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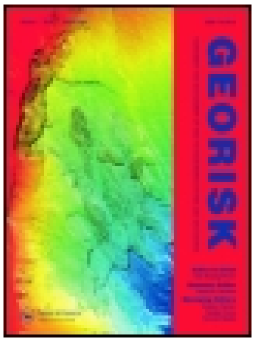

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ABSTRACT

This study investigates the storm surge caused by Typhoon Hato, which severely affected Macau, Hong Kong, and other coastal cities in China on 23 August 2017. A typhoon and storm surge coupling model demonstrated that the maximum storm surge height reached nearly 2.5 m along the coast of Macau, while that in Hong Kong was slightly below 2 m. Furthermore, a field survey of urban flooding revealed evidence of a 2.25-m inundation in downtown Macau and a 0.55-m inundation on Lantau Island, Hong Kong, which were likely exacerbated by a combination of storm surge, heavy rainfall, and surface water runoff over a complex hilly terrain. Significant wave overtopping and runup also occurred in beach and port areas. A typhoon track analysis confirmed that several comparably strong typhoons have followed similar ESE to WNW trajectories and made landfall in the Pearl River Delta in the last few decades. Although Hato was not the strongest of these storms, its forward speed of about 32.5 km/h was remarkably faster than those of other comparable typhoons. Higher levels of storm signal warnings were issued earlier in Hong Kong than in Macau, raising questions about the appropriate timing of warnings in these two nearby areas. Our analysis of the storm's pattern suggests that both regions' decisions regarding signal issuance could be considered reasonable or at least cannot be simply blamed, given the rapid motion and intensification of Hato and the associated economic risks at stake.

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2017 Typhoon Hato; storm surge; field survey; Hong Kong; Macau; Typhoon warning; numerical simulation; historical typhoons

1. Introduction

In 2017, many strong tropical cyclones were generated in the Atlantic Ocean, such as Hurricanes Harvey, Irma, and Maria, having significant impact on the United States and some Caribbean Islands. These three hurricanes in particular were widely covered by the media, contributing to raising awareness of the dangers faced by people in these affected countries. On the other hand, it seems that the world's attention was less focused on areas damaged by Typhoon Hato, which occurred at a similar time of the year in the western North Pacific.

Hato was one of the strongest TCs to make landfall in the Pearl River Delta of South China over the last several decades, severely impacting coastal cities such as Macau (population 0.6 mil), Hong Kong (7.4 mil), and Zhuhai in China's Guangdong Province (1.6 mil). The typhoon was assigned Signal 10 on Wednesday morning, 23 August 2017, the highest level noted in the Hong Kong and Macau storm warning systems; this signal has been issued only 15 times since 1946 (South China Morning Post 2017; The Japan Times 2017). The intensity of Hato can be compared with that of Typhoon Wanda that occurred in 1962, which left 130 people dead and 72,000 homeless in Hong Kong (South China Morning Post 2017). Hato was the worst storm to hit Macau in over 50 years, causing 10 fatalities and more than 200 injuries, amid massive damage to the city's casino hub. Almost half of the city was left without water and electricity, bringing businesses and public transportation to a standstill (South China Morning Post 2017). The storm made landfall at about noon in Zhuhai, where at least 4 people died and 26,817 people were evacuated to temporary shelters (The Guardian 2017).

TC-related disasters frequently occur in coastal Asian countries. For example, the storm surges caused by Cyclone Sidr in Bangladesh (2007), Cyclone Nargis in Myanmar (2008), and Typhoon Haiyan in the Philippines (2013) are considered to be the largest storm surges over the last decade and have been extensively studied by local and international researchers (Tasnim et al. 2014; Esteban, Takagi, and Shibayama 2015; Tasnim, Esteban, and Shibayama 2015; Mikami et al. 2016). On average, the frequency of annual TC landfalls in China is 7.8 [8], which is larger than that in the Philippines (5.9), Japan (2.9), or Vietnam (3.26) (Takagi and Esteban

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2016; Takagi, Anh, and Thao 2017). The frequency of TC occurrence in China decreases gradually from south to north, but is very high along the coast of the Guangdong Province. Although catastrophic storm surge events have not occurred in China, Hong Kong, or Macau in the past decade, the Chinese coast has experienced a high frequency of moderate storm surges greater than 1 m, with an average of 54 surges per decade (Needham, Keim, and Sathiaraj 2015). Among the coastal provinces of China, the typhoon storm surge risk in Zhejiang, Fujian, Guangdong, and Hainan is significantly higher than that in other provinces (Gao et al. 2014). The largest storm surge observed in China was generated by Typhoon No. 8007 in 1980, generating a water-level rise of 5.94 m in the Guangdong Province (Liu and Wang 1989). Although TCs that approach Hong Kong and Macau tend to induce relatively small storm surges, typically of 0.5–1.0 m, this is sufficiently high to cause coastal flooding if the typhoon occurrence coincides with astronomical high tide (Lee, Wong, and Woo 2010).

This study was conducted in four stages. First, we identified all typhoons approaching the Pearl River Delta over the last seven decades using Best Track Data from the Joint Typhoon Warning Center (JTWC). Second, we assessed the situation immediately following Hato based on a field survey, particularly focused on the extent of storm surge in Macau and Hong Kong. Third, we used a typhoon and storm surge coupling simulation model to demonstrate the characteristics of the typhoon's wind field and resultant storm surge over a wide area of the Pearl River Delta. Finally, we reviewed the typhoon warning signals that were separately issued in Macau and Hong Kong by comparing them with intensity data such as wind speed and surface pressure.

