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Field surveying and numerical simulation of the Typhoon Hato storm surge event in Guangdong province, China

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Abstract. In 2017, Typhoon Hato hitting Zhuhai city, Guangdong province, caused a severe storm surge disaster. In this study, a systematic field survey of the "Hato" storm surge was conducted and the numerical modeling of inundation extent and depth was performed. The survey integrated floating debris tracking, inundation tracing, and local inquiries to determine the seawater inundation edge points, water depths, and overall extent of the flooding. Combined with field reconnaissance, the mechanisms damaging typical hazard-bearing bodies during marine disasters were clarified, and the effects of the "Hato" storm surge were analyzed. Inundated areas were distributed in coastal cities, with the maximum inundation depth up to about 2 m, and the inundated area exceeding 54.08 km^2. Compared to historical storm surge records, Typhoon Hato ranked as the fourth most severe and stands as one of the most devastating storm surges to impact Guangdong province over the past decade. In addition, the proposed model can reproduce this typhoon and storm surge event, which was evaluated by comparing field observations with numerical simulations, showing good consistency with the observed flooding records. These results could provide detailed data and decision support, which can be used as guidance for the mitigation of future storm surges in coastal areas.

1 Introduction

Coastal flooding induced by tropical cyclones is among the most destructive marine hazards worldwide and poses an increasing threat to densely populated coastal regions (Feehan et al., 2024). Under the combined influence of climate change, accelerated sea-level rise, rapid urbanization, and the growing exposure of coastal infrastructure, storm surge disasters are becoming increasingly frequent and severe, resulting in substantial losses of human lives, economic assets, and ecosystem

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services (Guo et al., 2023; Zhang et al., 2026). In low-lying estuarine regions, storm surge hazards are often further amplified by complex interactions among astronomical tides, river discharge, coastal geomorphology, and local topography, producing extensive inundation with highly heterogeneous spatial characteristics (Du et al., 2024b). Consequently, accurately characterizing storm surge inundation processes and their impacts has become a fundamental prerequisite for improving coastal flood modelling, disaster risk assessment, and climate adaptation strategies. As one of the countries most frequently affected by tropical cyclones, China experiences severe storm surge disasters almost every year, particularly along the southeastern coast, where densely populated urban agglomerations and rapidly expanding coastal economies are highly vulnerable to extreme marine hazards (Shi et al., 2015, 2020).

Over the past two decades, considerable progress has been made in understanding storm surge processes through numerical modelling, remote sensing observations, and post-event field investigations (Gharehtoragh and Johnson, 2024; Vogt et al., 2024; Zhang and Zhang, 2024). Hydrodynamic models have been widely applied to simulate storm surge propagation and coastal inundation under historical and future climate scenarios, providing valuable tools for storm surge prediction and risk assessment (Passeri et al., 2018). Furthermore, Satellite remote sensing has also significantly enhanced the capacity for rapid, large-scale identification of inundated areas following extreme events (Khan and Basalamah, 2023). However, both approaches have inherent limitations. Numerical simulations are affected by uncertainties associated with topography, boundary conditions, model parameterization, and the representation of urban infrastructure. While high-resolution optical imagery is constrained by satellite revisit frequency, image availability, and spatial resolution, and primarily provides information on inundation extent rather than maximum inundation depth or field evidence such as flood marks and damage characteristics required for comprehensive disaster assessment and model validation (Cao et al., 2023; Muis et al., 2023). In contrast, post-event field investigations provide irreplaceable first-hand information on flood marks, inundation extent, water depth, debris distribution, infrastructure damage, and eyewitness observations, making them indispensable for understanding disaster processes and validating numerical simulations (Widiyanto et al., 2019).

Previous post-event field investigations have substantially improved the understanding of storm surge inundation characteristics and disaster impacts, several gaps remain. First, uncertainties associated with field-based evidence reconstruction have not been sufficiently addressed, despite the fact that inundation boundaries and flood depths are often derived from indirect indicators such as floating debris, vegetation damage, seawater traces, and local interviews (Bösmeier et al., 2022). Furthermore, while numerical models have become important tools for storm surge simulation and coastal flood risk assessment, the potential of field observations as benchmark datasets for model validation has not been fully exploited (Jiao et al., 2025). Limited integration between comprehensive post-event observations and numerical simulations may constrain the evaluation of model reliability and the improvement of coastal flood prediction. Therefore, integrated approaches combining field surveys, disaster mechanism analysis, and numerical model validation are still needed to better understand towards storm surge impacts and enhance coastal flood risk assessment.

This study conducted a systematic post-event field investigation of the storm surge induced by Typhoon Hato in Guangdong Province. The objectives were to: (1) characterize the spatial distribution and inundation characteristics of the storm surge

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using field reconnaissance, RTK measurements, inundation tracing, and interviews; (2) investigate the damage mechanisms of representative hazard-bearing bodies and analyze the regional disaster impacts; and (3) evaluate the capability of a previously developed numerical model to reproduce the distribution of the inundation depth and extent using field-surveying observations. By integrating large-scale field investigations with numerical model validation, this study provides valuable evidence for improving storm surge disaster assessment, enhancing confidence in coastal flood simulations, and supporting future coastal disaster prevention and risk management.

