

Article

Analysis of Coastal High-Tide Flooding Events in China: A Case Study of the Event in November 2024

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Abstract

Under the background of global warming, high-tide floods pose growing threats to China's coastal ecosystems, infrastructure and freshwater supplies. Although the occurrence of high-tide flooding events is widely recognized as being related to relative sea-level rise, tides, and residuals, the analysis and attribution of individual events remain relatively scarce. Based on tide-gauge data and numerical simulations, this study conducted a quantitative analysis of the high-tide flooding events along China's southern coast around 19 November 2024 and provides mitigation recommendations. Results indicate that coastal sea levels south of the Yangtze River Estuary in November 2024 hit the third-highest November value on record. Sea levels south of the Taiwan Strait were 26 cm above those of normal years, with the highest monthly level since that recorded in 1980. Around 19 November, the coastal area levels coincided with the astronomical spring tide period, with the astronomical high water levels in Shanwei (Guangdong), Dongfang (Hainan), and Beihai (Guangxi) reaching 116 cm, 186 cm, and 292 cm above local mean sea level, respectively. Additionally, influenced by the outer circulation of the tropical cyclone Man-Yi and a cold-air process, an extensive coastal surge occurred, with 30~80 cm surges persisting for nearly 30 h. The combined effects of high sea levels, spring tides, and abnormal surges triggered extreme sea levels that broke historical records, with multiple stations reaching once-in-20-year levels. The contributions of astronomical tides to the extreme sea levels in Shanwei, Dongfang and Beihai were 49.5%, 69.3%, and 77.8%, respectively, while the contributions of surges were 23.6%, 6.4%, and 4.6%. This high-tide flooding event affected multiple coastal areas in Guangdong, Guangxi, and Hainan. Developing a comprehensive adaptation strategy encompassing emergency observation and early warning, risk assessment and zoning, coastal protection, coastal adaptive planning, and freshwater resources management is crucial for effectively addressing the risks of high-tide flooding events.



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Keywords: high-tide flooding; extreme sea level; spring tide; sea level rise; countermeasures

1. Introduction

Global mean sea level (GMSL) rose at a faster rate in the 20th century than in any century of the past three millennia. Since the late 1960s, the rise rate of the GMSL has accelerated, with an average rate of 2.3 mm/yr from 1971 to 2018 and an estimated acceleration of 0.075 mm/yr². From 1993 to 2018, the GMSL rose at 3.15 mm/yr, with an acceleration of 0.094 mm/yr². It will continue to rise in the 21st century, with projections of 0.38 m

under SSP1-2.6 and 0.77 m under SSP5-8.5 by 2100, compared to 1995–2014 levels [1–5]. In the long term, although the extent of sea level rise may appear limited, its cumulative and intensifying effects on coastal saltwater intrusion are significant [6,7]. Accompanied by the accelerated rise in sea level, rare extreme sea level events are expected to occur more frequently under all RCP scenarios, especially in the tropics [1]. In 2050, many low-latitude metropolises and small islands will experience a Historical Centennial Event (HCE) at least once a year. Under the background of sea level rise, the probability of high-tide flooding along the U.S. coast more than doubled from 2000 to 2020, and this frequency is projected to double again by 2030. By 2050, relative sea level rise will increase tidal and storm surge heights and alter flood mechanism along the U.S. coast. The frequency of large and medium flood events will match that of current medium and small events. U.S. coastal infrastructure, communities, and ecosystems will face severe consequences in the absence of additional risk-reduction measures [8]. Along European coasts, high-tide flooding is rising as sea levels continue to increase. Without improved coastal protection, sea level rise will increase the frequency of extreme high sea levels by 10 times along most European coasts by 2050. Meanwhile, the simultaneous occurrence of high sea levels and intense precipitation may lead to a surge in river runoff, potentially triggering compound flooding in coastal regions [9]. By raising the baseline for storm surges, sea level rise, in conjunction with climatic drivers such as tropical cyclones, extreme waves, and El Niño-Southern Oscillation (ENSO), exacerbates the severity of high-tide flooding events [10,11]. Higher sea levels, compounded by high tides and storm surges, impact coastal communities and infrastructure, while some low-lying islands and regions may experience extensive inundation during every high tide or storm. A major high-tide flooding event in Papua New Guinea and the Solomon Islands in 2008 displaced approximately 63,000 people. The disaster severity was amplified by rising baseline sea levels combined with regional anomalous sea levels caused by ENSO [12,13].

China has the largest global population in low-elevation coastal zones, and these are characterized by high socioeconomic vulnerability. Since 1980, China's coastal sea level has exhibited a significant accelerating trend. The rate of sea level rise was 3.5 mm yr^{-1} for 1980–2023 and 4.0 mm yr^{-1} for 1993–2023 [14]. Driven by multiple factors, including sea level rise and the increasing frequency and intensity of storm surges, the frequency of extreme sea level events and coastal flooding has increased significantly in recent decades [15–19]. Projections indicate that under the intermediate (SSP2-4.5) and high (SSP5-8.5) scenarios, sea levels in the marginal seas of China will rise by 0.22 m and 0.24 m by 2050, reaching 0.59 m and 0.83 m by 2100, respectively [6]. With accelerated sea level rise and growing socio-economic exposure in coastal regions, high-tide flooding events, which were rare in the past, are projected to become more intense and frequent in the future, leading to an increasing risk of high-tide flooding in coastal regions [20,21].