2. Methodology

2.1. Field survey

We conducted an intensive 4-day storm surge survey, beginning 10 days after the typhoon made landfall, covering 12 locations in various parts of Macau and Hong Kong (Figure 1). A system comprising a laser range finder, a prism, and a GPS receiver was used to measure the inundation height at each location within a few centimetres accuracy. The measured height was then adjusted according to the tidal level at the time of Hato's landfall, using the astronomical tide as estimated by WXTide32 software.

We also interviewed local residents to assess the flooding conditions caused by the typhoon. Several interviewees witnessed flooding in their houses or workplaces and clearly remembered the rise in water level. Some even took photos or videos of the flooding, which were invaluable for precisely locating and measuring inundation depths. Photos and videos posted on a social networking service were also used to assess the context for flood conditions (such as whether water levels were caused by storm surge or high waves).

2.2. Typhoon track analysis and storm surge simulation

We conducted a historical analysis of high-intensity typhoon tracks around the Pearl River Delta using JTWC's Best Track Data for the last seven decades. These data contain the geographical position, atmospheric pressure at the storm's centre, and wind speed at 6-h intervals. Hato's track and wind speed were compared with those of other TCs above Category 1 on the Saffir–Simpson hurricane scale, with a focus on TCs passing through Macau and Hong Kong.

The fluid dynamics model Delft3D-FLOW (Deltares 2011) was coupled with a parametric typhoon model developed to simulate storm surge during typhoon passage (Takagi et al. 2017). The reliability of this model was verified for recent strong typhoons such as the 2013 Haiyan (Takagi et al. 2016) and 2015 Typhoon Goni (Takagi and Wu 2016). The typhoon model calculated both the pressure and wind fields using parameters, such as central pressure and position at every recording period, obtained from the Japan Meteorological Agency's (JMA) TC Best Track Data. The distribution of atmospheric pressure at a distance r around a TC's centre was estimated by the Myers formula (Myers 1954):

$$P(r) = P_c + \Delta P \exp\left(-\frac{R_{\max}}{r}\right) \tag{1}$$

where ΔP denotes the drop in pressure. The maximum wind radius R_{max} was estimated from the central pressure P_c using the equation $R_{\max} = 0.676\ P_c - 578$, with $R_{\max}$ and P_c in km and hPa, respectively (Takagi and Wu 2016). Since the Best Track Data provide these parameters at only 6-h intervals, our model created interpolated data with finer time intervals (3 hours) to avoid sudden changes in the pressure and wind fields.

Although the Delft3D model can be applied to three-dimensional phenomena, in this study we used a two-dimensional horizontal grid. Thus, the code employed is that of a shallow-water wave model, which is commonly used to simulate long waves such as storm surges, tsunamis, and tidal propagation (Takagi and Bricker 2014). Oceanic bathymetry data within the computational domain were obtained from the General Bathymetric

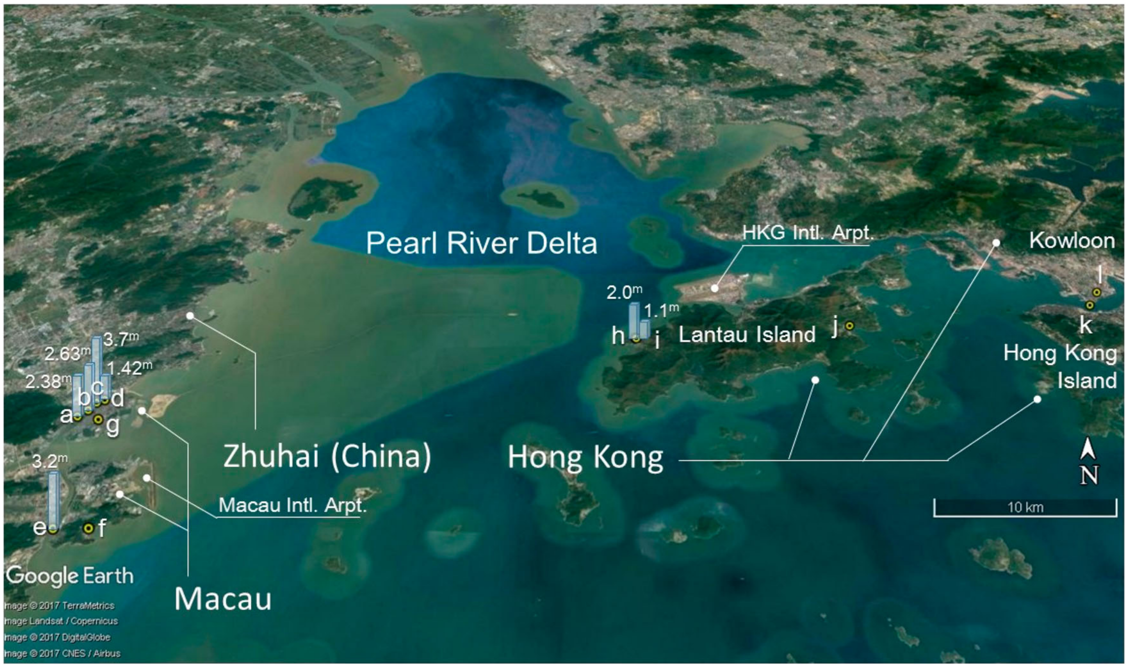


Figure 1. Survey locations for storm surge and damage caused by the 2017 Typhoon Hato in Macau and Hong Kong, at the mouth of the Pearl River. Vertical bars show inundation heights above sea level, described in Figure 4, and indicate that the overall range at these locations is 1.1–3.7 m.

