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Editorial: Advanced monitoring, modelling, and analysis of coastal environments and ecosystems

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Editorial on the Research Topic
Advanced monitoring, modelling, and analysis of coastal environments and ecosystems

Coastal ecosystems are under unprecedented stress driven by anthropogenic activities and climate change. Originating from the 9th Youth Geoscience Forum in 2024, this Research Topic complies 38 studies that span coastal, offshore and open-ocean environments. By integrating in-situ monitoring, remote sensing, numerical modelling and statistical analysis, these contributions advance our understanding of biophysical processes and establish a robust scientific foundation for sustainable management. The 38 articles in this Research Topic are systematically categorized into three sections: Coastal and Estuarine Systems, Offshore and Shelf Systems, and Open Ocean Systems.

Coastal and estuarine systems

The first group focuses on the land-sea interface, a dynamic region where riverine inputs, tides forcing and human activities generate highly dynamic conditions. Halvorsen et al. developed an operational closed-loop system that assimilates CubeSat and USV data into an Ensemble Kalman Filter, demonstrating adaptive multi-scale chlorophyll-a monitoring along the Norwegian coast. Yu et al. revealed that turbulence, rather than wave orbital motion, serves as the primary driver of sediment resuspension on an intertidal beach, while net transport is controlled by mean flows. Lin et al. used holographic imaging and deep learning to reveal that elongated diatoms settle deeper under typhoon mixing, whereas

short-straight forms remain in the surface layer. Bai et al. quantified wave-current interactions in the Pearl River Estuary, showing that wave-enhanced bottom friction substantially attenuates tidal currents and fundamentally alters freshwater plume dynamics. Ye et al. found that light availability, not nutrients, limits phytoplankton biomass during wet seasons in Lianzhou Bay, with nanophytoplankton dominating the community. Lin et al. derived a new light attenuation parameterization for the Changjiang Estuary, demonstrating that suspended sediment dominates Kd variability and improves spring bloom simulations. Niu et al. applied two-stage GAMs to investigate ichthyoplankton in the Yellow River Estuary, identifying SST, chlorophyll-a, bottom salinity and depth as key predictors of presence, while SST, surface salinity and distance to shore were key drivers of abundance. Employing hydrogeochemical and isotopic tracers, Liu et al. revealed three-component mixing of freshwater, seawater and brine in North Shandong coastal aquifers, with distinct shallow and deep characteristics. Zhu et al. conducted an assessment of heavy metal contamination in Yangshan Port, finding higher accumulation in benthic organisms than in fish, and identifying As and Hg as ecological risks requiring attention. Cao et al. traced organic and black carbon in Pearl River Estuary sediments using stable isotopes, showing that >70% of BC originates from fossil fuels and C3 plant combustion. Liu et al. studied the seasonal DOM dynamics across a tropical estuary-bay continuum, demonstrating that while conservative mixing shapes its spatial distribution, non-conservative processes such as flocculation and microbial activity induce significant modifications. Yang et al. tracked 40-year coastline changes in the Yellow River Delta, identifying three phases and demonstrating that human reclamation has replaced river diversions as the dominant driver. Yoo et al. introduced a novel shoreline tracking method (MCGWSD) that captured typhoon-induced retreat without requiring pre-training or shore-normal transects. Lakku et al. improved hybrid shoreline modelling by incorporating spatially variable depth of closure, illustrating that traditional assumptions of constant depth systematically overpredict coastal erosion. Familkhalili et al. demonstrated that nearshore coral restoration reduces wave-driven flooding, while offshore placement may increase setup and flood risk. Tong et al. found that the Pearl River plume causes severe nitrogen depletion in the Taiwan Strait, leading to a community shift from diatoms to *Synechococcus* dominance. Xu et al. reported that nanophytoplankton contribute 61-64% of total chlorophyll-a in Leizhou Peninsula coastal waters, further noting that nutrient-driven regulation mechanisms vary significantly across different size fractions. Lin et al. quantified submarine groundwater discharge in Zhanjiang Bay using ^{222}Rn, finding SGD rates of 7–15 $cm \cdot d^{-1}$ and comparable nutrient inputs to river discharge. Rong et al. developed a 3D baroclinic model showing that density stratification induced by suspended sediments effectively dampens saltwater intrusion within the Qiantang Estuary. Gao et al. proposed a particle composition-based water classification using POM/SPM ratio as an optical discriminator, significantly improving chlorophyll-a retrieval from OLCI. Salama et al. modelled the Benguela Upwelling System over four decades, detecting coastal cooling trends and upwelling intensification, but with decoupled chlorophyll responses. Ahmad et al. comprehensively reviewed coral reefs in Pakistan, documenting 50 live coral species and identifying overfishing (24% of studies), marine pollution (29%) and climate change as primary threats, calling for MPAs and community engagement.

