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Jiayi Pan
Portland State University

Yeqiang Shu
Chinese Academy of Sciences

Zhe-Wen Zheng
National Taiwan Normal University

Adam T. Devlin
University of Hawai'i at Mānoa

Majid Nazeer
The Hong Kong Polytechnic University

See next page for additional authors

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Charitha Bandula Pattiaratchi,
University of Western Australia, Australia

*CORRESPONDENCE
Jiayi Pan
panj@cuhk.edu.hk

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Editorial: Advances in ecological environment changes in coastal and estuarine waters in response to hydrodynamic variability

Jiayi Pan[1,2]*, Yeqiang Shu[3], Zhe-Wen Zheng[4], Adam T. Devlin[5], Majid Nazeer[6] and Andrew M. Fischer[7]

[1]School of Geography and Environment, Jiangxi Normal University, Nanchang, Jiangxi, China, [2]Department of Civil and Environmental Engineering, Portland State University, Portland, OR, United States, [3]South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou, Guangdong, China, [4]Department of Earth Science, National Taiwan Normal University, Taipei, Taiwan, [5]Department of Oceanography, University of Hawai'i at Mānoa, Honolulu, HI, United States, [6]Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR, China, [7]Institute for Marine and Antarctic Studies, University of Tasmania, Launceston, TAS, Australia

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Editorial on the Research Topic
Advances in ecological environment changes in coastal and estuarine waters in response to hydrodynamic variability

1 Introduction

Over the past few decades, coastal and estuarine ecological environments have undergone significant and rapid transformations, driven by a range of factors, with the variability in hydrodynamic conditions being one of the most prominent (Elliott et al., 2019; Statham, 2012; Da et al., 2024). These dynamic forces influence water movement, sediment transport, and nutrient cycling, all of which are critical components affecting the health and stability of these ecosystems (van Vliet et al., 2023; Li et al., 2023). Consequently, understanding and interpreting hydrodynamic processes in coastal and estuarine waters are fundamental to unraveling the mechanisms behind ecological changes. This task requires a multidisciplinary approach, incorporating advanced methodologies such as remote sensing, *in-situ* observations, and numerical modeling. Each of these methods offers unique insights, from large-scale monitoring to fine-scale process modeling, providing a comprehensive understanding of these complex systems. While the immediate effects of local hydrodynamic conditions are significant, they do not act in isolation. Broader regional or even global events, such as climate change, sea-level rise, and extreme weather patterns, can exacerbate or modify these local processes. Therefore, analyzing hydrodynamic variability across different temporal and spatial scales is crucial to fully grasp how ecological environments evolve in response to various external forces, both immediate and long-term. Gaining a deeper understanding of both the ecological changes and the dynamic mechanisms driving them is essential for developing effective conservation and management strategies. Clarifying these relationships will enhance our ability to protect coastal and estuarine ecosystems from further degradation and to anticipate future changes. Furthermore, such knowledge is invaluable for environmental managers seeking to adopt appropriate mitigation and adaptation measures, ensuring the sustainability of these vital ecosystems. In this Research Topic, we present a collection of six papers that highlight cutting-edge research on ecological environment changes in response to hydrodynamic variability in coastal and estuarine waters. The titles of these papers are listed in Table 1.

We will provide brief descriptions of these studies in the following section, offering insights into their key findings and contributions to the understanding of ecological environment changes in coastal and estuarine waters. Each study presents a unique perspective on the interplay between hydrodynamic variability and ecosystem dynamics, highlighting innovative methodologies and novel research approaches.

2 Focus areas and findings in this Research Topic

The seasonal transition of the Western Boundary Current (WBC) in the southern South China Sea (SCS) from summer to winter is a complex process that typically begins in early October and lasts for about two weeks. Tian et al. analyzed this process using data from the Hybrid Coordinate Ocean Model (HYCOM) and AVISO altimeter measurements. They found that the transition occurs uniformly above the thermocline (~100 m), but lags in deeper layers. This process is mainly governed by geostrophic balance. Above the thermocline, the barotropic pressure gradient drives the transition, while below, both barotropic and baroclinic gradients play a role. Initially, these gradients offset each other in deeper waters, causing a delay in reaching geostrophic balance. This delay increases with depth as it takes time for the barotropic pressure to dominate. Changes in the barotropic gradient are influenced by wind stress curl, while shifts in the baroclinic gradient below the thermocline are linked to deep water warming, downwelling near the slope, and reduced upwelling off Vietnam.

TABLE 1 The papers published in this Research Topic.

Title	Authors
Longitudinal dissolved oxygen patterns in Atlantic salmon aquaculture sites in British Columbia, Canada	Jeong et al.
Southern South China Sea boundary current transition from summer to winter	Tian et al.
Studying the evolution of hypoxia/anoxia in Aitoliko lagoon, Greece, based on measured and modeled data	Knutsen et al.
Geochemical behavior of C, N, and S in sediments of Hangzhou Bay, Southeastern China: implications for the study of paleoclimate and sea-level changes	Gao et al.
Utilizing residual networks for remote sensing estimation of total nitrogen concentration in Shandong offshore areas	Zheng et al.
From green to brown: two decades of darkening coastal water in the Gulf of Riga, the Baltic Sea	Aigars et al.