Chart of the Oceans (GEBCO). The computational domain encompassed a wide area including the Pearl River Delta between 20.0°N–111.0°E and 23.0°N–116.0°E with a spatial grid of 0.01° (a ~1 km grid). The initial conditions of sea surface elevation and velocity were both set to be zero within the computational domain. Although the model can simulate inundation over land areas, it may not be reliable because the computational grid is too coarse to precisely reproduce the complex terrain of the areas of interest. Hence, we focused on the propagation of a storm surge within the oceanic area.

3. Results

3.1. Historical analysis of Typhoon tracks

Figure 2 shows the tracks of all TCs passing near Macau and Hong Kong over the last 7 decades. Storms of at least Category 1 strength are estimated to pass the Pearl River estuary about once every 10 years. The forward direction of TCs in this region is primarily WNW to N. According to a disaster report by the Hong Kong Observatory (http://www.hko.gov.hk/), Typhoons Mary (1960), Wanda (1962), Ruby (1964), and Rose (1971) were the four most catastrophic typhoons since 1960, claiming 45, 130, 28, and 110 lives, respectively. Interestingly, all four typhoons made landfall on Lantau Island, implying that a typhoon impacting this particular location tends to cause severe damage in Hong Kong. As Macau has a much smaller territory than Hong Kong, the chance of typhoon landfall in Macau is inevitably lower. Nevertheless, Typhoons Wanda (1962) and Ruby (1964) were noted to make a second landfall (after Landau Island) in Macau, accompanied by strong winds.

In comparison, Hato made landfall along the southern coast of Zhuhai with a Category-2 intensity, strong but not stronger than other more powerful storms. Three other major typhoons, Wanda (1962), Ruby (1964), and Vicente (2012), followed a similar trajectory as that of Hato (from ESE to WNW), making landfall on slightly different parts of the coast. Hato's forward speed was the fastest of these typhoons, reaching 32.5 km/h, nearly twice as fast as the speed of Wanda (Figure 3). The forward speed at the time of landfall was estimated by dividing the distance of two points shortly before and after landfalls by 6 h, which is the recording interval of the Best Track Data.

3.2. Field survey

Figure 4 summarises the water-level conditions at 12 locations (*a*–*l*, Figure 1) where we clearly observed evidence of inundation during the field survey. The inundation at *a* was the most obvious case of storm-surge-induced inundation because this spot was immediately adjacent to a seaport. At this location, we measured the storm surge height by interviewing a port worker who received a video of the flood taken by a colleague, documenting the water's rise.

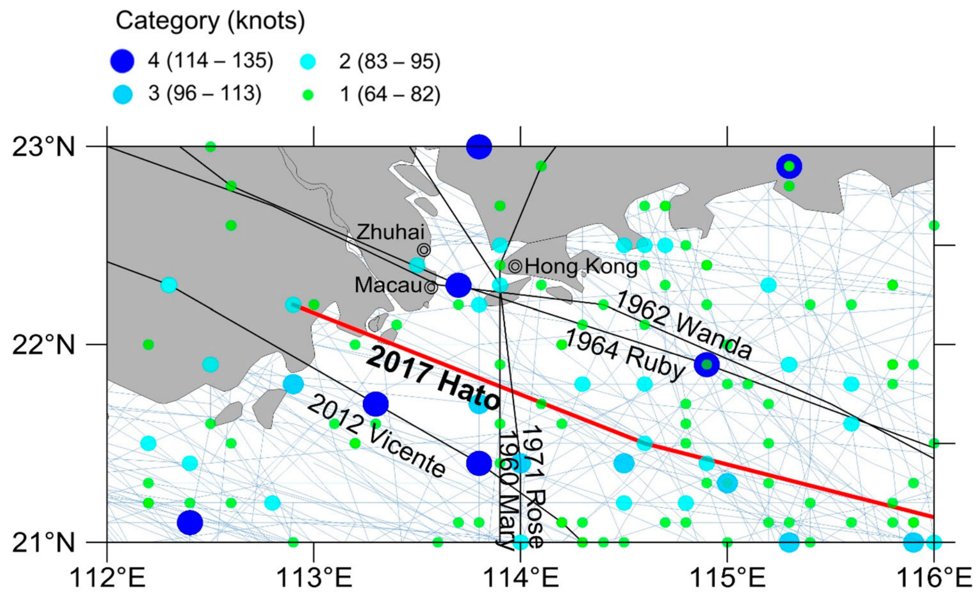


Figure 2. Tracks and wind speeds of tropical cyclones near the Pearl River Delta from 1945 to 2016, along with the track of the 2017 Typhoon Hato. Major storms affecting Macau and Hong Kong are indicated by placing their names over their trajectory lines.

