Mixing and Transport in Estuaries and Coastal Waters

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Highlights

Abstract

Mixing and transport in the estuaries and coastal waters must be informed by advanced and up-to-date research to consider the underlying natural and anthropogenic effects on physical and biogeochemical processes. To that end a session was organized during the 2021 Coastal and Estuarine Research Federation conference entitled "Mixing and Transport in Estuaries and Coastal Waters". The focus of this session was to improve understanding through comprehensive studies associated with mixing and transport processes in estuaries and coastal waters based on observations, analytical models, laboratory experiments, and numerical models. This Special Issue (SI) 'Mixing and Transport in Estuaries and Coastal Waters' in the esteemed journal 'Estuarine Coastal and Shelf Science' is an outcome of the talks presented at the conference session. The key research interests covered comprisecomprised five themes: Estuarine dynamics, Wave-current-surge processes, Sediment dynamics, Plume dynamics, and Estuarine physical-biogeochemical processes. The articles contained in the SI represent the latest advances in mixing and transport in estuaries and coastal seas all over the world. As well as common methods including observations, remote sensing, and numerical modelling, a data framework is also used, which is the methodological highlight of this SI. While continued progress is still being made on understanding estuarine and coastal sea dynamics, the effects of these physical processes on biological and biogeochemical issues (i.e., larval transport and water quality dynamics) should also be considered in future studies.

1. Introduction

The processes of mixing and transport in estuaries and coastal waters are critical to the dynamics of these systems given their close association with water quality, pollutants, and primary production (Whitney and Garvine, 2006; Kang et al., 2017). In addition, a better understanding of such processes can benefit surrounding communities by improving management practices and/or emergency response situations. The controlling mechanisms of mixing and transport vary between different coastal systems as well as within an individual system due to complex interactions with local topography and hydrodynamic processes (Ganachaud and Wunsch, 2000; Prandle, 2006) that operate over a wide range of spatiotemporal scales, incorporating the effects of tides (Allen et al., 1980; Cheng et al., 2013), runoff (Horner-Devine et al., 2015; Simonsen et al., 2019), winds (Wang et al., 2022), wave-current interactions (Röhrs et al., 2014; Polton et al., 2005; Rodriguez et al., 2018), stratification (Ivey et al., 2008; Lu et al., 2013) and extreme storms (Mohapatra et al., 2007; Kang and Xia, 2020). Mechanisms controlling mixing and transport also affect sediments, playing a fundamental role in the morphological changes seen in these areas. Additional complexities arise from the impact of direct and indirect anthropogenic activities that alter sea level rise rates, sedimentation, and erosion, which in turn modify the mixing and transport processes (Ensing et al., 2015; Prandle and Lane, 2015; Rapuc et al., 2022). While advancing our understanding of these processes is a challenge, their importance in managing coastal regions is beyond doubt. At local scales, mixing and transport are important factors in coastal pollution, water quality, and aquaculture. At the same time, large-scale global changes caused by increased concentrations of anthropogenic carbon dioxide may lead to changes in coastal and estuarine boundaries and forcing conditions, which can in turn modify mixing and transport processes. Such physical changes could subsequently change biogeochemical cycling and ecosystem health in ways that are difficult to predict.

An additional issue related to the management implications is the role of storms on mixing and transport processes in coastal and estuarine systems as these events are major natural hazards that have significant impacts in coastal regions. ln addition to intense wind and surge, storms can dramatically modify hydrography and circulation, potentially shifting the trajectory of seasonal conditions and/or contributing to subsequent compound events. Furthermore, increased storminess under changing climate scenarios is expected to have permanent effects on coastal dynamics.

While the investigation of such mixing and transport processes in estuarine and coastal systems started largely with observations prior to 1950, a broad range of tools and methodologies now exist to improve the understanding of system responses to both typical conditions and storm events. Studies using numerical modelling, analytical studies, laboratory experiments, and/or ocean observations have the potential to deliver a new understandings of local dynamics (e.g. frontal processes, turbulence) as well as system-wide scale phenomena (e.g. general circulation, salt budgets). Still, research gaps persist in understanding the dynamics at various spatial and temporal scales of coastal and estuarine systems, which have characteristics and climatological trends distinct from those in the global ocean. To continue addressing these issues a special session entitled "Mixing and Transport in Estuaries and Coastal Waters" was organized during the 26th Biennial Coastal and Estuarine Research Federation Conference, in November 2021. Following these presentations, an SI was proposed for and approved by the editorial board of the journal Estuarine, Coastal, and Shelf Science to present the major findings. As such, this SI comprises a series of papers that improve our understanding of mixing and transport processes in estuaries and coastal waters through comprehensive studies using the many tools and techniques that are readily available to researchers (i.e. observations, laboratory experiments, and analytical and numerical models).