From October to November 2024, two large-scale high-tide flooding events occurred along China's coast, without significant weather system influences. Around 20 October, multiple tide gauges in the Bohai and Yellow seas recorded historically high extreme sea levels, leading to high-tide flooding in Liaoning, Hebei and Tianjin [22]. Around 20 November, another high-tide flooding event occurred south of the Yangtze River Estuary, causing coastal high-tide flooding in Guangdong, Hainan and Guangxi, resulting in varying impacts on marine aquaculture, residents' livelihoods, agricultural production, and tourism facilities, drawing widespread attention [23]. Unlike historical storm surge events, rising sea levels are now posing visible risks and challenges to coastal areas [24]. Although it is widely recognized that the occurrence of high-tide flooding events is mainly related to relative sea level rise, tides and residuals, there is still a lack of analysis and attribution research on individual events. We conducted a quantitative analysis of the main contributing factors

of the high-tide flooding event in China's coastal areas in November 2024, based on the latest tide-gauge observation data and on-site investigation information combined with ocean numerical simulations. We also proposed countermeasures and suggestions, hoping to provide reference for coastal disaster prevention and reduction, coastal zone planning, and freshwater resource management.

2. Materials and Methods

2.1. Materials

This study uses tide-gauge observations from 32 long-term ocean stations of the national ocean observation network. These stations are evenly distributed along the mainland coast of China (Figure 1). The tide-gauge records cover the period of 1980–2024, and the temporal resolution is hourly (Table S1). All records have undergone quality control, gap filling, and homogeneity adjustment [25]. In this study, the period of 1993–2011 is defined as the 'normal years', and each specific month within this period is referred to as the 'the same period of normal years'. Unless otherwise specified, all sea levels mentioned in this paper are relative to these baselines.

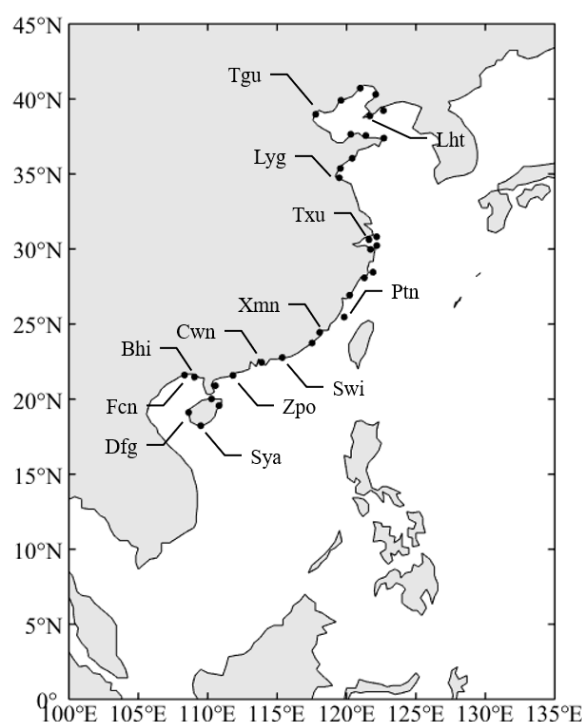


Figure 1. Distribution of tide-gauge stations used in the present study.

Satellite altimeter data were obtained from the multi-satellite merged sea level anomaly monthly products provided by the AVISO Data Center of the French National Center for Space Studies (CNES). The product has a spatial resolution of $0.25^\circ \times 0.25^\circ$ and a temporal interval of one month. Hourly wind field data were obtained from the ERA5 reanalysis provided by the European Center for Medium-Range Weather Forecasts (ECMWF). This dataset includes the 10 m zonal (U) and meridional (V) wind components, as well as sea level pressure reanalysis data. The data have a horizontal spatial resolution of $0.125^\circ \times 0.125^\circ$ and a temporal resolution of 1 h. Information on coastal disaster impacts was obtained from the National Coastal Sea Level Change Impact Survey Program, covering the period from 2009 to 2024.

2.2. Methods

This study employs the ADCIRC model to establish a numerical model covering the South China Sea. The model utilizes an unstructured triangular mesh to effectively resolve complex coastlines and island boundaries. The horizontal resolution is approximately 500 m along the coastlines, gradually coarsening to 50 km at the open boundaries. Model grid bathymetry is interpolated from the ETOPO1 dataset merged with nautical chart data. Meteorological forcing fields, including wind and atmospheric pressure, were derived from ERA5 reanalysis data provided by the ECMWF. The model simulates wind-driven currents and water levels under barotropic conditions, covering the period from 00:00 UTC on 15 November to 23:00 UTC on 24 November 2024.