Points *b*–*e* are situated in built-up areas of Macau. Inundation depths were confirmed by witnesses as well as a watermark noted on a shop window. Because the seawater most likely reached these areas through the street grid, we determined that this inundation was best explained by a storm surge. However, other causes of inundation in these urban areas could have included intense rainfall during the typhoon. The topography of Macau is not flat; that is, it comprises hilly coastal terrain. Hence, spatial variations in inundation depth could also be explained by complexity in surface runoff patterns. Point *f*, located behind a sandy beach, was impacted by high waves in addition to the storm surge, as witnessed by a restaurant owner. We confirmed that the wave runup reached approximately 70 m inland from the shoreline. Point *g*, within the northern island of Macau, showed an inundation of at least 30 cm; however, we could not determine the height above sea level, as this location was confirmed through a photo taken at a street likely after the passage of the typhoon.

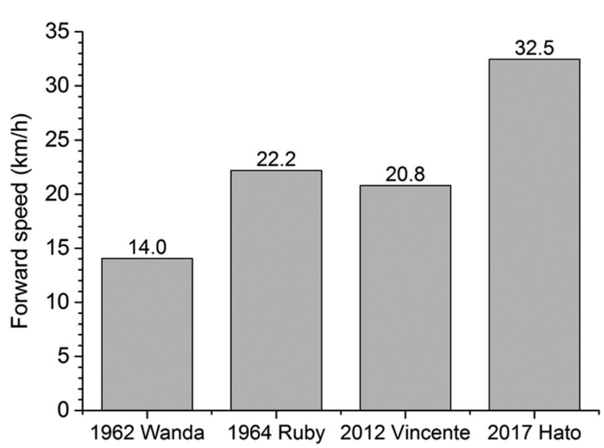


Figure 3. Forward speeds of Typhoon Hato and the other three major typhoons affecting the Pearl River Delta that followed a similar trajectory as that of Hato. Values were calculated based on the geographical locations of the system before and after landfall.

Points *h*–*l* present the situation in Hong Kong, covering Lantau Island, Hong Kong Island, and Kowloon. Although the maximum water levels seemed to be slightly lower than those in Macau, the storm surge caused substantial inundation at points *h* and *i*, as confirmed by multiple local witnesses. On the other hand, remarkable storm surge was not substantiated at points *j*–*l*, which were located slightly further away from the typhoon track. Nevertheless, these areas suffered damage due to high waves. According to the Windguru database (https://www.windguru.cz/), the maximum significant wave height was estimated to reach 5.5 m at 11:00 a.m. on 23 August 2017, at a location near Hong Kong Island. Given this extent of offshore waves, it is not difficult to imagine that wave overtopping occurred along many portions of the coasts of Hong Kong, Macau, and other adjacent regions under the direct influence of the typhoon.

3.3. Verification and discussion of Typhoon and storm surge simulation

Before importing the typhoon model's output into the hydrodynamic model, we verified it by comparing observed and calculated surface pressures in Macau

Figure 4. Summary of field investigations into inundation conditions in Macau and Hong Kong produced by the 2017 Typhoon Hato. Water-level heights were determined through witness accounts and imagery. Locations *a–l* are mapped in Figure 1. Photos were taken by the authors or provided by anonymous residents.

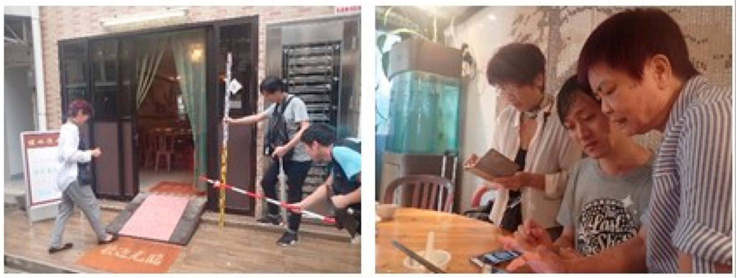
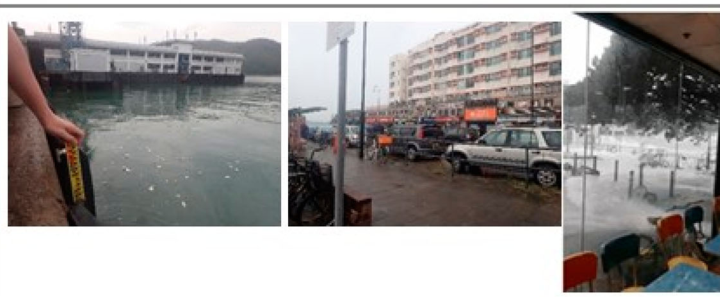
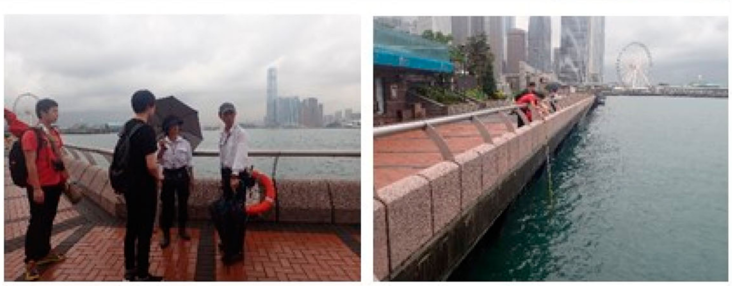
g		Macau, 友谊大马路 22°11′24″N, 113°32′48″E Type: Inundation Height above the surface: 0.30 m Height above sea level: no data Evidence: SNS
h		Hong Kong, 大澳 22°15′16.3″N, 113°51′45.2″E Type: Inundation Height above the surface: 0.55 m Height above sea level: 2.00 m Evidence: Witness
i		Hong Kong, 大澳 22°15′13.4″N, 113°51′47.8″E Type: Inundation Height above the surface: 0.55 m Height above sea level: 1.10 m Evidence: Witness
j		Hong Kong, 梅窝 22°15′52″N, 114°00′07″E Type: Wave overtopping Height above the surface: no data Height above sea level: >1.4 m Evidence: SNS
k		Hong Kong, 中环 22°16′60″N, 114°10′00″E Type: Wave overtopping Height above the surface: no data Height above sea level: >2.3 m Evidence: Witness
l		Hong Kong, 尖沙咀 22°17′46″N, 114°10′38″E Type: Wave overtopping Height above the surface: no data Height above sea level: >1.5 m Evidence: Witness