In total, 21 papers are contained in the SI. Among these papers, the study areas range from estuaries to coastal seas all over the world. For example, estuaries and bays along U.S. coasts (Chen et al., 2022; Cook et al., 2023; Dawson et al., 2022; Delatolas et al., 2023; Duvall et al., 2022; Shen et al., 2022), the Bay of Plenty in Aotearoa, New Zealand (Montaño et al., 2023), Haringvliet, Netherland (Kranenburg et al., 2023), the Bohai Sea (Kuang et al., 2022; Mou et al., 2022; Peng et al., 2023), the Yellow Sea (Liu et al., 2022a; Zhang et al., 2022), Yangtze River Delta (Wang et al., 2022), Pera River Estuary (Li et al., 2023), southern-central Arabian Gulf (Al-Thani et al., 2023), West coast of Florida (Liu et al., 2022b), Salish Sea (Premathilake and Khangaonker, 2022),

Coos Estuary in the Pacific Northwest (Jarrin and Sutherland, 2022). The findings obtained from mathematical modelling undertaken by Hoang et al. (2022) and laboratory experiments conducted by Zahedi et al. (2023) can be applied to fine-tune numerical models for various local and global domains. In terms of methodology, besides the common methods including analytical and numerical modelling, observations, and remote sensing, a data framework using estuarine geophysical attributes and water exchange datasets is designed by Shen et al. (2022) to characterize estuarine circulation for 360 estuaries in the continental U.S., which is a methodological highlight of this SI.

A summary of the articles in this SI is enlisted in Table 1 and described in Section 2. To help readers to gain an overview of the specific area of investigation in this SI, the papers are grouped into five themes. Theme 1 focuses on estuarine dynamics, which is a key part of this SI. Theme 2 is about waves, currents, surge, and their interactions. Theme 3 shows some recent research on sediment dynamics. Theme 4 concerns plume dynamics and the mixing that occurs as estuarine waters transition to the shelf. Theme 5 is related to physical-biogeochemical processes in the coastal zone.

Table 1. Papers containedPaper summaries in thethis SI

Paper	**Study area**	**Main theme**	**Methodology**
Al-Thani et al., 2023	southern-central Arabian Gulf	Physical-biogeochemical processes in the	Observations

		coastal zone	
Chen et al., 2022	Hillsborough Bay, USA	Estuarine dynamics	Modelling
Cook et al., 2023	Delaware Bay	Estuarine dynamics	Modelling
Dawson et al., 2023	bar-built estuaries in Carmel, California, USA	Physical-biogeochemical processes in the coastal zone	Observations
Delatolas et al., 2023	Connecticut River plume	Plume dynamics	Observations
Duvall et al., 2022	Pensacola Bay in Florida, USA	Estuarine dynamics	Modelling
Hoang, 2022	Analytical	Sediment dynamics	Mathematical Modelling
Jarrin and Sutherland, 2022	Coos Estuary in the Pacific Northwest	Estuarine dynamics	Observations+ Modelling
Kranenburg et al., 2023	Haringvliet, Netherland	Estuarine dynamics	Observations
Kuang et al., 2022	Bohai Bay	Sediment dynamics	Numerical Modelling
Li et al., 2023	Pear River Estuary	Plume dynamics	Observations
Liu et al. 2022a	Yellow Sea	Estuarine dynamics	Modelling+ satellite images
Liu et al., 2022b	West coast of Florida	Physical-biogeochemical processes in the coastal zone	Numerical Modelling
Montaño et al., 2023	Bay of Plenty in Aotearoa, New Zealand	Estuarine dynamics	Modelling
Mou et al., 2022	Bohai Sea	Estuarine dynamics	Modelling
Peng et al., 2023	Bohai Sea	Wave, current, surge and their interaction	Numerical Modelling
Premathilake and Khangaonker (2022)	Salish Sea	Wave, current, surge and their interaction	Numerical Modelling
Shen et al., 2022	Estuaries along the US east coasts	Estuarine dynamics	Data frameworks
Wang et al., 2022	Yangtze River delta	Wave, current, surge and their interaction	Numerical Modelling
Zahedi et al., 2023	Laboratory	Wave, current, surge and their interaction	Laboratory Experiment
Zhang et al., 2022	Yellow River Delta	Sediment dynamics	Observations