The storm surge refers to the residual part of the real-time water level after removing the astronomical tide. The formula adopted to calculate the storm surge at each station in this study is given as follows:

$$\gamma(t) = \zeta(t) - A_0 - \sum_{i=1}^m f_i H_i \cos(\sigma_i t + v_{0i} + u_i - g_i) \quad (1)$$

where t denotes time; $\gamma(t)$ represents the residual; $\zeta(t)$ is the observed hourly tidal level; A_0 is the mean sea level during the observation period; f_i and u_i are the nodal factor and nodal angle of the i -th tidal constituent; H_i and g_i are the harmonic constants (amplitude and phase lag); σ_i is the angular velocity and v_{0i} is the astronomical initial phase angle of the i -th tidal constituent. In harmonic analysis of coastal tides, the nonlinear effects in shallow water areas cannot be ignored, and the waveform of tidal curves often produces significant distortions, requiring the consideration of high-frequency vibrations. Following the methods of Fang and Yu [26], the high-frequency vibrations within 12 cycles per day were taken into account in the calculation of astronomical tide, considering the significant characteristics of high-frequency vibrations in China's coastal waters.

Extreme sea levels associated with different return periods were estimated using the Gumbel extreme-value distribution. Given that the tide-gauge records exceed 19 years at all stations, the Gumbel distribution provides a suitable framework for estimating extreme high and low sea levels [7], and its rationality has been validated by abundant previous studies [27]. Naturally, non-stationary extreme value models are also available at present [28], which are mostly adopted for risk projection. The present study reviews the historical extreme high-tide flooding event analyzed herein, and thus, a non-stationary Gumbel model was not constructed. For annual extreme high sea level values or extreme low sea level values h_i in n years, the extreme high or extreme low sea level with different return periods can be calculated by:

$$h_p = \bar{h} \pm \lambda_{p_n} S \quad (2)$$

$$\bar{h} = \frac{1}{n} \sum_{i=1}^n h_i \quad (3)$$

$$S = \sqrt{\frac{1}{n} \sum_{i=1}^n h_i^2 - \bar{h}^2} \quad (4)$$

where h_p is the extreme high sea level or low sea level corresponding to frequency P ; high sea level is represented by '+', while low sea level is represented by '-'; $\bar{h}$ is the mean of h_i in n years; λ_{p_n} is a parameter related with frequency P and data time span n , which can be obtained in the Code of Hydrology for Harbour and Waterway (JTS 145-2015) released by the Ministry of Transport of the People's Republic of China [29]; S is the mean square deviation of h_i in n years; n is the time span of data; h_i is the annual extreme high sea level or annual extreme low sea level in year i .

3. Results and Discussion

3.1. Characteristics of Coastal Sea Level Change

Sea levels along the China coast show distinct seasonal variability. Seasonally high sea levels in the Bohai Sea and northern Yellow Sea usually occur in July and August, a period marked by peak air temperatures, minimum atmospheric pressure, maximum precipitation, and weak monsoon forcing. From October to November, driven by the northeast monsoon, a large volume of seawater flows into the South China Sea via the Bashi Channel, Balintang Channel and Taiwan Strait. Consequently, sea levels in the South China Sea reach annual maximums during this period [30].

From 1980 to 2024, sea levels along the coast of China exhibited an accelerating rising trend, with an average rate of $3.5 \pm 0.3 \text{ mm yr}^{-1}$ ($p < 0.05$). From 1993 to 2024, the rate reached $4.0 \pm 0.3 \text{ mm yr}^{-1}$ ($p < 0.05$), which was higher than the global average over the same period. In 2024, sea levels along the coast of China hit the highest record since 1980, 9.6 cm above the levels for normal years. Monthly sea level fluctuations along the coast were pronounced throughout 2024. In November 2024, sea levels south of the Yangtze River Estuary ranked as the third highest on record for the same month. Among these regions, sea levels south of the Taiwan Strait reached their highest level in November since 1980, approximately 26 cm above the average level for normal years and 13.8 cm above the level for the same time period of normal years. Seasonal high sea levels contributed roughly 47% of this total surge (Figure 2). In terms of long-term trends, the November sea levels along the coast south of the Taiwan Strait showed a fluctuating upward trend from 1980 to 2024, with a rising rate of $3.3 \pm 0.3 \text{ mm yr}^{-1}$ ($p < 0.05$) (Figure 3).

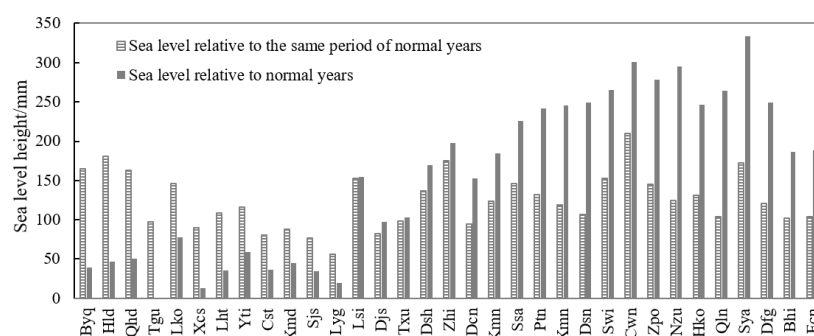


Figure 2. Sea level anomalies along the coast of China in November 2024 compared to overall levels for normal years and those for the same period of time in normal years.