Figure 4a *Continued*

and Hong Kong (Figure 5). The observed data, measured at the relevant international airports (Figure 1), were derived from the Global Surface Data provided by the University of Wyoming (http://weather.uwyo.edu/surface/meteorogram/index.shtml). The observed lowest pressures at the Macau and Hong Kong airports were 967 hPa and 983 hPa, respectively. Hato approached these islands at around 11:00–12:00 a.m. on 23 August 2017, as confirmed by the pattern of the low-pressure system. The calculated pressures agreed well with the observed data, with an error of ± 5 hPa.

Figure 6 shows the spatial distributions of pressure and wind at the time of the landfall. Hato's course appears to be disastrous for both Macau and Hong Kong, as the counter-clockwise wind field directs the maximum wind radius across Lantau Island. Therefore, seawater would be expected to be pushed towards Lantau Island and the east side of Macau, resulting in substantial storm surges in these areas. This expectation is also supported by the result obtained from the storm surge simulation (Figure 7). The maximum storm surge height was estimated to reach nearly 2.5 m along the coasts of Macau and Zhuhai, and just below 2 m in Hong Kong. Figure 8 assesses the accuracy of the simulation by comparing the estimated storm surge and storm tide (storm surge + astronomical tide) with data measured by the Hong Kong Observatory at Shek Pik (Figure 7). The observatory reports a maximum water level of 3.91 m above chart datum at 11:30 a.m. on 23 August 2017 (Hong Kong Observatory, http://www.hko.gov.hk/), similar to the simulation. Although the present study did not simulate the astronomical tide, the storm tide above chart datum can be roughly estimated by adding the tide at the peak timing of the storm surge (i.e. 2.5 m, as confirmed from Figure 8) to the distribution shown in Figure 7.

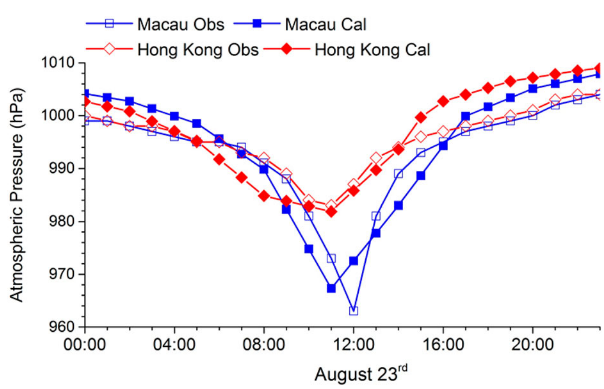


Figure 5. Comparison of surface pressures for Typhoon Hato between observed (Obs.) and calculated (Cal.) data.

It should be noted that the numerical model only considered two primary mechanisms (pressure- and wind-induced setup components), neglecting other mechanisms. Apart from these primary drivers, strong winds can also generate high waves, which sometimes cause the most predominant physical impact during the course of a TC (Roeber and Bricker 2015). High waves can also induce changes in mean water level caused by breaking waves (known as the breaking-wave-induced set-up), which are denoted by $\bar{\eta}$ and can be evaluated by numerically integrating the following differential equation from deep water toward the shoreline (Goda 2000):

$$\frac{d\bar{\eta}}{dx} = -\frac{1}{(h+\bar{\eta})}\frac{d}{dx}\left[\frac{1}{8}H^2\left(\frac{1}{2}+\frac{(4\pi h/L)}{\sinh 4\pi h/L}\right)\right] \quad (2)$$