2 Materials and methods

2.1 Study area and data

Typhoon Hato (No. 13) formed over the northwestern Pacific Ocean at 14:00 on August 20, 2017 (local time). Its intensity continuously increased, and it became a severe tropical storm by 08:00 on August 22 and changed to a typhoon at 15:00 with maximum wind speed exceeding 25 m/s. “Hato” finally became a severe typhoon at 07:00 on August 23 and made landfall on the coast near to the Jinwan District of Zhuhai City, Guangdong province, at 12:50. During the landfall (Fig. 1), the maximum wind speed reached 45 m/s, and the lowest pressure at the center was 950 hPa. After making landfall near Zhuhai in the Pearl River Delta, Hato generated an extreme storm surge that coincided with high astronomical tide, causing widespread coastal inundation and severe socioeconomic losses throughout Guangdong Province. The maximum storm wave height was recorded over 8 m at an offshore station. The National Marine Forecasting Center released an orange alert with respect to the storm surge and a red-alert with respect to waves on August 22. Affected by the typhoon, a conspicuous storm surge occurred along the coast from eastern Guangdong to Yangjiang. Typhoon Hato (2017) provides an ideal case for investigating storm surge inundation characteristics and evaluating numerical model performance in a highly urbanized estuarine environment. The Pearl River Delta is characterized by a highly urbanized coastline, complex estuarine geomorphology, dense river networks, and extensive coastal infrastructure, making it one of the regions most vulnerable to storm surge disasters in China (Qiu et al., 2022; Wang et al., 2021). The large spatial extent of the affected area and the availability of comprehensive post-event field observations provide a valuable opportunity to investigate regional inundation characteristics and assess the reliability of numerical storm surge simulations.

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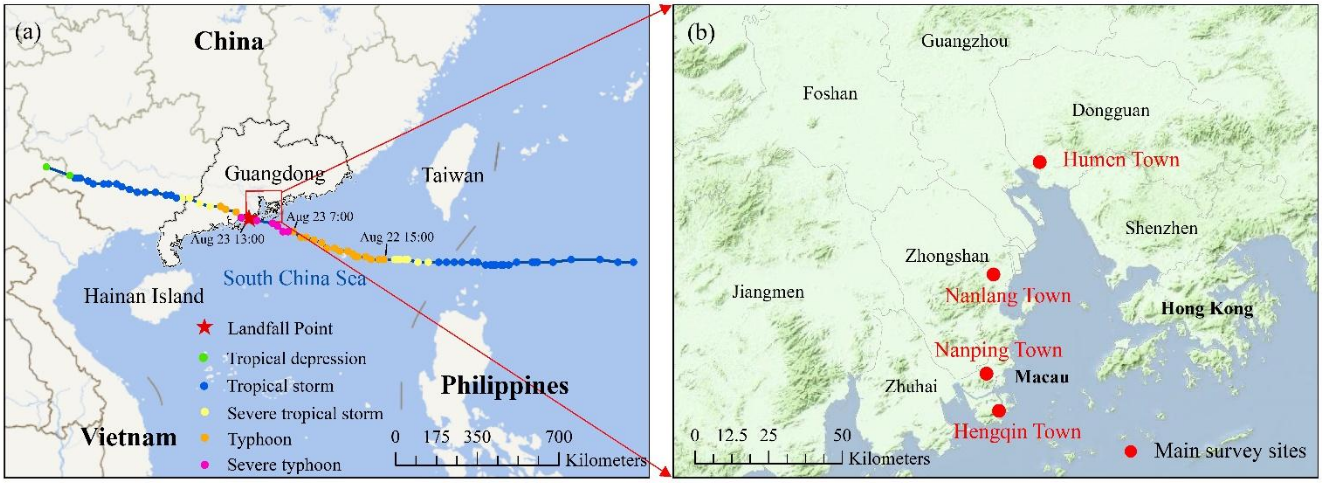

Figure 1. (a)Track and intensity variation of Typhoon Hato. (b) Location of the main surveyed inundation sites.

This study focused on Guangdong province influenced by "Hato" and the induced storm surge. Guangdong province has a coastline of 4,114 km which includes 14 coastal cities. Guangdong province is one of the provinces where the most serious marine disasters occur. In the past decade (2011 to 2020), the average direct economic loss owing to marine disasters in Guangdong province was 2.8 billion yuan. Many places in Guangdong were inundated to varying degrees, resulting in severe losses by "Hato" storm surge. Based on the statistics, more than 1 million people in the Guangdong province were affected by the disaster, and six people died. The typhoon storm surge affected 18,238.80 ha of aquaculture (>10% loss). It caused the losses of 22,800 t of aquaculture output and 330 sets of aquaculture equipment and facilities, as well as damaged 275 fishing vessels, 240.18 km of groins, and 532.08 km of seawalls and revetments (Guangdong Provincial Department of Oceans and Fisheries, 2018). This study analyzes the influence of typhoon "Hato" storm surge. Additionally, multisource data were collected in this study (Table 1).

