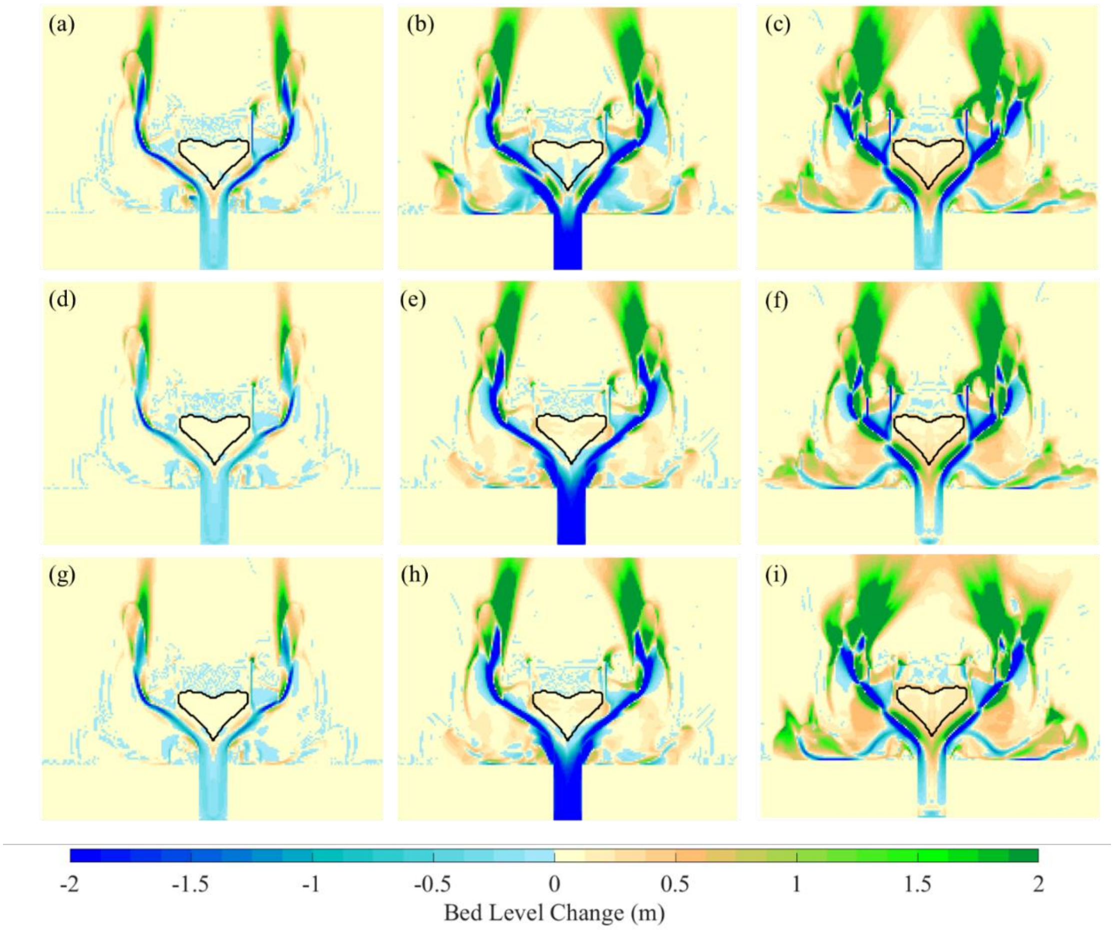

Figure S2. The comparison of elevation changes after high flow between different scenarios: (a) R1S1T2D1; (b) R2S1T2D1; (c) R2S2T2D1; (d) R1S1T2D2; (e) R2S1T2D2; (f) R2S2T2D2; (g) R1S1T1D1; (g) R1S1T1D1; (h) R2S1T1D1; (i) R2S2T1D1. The black line is mouth bar outline before high flow stage

Reference

Bao, D.Y. (2017). The effects of morphological changes in the Changjiang Estuary on salinity intrusion. M.S. Dissertation, State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, China.

Carle, M.V. and Sasser, C.E. (2016). Productivity and resilience: Long-term trends and storm-driven fluctuations in the plant community of the accreting Wax Lake Delta. Estuaries and Coasts, 39, 406–422.

Carle, M.V., Sasser, C.E. and Roberts, H.H. (2015). Accretion and vegetation community change in the Wax Lake Delta following the historic 2011 Mississippi River Flood. Journal of Coastal Research, 313, 569-587.

Changjiang Water Resources Commission (2017). Changjiang Sediment Bulletin 2016. Retrieved from http://www.cjw.gov.cn/ (in Chinese)

Fan, Y.S. (2019). Seabed erosion and its mechanism in the littoral area of Yellow River Delta. Ph.D. Dissertation, State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, China.

Guo, X.B. (2013). Characteristics of recent tidal current and suspended sediment concentration distribution and sediment transport in the Yangtze Estuary. M.S. Dissertation, State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, China.

Ma, H.B., Nittrouer, J.A., Naito, K., Fu, X.D., Zhang, Y.F., Moodie, A.J., Wang, Y.J., Wu, B.S. and Parker, G. (2017). The exceptional sediment load of fine-grained dispersal systems: Example of the Yellow River, China. Sci. Adv. , 3.

Olliver, E.A., Edmonds, D.A. and Shaw, J.B. (2020). Influence of floods, tides, and vegetation on sediment retention in Wax Lake Delta, Louisiana, USA. Journal of Geophysical Research: Earth Surface, 125(1).

Shaw, J.B., Mohrig, D. and Whitman, S.K. (2013). The morphology and evolution of channels on the Wax Lake Delta, Louisiana, USA. Journal of Geophysical Research: Earth Surface, 118, 1562-1584.

USGS Water Data for the Nation (2023). Retrieved from https://waterdata.usgs.gov/

Xing, F., James P.M. Syvitski, Albert J. Kettner, Ehab A. Meselhe, John H. Atkinson and Khadka, A.K. (2017). Morphological responses of the Wax Lake Delta, Louisiana, to Hurricanes Rita. lem Sci Anth, 5(80), 1-20.

Yellow River Conservancy Commission (2019). Yellow River Sediment Bulletin 2018. Retrieved from http://www.yrcc.gov.cn/ (in Chinese)

Zhang, X., Fagherazzi, S., Leonardi, N. and Li, J. (2018). A Positive Feedback Between Sediment Deposition and Tidal Prism May Affect the Morphodynamic Evolution of Tidal Deltas. Journal of Geophysical Research: Earth Surface, 123, 2767–2783.

Zhou, Z., Ge, J., Wang, Z.B., Maren, D.S., Ma, J. and Ding, P. (2019). Study of Lateral Flow in a Stratified Tidal Channel-Shoal System: The Importance of Intratidal Salinity Variation. Journal of Geophysical Research: Oceans, 124(9), 6702-6719.