Decadal variability of tidal dynamics in the Pearl River Delta: spatial patterns, causes, and implications for estuarine water management

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Introduction

In this study, we examine the decadal variability of tidal dynamics in terms of the tidal range in the Pearl River Delta (PRD) from the 1950s to 2016. The Mann–Kendall (MK) trend test and Empir- ical Orthogonal Function (EOF) method are employed to identify the long-term trends and spatial patterns of the annual tidal range series observed at 26 stations over the whole PRD, respectively. The results show that most stations display an increasing tidal range trend, except for some stations near estuarine outlets, which corresponds to the 1st EOF mode characterized by a rapid increase of the tidal range since the 1990s. This means that the cumulative impacts of human interventions reached their peak in the 1990s, exceeding the threshold of tidal dynamics in the PRD. To quantify human-induced alternations of the tidal range, the tidal regime shift was subsequently explored by comparing the tidal ranges of the pre- and post-1992 periods reconstructed from the EOF decomposi- tion. The mechanism causing the tidal regime shift in the PRD can be attributed to the substantially reduced residual water level slope (hence, the effective bottom friction) that greatly enhances the tidal dynamics. Our study describes the shift of spatial–temporal tidal dynamics patterns in detail, which is particularly useful to guide effective and sustainable water management in the PRD and other river deltas that are subjected to intensive human interventions.

Highlights

1.The tidal dynamics in the PRD have been greatly enhanced since the 1990s due to the cumulative effect of human interventions.

2.The mechanism causing the tidal regime shift is the reduced residual water level slope and hence effective bottom friction.

3.The tidal regime shift has a profound impact on estuarine water management such as flood control and salt intrusion.

Study cite

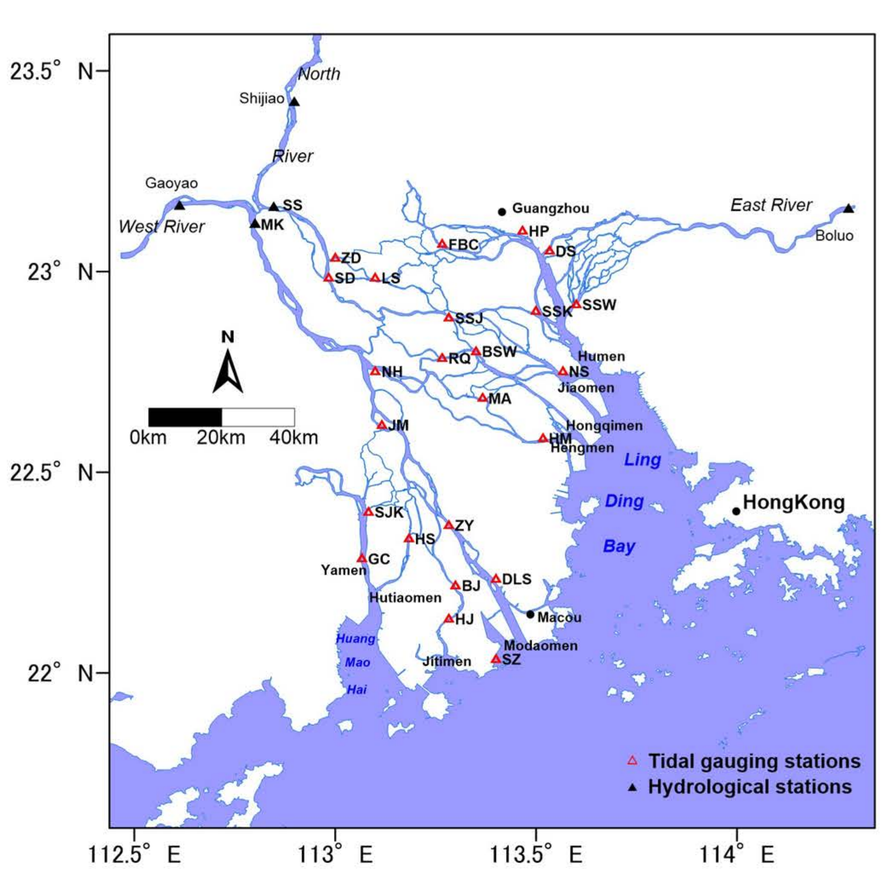

Figure 1: Sketch of the Pearl River Delta (PRD) displaying the locations of tidal gauging and hydrological stations.

Mechanism leading to the significant increase of the tidal range

It is important to note the residual water level slope can be derived from the 1D momentum equation, which is described by:

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + g\frac{\partial Z}{\partial x} + g\frac{U|U|}{K^2 h^{4/3}} = 0 \qquad (1)$$

where U is the cross-sectional averaged velocity, Z the free surface elevation, h is the water depth, g the gravity acceleration, t is the time, x is the longitudinal coordinate directed landward, K is the Manning-Strickler friction coefficient.

Assuming a periodic variation of flow velocity, the integration of equation (1) over a tidal cycle leads to [1, 2, 3]:

$$\overline{\frac{\partial Z}{\partial x}} = -\frac{\overline{U|U|}}{K^2 h^{4/3}} \qquad (2)$$

where the overbars denote the tidal average. Eq. (2) is particularly useful for understanding the long-term evolution of bottom friction because the residual water level slope can be easily estimated from the observed water levels. To quantify the changes in bottom friction, the residual water level slopes estimated for the pre-1992 period with corresponding river discharges were compared with the values for the post-1992 period for the main channel of the West and North rivers, respectively (see Figure 3). Notably, we observe a considerable decrease of the residual water level slope (hence, residual bottom friction) due to the overall impact of human interventions.