Table 1. Multisource data collected in this study

Data type	Time series	Description	Source
Historical typhoon records	1949–2025	Time, location, and intensity of each typhoon track point	Shanghai Typhoon Institute, China Meteorological Administration
Historical storm surge loss data	1990–2025	Loss data including economic, death, and building destroyed	National Marine Mitigation Service
Tidal observational data	1990–2025	Hourly observational data of surge and water level for tidal station during typhoon periods	South China Sea Marine Forecasting Center, Oceanic Administration of China

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Remote sensing image data	2024	Remote sensing image of Guangdong province	National Marine Mitigation Service
National Gross Ocean Product	2024	The value of National Gross Ocean Product in Guangdong Province	State Oceanic Administration of China

2.1.1 Numerical simulation

The numerical simulation results used in this study were derived from an integrative compound flood modelling framework developed by Du et al. (2024), which was applied to reproduce the extreme compound flood event induced by Typhoon Hato (2017) in the Pearl River Delta (PRD) (Fig. 2). The framework integrates coastal, fluvial, and pluvial flood processes within a unified two-dimensional hydrodynamic modelling system, allowing the interactions among storm surge, astronomical tide, rainfall, and river discharge to be represented simultaneously. The core of the framework is a two-dimensional depth-averaged hydrodynamic model based on unstructured triangular meshes. The model solves the shallow water equations with additional source terms representing rainfall forcing, atmospheric pressure gradients, and wind shear stresses, enabling the simulation of compound flooding processes induced by tropical cyclones. The model is driven by multiple forcing datasets, including astronomical tidal constituents from the TPXO9 global tidal model, typhoon-induced wind and atmospheric pressure fields reconstructed from official typhoon track data, rainfall forcing from the Weather Research and Forecasting (WRF) model, and river discharge simulated by the CREST distributed hydrological model. The model provides spatially continuous inundation depth and water-level outputs throughout the typhoon lifecycle. In the original study, the model performance was evaluated using multiple observational datasets, demonstrating its capability to reproduce the hydrodynamic processes and compound flood characteristics associated with Typhoon Hato. In this study, the simulated inundation extents and depths were extracted and compared with post-event field survey observations to evaluate the agreement between numerical simulations and observed flooding characteristics.

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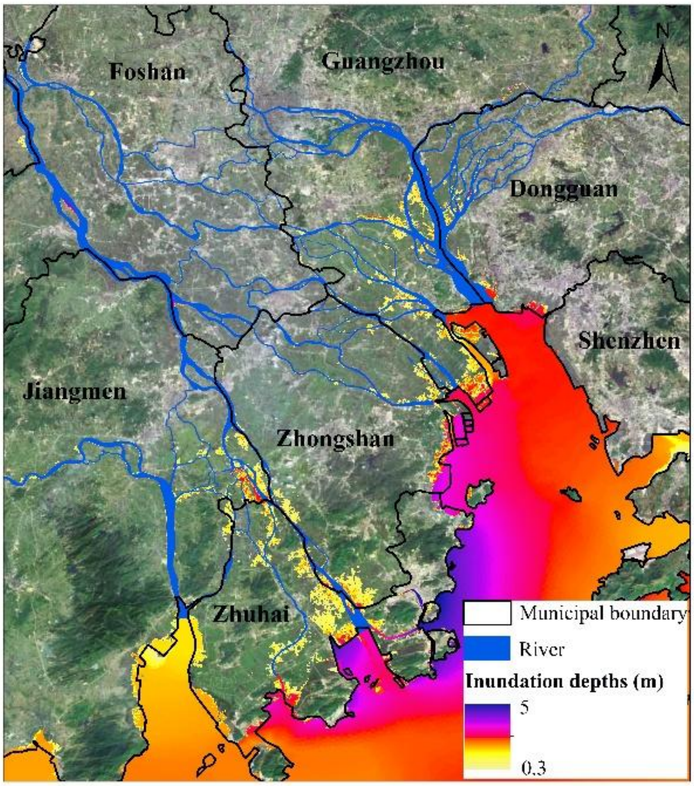

Figure 2. Simulated storm surge inundation depth distribution caused by Typhoon Hato in the Pearl River Estuary.

2.2 Investigation of Damage to exposures

Mariculture areas, fishing ports, and coastal dike are the most severely affected by storm surge. In this study, the disaster-causing mechanisms and damage to typical hazard-bearing bodies affected by storm surge were analyzed using visual interpretation, field measurements, and field reconnaissance. The damage to the mariculture area is mainly reflected in the death and damage of the aquaculture and the aquaculture facilities affected by the disaster. Through on-site inquiries, the damages to different types of aquaculture and aquaculture facilities, the sales price of the aquaculture and the purchase price of the aquaculture facilities were recorded, and the damage to the marine aqua-culture industry was calculated. The damage to the fishing port is reflected in the loss caused by the collision of fishing boats in the port area affected by the disaster. Through field surveys, the number and extent of damage to different types of fishing boats were counted, and the cost and repair prices of different types of fishing boats were understood. To identify the extent of damage to the coastal dike, the basic conditions of the embankment engineering construction standards, construction materials, etc., the length of the damage (using tape measure and laser rangefinder) were investigated. During field reconnaissance, photos were obtained using far and near angles. At least six photos of a single characteristic point were obtained to completely reflect the location and degree of damage to disaster-bearing bodies (Fig. 3).

