XVIII
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Nonlinear interaction of tide-storm-river during coastal floods in Pearl River Estuary

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Humans and Nature

第18届
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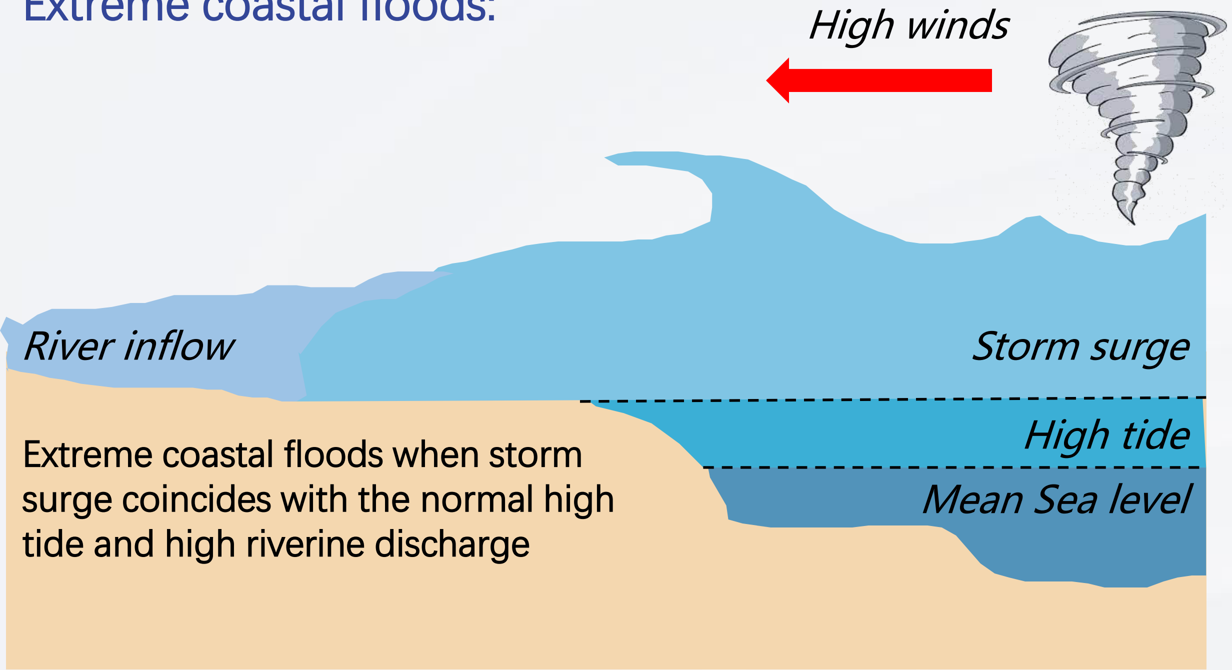
Introduction

1.The increase in storm surge and compound flood events caused by climate change exacerbates adverse effects on the estuaries.

2.Coastal floods in river deltas are typically categorized into three types: 1. rainfall floods when heavy rainfall accumulates on the ground, 2. riverine floods when upstream overflows their banks and 3. estuarine flood due to astronomical tides, storm surges, and wind.

3. Nonlinear interactions: The extreme surge levels caused by multi-drivers including tide, storm surge, and river streamflow are not a superposition of water elevations caused by a single driver. These interactions can be referred to as tide-surge-river interactions (TSRI).

Extreme coastal floods:



Extreme coastal floods when storm surge coincides with the normal high tide and high riverine discharge

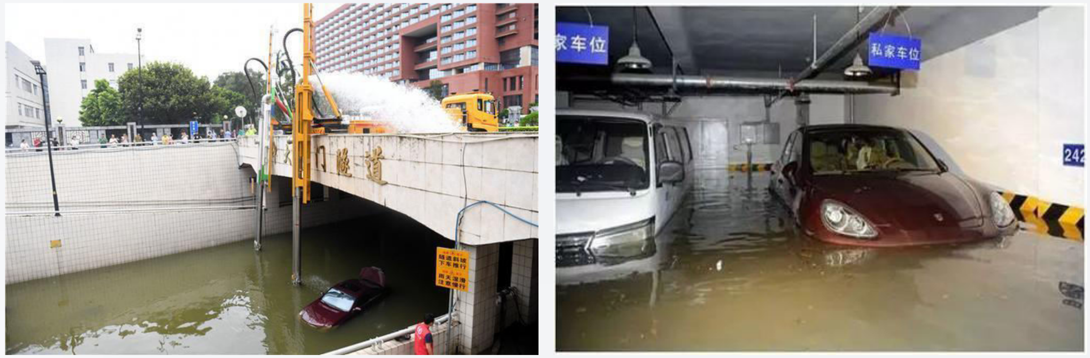
Study area

Study area:

The Pearl River Estuary (PRE) is frequently impacted by floods from upstream riverine high discharge and storm surges caused by typhoons.

