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Estuarine and coastal natural hazards: An introduction and synthesis

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ABSTRACT

Two sessions were organized during the 2018 Fall AGU Meeting entitled, (1) Coastal Response to Extreme Events: Fidelity of Model Predictions of Surge, Inundation, and Morphodynamics and (2) Improved Observational and Modeling Skills to Understand the Hurricane and Winter Storm Induced Surge and Meteotsunami. The focus of these sessions was on examining the impact of natural disasters on estuarine and coastal regions worldwide, including the islands and mainland in the northwestern Atlantic and the northwestern Pacific. The key research interests are the investigations on the regional dynamics of storm surges, coastal inundations, waves, tides, currents, sea surface temperatures, storm inundations and coastal morphology using both numerical models and observations during tropical and extratropical cyclones. This Special Issue (SI) 'Estuarine and coastal natural hazards' in *Estuarine Coastal and Shelf Science* is an outcome of the talks presented at these two sessions. Five themes are considered (effects of storms of wave dynamics; tide and storm surge simulations; wave-current interaction during typhoons; wave effects on storm surges and hydrodynamics; hydrodynamic and morphodynamic responses to typhoons), arguably reflecting areas of greatest interest to researchers and policy makers. This synopsis of the articles published in the SI allows us to obtain a better understanding of the dynamics of natural hazards (e.g., storm surges, extreme waves, and storm induced inundation) from various physical aspects. The discussion in the SI explores future dimensions to comprehend numerical models with fully coupled wind-wave-current-morphology interactions at high spatial resolutions in the nearshore and surf zone during extreme wind events. In addition, it would be worthwhile to design numerical models incorporating climate change projections (sea level rise and global warming temperatures) for storm surges and coastal inundations to allow more precisely informed coastal zone management plans.

1. Introduction

A storm surge is an abnormal change of water level generated by a storm that is closely associated with extreme atmospheric pressure and wind forcing (Kerr et al., 2013). Both storm surges and extreme waves can threaten the socio-economic balance along coastal belts (Irish et al., 2010). In response to climate change and global warming, frequent and intense surges and high waves during extreme weather activities have been witnessed in recent years (Bender et al., 2010). In this regard, a comprehensive understanding of storm surge dynamics is essential for relevant policy makers to build better and more informed decision support systems to minimize the impact of natural hazards on the economy, infrastructure, and coastal communities.

In recent years, the coastal and oceanographic community has made considerable progress in understanding the physics governing the hydrodynamics and morphological changes in littoral and nearshore regions (Roelvink et al., 2018). Model predictions of storm surge (Mao and Xia, 2018), extreme waves (Mao et al., 2016), storm inundation (Blumberg et al., 2015), and changes in morphology (Roelvink et al., 2018) have all shown vast improvement. The majority of studies focus on validating numerical models so that we can predict the potential impacts of future storms. Increases in sea surface temperature (SST) are expected to increase the severity and intensity of storms due to higher potential energy in driving the storms (Emanuel, 2013), which in turn increases the vulnerability of coastal communities to extreme flooding events (Oey and Chou, 2016). Higher SST also tends to destroy coral reefs that can act as barriers against large waves impacting the coast. Sea level rise will amplify risks of storm surge along the coast with augmented inundation in terms of volume and extent. To safeguard coastal ecosystems and infrastructure, greater precision in ocean modeling and continued detailed observations are essential.

With the aim of addressing storm surge and its related issues using the most recent developments in this area, two special sessions were organized on the physical impacts of natural hazards during the AGU Fall Meeting in December 2018: (1) Coastal Response to Extreme Events: Fidelity of Model Predictions of Surge, Inundation, and Morphodynamics; and (2) Improved Observational and Modeling Skills to Understand the Hurricane and Winter Storm Induced Surge and Meteotsunami. These sessions included a total of 50 presentations, and an SI was proposed for and approved by *Estuarine, Coastal and Shelf Science* (ECSS) to disseminate the findings. The themes are of clear current interest to the coastal research community, and comprise descriptions of recent tropical cyclones in the global basin and the associated catastrophic damage and devastation in the coastal zone. These

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modeling studies focus on various aspects of the impacts of storms along the coast, allowing a better understanding of hazard systems under different conditions, which can be useful for disaster management.