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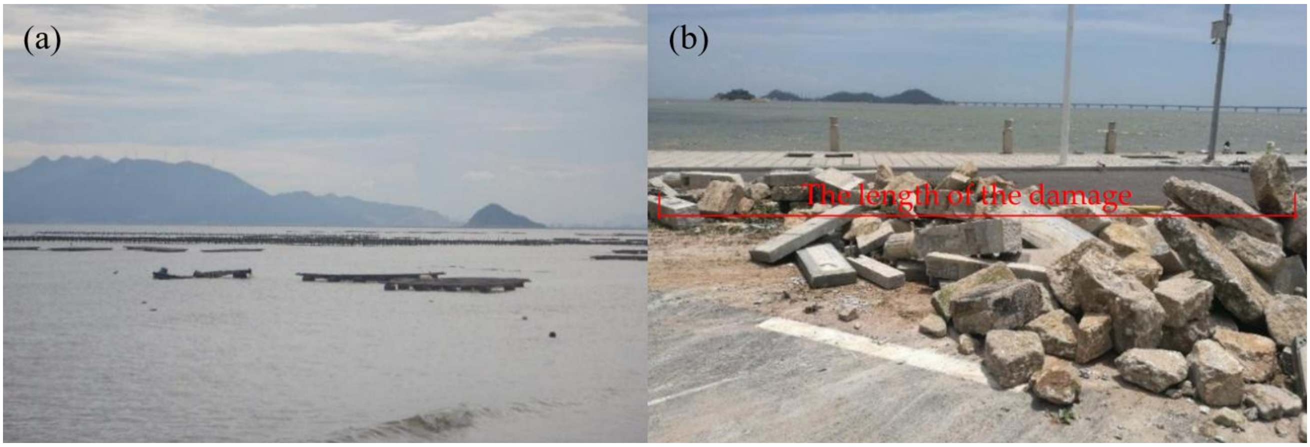

Figure 3. (a) Damaged aquaculture fish rafts in Mutouchong village, Zhuhai city. (b) Damage length of the guardrail along the Qinglu Middle Road in Zhuhai city (~50 m).

2.3 Inundation Investigation

To quantify the water depth and inundation areas caused by storm surge, the survey of the submerged area generally involves three methods: searching for drifting objects, submerged traces, and visiting inquiries. In this study, a set of methods was used to assess the reliability of the inundation extent of the storm surge disaster (Table 2). Firstly, the inundation edge points were determined by identifying the locations at which floating objects, such as dead tree branches transported to the edge of inundated land area, are accumulated; enquiring coastal residents to confirm whether there was inundation; and by determining residual inundation traces on coastal buildings, ensure that more than 50% of the investigation evidence is reliable. After the edge points were determined, the longitudes, latitudes, and elevations of the edge points were measured with the RTK and other techniques (Fig. 4). Based on the positions of the edge points, plane survey grids were established. Survey grids were densely distributed on the coast with residential areas, schools, ports, and breeding areas. The distances between each survey points were less than 300 m. The investigation team determined the inundation depth by measuring the inundation trace lines in inundated residential areas and completed a storm surge-related inundation form. Finally, the team interviewed residents and re-vised the extent and depth of investigated inundated areas based on the results.

Table 2. Determination of the reliability of the storm surge inundation investigation.

Item	Level		
	Reliable	**Less reliable**	**Reference only**
Location of floating objects	Large-scale floating garbage piled up in coastal areas; marine flora and fauna as well as breeding facilities accounted for	Some floating garbage piled up in coastal areas	A small portion of floating garbage was scattered in coastal areas; land-based garbage accounted for the largest

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	the largest proportion of the garbage		proportion
Vegetation condition	Most terrestrial plants with belt-shaped distribution in coastal areas withered and died	Several terrestrial plants with belt-shaped distribution in coastal areas withered	A small portion of terrestrial plants in low-lying coastal areas withered
Status and seawater inundation traces based on respondents	Witnessed; the traces were clear and specific	Witnessed; the traces were less clear and specific	Heard from others or did not remember in detail; the traces were ambiguous

Figure 4. Example of topographic tools and techniques used for flood range measure. (a) and (b) location of flood range using RTK, (c) and (d) determination of flood height or water depth during flood using a measure tape.