Extreme floods:

1713 Typhon Hato, 1822 Super Typhoon Mangkhut, 22.6′ Beijiang river flood,05.6′ Xijiang river flood.



During Super Typhoon Mangkhut, tunnels and underground car parks in Guangzhou were flooded.

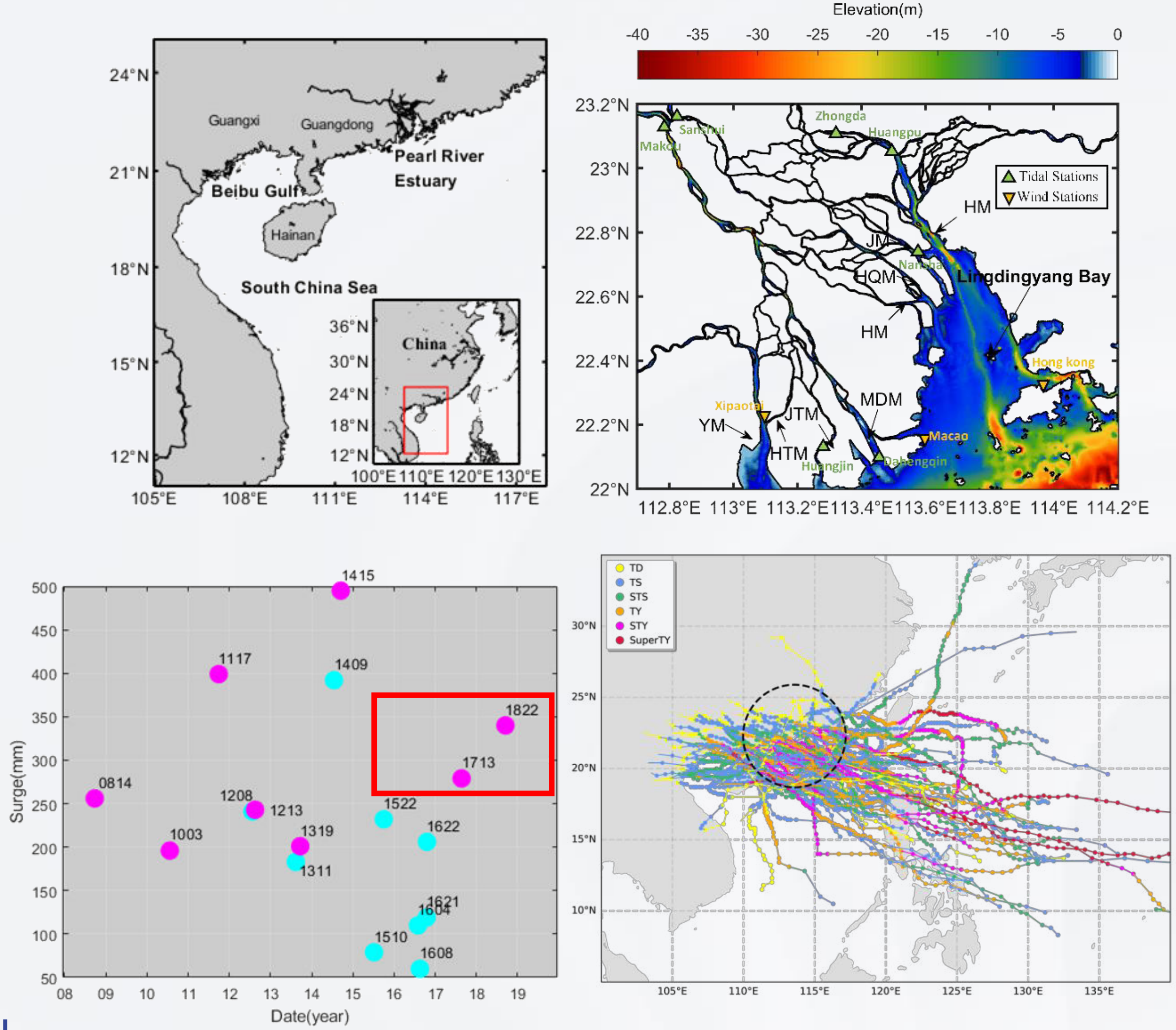


Fig. Study area, stations and typhoons

Methods

Storm surge model:

ADCIRC(Advanced Circulation Hydrodynamic model)+SWAN coupled model （Simulating WAves Nearshoure） was applied to simulate storm surges, tides, and coastal water circulation processes in PRE.