2. Major themes in this SI

2.1 Theme 1: Estuarine dynamics

Most of the papers in this theme adopt various numerical models including FVCOM (Chen et al., 2003), EFDC (Hamrick, 1992) and ROMS (Shchepetkin and McWilliams, 2005). In addition, a new analytical methodology for estimating stratification parameters and flushing time was used by Shen et al. (2022). These studies were conducted across a wide range of systems across the globe from the Bohai Sea and the Yellow Sea in Asia to the bays in the US and New Zealand. As well as dealing with primary estuarine hydrodynamics under normal weather conditions, the effects of climate change and typhoons on the estuarine and coastal hydrodynamics are also presented in this theme.

A major area of focus was exchange flow and its relationship with salinity intrusion. This focus on exchange flow was highlighted by **Mou et al. (2022**), who applied a three-dimensional Finite Volume Community Ocean Model (FVCOM) to investigate the influence of wind and baroclinic processes on water exchange across the 10-m and 20-m isobaths in the Bohai Sea during ice-free cycles of 1998–2019. Their results indicate that both the water exchange across the 10-m and 20-m isobaths showed significant seasonal and spatial variations It was also found that wind regulated the upper-layer water exchange across the 10-m isobath via wind-induced advection, while it altered the water exchange across the 20-m isobath mainly through enhanced mixing and subsequent weakening of the baroclinic pressure gradient force in the subsurface layer. Thermal and salinity gradients also contributed to cross-isobath exchange to varying degrees in different sub-bays.

Similarly, **Montaño et al. (2023)** used a high-resolution, one-way nested, hindcast ROMS model for the Bay of Plenty, New Zealand to investigate coastal circulation and Lagrangian particle transport with an interest in cross-shelf exchange. Up to 30% of the cross-shelf current variability was explained by along-shore wind stress, and particle transport simulation showed that the eastern region can be regarded as a retention zone due to weak currents and particle stranding.

Additional investigations of estuarine exchange processes were conducted by Cook et al. (2023), Chen et al. (2022), Duvall et al. (2022), and Kranenberg et al. (2023), which focus on circulation and saltwater intrusions in estuaries. **Cook et al. (2023)** utilized the Coupled Ocean Atmosphere Wave and Sediment Transport (COAWST) modelling system to study salinity intrusion in Delaware Bay in 2019. The model simulation showed that the salt front position was highly variable until passing a bathymetric control at the Delaware Memorial Bridge. In addition they show some locational variability, and the propagation speed of the salt front was time dependent with sensitivities to storm or discharge events.

The Tampa Bay Coastal Ocean Model (TBCOM) was used to estimate the potential impact that the removal of the Howard F. Curren Advanced Wastewater Treatment Plant (HFCAWTP) outflow may have on the salinity and flow fields of Hillsborough Bay, USA (**Chen et al. 2022**). Numerical simulation indicated that the removal of HFCAWTP inflow will not significantly affect Hillsborough Bay, and the effects of circulation or the salinity distributions are very localized. The numerical modelling results compared favourably to the Knudsen theorem, highlighting the usefulness of both numerical and analytical approaches.

Duvall et al. (2022) also applied a three-dimensional hydrodynamic model (EFDC) to investigate potential modifications to the spatial and temporal patterns of salinity, temperature, and density in Pensacola Bay, Florida, USA. However, their focus was on the variations expected due to climage change. Changes in radiative forcing, temperature, freshwater discharge, sea level rise, and wind intensification were taken into account. Their results underscore the importance of considering the natural variability of freshwater and wind forcing as well as local phenomena that global climate models generally cannot address.

In contrast to these modelling studies, **Kranenburg et al. (2023)** used observational data in two former tidal channels to investigate stratification, flow circulation and salt transport in the Haringvliet, Netherlands, a system with floodgates. Their findings on the behaviour of the salt intrusion upon opening the floodgates has significant management implications for water quality and freshwater availability in such systems.