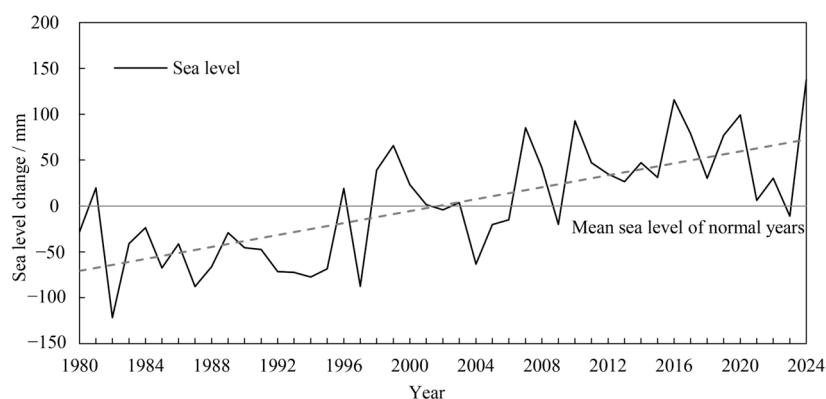


Figure 3. The long-term sea level change along the south of the Taiwan Strait coast in November. Dashed line means linear trend.

3.2. Coastal Astronomical Tides and Storm Surges During This Event

3.2.1. The Characteristics of Coastal Astronomical Tides

In terms of tidal characteristics, Zhejiang and Fujian, the provinces along the coast south of the Yangtze River Estuary, are dominated by regular semidiurnal tides. Areas from southern Fujian to Guangdong feature irregular semidiurnal tides. The eastern and southern coasts of Hainan exhibit irregular diurnal tides. The coasts of the Leizhou Peninsula, northern and western Hainan, and Guangxi are mainly characterized by regular diurnal tides [31].

Regarding mean tidal ranges, Bhi station, which is dominated by regular diurnal tides, has the largest mean tidal range of 225 cm. Chiwan and Zhapo, dominated by irregular semidiurnal tides, rank second, with mean tidal ranges of 142 cm and 159 cm, respectively. Shanwei and Sanya, characterized by irregular diurnal tides, have the smallest mean tidal ranges of 98 cm and 89 cm, respectively. In terms of flood and ebb durations, the average flood duration at Shanwei and Zhapo ranges from 6 h 57 min to 7 h 12 min, with ebb durations from 6 h 28 min to 6 h 56 min. Shanwei has an average flood duration of 8 h 30 min and an ebb duration of 6 h 36 min, with a duration difference of 1 h 54 min. The average flood durations for Sanya, Dongfang and Beihai are 11 h 16 min, 10 h 18 min and 11 h 13 min, with corresponding duration differences of 3 h 25 min, 1 h 18 min and 2 h 24 min, respectively (Table 1).

Table 1. Tidal characteristics at typical tide gauges along the south coast of the Yangtze River.

Station Name	Tidal Coefficient	Tidal Type	Mean Tidal Range/cm	Flood Duration	Ebb Duration
Shanwei	2.16	Irregular diurnal	98	8 h 30 min	6 h 36 min
Chiwan	1.24	Irregular semidiurnal	142	7 h 12 min	6 h 56 min
Zhapo	1.19	Irregular semidiurnal	159	6 h 57 min	6 h 28 min
Sanya	2.82	Irregular diurnal	89	11 h 16 min	7 h 51 min
Dongfang	6.51	Regular diurnal	128	10 h 18 min	11h 36 min
Beihai	4.2	Regular diurnal	225	11 h 13 min	8 h 49 min

The period around 19 November 2024 experienced the spring tide phase along the coast south of the Yangtze River Estuary, with the superposition of a storm surge and a relatively elevated sea level, triggering this high-tide flooding event. During this event, the astronomical high tide levels at Shanwei, Dongfang, and Beihai reached 116 cm, 186 cm, and 292 cm above the local mean sea level, respectively. Their contributions to the extreme sea level were 49.5%, 69.3%, and 77.8%, respectively, while the contributions of the storm surge were 23.6%, 6.4%, and 4.6%, respectively (Figure 4). After deducting the astronomical tide component and the storm surge, the contributions of background sea level to the extreme sea level were 26.9%, 24.3%, and 17.6%, respectively. The contributions of sea level contain both the long-term accumulations and the yearly abnormal changes, which are set to grow progressively in the context of climate change [7]. Our quantitative analysis of the contributions of dominant driving factors to this high-tide flooding event reveals the major contributions from astronomical tides. Meanwhile, sea level rise and storm surge also exert remarkably pronounced impacts on flood development. Nevertheless, we acknowledge that the calculated contribution ratios could be subjected to inherent uncertainties to a certain degree, mainly stemming from astronomical tidal prediction, tide–surge interactions and so on.