Typhoon parameters model:

The widely used Holland model (Holland, 2008; Holland, 1980) is applied in the simulation of the storm surge for wind input, which requires only a few fundamental parameters such as sea level pressure, maximum wind speed, and maximum wind radius

ADIRC Basic Equation:

$$\frac{\partial^2 \xi}{\partial t^2} + \tau_0 \frac{\partial \xi}{\partial t} + \frac{\partial \tilde{J}_x}{\partial x} + \frac{\partial \tilde{J}_y}{\partial y} - UH\frac{\partial \tau_0}{\partial x} - VH\frac{\partial \tau_0}{\partial y} = 0$$

Swan Basic Equation:

$$\frac{\partial}{\partial t}N + \frac{\partial}{\partial x}(C_x N) + \frac{\partial}{\partial y}(C_y N) + \frac{\partial}{\partial \sigma}(C_\sigma N) + \frac{\partial}{\partial \theta}(C_\theta N) = \frac{S}{\sigma}$$

Holland model Basic Equations:

$$P = P_c + (P_n - P_c)\exp(-A/r^B)$$

$$V_c = [AB(P_n - P_c)\exp(-A/r^B)/\rho r^B]^{1/2}$$

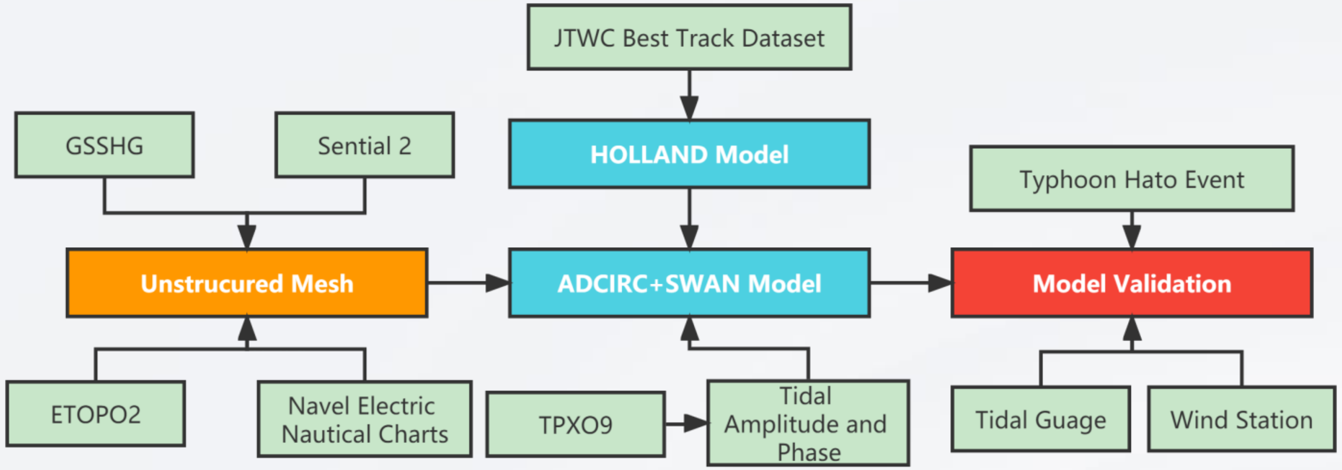
Methods

Storm surge model:

The ADCIRC+SWAN model was simulated by tides, sea level pressure, wind speed, and upstream runoff input.

Data for model setup and validation:

1. Coastline: GSSHG dataset and Sentinel-2
2. Bathymetry: ETOPO2 and electronic nautical charts.
3. Tides: TPXO9
4. River boundary: measured daily flow data.
5. Typhoon tracks: JTWC best track dataset.
6. Validation: Measured tidal levels and wind speeds during Typhoon Hato