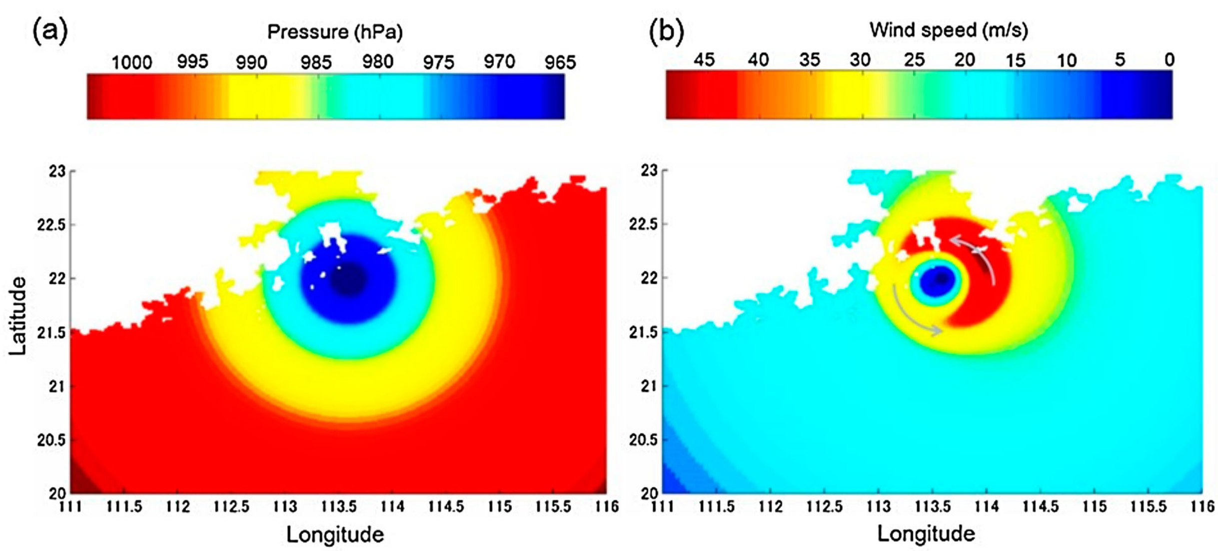


Figure 6. Calculated distributions of (a) sea-surface pressure and (b) wind speed at the landfall timing of Typhoon Hato.

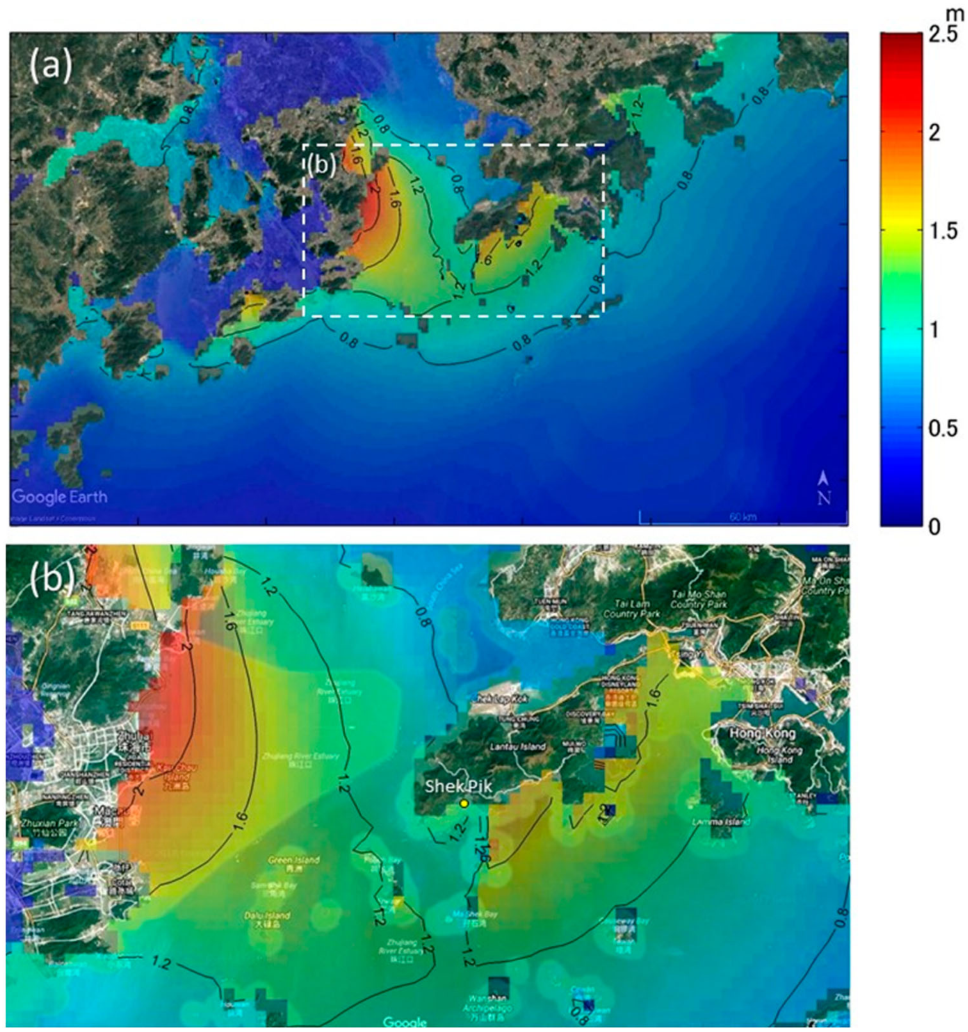


Figure 7. Simulation of maximum storm surge height around (a) the Pearl River Delta and (b) the area surrounding Macau and Hong Kong. Shek Pik is the location where observed and calculated surge data are compared in Figure 8.

where H denotes the wave heights, h is the water depth, and L is the wave length.