3 Results and Analysis

3.1 Analysis of the Disaster Characteristics

Typhoon Hato hit the mouth of the Pearl River. The powerful typhoon pushed the sea water inward from the horn, and the sea water spread to the river network area. The maximum storm water happened 1-2 h after the astronomical climax of the day, Thus, the maximum storm water was superimposed on the astronomical tide, resulting in a significant storm water increase near the Pearl River Estuary, with obvious super-alert features. The high-tide levels at the Huizhou, Yantian, Chiwan, Huangpu, Hengmen, and Zhuhai stations in the Guangdong province exceeded the local red-alert tidal levels and the historical highs recorded at the stations (Table 3). Compared with the processes of catastrophic marine disasters of the past decade, the sea-level rise caused by Hato marine disaster was relatively significant, ranking fourth, higher than the average value of 3.663 billion yuan, and accounted for 0.066% of National Gross Ocean Product in 2017.

Table 3. Elevation of the water and tidal levels at each tidal station during the Hato storm surge in Aug. 23.

Observation station (point)		**Maximum storm surge**		**Maximum tide level**		**Warning water level (cm)**
		Time	**Surge (cm)**	**Time**	**Tidal level (cm)**	
1	Huizhou	10:00	120	10:24	445	440 (Red)
2	Chiwan	13:00	203	12:51	559	487 (Red)
3	Yantian	10:00	129	09:44	421	412 (Red)
4	Huangpu	16:00	194	15:00	273	261 (Red)
5	Hengmen	14:00	215	14:00	294	236 (Red)
6	Zhuhai	12:00	279	12:00	614	467 (Red)
7	Sanzao	13:00	216	13:00	248	226 (Orange)
8	Shanwei	12:00	118	11:49	304	297 (Yellow)

Based on the field survey and disaster statistics, this storm surge seriously affected seven cities in the Guangdong province, such as Guangzhou, Zhuhai, Shenzhen, Dongguan, Zhongshan, Jiangmen, and Huizhou, and led to direct economic losses of 5.154 billion yuan (Table 4). The direct economic loss was the highest in Zhuhai of 4.401 billion yuan, accounting for 85% of the total direct economic loss. Table 5 shows that the population affected by the Typhoon Hato storm surge accounts for 65.8% of the annual disaster-affected population in the Guangdong province. The number of dead people accounts for 100% of the annual typhoon-related deaths, and the disaster-affected aquaculture area accounts for 74.7% of the annual affected area. The length of damaged coastal structures accounts for 99.5% of the length of the annual damaged coastal structures, the number of damaged vessels accounts for 76.8% of the annual damaged vessels, and the direct economic losses account for 96.1% of the annual direct economic losses. The direct economic losses caused by the Hato marine disaster are higher than

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those due to marine disasters of the past decade (≳1 billion yuan), ranking fourth, and higher than the average value of 3.663 billion yuan.

Table 4. Analysis of the main disaster indicators.

City	Disaster-affected population (people)	Death (including missing; people)	Disaster-affected aquaculture area (ha)	Damaged coastal structures (km)	Sunk vessels (vessels)	Damaged fishing vessels (vessels)	Direct economic losses (10,000 yuan)
Guangzhou	43,500	0	2,337.99	0.62	0	0	11,235
Zhuhai	750,357	2	81.59	2.6	36	152	440,143
Jiangmen	291,070	4	5,558.5	0.08	7	42	30,762.1
Zhongshan	36,300	0	4329	0	0	9	27,781.1
Shenzhen	—	0	—	1.96	0	11	3,737
Dongguan	7,421	0	4.69	0	0	0	101
Huizhou	—	0	5,927.0	767	0	18	1,665.2
Total	1,128,648	6	22,848.55	772.26	43	232	51,5424.4

185 Note: "—" indicates no statistics.

Table 5. Comparison between the losses due to the Hato typhoon storm surge and those caused by other typhoon storm surges that occurred throughout the year.

Index	Typhoon storm surges of the whole year	Hato typhoon storm surge	Proportion (%)
Disaster-affected population (10,000 people)	171.46	112.86	65.8
Dead population (people)	6	6	100.0
Disaster-affected aquaculture area (1000 ha)	24.42	18.24	74.7
Length of damaged coastal structure (km)	776.01	772.26	99.5
Number of damaged vessels	358	275	76.8
Direct economic losses (100 million yuan)	53.61	51.54	96.1

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3.2 Inundation

Based on the above-mentioned inundation survey methods, the cities Guangzhou, Zhuhai, Shenzhen, Zhongshan, Jiangmen, and Dongguan as well as other places in the Guangdong province were inundated to varying degrees. The seawater inundation was mainly caused by dike overflow, dike breach, and piping inundation. Based on the statistics, 13 townships in the Guangdong province were affected by the storm surge, resulting in 19 inundated sites with an accumulated inundated area exceeding 54.08 km2. Inundated areas were mainly distributed in the Panyu, Huangpu, and Nansha districts of Guangzhou city; Xiangzhou District of Zhuhai city; Bao'an, Yantian, and Longgang districts of Shenzhen city; Nanlang Town of Zhongshan city; Guanghai, Duhu, and Chixi towns of Taishan, a county-level city of Jiangmen city; and Hongmei and Humen towns of Dongguan city (Table 6). In Zhuhai city, mainly the urban areas were in-undated. Passenger docks, office buildings, shops, and residential areas along the coast near to Qinglu Road, Xiangzhou District, were heavily inundated by seawater, with a maximum inundation depth of 2 m. Underground garages in several coastal communities were severely inundated, resulting in deaths. The most severe seawater inundation occurred in Jiangmen city. The inundated region mainly included mariculture area with a maximum inundation depth of 1 m and inundation extent of 24.75 km^2.