JTWC Best Track Dataset

GSSHG

Sential 2

HOLLAND Model

Typhoon Hato Event

Unstrucured Mesh

ADCIRC+SWAN Model

Model Validation

ETOPO2

Navel Electric Nautical Charts

TPXO9

Tidal Amplitude and Phase

Tidal Guage

Wind Station

Fig. The process of model setup and validation

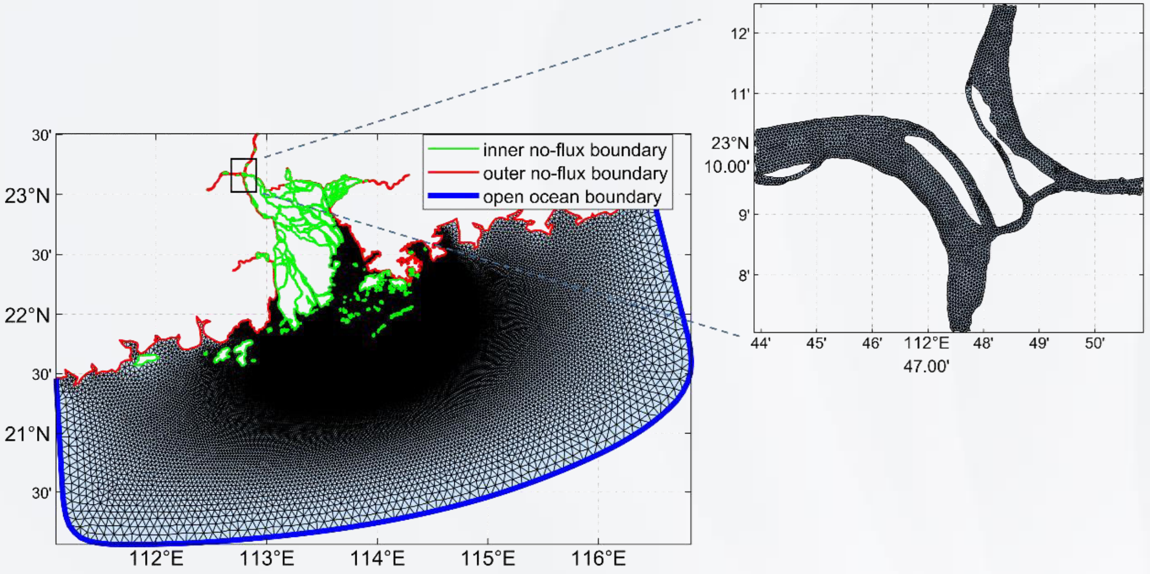


Fig. The model mesh and boundary

Methods

Quantification of the TSRI:

Quantifying the nonlinear interactions among the TSRI during floods can be obtained by calculating the nonlinear residual water level.

ζ: the total water levels from the model forced by the tide, storm, and riverine inflow, can be decomposed into :

(1) ζ_T the astronomical tide level by forcing the tidal boundary in the model;

(2) $\zeta_W$the typhoon-driven water level by forcing the storm in the model;

(3) $\zeta_R$the riverine water levels by forcing the riverine input in the model;

(4) $\zeta_{NL}$the non-linear residual water level calculated by:

$$\zeta_{NL}=\zeta-\zeta_T-\zeta_W-\zeta_R$$

The following **nonlinear indicators** can be derived according to the distinct physical processes in the 2D momentum equation.

(1)The nonlinear local acceleration term (ACC) representing the acceleration of nonlinear flow velocity,
(2)The nonlinear convection term (CON) representing the significant gradient of nonlinear residual level,
(3)nonlinear Coriolis force term (COR)

(4)nonlinear friction term(FRI) representing the combined effects of wind stress and bottom friction.

$$\boxed{\begin{matrix}\frac{\partial U_{NS}}{\partial t}\\[3ex]\frac{\partial V_{NS}}{\partial t}\end{matrix}}\begin{matrix}+\\[3ex]+\end{matrix}\boxed{\begin{matrix}\psi_x(U_{NS},V_{NS})\\[3ex]\psi_y(U_{NS},V_{NS})\end{matrix}}\begin{matrix}-\\[3ex]+\end{matrix}\boxed{\begin{matrix}fV_{NS}\\[3ex]fU_{NS}\end{matrix}}\begin{matrix}-\\[3ex]-\end{matrix}\boxed{\begin{matrix}{\tau_x}^{NS}\\[3ex]{\tau_y}^{NS}\end{matrix}}\begin{matrix}=-g\frac{\partial\zeta_{NS}}{\partial x}\\[3ex]=-g\frac{\partial\zeta_{NS}}{\partial y}\end{matrix}$$

ACC CON COR FRI

Results

Model Validation:

During the simulation of Typhoon Hato, we forced the tide, storm, and river boundaries in the numerical model.

The water level and velocity changes of the model output were validated with the observation data.

Thus, the total water level of the model can capture the combined effect of tide, runoff, and storm.

Hourly observed data of tidal levels from seven tidal stations(A), wind speeds from three meteorological stations(B), and currents from one buoy(C) in the PRE were used to validate the mode