In recent years, the oceanographic community has made significant progress in understanding the physical processes that govern wave transformation in the nearshore and surfzone, including the circulation and morphological response to altered bathymetry and topography resulting from extreme events. However, some key research gaps still prevent us from precisely predicting the post-hazard modulations to the bathymetric and topographic envelope. We are still unable to predict with much confidence how the bathymetry and topography evolve during intense storm events. Numerical models can replicate, with reasonable accuracy, the evolution of the seabed observed during controlled laboratory experiments. Ensemble numerical models and laboratory experiments with field observatories provide the way forward to assess the post-storm deformations to seabed topography. However, under realistic field conditions, the models tend to underperform, and the key concern is then to identify the missing (yet to be understood) physical parameters responsible for the difference between the observations and model results. In addition, the oceanographic community also needs more detailed observations (especially in coastal and nearshore regions) to validate the numerical models and to improve our understanding of the physical parametrization.

In total, the Guest Editors of this SI received 25 submissions of which 12 were accepted for publication. Among these papers, the study areas cover the Atlantic coast (Liu et al., 2020; van der Lugt et al., 2019), the Salish Sea of the Pacific Ocean (Yang et al., 2020), the Arctic archipelago (Guo et al., 2020), the Bohai Sea (Cao et al., 2019; Song et al., 2020), the East China Sea (Chu et al., 2019; Xu et al., 2020; Wang et al., 2020a), and the South China Sea (Chen et al., 2019; Li et al., 2020; Wang et al., 2020b). Some of the presentations from the AGU Natural Hazards sessions were published elsewhere (Hegermiller et al., 2019; Kang and Xia, 2020; Shi et al., 2020). A summary of the articles contained in this SI is given in Table 1.

The articles in this SI clearly highlight a few case studies that show significant impacts of natural hazards in terms of socio-economic mobility. Song et al. (2020) describe the cold front event in the Bohai Sea during October 10–13, 2003, which caused economic losses of 1.31 billion Yuan. Both van der Lugt et al. (2019) and Liu et al. (2020)

Table 1
Summary of articles in this SI.

Paper	Study domain	Main theme	Methods
Xu et al. (2020)	East China Sea	Wave dynamics	SWAN
Wang et al. (2020a)	East China Sea	Storm surge and wave setup	ADCIRC+SWAN
Guo et al. (2020)	Canadian Arctic Archipelago	Tidal dynamics	FVCOM
Yang et al. (2020)	Salish Sea	Storm surge	FVCOM
Chu et al. (2019)	East China Sea	Storm surge sensitivity	FVCOM
Chen et al. (2019)	Pearl River Estuary	Wave-current interaction	COAWST
Song et al. (2020)	Bohai Bay	Tide-surge-wave interaction	Delft3D
Li et al. (2020)	South China Sea	Storm surge and wave setup	ADCIRC+SWAN
Liu et al. (2020)	Mid-Atlantic Bight and New York City	Storm surge, tides, and inundation	SCHISM+ELCIRCSub
Cao et al. (2019)	Bohai Sea	Wave-induced mixing	POMgcs+SWAN
van der Lugt et al. (2019)	Matanzas (FL) and Fire Island (NY)	Morphodynamics	XBeach
Wang et al. (2020b)	northwestern South China Sea	Storm-induced transport	Observations

consider Hurricane Sandy, which was the strongest, deadliest, and most destructive hurricane of the 2012 Atlantic hurricane season. Sandy reportedly caused nearly $70 billion (2012 USD) in damage and killed at least 233 people in eight countries. van der Lugt et al. (2019) also assess the impact of Hurricane Matthew, which was a category 5 hurricane that took place in 2016 costing 603 lives, in which the net damage was reckoned to be $16.47 billion (2016 USD) in multiple countries. Xu et al. (2020) discuss wave growth during Typhoon Chan-hom (2015), a category 4 storm that caused considerable damage with 18 human fatalities and a loss of $1.58 billion (2015 USD) in the western Pacific, with the Philippines, Japan, China, and Korea sustaining the most damage.