Wind effects on estuarine dynamics were central to the work of **Jarrin and Sutherland, (2022)** where a system with non-traditional geomorphology (Coos Estuary) was investigated with observations and numerical simulations. The inverted 'U'shape of the small, strongly tidally-forced system was a significant factor, capable of modifying the circulation in unexpected ways. The wind-driven spatiotemporal variations emphasize the importance of local geometric constraints on estuarine dynamics, especially as many estuaries continue to evolve due to natural environmental changes or anthropogenic influences.

Wind forcing was further explored by **Liu et al. (2022a**), who investigated the extreme weather event of Typhoon Lekima in the Yellow Sea. Their study combined satellite observations and high-resolution numerical simulations using ROMS to examine the three-dimensional temperature changes and the underlying dynamics in the Yellow Sea during the passage of this storm. The study provides deep insights into the oceanic response to the passage of typhoons, particularly in the coastal ocean of Shandong and Liaodong Peninsulas, which is one of the most densely maricultured areas in the world.

Taking a broader perspective of estuarine dynamics, **Shen et al. (2022)** developed a framework for characterizing estuarine circulation using geophysical attributes and water exchange. This framework was applied to characterize 360 estuaries in the continental U.S. over a long-term period (1950 - 2015). Thanks to Shen's efforts, the data in this study are integrated into the EDM database (www.epa.gov/edm; Detenbeck et al., 2009) making it available for public use. These data will help to develop indices of estuarine vulnerability to nutrient inputs and extreme climate events for future management and assessment of estuaries.

2.2 Theme 2: Wave, current, surge and their interactions

Waves and currents are often especially critical components in mixing dynamics and transport pathways in shallow coastal regions relative to those found in the open ocean. The interaction between ocean waves and turbulent currents is complex due to the variable spatiotemporal phenomena occurring in the process. More specifically, kinematics and dynamics in the wave-current interaction govern the bed shear stresses or the sediment transport (Ardhuin et al., 2008; Mellor, 2011; Zheng et al., 2014). Despite significant progress in the study of waves, currents, tides, and wave-current-tide interactions through mathematical, numerical, and experimental approaches, the field is still challenging and lacks knowledge in many perspectives, i.e., local-scale dynamics and remote factors. This special issue has several studies that address these issues in coastal and estuarine systems.

Wave-current interactions in the estuaries govern complex mechanisms such as mixing and stratification. Surge tides and inundation in case of a cyclonic episode enhance saline water intrusion and vertical stratification in the estuaries. **Wang et al. (2022)** investigated the typhoon effects on salinity intrusion and vertical mixing in the Yangtze River delta, on the east coast of China, using the coupled wave and hydrodynamic and salinity transport module of MIKE 3 (www.dhi.com). The study reported that the wave-current-surge interaction action during strong typhoon events caused higher salinity in the upper river stream in the case of tide-dominated rivers and vice versa. The typhoon resulted in destratification in the vertical direction and the differences between surface and bottom salinity present a cyclical variation with tides. Increased vertical mixing is reported due to high saline water distribution. Wave-current interaction in the estuary denoted the impact of waves in modulating the currents, which in turn strengthened the saline intrusion.

The processes of wind-wave generation, growth, and dissipation in coastal environments are critical and basin phenomena that must be understood before analyzing the wave-current interactions and their impacts in mixing and sediment transport. Reflecting on this, **Peng et al. (2022)** contributed to the special issue by investigating the wave dynamics in the semi-enclosed Bohai Sea during cold weather events. The study made use of SWAN (Simulating Waves Nearshore, www.tudelft.nl) to understand the wave growth, wave spectra, and dissipation considering whitecapping, bottom induced breaking in a fetch limited long duration strong wind conditions during a cold wave.

Internal solitary waves are finite-amplitude internal waves generated from the interaction between tide and topography. Shoaling of internal solitary waves is difficult to track as they split into boluses and dissipate after shoaling. **Zahedi et al. (2022)** conducted experiments in an internal wave flume to measure the rate of dissipation of turbulent kinetic energy as boluses shoaled. The experiments depicted the proportionality of dissipation to incident wave amplitude and wave Reynolds number. The authors proposed the parametrization such as wave Reynolds numbers varying from 102 to 106 from laboratory to open ocean, internal Iribarren number, and the wave Froude number.