Table 6. Main inundation status in the survey area in the Guangdong province.

No.	Inundated area		Inundation type	Submergence depth (cm)
1	Zhuhai	Xiangzhou District	Overflow dike	100–200
2		Hengqin Town	Overflow dike	30–80
3		Nanping Town	Overflow dike	30–80
4	Shenzhen	Bao'an District	Overflow dike	30–90
5		Yantian District	Overflow dike and dike breach	120–200
6		Longgang District	Overflow dike and dike breach	10–50
7	Guangzhou	Panyu District	Overflow dike	50–60
8		Huangpu District	Overflow dike	40–50
9		Nansha District	Overflow dike	50–60
10	Zhongshan	Nanlang Town	Overflow dike and floodplain	50–60
11	Jiangmen	Taishan (county-level city)	Overflow dike and dike breach	20–100
12	Dongguan	Humen Town	Overflow dike and piping	120–140
13		Hongmei Town	Overflow dike and piping	80–90

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Field surveys provided valuable information on determining the spatial inundation range and depth distribution caused by storm surge. However, field observations mainly represent discrete locations and reconstructed inundation boundaries, whereas numerical models can provide spatially continuous estimates of inundation patterns. In this study, the simulated inundation results were further compared with field-derived inundation information to evaluate the capability of the numerical model in reproducing the flooding characteristics.

The simulated and observed inundation extents was presented in Figure 5, which could be found that the numerical model successfully reproduced the major spatial patterns of storm surge inundation during Typhoon Hato. The simulated inundation areas were primarily distributed along low-lying coastal zones, estuarine regions, and areas adjacent to river networks, which were consistent with the inundation characteristics identified through post-event field surveys. A high degree of spatial consistency was observed between the simulated and field-observed inundation areas in several severely affected coastal regions, particularly Panyu District, Nanlang Town and Nansha District. In these areas, most of the observed inundated zones were located within or adjacent to the simulated inundation extents, indicating that the model effectively captured the dominant pathways of storm surge propagation and coastal flooding. Some differences were concentrated along coastal margins and complex land-water interaction regions, which may reflect the difficulties of resolving complex coastal environments such as small-scale topography, coastal protection works, and local hydrodynamic processes.