Offshore and shelf systems

Transitioning seaward, studies address processes on continental shelves and marginal seas, where boundary currents, coastal upwelling and mesoscale eddies play key roles. Rivas et al. identified SSH and alongshore velocity as primary drivers of chlorophyll-a variability along the South American coast, and SST-SSH upwelling proxies were found to be the dominant factors along the corresponding African coast. Liu et al. showed that wind stress directional steadiness enhances mesoscale air-sea coupling in the western Arabian Sea, with coupling coefficients increasing from 0.80 to 0.93 during summer monsoons. Zha et al. found that the Great Whirl transports surface POC to its edges but enriches subsurface POC (50-175 m) at the eddy center via Ekman pumping. Kuroda et al. used Sentinel-3 to map a 400-km *Karenia* bloom off Hokkaido lasting ~45 days, moving westward at ~4 $cm \cdot s^{-1}$, one-third of the Coastal Oyashio velocity. Yu et al. coupled satellite and numerical models to simulate the dynamics of *Margalefidinium polykrikoides* in the York River, showing that subsurface aggregation at 2 m and a 5-m swimming depth optimised performance. Dang et al. used Himawari-8 SST datasets to document internal wave-induced cooling (1-1.5 °C) in the northern South China Sea, with shoaling effects at depths <300 m. Zimin et al. analyzed 3,895 internal wave events from Sentinel-1 off Kamchatka, identifying hotspots linked to diurnal tidal currents and showing NLIW effects on chlorophyll and fish recruitment. Jia et al. and Zhang et al. (Parts I-II) developed a high-resolution (50-m) hydrodynamic model for St. John, USVI, showing that wind-driven stratification controls bay residence time through vertical vs. lateral shear exchange. Horne et al. deployed fiber-optic DAS to monitor the movements of fin whales and maritime vessels off Oregon, demonstrating behavioural avoidance responses to an approaching container vessel. Mishra et al. modelled microplastic pathways in the Gulf of Finland, showing that ~75% of particles settle on the seabed and only ~1% exit the gulf.

Open ocean systems

The final group addresses basin-scale processes that connect coastal regions to the global ocean. Shi et al. analyzed air-sea CO_2 flux in the Northwest Pacific (1982-2021), revealing that high-latitude regions function as winter carbon sources due to deep convective mixing, but transition into summer sinks driven by biological upwelling, with ENSO modulating eastern Pacific uptake. Anthony et al. comprehensively reviewed microplastic pollution in the Indian marine environment, identifying sources, transport pathways, ecological impacts and mitigation strategies including advanced filtration and biodegradation.

Conclusion and outlook

Collectively, these 38 studies demonstrate that integrating multi-platform observations (satellite, UAV, in-situ), advanced modelling (coupled physical-biogeochemical, data assimilation, machine learning) and rigorous statistical analysis is essential to understand and manage coastal ecosystems under intensifying anthropogenic and climatic pressures. Future priorities should include real-time operational forecasting systems, standardized and open datasets, cross-regional comparative studies, and the implementation of nature-based solutions such as coral restoration and marine protected areas. This Research Topic provides a robust scientific foundation for sustainable coastal management and policy development.

Author contributions

HZ: Writing – original draft. MW: Writing – original draft, Writing – review & editing. JY: Writing – review & editing. DJ: Writing – review & editing. WX: Writing – review & editing. QW: Writing – review & editing. XS: Writing – review & editing. RM: Writing – review & editing. JG: Writing – review & editing. ZW: Writing – review & editing.

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