At the same time, these studies relate to the impact of natural hazards in diverse areas covering the islands and mainland of the northwestern Atlantic and northwestern Pacific, which are frequently impacted by tropical storms. Estuarine and coastal regions are typically vulnerable to high energy events and deserve particular attention. These areas are often densely populated or have significant tourist industries with high economic value. Areas around islands typically have coral reefs that are ecologically significant for marine diversity. Wetlands and mangroves in coastal areas are particular areas of concern for their resilience to the impacts of natural hazards, and their sustainability and recovery is thus critical for future protection from storms.

In terms of methodology, most of these studies use coupled numerical models except one that is based on data analysis (Wang et al., 2020b). Among the modeling work, coupled ADCIRC+SWAN (ADvanced CIRCulation Model + Simulating WAves Nearshore; Dietrich et al., 2012) is used by Wang et al. (2020a) and Li et al. (2020); standalone SWAN (Booij et al., 1999) is used in Xu et al. (2020); FVCOM (Finite-Volume Community Ocean Model; Chen et al., 2003) is used in Guo et al. (2020), Yang et al. (2020), and Chu et al. (2019); SCHISM (Simi-implicit, Cross-scale, Hydroscience, Integrated System Model; Zhang et al., 2016) and ELCIRC-Sub (Eulerian-Lagrangian CIRCulation Sub-grid inundation model; Zhang et al., 2004) are used in Liu et al. (2020); a coupled COAWST (Coupled Ocean-Atmosphere-Wave-Sediment-Transport; Warner et al., 2010) system is used in Chen et al. (2019); coupled POMgcs-SWAN (Princeton Ocean Model with a Generalized Coordinate System + SWAN; McWilliams and Restrepo, 1999; Ezer and Mellor, 2004; Harcourt, 2015) is used in Cao et al. (2019); a coupled Delft3D model (Lesser et al., 2004) is used in Song et al. (2020); and a morphological model XBeach (Roelvink et al., 2018) is coupled with the hydrodynamic model and wave model D-Flow FM/SWAN by van der Lugt et al. (2019). Despite the geographic diversity and variety of the numerical models discussed in this SI, some similar but crucial issues relevant to physical natural hazards are highlighted. To help readers to gain an overview of the themes in this SI, the papers are grouped into five themes. Theme 1 focuses on the effects of typhoons on wave dynamics. Theme 2 concerns tide and storm surge simulations. Theme 3 pays attention to wave-current interaction during typhoons. Theme 4 concerns wave effects on storm surges. Theme 5 is related to hydrodynamic and morphodynamic responses to typhoons.

2. Major themes in this SI

2.1. Theme 1: Effects of typhoons on wave dynamics

In a key paper in this SI, Xu et al. (2020) analyze the spatio-temporal sensitivities of key parameters to wave simulations during Typhoon Chan-hom (2015) along the eastern coast of China. In their findings they emphasize suitable combinations of physical parameters and feasible tuning of wind input, white-capping, bottom friction, and depth-induced breaking formulations to be the critical factors for significant wave height (SWH). Moreover, the threshold depth for depth-induced breaking depends on the sea state, which ranges from 5 to 30 m. In shallow water regimes where the depth is less than the threshold, the simulated SWH is most sensitive to the parameter gamma (i.e., the ratio of maximum individual wave height to local water depth) of the depth-induced wave breaking term. In deep water, SWH is primarily influenced by wind input and white-capping terms, and higher SWH is associated with a deeper threshold depth. Additional wave simulations indicate that four wave-wave interactions (i.e., quadruplets) mainly affect the distribution of wave energy and wave period, not the SWH. This paper stresses the complexity and significance of simulating extreme wave dynamics during Typhoon Chan-hom, indicating the complexities of the wave dynamics in the numerical model.