Dissolved oxygen (DO) is a critical water quality parameter necessary for supporting aquatic life and is particularly important for the growth and health of salmon. The study by Jeong et al. examined hourly DO concentration data from 21 aquaculture sites in British Columbia, Canada, collected between 2015 and 2017. Using a two-stage time-series analysis, the study revealed that 42.3% of the DO data was classified as 'optimal,' 56.5% as 'suboptimal,' and 1.2% as 'stressed.' The occurrence of hypoxic conditions varied significantly depending on the season, site, and even between different cages at the same location. Environmental factors, including temperature, wind direction, and phytoplankton absorption showed strong seasonal associations with DO concentrations. In particular, temperature had a significant impact during summer and winter, while wind and phytoplankton absorption played key roles in winter. The findings provide important baseline information on deviations from recommended DO levels and offer insights for improving water quality monitoring and resource management in aquaculture environments.

Aitoliko Lagoon, Greece has recently faced worsening anoxic conditions, largely attributed to human activities, raising significant environmental concerns. Knutsen et al. investigated the development of hypoxia and anoxia in this area. With data from two measurement campaigns (2013–2014, 2023) and results from the 3D ocean model SINMOD, which simulates hydrodynamics, biochemistry, and ecology, the study assessed changes in oxygen depletion over time. The SINMOD model was used to analyze multiple factors, including dissolved oxygen, temperature, salinity, density, currents, wind, Brunt-Väisälä frequency, and Richardson number, focusing on monthly, annual, and interannual variability. The key findings showed that anoxia is prevalent at depths of 5–7 meters, with distinct seasonal patterns. Ventilation in the upper water column is notably stronger during the winter months when surface stratification weakens, allowing for better oxygen exchange. Additionally, anoxic water occasionally rises to the surface, though only for brief periods. These results provide critical insights into the oxygen dynamics of the lagoon, offering a baseline for improved environmental management and future mitigation strategies.

The organic carbon (OC) to sulfur (S) ratio in sediments is a common paleosalinity indicator used to differentiate between marine and freshwater environments. With this ratio, Gao et al. explored the relationship between carbon, nitrogen, and sulfur in Hangzhou Bay (HZB) and adjacent sea areas, where sediment dispersal plays a significant role. An 80-meter sediment core from HZB provides key insights into environmental changes in coastal eastern China since the Last Glacial Maximum. Analysis of 82 subsamples showed that from 33.6 to 12.3 ka BP, low TOC (0.21%), TN (0.02%), and TS (0.06%), with a high TOC/TS ratio (9.1), suggested freshwater organic matter from terrestrial sources during a cold climate. In the Holocene, increases in TOC, TN, TS, and $\delta 13C$, along with a lower TOC/TS ratio (2.7), indicated greater seawater influence as the climate warmed post-12.3 ka BP. The

TOC/TS ratio effectively tracked seawater intrusion, distinguishing freshwater, transitional, and marine environments, and proving useful for interpreting past environmental and climate changes.

Nitrogen is a key factor contributing to water eutrophication, making accurate estimation of nitrogen levels essential for effective environmental monitoring. Zheng et al. present a two-step feature extraction method using deep learning to overcome the limitations of satellite spectral bands for nitrogen inversion in Shandong's offshore waters. The first step involves fusing spectral bands for manual feature extraction to enhance the dataset. Next, a one-dimensional convolutional residual network (ResNet-1D) is used to automatically extract deep features, with residual learning simplifying the training process. This approach reduces the Mean Relative Error (MRE) by 10% in both test and validation datasets. The study also examines the spatiotemporal distribution of total nitrogen concentration (TNC) in Shandong's coastal waters, revealing higher concentrations near the coast and seasonal variations, with the highest levels occurring in October. The annual average TNC (0.3 mg/L) has shown a gradual decline since 2014.

In recent years, there has been growing attention on the darkening of coastal waters, a phenomenon associated with water browning and changes in light conditions. While it is widely accepted that this darkening is influenced by climate shifts, the precise relationship between light attenuation and its driving factors remains debated, as causal links are often drawn from indirect evidence. Aigars et al. used high-resolution remote sensing and modeled data, along with *in-situ* observations, to investigate this issue. The study compared two periods (1998–2007 and 2008–2018) to assess the impact of climate-related factors such as freshwater runoff, dissolved organic carbon mobilization, and shifts in the freshwater-saline water balance on the darkening of coastal waters in the Gulf of Riga, Baltic Sea. The results indicate that milder winter conditions are the most likely cause of the observed darkening. However, the study also emphasized the need for more detailed and time-sensitive data, as the current findings were not entirely conclusive.

3 Conclusion

The studies in this Research Topic offer key insights into coastal and marine environmental processes. Tian et al. examined the seasonal shift of the Western Boundary Current, highlighting the role of geostrophic balance and deep-water warming. Jeong et al. emphasized the importance of temperature and wind on dissolved oxygen variability in aquaculture. Knutsen et al. explored anoxic conditions in Aitoliko Lagoon, stressing the need for ongoing monitoring. Gao et al. used the OC/S ratio to trace paleosalinity shifts in Hangzhou Bay, while Zheng et al. improved nitrogen monitoring in Shandong's waters through deep learning. Aigars et al. linked coastal water darkening in the Gulf of Riga to milder winters, highlighting the need for more precise data.

Together, these studies underscore the importance of integrating advanced technologies such as remote sensing, machine learning, and high-resolution models to better understand and manage the complex processes affecting coastal environments. As climate change continues to reshape marine and coastal systems, the findings presented here highlight the need for more precise, long-term data Research Topic and adaptive management strategies to protect these vulnerable ecosystems.

Author contributions

JP: Writing – original draft, Writing – review & editing. YS: Writing – review & editing. ZZ: Writing – review & editing. AD: Writing – review & editing. MN: Writing – review & editing. AF: Writing – review & editing.

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Conflict of interest

The authors declare the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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