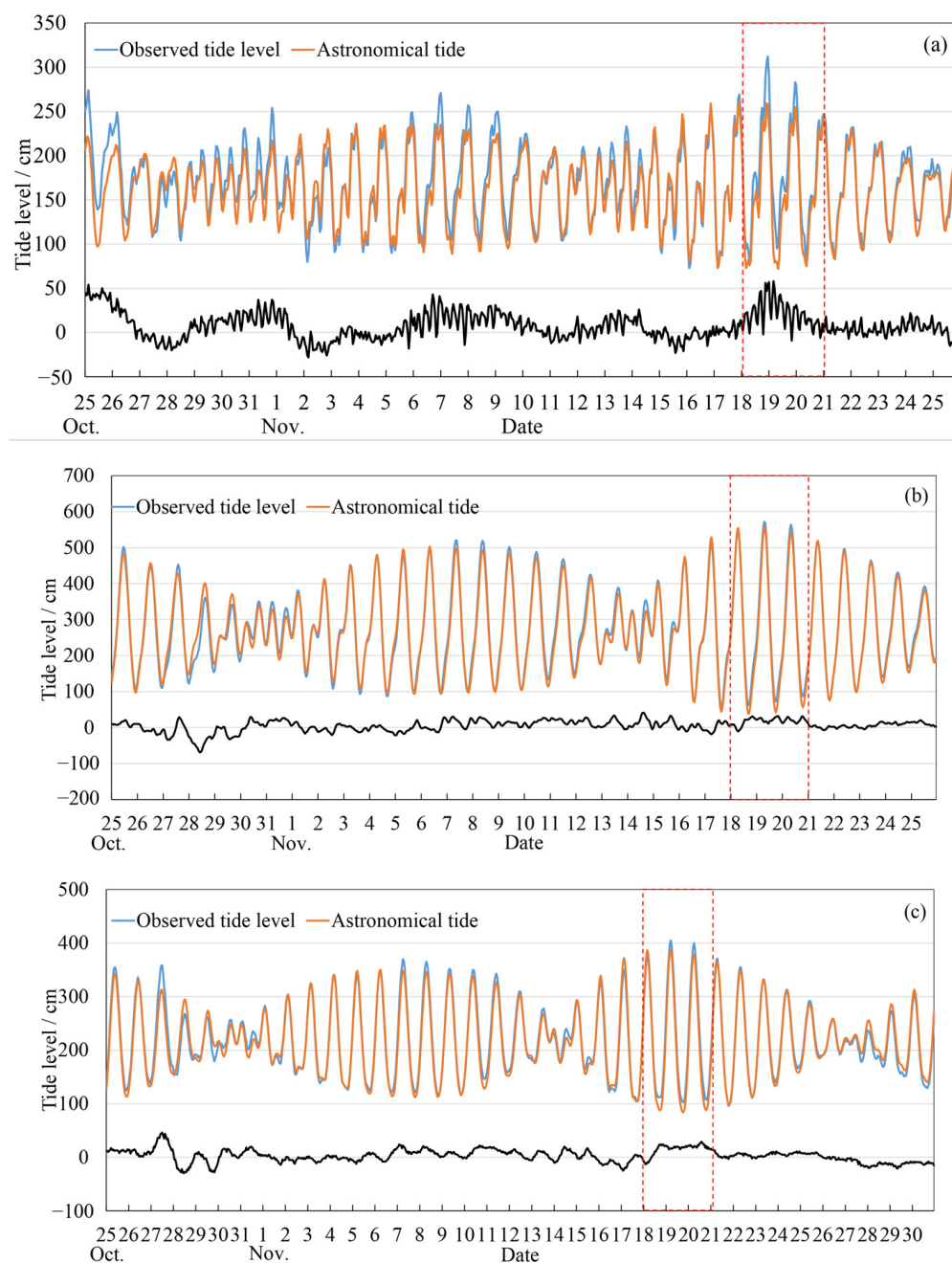


Figure 4. The observed tide level (blue solid line), astronomical tide (orange solid line), surge (black solid line) and main impact time of the extreme sea level event (red dashed line) at Shanwei station in Guangdong (a), Beihai station in Guangxi (b) and Dongfang station in Hainan (c) from 25 October to 25 November.

Against the backdrop of ongoing sea level rise and changing offshore marine environments, the Mean Higher High Water (MHHW) level along coastlines has exhibited an overall fluctuating upward trend. From 1980 to 2025, the annual average rise rate of MHHW along China's coasts stood at 4.8 mm per year. Specifically, the MHHW along the coasts of Guangdong and Hainan follows a predominantly linear rising trend, with respective rising rates of 3.3 ± 0.3 mm/yr and 4.8 ± 0.5 mm/yr; the MHHW rise rate for the Guangxi coast is 2.9 ± 0.4 mm/yr, accompanied by prominent periodic oscillations, and the period around 2024–2025 corresponds to the peak phase (Figure 5).