Results

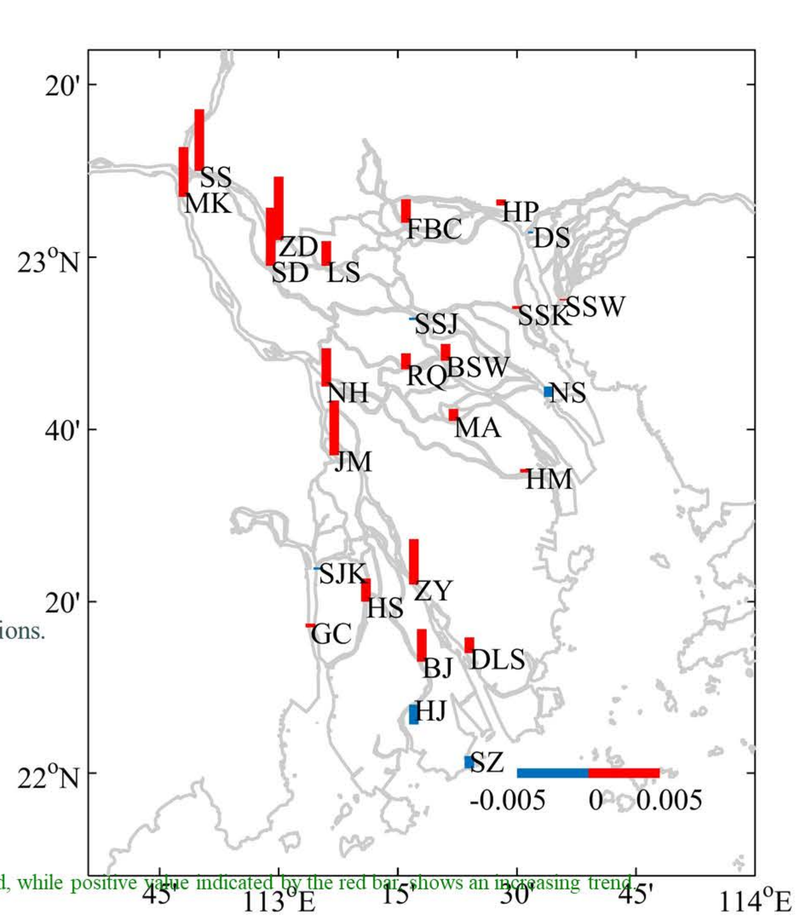

Figure 2: Magnitude in trend β (mm/yr) obtained from Mann-Kendall trend test. The negative value indicated by the blue bar, shows a decreasing trend, while positive value indicated by the red bar, shows an increasing trend.

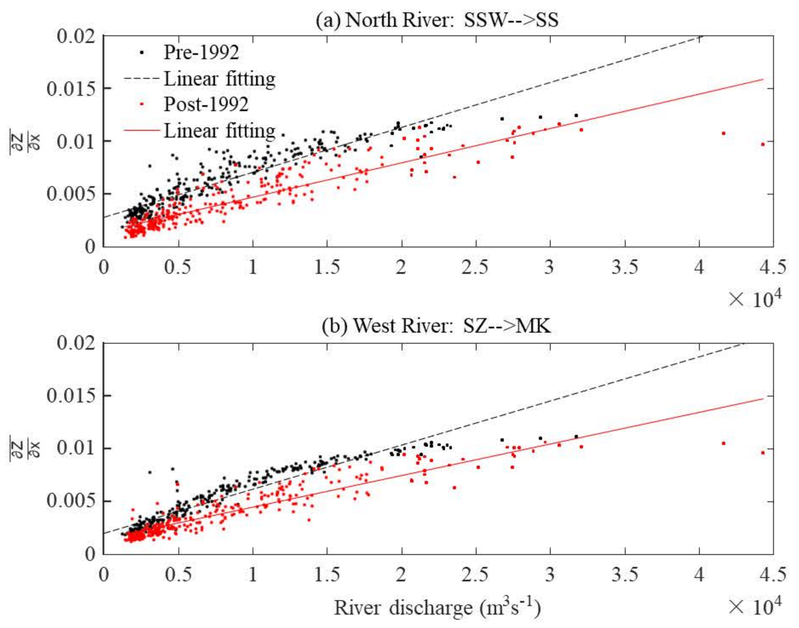

Figure 3: Observed residual water level slope as a function of the river discharge for different periods. The black and red lines indicate the linear trend of tidal range for the pre-1992 period (a) and for the post-1992 period (b), respectively.

Conclusions

•The results show that the tidal range of most stations in the upper and central parts of the PRD has significant increasing trend, which corresponds to the 1st EOF mode characterized by rapid increase of the tidal range since the 1990s when the cumulative impacts of human interventions exceeded the threshold of natural tidal dynamics changes.

•The residual water level slope dramatically decreased after the 1990s compared with the more natural period before the 1990s. Consequently, the effective bottom friction reduced as the tidal waves traveled into the PRD, causing an increasing tidal range.

•The results obtained from this study will, hopefully, contribute to set scientific guidelines for water resources managers when assessing the impacts of human activities and climate changes on tidal dynamics in other river delta systems.

References

[1] H. Cai, H. H. G. Savenije, C. Jiang, L. Zhao, and Q. Yang. Analytical approach for determining the mean water level profile in an estuary with substantial fresh water discharge. Hydrology and Earth System Sciences, 20(3):1177–1195, 2016.

[2] H. Cai, H. H. G. Savenije, and M. Toffolon. Linking the river to the estuary: influence of river discharge on tidal damping. Hydrology and Earth System Sciences, 18(1):287–304, 2014.

[3] H. Cai, Q. Yang, Z. Zhang, X. Guo, F. Liu, and S. Ou. Impact of river-tide dynamics on the temporal-spatial distribution of residual water levels in the Pearl River channel networks. Estuaries and Coasts, pages 1–19, 2018.