The next paper focuses on the substantial wave effects on storm surge during the same typhoon event. Specifically, the study by Wang et al. (2020a) applies a coupled wave-circulation model ADCIRC+SWAN to investigate the spatial and temporal characteristics of storm surge and wave setup in the East China Sea (ECS) during two severe weather events with different tracks: the land-falling Typhoon Saomai (2006), and the bypassing Typhoon Chan-hom (2015). Simulation results show that different spatial patterns occur in response to different typhoon tracks, and the maximum storm surges resulting from the accumulation of local onshore wind forcing are located on the right side of the path of Typhoon Saomai and the left side of the path of Typhoon Chan-hom. Because of the stronger cumulative effect of local onshore wind forcing, extremely high storm surges are more likely to occur during Typhoon Saomai. It is found that the maximum wave setup is determined by both the ocean swell and the slope of the sea floor. During Typhoon Saomai, the locations of maximum wave setup and surge level are spatially close together, while they are separated during Typhoon Chan-hom. This research suggests that the typhoons with direct landfall probably cause extremely high storm surges on the right-hand side of the typhoon track, while the typhoons bypassing the land may introduce significant risks along a wide segment of the coast.

2.2. Theme 2: Tide and storm surge simulations

This theme brings three papers together, all of which adopt the same numerical model FVCOM. However, their domains vary from the Canadian Arctic Archipelago (CAA) and Salish Sea to the ECS. Unlike the U. S. or China coasts, the CAA is an important study domain for water mass transport between the Arctic and Atlantic Oceans. The tides on the CCA play a significant role in thermohaline circulation and sea-ice cover at high-latitudes, and could potentially influence the Arctic and global climate. Guo et al. (2020) apply a high-resolution FVCOM model to investigate the ice-free tidal dynamics and the interaction mechanism between the Arctic and the Atlantic tides. Their results show that the Atlantic tides are stronger throughout the CAA but decrease rapidly when they encounter the open Arctic shelf. The Arctic tide is mainly constrained to the Arctic Ocean and Amundsen Gulf. Nonlinear interactions between the Arctic and Atlantic tides are generally weak in most regions, except for in the southern and northern CAA, where the nonlinear contribution can reach 10–20% of the tidal variability. The tidal energy flux is also analyzed, which indicates that Lancaster Sound and Jones Sound are the main pathways of the tidal energy from Baffin Bay to the CAA, and the energy is dissipated mainly due to the vertical diffusion and the bottom friction.

In another contribution, Yang et al. (2020) mainly present a modeling assessment of 34 major historic storm events from 1980 to 2016 in the Salish Sea, with the application of FVCOM. Their simulations show that the maximum storm surge in the Salish Sea is generally between 0.80 m and 1.03 m, and is spatially heterogeneous. They find that the southerly winds are the major reason behind a strong north-south gradient with larger magnitudes of surge in the north. Sensitivity analysis shows that storm surge in the Salish Sea is dominated by remote surge from the Pacific Ocean, and that local winds contribute up to approximately 20% of the surge variability.

In another application of FVCOM, Chu et al. (2019) investigate the sensitivities of the modeled storm surges to bottom friction, wind drag coefficient, and four meteorological products in the ECS. Based on model-to-data comparison during Typhoon Winnie (1997), it is found that the NCEP-CFSR wind field performs the best among the four wind field products (ERA-Interim, ERA5, CCMP, NCEP-CFSR). The wind drag coefficient formulae of Large and Yeager (2009) produces better results than the other formulae. The best combination of the wind field and parameters can improve the performance of storm surge simulations. In addition, Chu et al. (2019) also conclude that non-linear tide-surge effects contribute 37% at the time of peak surge.

Taken together, these three papers improve our understanding of tides, storm surges, and wave dynamics, and partially resolve some complex air-sea interactions. Further research directions could be the development of fully coupled atmosphere-ocean-wave models to understand complex storm surge dynamics.