For example, here we assumed that the offshore significant wave height was $H_s = 5.5$ m, based on the hindcast obtained using Windguru, and that the waves propagated normal to the shoreline over a uniform slope of 1/100. Thus, we calculated that, as the water depth decreased, the wave setup increased and reached up to ~40 cm at a water depth of 2 m. Therefore, any slight underestimations in the simulation could be partially attributed to this extra addition of water level.

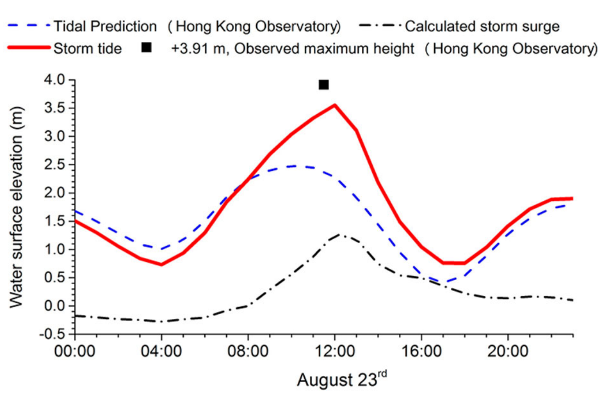


Figure 8. Comparison between simulated and observed storm surge height for Typhoon Hato at Shek Pik, Hong Kong (location shown in Figure 7). "Storm tide" is astronomical tide + storm surge.

4. Discussion

Macau and Hong Kong use analogous warning systems based on sustained winds or gusts (Table A1), whereas mainland China uses a different warning system (promulgated by the China Meteorological Administration) that indicates typhoon intensity by colour (blue, yellow, orange, and red) (Zhang et al. 2017). Wind speed and atmospheric pressure were almost equivalent in the two regions in the morning, although the pressure in Macau dropped much lower than that in Hong Kong during Hato's passage (Figure 9). Therefore, it is theoretically reasonable to assume that similar warnings should have been issued in Macau and Hong Kong at least in the morning time. However, announcements of TC warnings were issued separately in Macau and Hong Kong. Furthermore, in both Macau and Hong Kong, increasing signal levels are linked to higher levels of precautionary measures; the difference between Signals 3 and 8 could cause a major difference in how social and economic impacts are managed. For example, in Macau, all schools and offices will be shut down during Signal 8 or at higher signals, and three long bridges connecting the two main islands of Macau will also be closed, significantly impacting Macau's economic reliance on casino tourism.

In the early morning of 23 August 2017, Hong Kong issued a Signal 8 warning as Hato intensified, while the Macau Meteorological and Geophysical Bureau issued only a Signal 3 warning. Local news media later reported that the meteorological bureau in Macau simply relied on personal decisions by the observatory's director, who subsequently resigned amid complaints over the late issuance of a higher warning signal for Hato. Furthermore, the bureau's forecasters could not raise the warning signal without instructions from the director (South China Morning Post 2017). This demonstrates the difficulty faced by decision-makers with regard to the appropriate timing for issuing TC warnings before landfall. Cities with highly valuable economies and/or tourist districts (such as Macau and Hong Kong) will inevitably suffer significant economic losses when a higher signal level is issued, even if the area is not affected by severe storm damage.

The Hong Kong Observatory uses wind data gathered from a network of 8 anemometers covering the whole of Hong Kong when issuing TC warnings. This sophisticated system should have assisted the concerned authorities and provided them with evidence to issue a Signal 8 warning before the typhoon reached peak intensity, as demonstrated in Figure 9. In the case of Macau, there were no clear publicised criteria clarifying the determination of TC warnings. Thus, the decision of signal issuance may have been crucially difficult, particularly because the wind rapidly intensified from 50 to 70 km/h in only 1 h (from 8 a.m. to 9 a.m.). This rapid intensification can be partially explained by Hato's higher approach speed, nearly twice as fast as the 1962 Typhoon Wanda (Figure 3). Nevertheless, when considering the correlation between wind speed and signal level shown in Figure 9, the signal issuance in Macau cannot be simply blamed because the signal was raised from 3 to 8 as soon as the wind speed reached about 70 km/h, which corresponds with the lower range of the Signal 8 wind state (63–117 km/h).

On the other hand, it seems that Hong Kong took a safer and conservative decision by raising the signal level to 8 when the wind speed could be still categorised under Signal 1 or 3. Nevertheless, this cannot be considered as an early decision, because it was made only 2–3 h before the storm remarkably intensified. Although public warning notifications through TV, radio, and loudspeaker systems are effective in raising people's awareness about evacuation needs during a coastal disaster (Esteban et al. 2016; Anh et al. 2017; Esteban et al. 2017), it is evident that such warnings can only be effective when they are issued sufficiently in advance of a TC's landfall.

Hence, the improvement of TC forecasts is crucial, particularly for small countries and territories with areas of only a few tens of kilometres, such as Hong Kong and Macau. Although forecasts using mesoscale models have gradually improved, their error in forecasting TC courses remains about 100 km for 24-h forecasts (Japan Meteorological Agency 2009). Such a degree of error in the current forecast system will inevitably make it difficult for responsible authorities to judge whether a TC signal level needs to be raised in the face of an approaching TC.