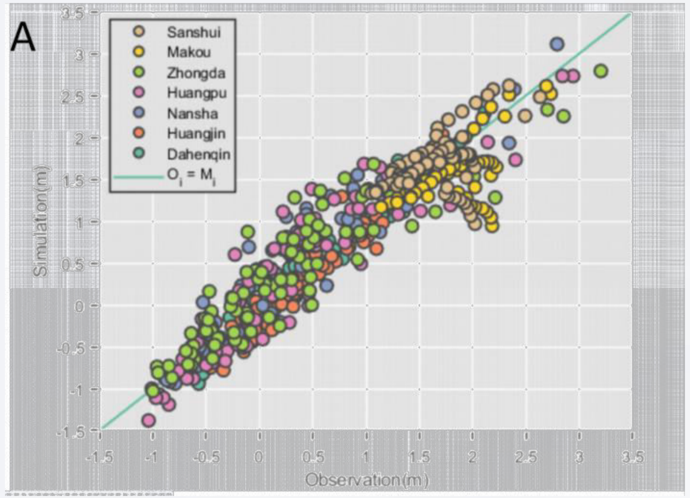


Fig.A Water levels validaton

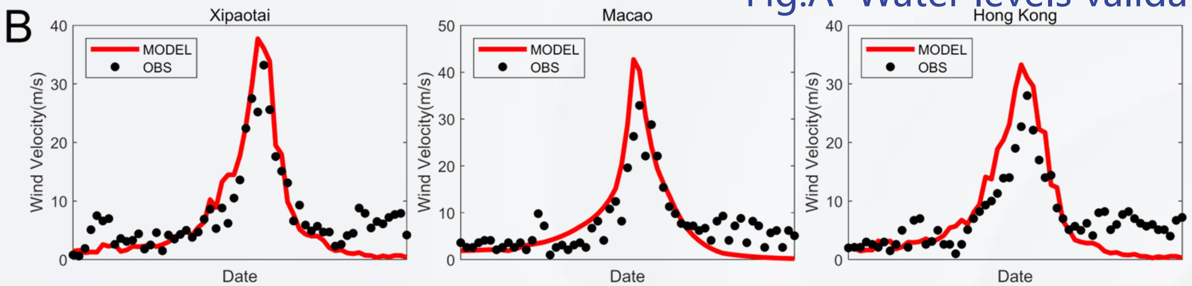


Fig.B Wind speed validaton

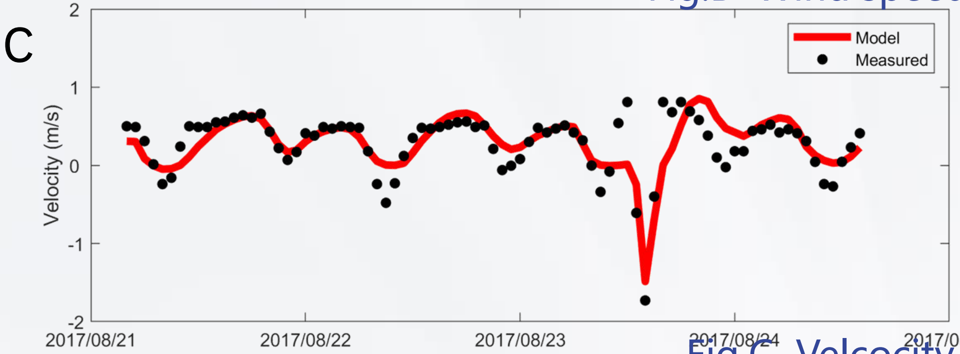


Fig.C Velcocity validaton

Results

Numerical simulation experiments:

The numerical model is used to simulate the various conditions under the influence of different factors during storm surges ,which are quantitatively decomposed as follows:

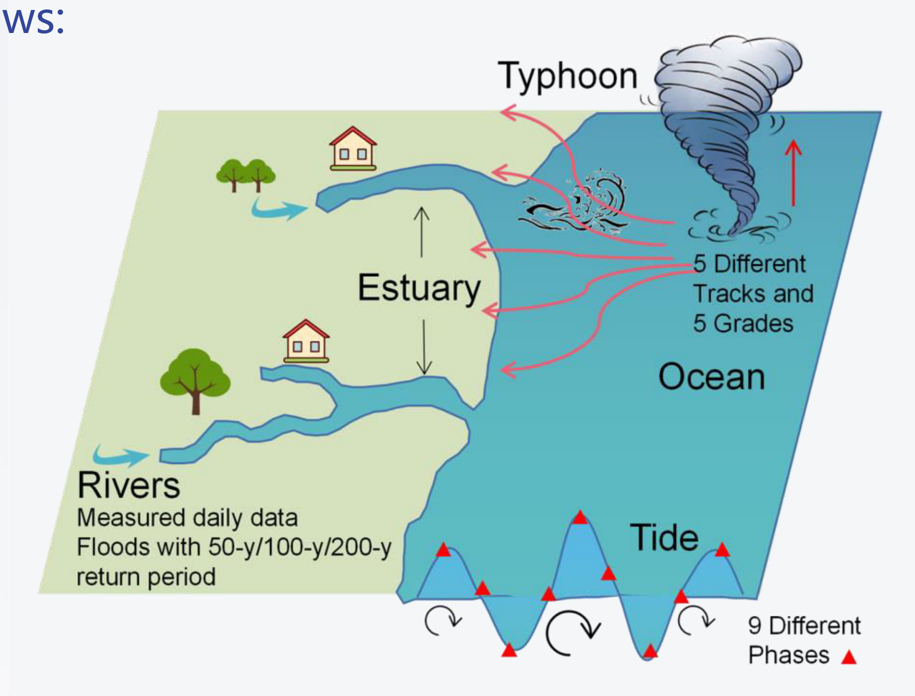


Fig. Typical scenarios for quantification of nonlinear interactions

Table. 1

Typical scenario for quantification of nonlinear interactions

Case number	Environmental Loads			Condition
	Tide	Wind	River	
Case0	√	√		Storm surge
Case1	√			Tide level
Case2		√		Wind surge
Case3-11	√	√	√	Nine phases of the Tidal cycle
Case12-16	√	√	√	Five levels for typhoon input
Case16-20	√	√	√	Five different typhoon path
Case21	√	√	√	River inflow for storm surge
Case22-24	√	√	√	Storm surge with 50/100/200 return year floods

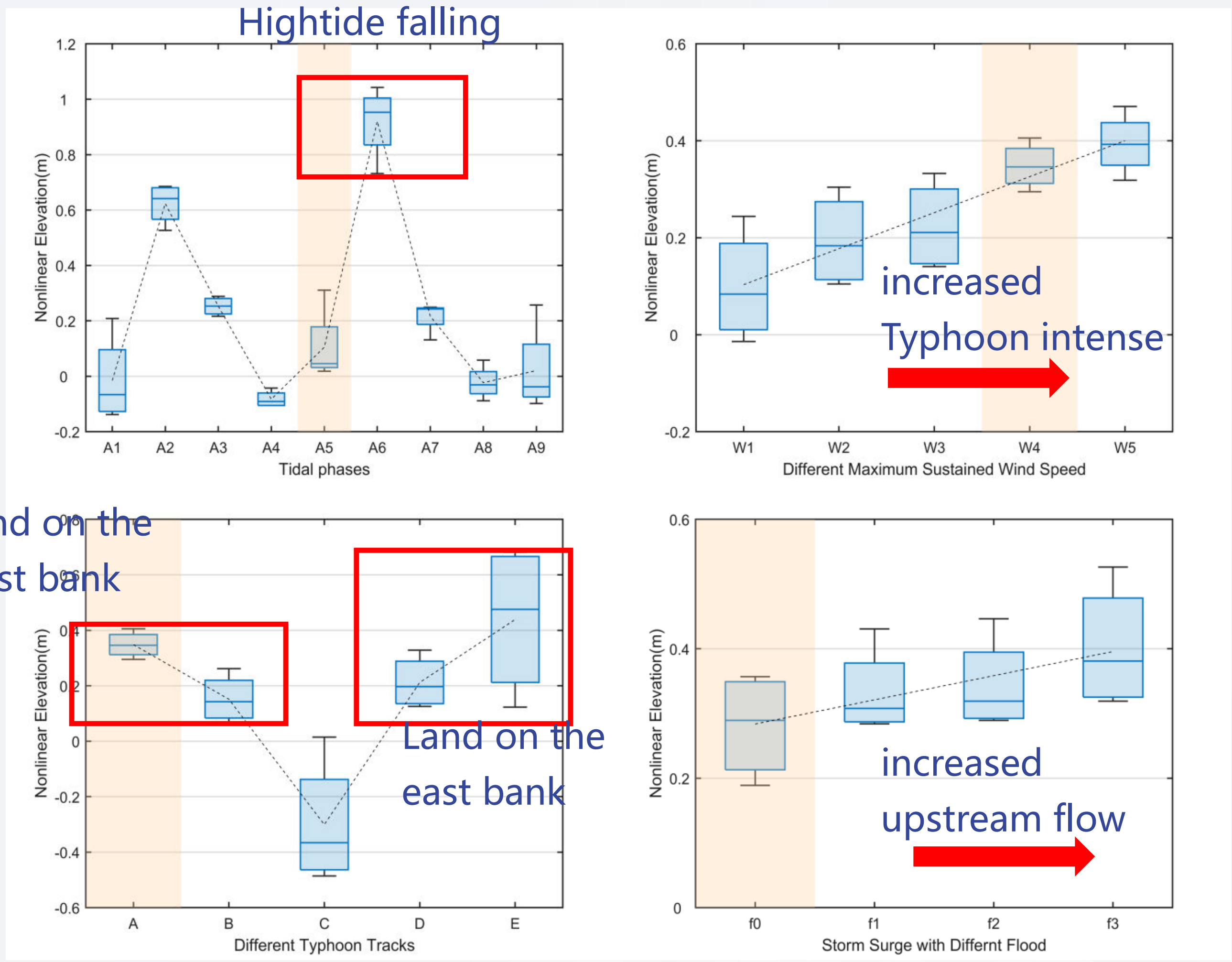
Results

Nonlinear interactions under different drivers

1. The distinct tidal-surge phase differences remain the most influential factor on extreme water levels.

2. The nonlinear effects varied significantly when typhoons landed on different areas.

3. The TSRI nonlinear effect between the multiple drivers is also enhanced by the effects of compound floods and more intense typhoons, which can lead to more extreme water levels.