2.3. Theme 3: Wave-current interaction during typhoons

Under this heading, Chen et al. (2019) use a 3D wave-current coupled model COAWST to evaluate the effects of wave-current interaction (WCI) on the storm surge and stratification observed in the Pearl River Estuary (PRE) during the passage of Typhoon Hato (2017). The results show that the WCI increased the maximum storm surge by 20–30%, which is larger than, but consistent with, archived literature on estuary dynamics along the US coast by Mao and Xia (2018) (e.g., wave setup accounts for 10% of the maximum storm surge during Hurricane Irene in late August 2011). Analysis of momentum balance indicates that the depth-integrated momentum is balanced with the pressure gradient force, Coriolis force, and bottom stress in the early stage of the storm, but is balanced with wind stress, pressure gradient force, and wave forces during the matured storm. These findings may be relevant to similar studies in other estuarine and coastal regions, and could have corresponding implications for regional coastal protection and environmental management.

Similarly, Song et al. (2020) apply a relatively complex, two-way coupled, tide-surge-wave model Delft3D to investigate the impact of harbor constructions from 2003 to 2016 on the comprehensive interactions of tides, storm surges, and waves during a storm in Bohai Bay. Their results indicate that wind forcing is a dominant driver of the storm surge. The maximum contribution from wave setup increases from 5-15% to 8–20% due to harbor constructions between 2003 and 2016. Harbor constructions mainly affect the coastal storm surge through nonlinear tide-surge-wave interactions, and this study provides new insight into the effect of harbor construction on storm surge hydrodynamics, and provides practical guidance for other similar proposed sites around the world. This study could be further improved by the use of a nested meteorological model or by considering bathymetric feedback on storm surge dynamics.

2.4. Theme 4: Wave effects on storm surges and hydrodynamics

Li et al. (2020) apply the coupled ADCIRC+SWAN model to investigate storm surge and wave dynamics in the South China Sea (SCS). The coupled system is well validated during the super-typhoon Hato (2017) over the PRE, with observations from several buoys and tide gauges. To further explore the influence of typhoon intensities and sizes on wave setup, information from nearly 70 typhoons that made landfall around southern China regions from 2000 to 2016 is assembled, and their normalized average of intensity over the storm lifetime is calculated. This averaged condition is treated as the control case, and simulation results indicate that both typhoon intensity and size influence the maximum storm surge, SWH, and wave setup. Additionally, the wave contribution to the storm surge ranges from 2% to 7% of the total storm surge height for typhoon intensities and sizes within 25–70 m/s and 10–60 km, respectively. The simulated storm surge and waves from the coupled model can be improved by using the gridded meteorological data with a high spatial and temporal resolution.

Like other storm surge modeling studies, Liu et al. (2020) apply a recently developed 3D unstructured SCHISM model, driven by the high-resolution NAM (North America Mesoscale) and ECMWF (European Centre for Medium-Range Weather Forecasts) atmospheric products to simulate storm surge, tide, and street-level inundation along the Mid-Atlantic Bight during Hurricane Sandy (2012). Based on a list of various sensitivity experiments, it is found that the 3D barotropic model forced by the ECMWF data with the inclusion of wave effects performs the best for the maximum total water level with a precise temporal resolution. Meanwhile, the ELCIRC-Sub model has been successfully developed to simulate the street-level inundation in New York City, and captured the highest peak surge (3.9 m) at Kings Point, NY. The modeled maximum inundation extent is also in good agreement with the FEMA maximum flooding event for Hurricane Sandy.

It should be noted that to date most hurricane inundation hazard models have simulated flooding in estuaries either as the results of the storm surge (via coastal ocean influence) or land flooding (via heavy precipitation in the watershed), but not via a combination of the two. This approach neglects the important interactions or 'interrelated processes' between the two extreme events occurring simultaneously or successively. When storm surge and heavy precipitation co-occur, the potential for flooding, called "Compounding Flooding", in the low-lying coastal area is often much worse than when they occur individually (Wahl et al., 2015). Ye et al. (2020) successfully applies the SCHISM model with coupling to a continental-scale hydrologic model to simulate compound flooding in an integrated creek-to-ocean 3D baroclinic model. The latest model better captures the rebounding water level and sustained high water level during the ensuing river flooding of Hurricane Irene (2011) in Delaware Bay. This new theme is likely to be of interest in the future research.