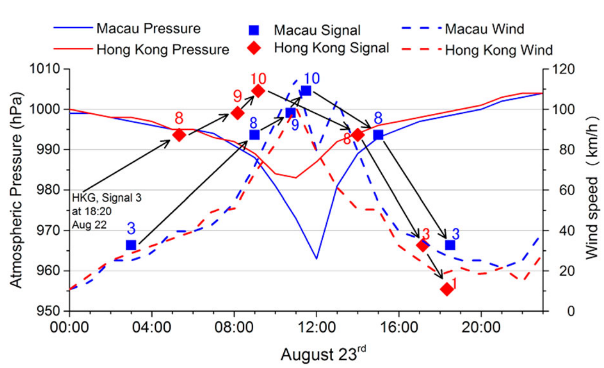


Figure 9. Pattern of Hato's sustained wind speeds and surface pressures observed at the Macau and Hong Kong international airports, along with typhoon signal levels issued by both locations (On.cc et al. 2017, Hong Kong Observatory).

5. Conclusions

Our study demonstrated that Typhoon Hato caused unprecedented storm surges of 2–3 m in Macau and Hong Kong, although human losses were relatively minor given the extent of inundation in these regions. Significant wave overtopping and runup also occurred on beaches and in ports. While our analysis suggests that Hato was not the strongest storm in the last several decades, the typhoon was noted to approach the coast at an unusually rapid speed of about 32.5 km/h, indicating that authorities at both locations did not have sufficient time to prepare. Thus, storm signal levels were not raised quickly enough (at least in Macau) prior to Hato's landfall. Nevertheless, our analysis confirmed that decisions regarding signal issuance were made reasonably in both regions, based on wind speed clarification, especially given how rapidly Hato moved and intensified. Using typhoon track analysis, we determined that typhoons of significant strength would severely affect Macau and Hong Kong in the Pearl River Delta about once every 10 years. This frequency does not appear to be high, but it is definitely not negligible. The significant consequences of Hato might eventually become a wakeup call for those involved in typhoon disaster management. We hope that this study contributes to raising the disaster response capability of concerned authorities by providing scientific evidence on the storm surge generated by the recent typhoon.

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Disclosure statement

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Appendix A

Table A1. Tropical cyclone warning signal definitions and relevant precautions for Hong Kong and Macau (Hong Kong Observatory, http://www.hko.gov.hk/informtc/tcService.htm, Macao Meteorological and Geophysical Bureau, http://www.smg.gov.mo/smg/severeWeather/e_typhoon_def.htm).

Signal Number	Meaning of Signals	Precautionary Measures	
		Hong Kong	Macau
1	A tropical cyclone is centred within about 800 km of Hong Kong/Macau and may affect the territory	Wait and observe; if it looks as if the signal will rise to T3, reconsider any plans that involve being out on open water	Check the safety of objects that might be carried or destroyed by the winds, such as fences, scaffoldings, flower pots, and antennae (aerials). Keep boats and small crafts in nearby shelters
3	Strong wind is expected or blowing generally in Hong Kong/Macau near sea level, with a sustained speed of 41–62 km/h. Gusts may exceed 110 km/h, and the wind condition is expected to persist	Stay tuned to TV and radio announcements. If the warning signal is expected to be raised to T8, start taking precautions immediately. Secure all loose objects around your home, especially plants and pots on rooftops or balconies and check to ascertain that any drains are free from blockage. Stay away from open water, or if out boating, return to shore as quickly as possible. If you live on an outlying island, then start preparing to return home as the ferry is the first transport system to be affected. At this stage, as all kindergartens and elderly centres are closed, make arrangements to collect your loved ones	Lead ships and other sailing craft into safe shelters or ports. Check the safety of doors and windows. Clear drains and rain collectors of obstructions. Follow bulletins broadcast by radio, television, and other electronic communications devices
8	Gale or storm-force wind is expected or blowing generally in Hong Kong/Macau near sea level, with a sustained wind speed of 63–117 km/h from the quarter indicated. Gusts may exceed 180 km/h, and the wind condition is expected to persist	All offices, schools, and non-essential services are closed during T8 signals. Public transportation continues to operate as long as it is safe to do so. Contact your HR department for severe weather guidelines. In addition to the actions taken during T3, you should make sure all windows are locked and valuable items are moved away from windows. If you do not have storm shutters and are exposed to the typhoon's approaching direction, then consider taping large windows to minimise any damage from possible shattering	Classes of all schools are suspended. Children should remain indoors. Doors and windows should be safely bolted. Conclude all precautionary safety measures. Bridges will close to all traffic at any moment, pending prior notice. Television and radio stations will broadcast round-the-clock
9	Gale or storm-force wind is increasing or expected to increase significantly in strength	Stay indoors and away from exposed windows. Close interior doors and ensure that you (and your children) are in a secure part of your home. If you are away from home, find a safe place and remain there until conditions are safe for you to return home	Circulation of pedestrians and vehicles should be reduced to a minimum. Reinforce doors and windows with crossbars or heavy furniture. Follow recommendations and warnings through information provided by media. Beware – a temporary calm in the midst of hurricane-force winds generally indicates that the centre of the tropical cyclone is over Macau Special Administrative Region
10	Hurricane-force wind is expected or blowing with sustained speed reaching upwards from 118 km/h and gusts that may exceed 220 km/h	Take the same precautions as T9. There may be periods of calm as the eye of the storm passes, but the winds will resume with a vengeance quickly afterwards	