The study by **Premathilake and Khangaonker (2022)** focuses on currents and explores the tidal transport and flushing processes in the inner Salish Sea region using the state-of-art Finite Volume Community Ocean Model (FVCOM) model. The study defined and quantified residence and flushing times in various sub-basins using Lagrangian particles and numerical/virtual dye experiments. The composite flushing time of smaller water bodies was found the same as the flushing time of larger parent basins. These compounded flushing times can be used as significant indicators in water assessments for smaller basins for the treatment of pollutants and nutrients.

2.3 Theme 3: Sediment Dynamics

Mixing and transport in estuarine and coastal systems is a fundamental driver for sediment dynamics and for the overall sediment budget as well. Yet, the quantification of the sediment budget through field measurements as well as numerical modelling challenging (Diaz et al., 2018). This special issue presents several detailed studies on sediment dynamics and the associated morphological change using in situ observation, numerical models, and analytical solutions. Two studies focus on Yellow River sediment dynamics, which is a key research domain as its sediment discharge ranks second in the world (Zhao et al., 2022). The accumulated sediments are mostly found within narrow coastal areas in summer and carried away offshore by strong winter storm waves (Wang et al., 2014; Yang et al., 2011). However, many aspects of the sediment dynamics and budget remain poorly resolved.

A study published in the special issue by **Kuang et al. (2022)** contributes to the sediment transport and morphodynamics of the coast in the southeast Bohai Bay and northwest regions of the Yellow River delta using a multi-sediment (sand, silt, and clay) model coupled with a wave-tide-surge model. Using the state-of-art Delft3D model (www.tudelft.nl) their study shows the distinctive responses of sand, silt, and clay to a cold wave storm. A component of the study focused on the role of wind waves which primarily caused offshore sediment resuspension and enhanced transportation to the nearshore by wind-induced currents. Additionally, the construction of two long jetties in 2006 and 2016 was linked to 70% and 30% reductions in sediment deposition and suspended sediment concentration in the waterways.

Another SI article by **Zhang et al. (2022)** revealed sediment dynamics over the abandoned Diaokou lobe (in the Chengdao Sea region in the northern part of the Yellow River Delta), which has suffered from serious erosion since the Yellow River diverted to the Qingshuigou course in 1976. In situ observation-based studies during winter of 2014-2015 determined the factors governing the sediment transport in the lobe. Here again, wind waves were a significant factor, causing seabed erosion, while tidal currents exported suspended sediments in the offshore direction in the study domain.

The sediment dynamics associated mixing and transport process is inevitability linked to shoreline changes. Identification and modelling of the shoreline changes incorporate challenges due to the large time span and various physical and anthropogenic factors involved during the period. The recent study by **Hoang (2022)** proposed an analytical method to model the shoreline changes by solving nonhomogeneous linear diffusion equations assuming the coastline to be both bounded and unbounded. The solutions, using the property of superposition, showed that reduced river sediment supply could retreat the shoreline at the delta tip, whereas the increase in the sediment supply could recover the shorelines. These derived solutions are expected to serve as a benchmark for numerical solutions and will be beneficial at the primary design stage for coastal development and restoration projects.

2.4 Theme 4: Plume dynamics

Plumes are the natural transition region betweenthat bridges coastal and estuarine systems. Under this heading, **Delatolas et al. (2023)** applied the observation tool-T-REMUS Autonomous Underwater Vehicle (AUV) to study the energetic frontal region of the tidally pulsed Connecticut River plume. The synchronous and high-resolution observations from this instrument platform provided detailed insights oninsight into the frontal structure and turbulence mixing in the reference frame of the propagating front. This allows the buoyant plume to be decomposed into three regions. Surprisingly, the study found barely any changes in turbulent core and elevated kinetic energy dissipation rates away from river mouth.

The study of **Li et al. (2022)** also used multi-vessel synchronous observation and represents the first such effort to characterize the plume bulge during the flood-ebb tidal cycle in Pear River Estuary. The study documents a plume structure over a range of different forcing conditions, revealing new insight into the sensitivity of the plume bulge to changes in river discharge. The work emphasizes that additional numerical simulation will be needed to quantify the precise discharge threshold at which the plume bulge is generated and disappears due to the limitations of the measured data.