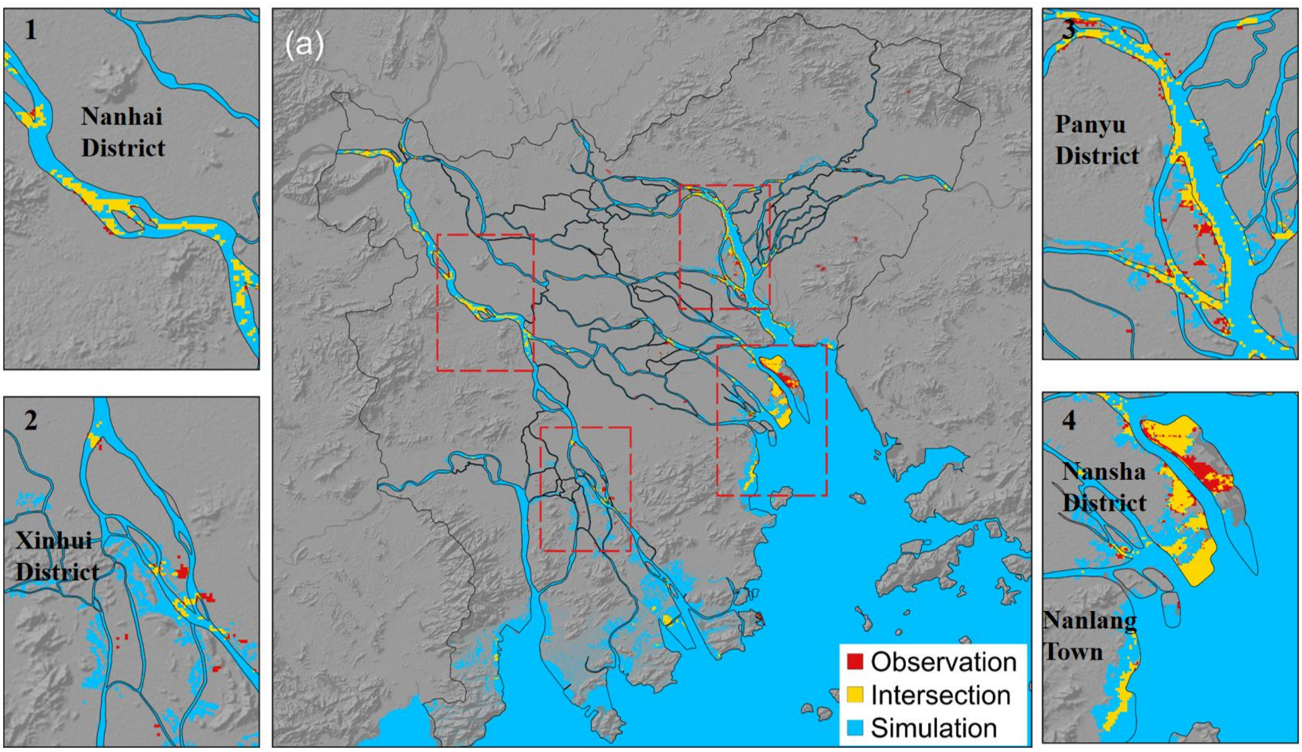

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Figure 5. Comparison of field-observed and model-simulated storm surge inundation extents during Typhoon Hato. The red areas represent observed inundation boundaries derived from post-event field surveys, the blue areas indicate simulated inundation extents from the numerical model, and the yellow areas show the spatial overlap between observations and simulations. Subfigures 1–4 provide enlarged views of representative inundated areas, allowing a detailed comparison between the observed and simulated inundation extents.

To further evaluate model performance, simulated inundation depths were extracted from representative inundated areas and compared with the depth ranges obtained from post-event field surveys (Figure 6). Overall, the simulated inundation depths showed good agreement with the surveyed depth ranges in most representative inundated areas, particularly in Hongmei, Humen, Nanping, Hengqin, Taishan, and Xiangzhou, where the median and mean simulated depths closely matched the field observations. The majority of simulated inundation depths fell within or close to the surveyed depth ranges, demonstrating that the numerical simulation successfully reproduced the overall flooding characteristics associated with Typhoon Hato.

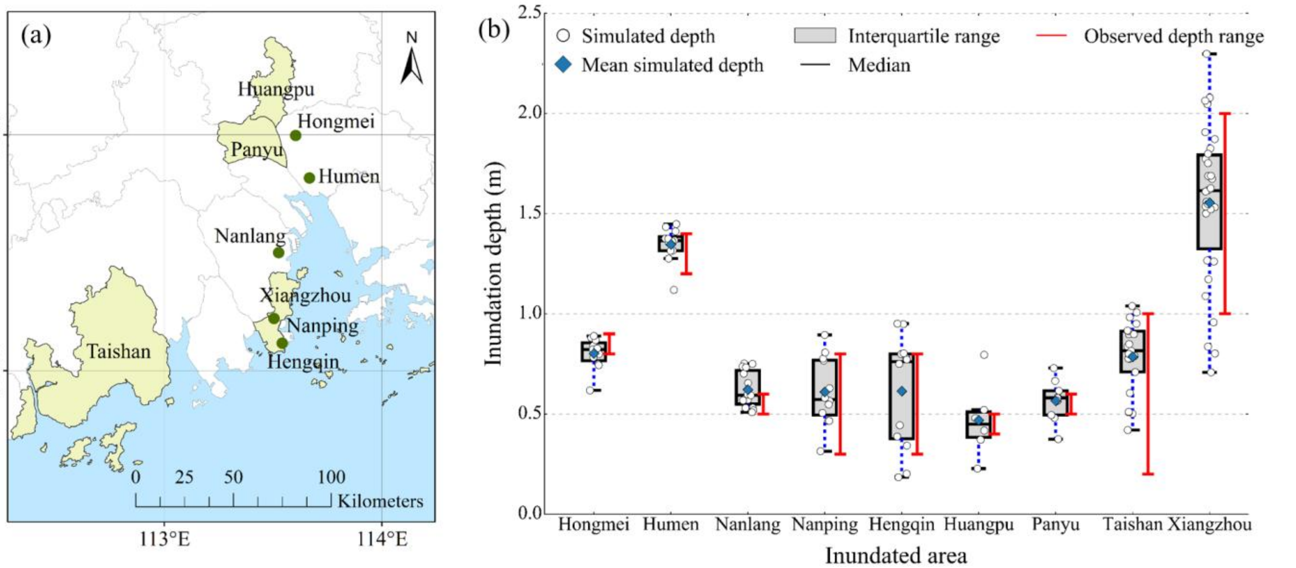

Figure 6. Validation of simulated inundation depths against post-event field observations in nine representative inundated areas affected by Typhoon Hato. (a) Locations of the representative validation areas in Guangdong Province. (b) Comparison between simulated inundation depths and observed inundation depth ranges. The boxplots summarize the distribution of simulated inundation depths extracted from validation points within each inundated area, where the box indicates the interquartile range (IQR), the horizontal line represents the median, the blue diamond denotes the mean simulated depth, and the circles represent individual simulated values. Red error bars indicate the observed inundation depth ranges obtained from post-event field surveys.