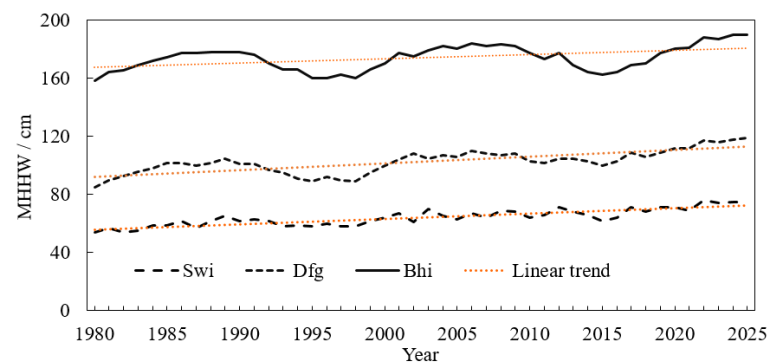


Figure 5. Long-term variations of Mean Higher High Water (MHHW) at typical stations including Shanwei (Guangdong), Beihai (Guangxi) and Dongfang (Hainan) during 1980–2024.

3.2.2. Variations in Residuals

Affected by the combined effects of cold air and the peripheral circulation of tropical cyclone Man-yi, a widespread surge process occurred along the coast south of the Yangtze River Estuary. Numerical analyses of the wind-driven current and wind-driven water level (Figure 6) show a counterclockwise wind-driven surge system along the South China Sea coast during this period. The anomalous storm surge lasted from the early morning of 18 November to 10:00 on 20 November. The maximum wind-driven surge along the coast reached nearly 80 cm. The storm surge ranged from 50 cm to 70 cm along the eastern, central, and western coasts of Guangdong, and 30 cm to 50 cm along the coasts of Hainan and the Beibu Gulf. Storm surges exceeding 10 cm persisted for more than 55 consecutive hours at all coastal stations. The analyses based on tide gauge observations show widespread storm surges along the coast south of the Yangtze River Estuary around 19 November, with 30 cm to 80 cm surges persisting for nearly 30 h. Hourly variations in storm surges at representative stations south of the Taiwan Strait in November 2024 are displayed in Figure 7. The superposition of the record-high background sea level for the same period, spring tides, and this long-lasting storm surge pushed multiple coastal stations to record historical maximum water levels. According to statistical analyses of in situ observation data and numerical simulation results, the spatial range and duration of the storm surges are generally consistent between the two methods. However, the observed surges from stations include residuals excluding astronomical tides, driven by storm surges, wave setup, low-frequency oceanic variations, river discharge effects (for estuarine sites), observational noises and additional factors. They are slightly larger than the wind-driven surges obtained from numerical simulations, which only consider forcing from wind and sea level pressure. We validated model residuals at Shanwei and Zhapo stations, with mean biases of 4.9 cm and 1.2 cm, respectively, during 18 November to 10:00 on 20 November, both falling within a reasonable range. Meanwhile, the ratio of simulated wind-driven residuals to observed values exhibits regional differences, and the maximum value of this ratio is around 80%.

3.3. Impacts of High-Tide Flooding on Coastal Areas and Countermeasures

3.3.1. Coastal High-Tide Flooding Conditions and Impacts

The coastal high-tide flooding is determined by the superposition of elevated background sea level (including seasonal sea level), astronomical tides, and storm surges induced by non-periodic meteorological conditions [24], and the compound effects of these multiple factors exacerbate extreme events [32]. According to the observed distribution of annual extreme sea levels (Figure 8), annual extreme sea levels north of the Yangtze River Estuary in 2024 mainly occurred during 19–21 October, marked by dashed shading in the bar chart. The extreme sea level at Bayuquan and Huludao reached 347 cm and

321 cm, respectively, exceeding the 200-year return period level. In 2024, annual extreme sea levels south of the Yangtze River Estuary occurred during 18–20 November, except for in Haikou, as indicated by solid gray shading in the bar chart. The annual extreme sea level at Haikou was recorded on 6 September, during the influence of tropical cyclone Yagi. During 18–20 November 2024, extreme sea levels from southern Zhejiang to Fujian all exceeded 320 cm, while the extreme sea levels along Guangdong coast ranged from 176 cm to 218 cm, reaching the 2–20 year recurrence extreme value. Along the Guangxi coast, extreme sea levels stood at 256 cm to 314 cm, matching the 20-year recurrence level. Record-high tide levels were observed at Dongfang station in Hainan and Fangchen station in Guangxi. During this event, the sea level at each station was significantly higher than the normal level.