Cao et al. (2019) apply a one-way coupled 3D POMgcs-SWAN model to investigate the impacts of three wave processes (i.e., Langmuir turbulence, Coriolis-Stokes forcing (CSF), and resolved-scale Craik-Leibovich vortex forcing (CLVF)) on the summer ocean dynamics in the Bohai Sea. Both the CSF and CLVF are added in the momentum balance. The parameterization of Langmuir turbulence with wave effects is considered in the modified MY-2.5 closure scheme (Harcourt, 2015). Several sets of numerical simulations with and without wave effects are carried out in June 2015. Resulting outputs show that all three wave effects influence the magnitude of the monthly surface currents significantly (e.g., 0.1 m/s) and weaken the currents by reducing their vertical variability through the turbulent mixing process. This wave-induced turbulent mixing reduces the monthly SST by up to 0.4 °C in the Central Area of the Bohai Sea. The hydrodynamic processes due to waves are primarily caused by Langmuir turbulence, followed by the increased upwelling and horizontal advection by both CSF and CLVF. The Langmuir number (La) in most of the Bohai Sea is below 0.3, demonstrating the significant influence of Langmuir turbulence in turbulent vertical mixing. This research is preliminary and fundamental to further exploration of other wave effects on ocean dynamics in a fully coupled wave-current model, including the Stokes advection term and vertical Stokes shear force.

2.5. *Theme 5: Hydrodynamic and morphodynamic responses to typhoons*

Hydrodynamic modeling of storm surge, tides, winds, waves, and storm inundation during Hurricane Sandy (2012) in the New York area, Long Island Sound and the U.S. East Coast was undertaken successfully by Liu et al. (2020) using the coupled SCHISM-WWMIII-ELCIRC-Sub system. Given the role of barrier islands in providing natural habitats and protecting mainland coastlines during storms (Nordstrom et al., 2000), it is also important to further evaluate the hurricane-induced morphodynamic impacts on barrier islands by considering dune erosion/deposition, beach developments, and breach formation. To achieve this goal, van der Lugt et al. (2019) use the morphodynamic model XBeach with hydrodynamic forcing extracted from a regional coupled D-Flow FM/SWAN model to investigate the morphological change that occurred during two Atlantic hurricane events on two barrier islands at Matanzas (Florida) and Fire Island (New York) with differing topographies and forcing conditions. For the case of Fire Island during Hurricane Sandy, the spatial extent of the reduction in roughness as a proxy for vegetation removal is accurately modeled. With the same model settings for Hurricane Mathew (2016) in the Matanzas case, the computed and observed erosion and sedimentation are in good agreement. For both Fire Island and Matanzas, the model successfully predicts erosion, deposition volumes as well dune-crest lowering. The occurrence of breach formation is also predicted by the model, but the exact location of these breaches does not match the observations. A 10% variation in boundary conditions (e.g., surge, wave direction, SWH, and bay water levels) produced regime shifts in the modeled barrier island. These results not only stress the critical role of boundary conditions in the skill of the morphodynamic model, they also show the limitations of single deterministic models in the forecasting system.

As well as being hazardous, tropical cyclones also favor productivity in the coastal ocean. Wang et al. (2020b) use the moored-buoy-observed horizontal velocities and temperatures from July 28 to August 2, 2005 to analyze the temporal-vertical variations of the diagnostic vertical velocity and mass transport during the passage of tropical storm Washi (2005) in the northwestern SCS. The results show that the total vertical velocity in the mixed layer above 25 m and in the lower layer is of the order of $O(10^{-4})$ m s^{-1} and $O(10^{-3})$ m s^{-1}, respectively. Under the passage of Washi, the upward vertical velocity is dominant and significantly enhanced to the order of $O(10^{-3})$ m s^{-1}. The vertical advection transport velocity reaches $O(10^{-5})$ kg s^{-1} m^{-3}, which is one order greater than that induced by turbulent mixing. Time-averaged transports by vertical advection and mixing are both upward in the layer above the thermocline during the storm passage. The results of Wang et al. (2020b) are of great value for understanding the 3D dynamic and biogeochemical responses of the ocean to tropical cyclones.