4 Discussion

The comprehensive post-event investigation of Typhoon Hato provides valuable insights into storm surge inundation processes in one of China's most densely urbanized coastal regions. By integrating field reconnaissance, RTK measurements, inundation tracing, floating debris surveys, eyewitness interviews, and numerical model validation, this study establishes a reliable dataset for understanding storm surge characteristics and evaluating hydrodynamic model performance. Such comprehensive field observations complement numerical simulations and provide valuable evidence for improving coastal flood risk assessment.

A major finding of this study is the pronounced spatial variability of storm surge inundation across Guangdong Province. Although all surveyed areas were affected by the same typhoon, inundation intensity varied considerably among different coastal cities. This variability reflects the combined influences of typhoon characteristics, estuarine geomorphology, astronomical tides, local topography, and regional exposure rather than typhoon intensity alone. The most severe inundation occurred in Zhuhai, where landfall near the Pearl River Estuary coincided with elevated astronomical tide. The funnel-shaped estuary and strong onshore winds further amplified storm surge propagation, whereas areas farther from the landfall location or with different coastal configurations experienced substantially lower inundation depths (Yang et al., 2019). These findings demonstrate the importance of local coastal characteristics in controlling storm surge hazards.

The favorable consistency between field-surveying and simulated inundation characteristics, in terms of both spatial extent and water depth, indicates that post-event field surveys provide reliable benchmark datasets for numerical model validation. Compared with conventional point-based validation, the integrated framework combining spatially distributed simulation outputs with field inundation data enables a more comprehensive evaluation of model performance. Despite the overall good agreement, notable discrepancies remain in several local areas. Such deviations can be attributed to multiple error sources, including uncertainties in topographic representation, simplified parameterization of coastal terrains and small-scale hydraulic facilities, and inherent limitations of field measurements. Coastal flood simulations are highly sensitive to local topographic variations, drainage conditions, and coastal protection infrastructures, which cannot be fully resolved in regional-scale numerical models. Furthermore, the limited inundation coverage in these areas amplifies the effects of local spatial heterogeneity, thereby exacerbating the mismatches between simulated and observed inundation features. Notwithstanding these local discrepancies, the integrated validation results verify that the numerical model reliably reproduces the overall spatial distribution and severity of inundation induced by Typhoon Hato. The synergistic combination of validated field observations and numerical simulations improves the credibility of hydrodynamic model applications for coastal flood hazard asse

The results also have important implications for coastal flood risk management. As sea-level rise and climate change are expected to increase the severity of future storm surge hazards, reliable field observations will remain essential for improving numerical prediction and supporting coastal flood risk assessment. The substantial spatial variability observed in this study further highlights the need for region-specific disaster prevention and emergency management strategies rather

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than uniform mitigation measures. However, several limitations should be further addressed. The flood marks may have been altered before the field investigation, introducing uncertainty into the reconstructed inundation characteristics. In addition, the relative contributions of various uncertainty sources to the simulation-observation mismatches were not quantitatively evaluated in this study. Future work will adopt quantitative uncertainty attribution techniques to identify the primary factors controlling model performance, which is expected to further enhance the accuracy and reliability of storm surge inundation simulations.

5 Conclusions

This study presents a comprehensive post-event field investigation of the storm surge induced by Typhoon Hato (2017) in Guangdong Province, and integrates extensive field observations with numerical model validation to improve the understanding of storm surge inundation processes and disaster impacts in a highly urbanized estuarine environment. By combining field reconnaissance, RTK measurements, inundation tracing, floating debris surveys, eyewitness interviews, and hydrodynamic simulations, this study establishes a valuable benchmark dataset for investigating storm surge hazards and evaluating numerical flood models. The field investigation demonstrated that the Hato storm surge caused one of the most severe coastal flooding disasters in Guangdong Province during recent decades, with inundated areas exceeding 54 km^2 and maximum inundation depths reaching approximately 2 m. Significant spatial variability in inundation characteristics was observed among different coastal cities, reflecting the combined influences of typhoon intensity, estuarine geomorphology, astronomical tides, local topography, and regional exposure. In addition, the survey revealed that different hazard-bearing bodies responded differently to storm surge impacts, indicating that disaster losses are jointly controlled by hydrodynamic conditions and the vulnerability of exposed infrastructure rather than inundation depth alone. Comparison between field observations and simulated inundation characteristics demonstrated good overall agreement across the representative survey sites, confirming that the previously developed hydrodynamic model successfully reproduced the principal inundation characteristics of typhoon Hato. These results highlight the essential role of comprehensive post-event field investigations in reducing uncertainties associated with numerical simulations and im-proving confidence in coastal flood modelling. The integration of detailed field observations with numerical simulations therefore represents an effective approach for advancing storm surge hazard assessment and validating coastal inundation models.

Data availability

All data used in the study are available from the corresponding author on request.

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Author contributions

Shi wrote and revised the manuscript, Chen wrote the manuscript, Du conducted the numerical simulation, Jia wrote the manuscript and participated in the field survey, Fang analyzed the storm surge loss data, Zhao participated in the field survey, Liu organized this research and prepared the manuscript with contributions from all co-authors.

Competing interests

The contact author has declared that none of the authors has any competing interests.

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