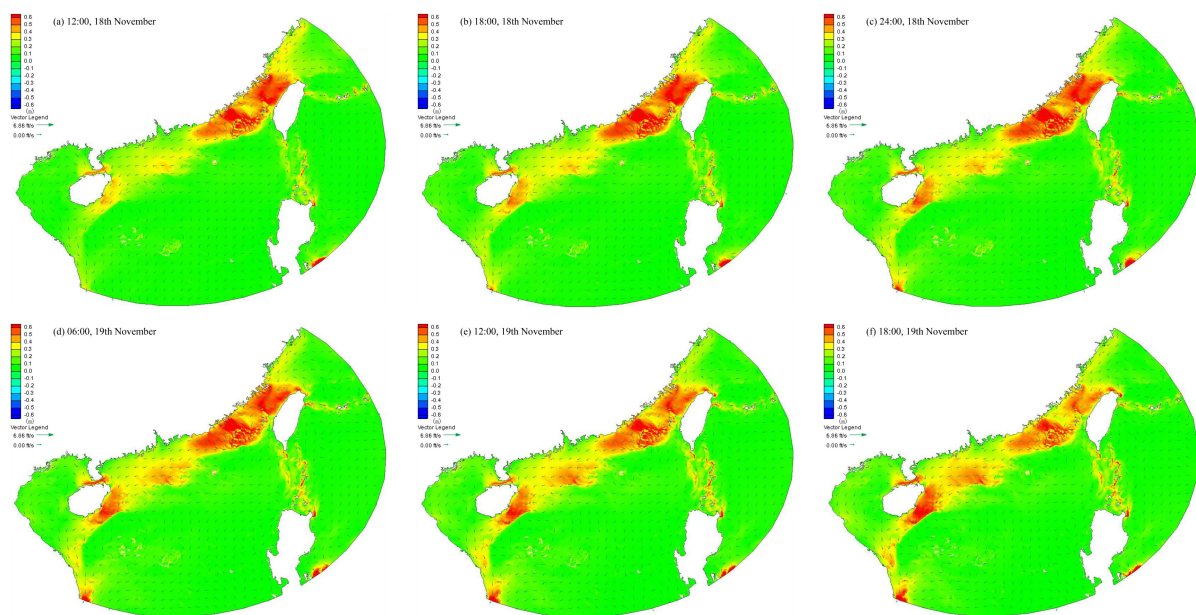


Figure 6. The simulated results of the surge processes during the extreme sea level event in November 2024.

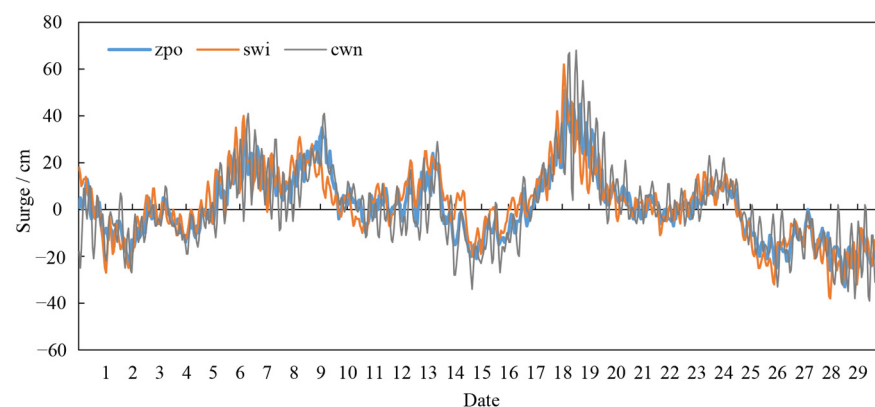


Figure 7. Variations in residuals at representative stations in November 2024.

The short-term sea levels (18 November to 20) at Shanwei (Guangdong), Dongfang (Hainan), and Beihai (Guangxi) were 35 cm, 35 cm and 42.6 cm higher, respectively, than those in average years. The projected mean sea level rise for China's marginal seas by 2050 reaches 22 (19–28) cm under the intermediate-emission scenario (SSP2-4.5) and 24 (21–33) cm under the high scenario (SSP5-8.5). Moreover, the short-term sea levels during the 13 h window around the peak of this extreme event at three stations hit 129 cm, 163 cm and

105 cm above the levels for normal years, respectively, values far exceeding the upper limit of the 2100 projected mean sea level rise of 77 (63–102) cm for China's coastal waters under SSP5-8.5. We acknowledge that these two metrics describe distinct physical processes, yet it is still worthwhile to compare their magnitudes intuitively. This disparity in magnitude does not imply that the projected future background SLR has already been exceeded. Instead, it highlights that sustained long-term SLR will substantially shorten the return period of analogous extreme water level events and increase the frequency of exceeding warning thresholds [15,22].

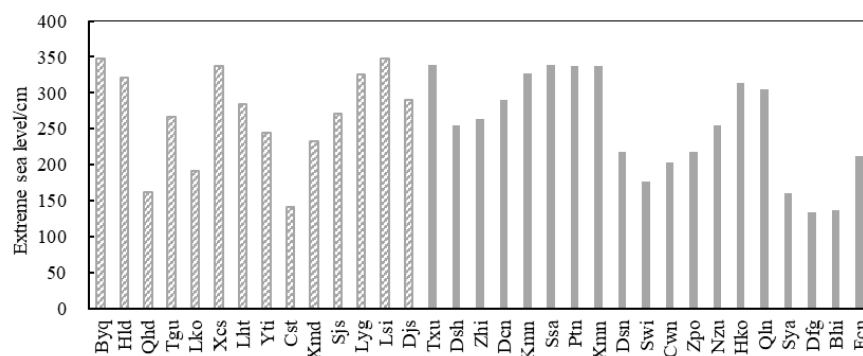


Figure 8. Extreme sea levels at representative stations in 2024. The dashed shading bars represent events mainly occurring during 19–21 October, while the solid bars represent those mainly occurring during 18–20 November, reflecting the two high-tide flooding events.