3. Discussion and future research directions

The key research areas of this SI and other current studies are mainly focused on storm surge, coastal inundations, waves, tides, currents, coastal morphology and sea temperatures using numerical models and observations. Numerical models allow researchers to conduct various sensitivity analyses on storm factors to examine storm surge dynamics in coastal areas. Observations enable us to obtain valuable information for real time scenarios, and help us to gain a better understanding of the dynamics of natural hazards (e.g., storms/typhoons/hurricanes) from various physical aspects. However, there are still research gaps that need to be filled to obtain a comprehensive understanding of storm dynamics and to help policymakers to formulate a fully informed decision support system. These include climate change impacts (i.e., sea level rise and warming sea temperatures) on storm surge dynamics and coastal inundations, greater awareness among the coastal community regarding upcoming threats, broad dissemination of research results to coastal zone management authorities and policy makers, all of which are key factors in effective coastal zone management.

Over the last 25 years, there has been a significant upgrade of computational power, which has enabled high precision modeling. As a result, model techniques and skills have advanced considerably in terms of complexity and flexibility. Moreover, models can be used to simulate processes at much higher resolutions than before. Furthermore, coupled modeling systems have evolved in recent years, which have facilitated the interaction of multiple processes in a more realistic manner (e.g., from 2D to 3D) allowing better understanding of the physics involved. The application of wave-current coupled models have encouraged the switch from 2D Longuet-Higgins and Stewart (1962, 1964) theory to 3D radiation stress (Mellor, 2003, 2005) and vortex-force formalism (McWilliams and Restrepo, 1999), allowing complex wave effects to be incorporated in the circulation. In reviewing the 5 themes covered in this SI: 1. Effects of typhoons on wave dynamics (Wang et al., 2020a; Xu et al., 2020); 2. tide and storm surge simulations (Chu et al., 2019; Guo et al., 2020; Yang et al., 2020); 3. Wave-current interaction during typhoons (Chen et al., 2019; Song et al., 2020); 4. Wave effects on storm surges and hydrodynamics (Cao et al., 2019; Li et al., 2020; Liu et al., 2020); 5. Hydrodynamics and morphodynamic responses to typhoons (van der Lugt et al., 2019; Wang et al., 2020b), we suggest the following three guidelines for future research directions:

1. There is a need to develop a fully coupled modeling system to consider the complex interaction processes, including the atmosphere-ocean interaction, wave-current interaction, atmosphere-wave interaction, hydrodynamic-morphodynamic interaction, and to further apply the nesting technique to investigate the multiple spatial scale dynamics from the coastal ocean, nearshore, and surf zone dynamics.
2. Field observations and data collection over wide spatial and temporal ranges relating to the key variables or indicators of natural hazards are paramount, together with the use of these data to validate numerical models during extreme weather conditions (e.g., typhoons/hurricanes/storms).
3. Further and ongoing progress is required to link the research outcomes from scientific studies with the coastal and estuarine management. Provision of sound scientific understanding of the physics of natural hazards and their impacts is helpful for related decision making by policymakers.

Although meteotsunamis are not directly tackled in this Special Issue, some of the work on meteotsunamis presented in the special AGU session has been recently published (e.g. Shi et al., 2020). The consideration of meteotsunamis in coupled atmosphere-ocean forecasting systems poses additional scientific and technological challenges. The progress made in all previous works (including this SI) and future potential studies (including numerical models and observations) could improve our understanding of natural hazards, which consequently would provide more robust and scientific basis to elicit better informed and optimized management plans in coastal areas.

Declaration of competing interest

The authors declare that they do not have any competing financial or associated interests that could have appeared to represent a conflict of interest in connection with this submitted paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecss.2020.106654.

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