Hightide falling

increased Typhoon intense

Land on the west bank

Land on the east bank

increased upstream flow

Fig. Nonlinear residual levels of the maximum water level(m) under different scenarios at each station

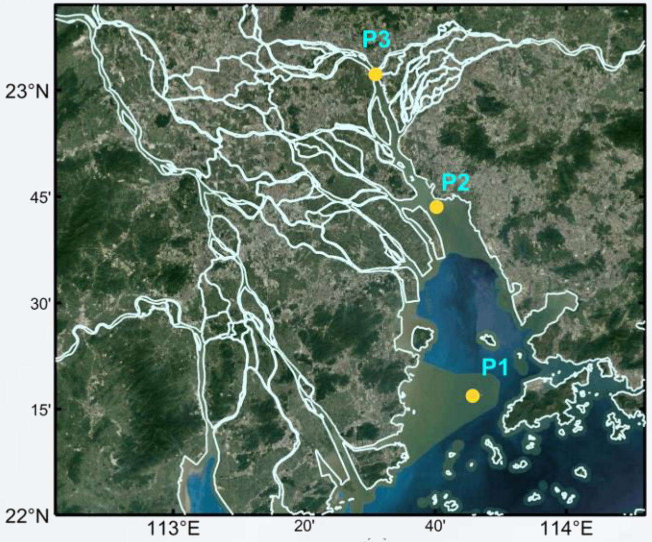
Results

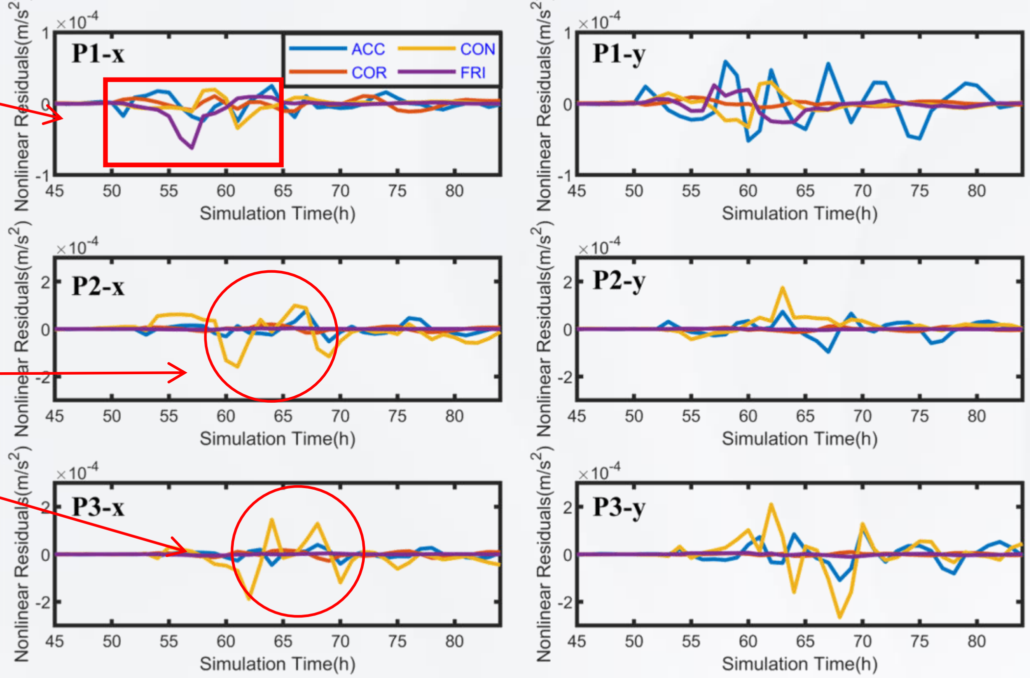
Source of the TSRI nonlinear effects in PRE:

1. The dynamics within and around river estuaries are largely governed by wind stress friction, bottom friction, and nonlinear convection, with localized differences due to proximity to typhoon centers and estuary shorelines.