The high-tide flooding event around 19 November 2024 triggered large-scale high-tide flooding along the coast. Field surveys results showed that mariculture, industrial and agricultural production, drainage facilities, and coastal water supply in Guangxi, Hainan, Guangdong and adjacent coastal areas suffered varying degrees of damage. Shenzhen City and Huidong County of Huizhou City sustained the most severe impacts. In Huidong County, four towns were affected, with 150 people impacted. Infrastructure damage is estimated at 100,000 yuan, and losses to aquaculture reached 396,600 yuan (Figure 9).



Figure 9. Impact status in the coastal areas of Shenzhen in 19 November 2024.

3.3.2. Countermeasures and Suggestions

As sea levels continue to rise and socio-economic exposure in coastal zones increases, high-tide flooding events will become more intense and frequent in the future. Consequently, the risk of high-tide flood along coastal regions will grow progressively. Based on the characteristics of high-tide flood in China, the following countermeasures and suggestions are proposed.

First, it is imperative to continuously upgrade emergency observation capabilities for high-tide flooding events. Priority should be given to high-incidence regions, including the Bohai Rim, Yangtze River Estuary, Hangzhou Bay, and the Guangdong–Hong Kong–Macao Greater Bay Area, to ensure the safety and operational stability of long-term monitoring stations. Furthermore, the three-dimensional monitoring and comprehensive management of coastal subsidence zones must be strengthened.

Second, early warning mechanisms for low-probability, high-risk high-tide flooding events require reinforcement. Disaster mitigation protocols must explicitly account for the compounding effects of high sea levels, astronomical spring tides, and storm surges. Additionally, scientific assessment mechanisms should be refined to advance risk assessment and zoning for high-tide flooding in major strategic regions, thereby precisely identifying high-risk zones.

Third, strategies to mitigate high-tide flooding and intrusion must be elevated, including the rational allocation of freshwater resources in major estuaries (e.g., the Yangtze, Qiantang, and Pearl River estuaries) to store freshwater and suppress salinity, ensuring water security during periods of elevated sea levels and dry seasons.

Fourth, nature-based adaptation capabilities should be effectively improved. The indicator system for coastal protection capability verification and standards for coastal flood control and drainage should be continuously optimized, and the construction of resilient coastal cities should be advanced. Ecological construction and renovation of coastal protection projects should be implemented according to local conditions, leveraging the disaster mitigation functions of ecosystems such as wave attenuation and embankment stabilization.

Fifth, synergy between coastal planning and scientific responses to high-tide flooding should be promoted. The outcomes of risk assessments should be integrated into resilient city development and the territorial spatial planning system. Coastal retreat lines and marine disaster defense zones should be scientifically delineated and consolidated to support major national regional strategies and coordinated regional development.

Sixth, public awareness and participation should be strengthened through enhanced communication. A whole-of-society response system led by the government, with participation from the public and non-governmental organizations, should be established, and cross-regional and cross-departmental emergency coordination should be reinforced. Disaster prevention and mitigation education should be expanded to raise public awareness, and a simple, green, and low-carbon lifestyle should be advocated.

4. Conclusions

Analysis reveals that coastal sea levels south of the Yangtze River Estuary in November 2024 rose markedly above climatological averages, ranking as the third-highest on record for that month. Notably, sea levels south of the Taiwan Strait hit a record-breaking peak for November, surpassing levels dating back to 1980. Around 19 November, the combined effects of cold air activity and peripheral circulations of tropical cyclone Man-Yi generated storm surges ranging from 30 to 80 cm along the coastline. Coinciding with spring astronomical tides across the South China coast during this period, the superimposition of anomalously high sea levels, spring tides and extreme storm surges pushed multiple coastal tide-gauges to their all-time water level maxima and triggered a widespread high-tide flooding disaster. Coastal regions including Guangxi, Hainan, and Guangdong suffered varying degrees of impact on mariculture, industrial and agricultural production, drainage facilities, and coastal water usage. To scientifically address and prevent the risk of high-tide flooding, efforts should be made to continuously improve the emergency observation and early warning capabilities for high-tide flooding events, strengthen high-tide flood risk assessment and vulnerability zoning in coastal areas, and upgrade coastal flooding defense

standards. Meanwhile, it is necessary to enhance adaptive planning for coastal cities and freshwater resource management and explore comprehensive response schemes based on ecological concepts that integrate adaptation and mitigation.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/w18141665/s1>, Table S1. Information of tide gauges used, including station names, abbreviations and data periods.

Author Contributions: Formal analysis, data curation, conceptualization, methodology, and writing: W.X. and H.W. Visualization, validation, and numerical simulation: W.L. Review and editing: H.W. Data process and translation: W.F. Software and validation: T.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available upon reasonable request at <https://mds.nmdis.org.cn/>.

Conflicts of Interest: The authors declare no conflicts of interest.

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