2.5 Theme 5: Physical-biogeochemical processes in the coastal zone

This theme focuses on the physical-biogeochemical process critical to understanding interdisciplinary issues in the coastal zone. This is particularly challenging because temporal and spatial scales of nutrients and primary production can be different from the relevant physical processes in operation in estuaries and coastal seas. Nonetheless several studies in the Special Issue seek to fill these knowledge gaps. For example, **Al-Thani et al. (2023)** investigated the concentrations of nutrients and chlorophyll measured in summer 2019 and winter 2020 in the southern-central Arabian Gulf. Analysis showed that summer thermal stratification is enhanced by intrusion of fresher surface water plume plume from the Arabian Sea, which developed a hypoxic zone (DO < 2.0 mL/L). Their findings may be relevant to similar studies in other estuaries and coastal areas and may have corresponding implications for regional coastal protection and environmental management.

Liu et al. (2022b) is similarly focused on the importance of transport and circulation in *Karenia brevis* harmful algal bloom, noted as a red tide, along the west coast of Florida. The study used the West Florida Coastal Ocean Model which relies on the Finite Volume Community Ocean Model for increased resolution nearshore and the Hybrid Coordinate Ocean Model for deep ocean forcings. Using a passive tracer, they found that the accumulation of *K. brevis* is the result of a combination of local hydrographic conditions as well as the generation and transport of cells from elsewhere.

Moving further inshore, bar-built estuaries or intermittently closed/open lagoons are common to coastal regions with episodic river flows and seasonal precipitation changes. Therefore, bar-built estuaries experience variations in hydrodynamics and water chemistry characteristics resulting from seasonal breaches and closures of their mouth and watershed inputs. **Dawson et al. (2022)** observed spatiotemporal variability in dissolved oxygen (DO) in a small bar-built estuary in Carmel, California from February to August 2020 with variable morphological states. Bar-built estuarine dissolved oxygen levels depended on the morphological state of the entrance (open vs. closed) and river flow conditions. The work indicates the need for a greater focus on various biogeochemical and physical processes and their impact on dissolved oxygen variability within the Carmel River system and elsewhere.

3. Discussion and future research directions

Mixing and transport are small-scale processes, yet important components in the large-scale ocean climate. Challenges underlie the parametrization of these small-scale processes and incorporating them into comparatively coarser grids associated with climate model simulations. Future research in this direction with optimum computation time and cost are worth consideration. On the other hand, studies on local mixing and transport often neglect remote, large-scale forcings. Research initiatives such as nesting methods are necessary to comprehend the remote forcings in local studies. Further, dynamic bathymetry and shoreline structures alongside the material properties are generalized with bulk parametrizations, which are expected to improve with continuous field observation and more precise laboratory experiments. Furthermore, mixing and transport in the estuarine environments influenced by ice dynamics are areas that have received barely any attention at all to date.

The objective of this SI is to improve the understanding of mixing and transport dynamics in estuaries and coastal waters by using observations, remote sensing, numerical models and data frameworks. Observations and satellite images could provide true and vivid environmental information to represent the dynamical processes in estuaries and coastal seas. Numerical modelling shows the advantages of spatial and temporal scales in presenting detailed information over large study areas. Data frameworks show the advantage of providing a simple and practical way to explore estuarine circulation through multiple stratification schemes and flushing time calculation methods. This SI brings attention to systems in the USA, Canada, China, Vietnam, Qatar, Netherlands, and New Zealand and presents the latest progress on mixing and transport research in 21 published articles in final. From the findings in these papers, we suggest the following three guidelines for future research directions:

- Anthropogenic impacts including topography and coastline shifting, river discharge regulations, dams and bridge constructions, were not taken into account in most of the studies, especially for interannual investigations. Future work needs to pay attention to the anthropogenic impacts on the transport and mixing processes in estuaries and coastal seas.

- Outcomes and data from research need to be linked with future management and assessment of estuaries and coastal seas, which is essential for relevant policymakers to encourage better and more informed decision-making at all levels.

- Future work and progress need to focus on estuarine physical-biogeochemical processes including larval transport and water quality dynamics etc. to provide a comprehensive understanding of estuaries and coastal seas from a range of different perspectives.

The studies in this SI provide us with a better perspective for understanding mixing and transport processes in estuaries and coastal seas. Future studies under the above three guidelines will help to continue to allow advances in the field of coastal and estuarine physics and their impact on interdisciplinary issues in this setting. By gathering similar studies together in a single volume, lessons can be shared and discussed more readily than is generally achieved in single-site research.

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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