2. In the X direction near the P1 point, the area is mainly influenced by the nonlinear friction(**FRI**), while the local acceleration and Coriolis forces are fairly balanced, hinting at the role of wind stress and bottom friction at the estuary's entrance.

3. For the P2 and P3 points at the top of the estuary, where the flow speed accelerates due to the gradually shallower topography, the effects of the convection (**CON**) control the nonlineaer interactions particularly in the Y direction, underlining the significant role of wind-generated flow, tidal flow, and estuarine runoff.





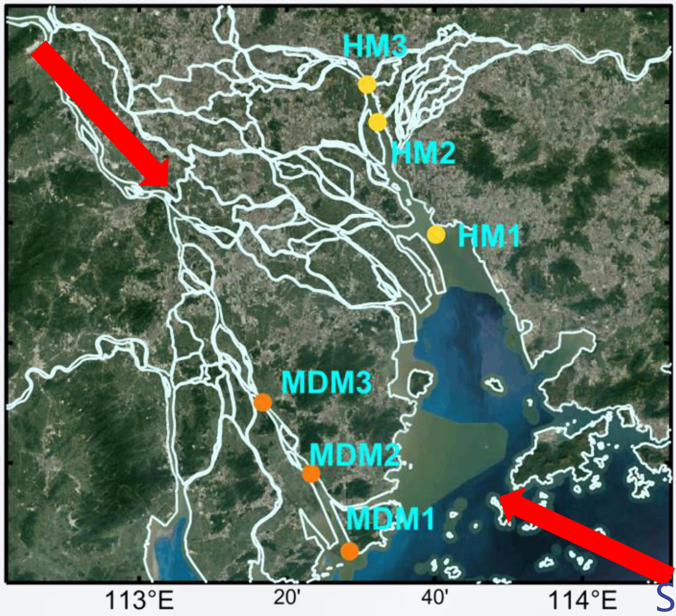
Results

Different responses of nonlinear interactions during compound floods in PRE:

1.The TSRI nonlinear effect is enhanced under compound flooding.

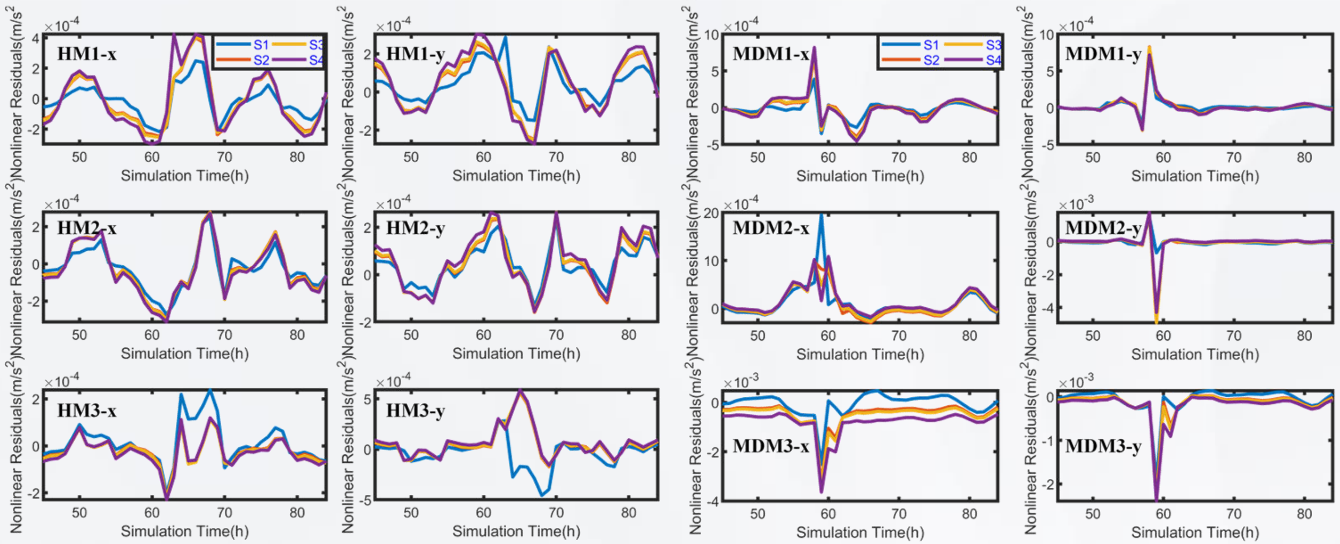
2.Variations in convective terms were calculated for the 2%,1%, and 0.5% compound flood scenarios.

3. In the river-controlled outlet Modaomen(MDM), the nonlinear convective term can exceed $-2*10^{-3}$ m/s^2 in the compound flood scenario, **which is larger compared** to the tidally controlled Humen(HM).



Increased upstream flood

Storm surge



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Thanks for listening

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