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Editorial: Eddy-current interactions in the ocean and their impacts on climate, ecology, and biology

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Editorial on the Research Topic
Eddy-current interactions in the ocean and their impacts on climate, ecology, and biology

Oceanic mesoscale eddies are ubiquitous and energetic in the world oceans (Chelton et al., 2011). Mesoscale eddies interact with large-scale currents intensely (Frolov et al., 2004; Magalhaes et al., 2017; Yan et al., 2019; Figure 1), playing important roles in variations of climate, marine ecology and biology (Ma et al., 2016; Baldocchi, 2020).

Eddy-current interactions have been observed in the regional ocean (Nan et al., 2011b; Nan et al., 2017; Wang R et al., 2022). However, the processes and dynamics of eddy-current interactions need to be further explored. How these interactions influence the climate, marine ecology and biology remain unclear. In addition, eddy-current interactions redistribute the nutrients in the ocean, and it is not clear how they impact the primary productivity and the plankton community in different ecoregions. It is important for marine researchers to know the effects of eddy-current interaction on the changes of physical environment for the ocean ecosystem as well as the subsequent biological processes impacted by the changes that can lead to enhanced primary productivity in the ocean.

This Research Topic focuses on studies exploring eddy-current interactions in the ocean based on *in-situ* observations and/or physical-ecological coupled models, and their impacts on climate, marine ecology and biology.

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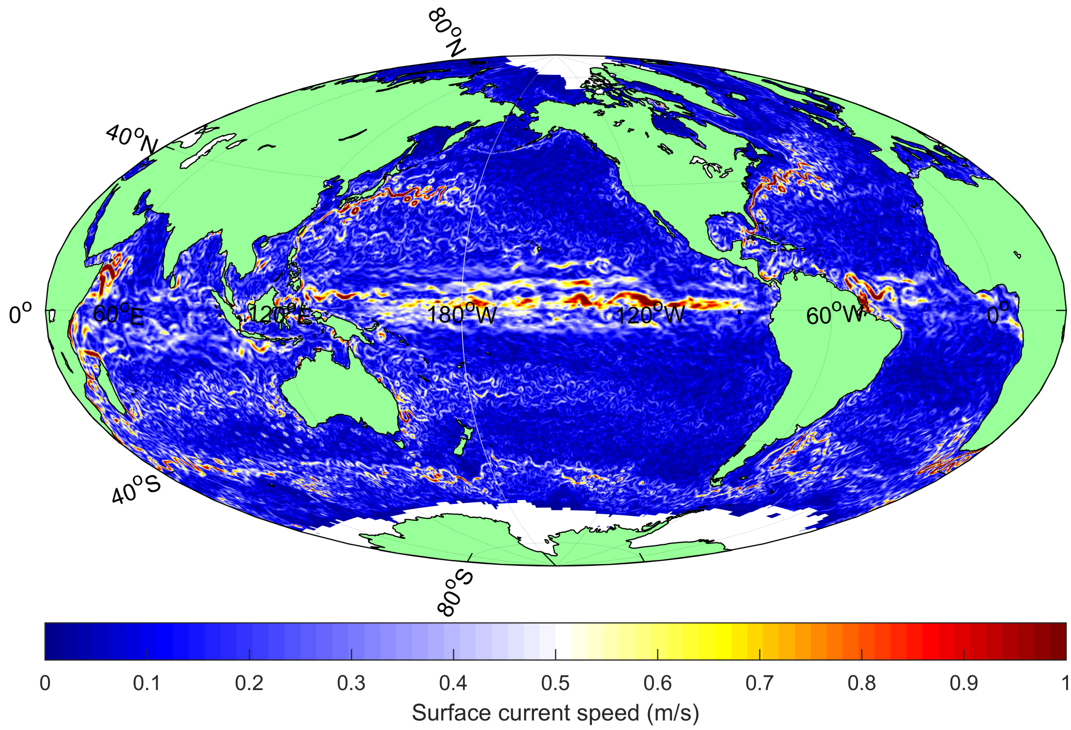

FIGURE 1
A snapshot of the surface geostrophic current speed (m/s) in the global ocean derived from satellite altimeter data.

Eddy-current interactions: observations and modeling

Over the past years, there are more and more observations of eddies, currents, and their interactions. For example, three anticyclonic eddies were detected by both *in situ* measurement and satellite altimeter data in the northern South China Sea (Nan et al., 2011a). Their horizontal/vertical structure, evolutionary processes associated with large-scale current were investigated. An extra-large subsurface anticyclonic eddy was captured by *in-situ* measurements east of the Kuroshio axis (Nan et al., 2017). When approaching the strong Kuroshio current, it can significantly increase the subsurface speed of the Kuroshio current. In this Research Topic, using mooring array observations, Huang et al. and Wang, et al. showed that there are significant seasonal and interannual variations of the currents both in the upper layer and in the subthermocline in the northwestern Pacific. In the subthermocline, there exist energetic subthermocline eddies with dominant intra-seasonal variations (Nan et al.). The subthermocline eddies enhanced both the isopycnal and diapycnal mixing of interhemispheric intermediate waters. Using the data from 12 Current–Pressure Inverted Echo Sounder (CPIES) during 2018–2019, Ren et al. observed the three-dimensional structure of eddies and investigated their interactions with Kuroshio current. The results showed that when anticyclonic/cyclonic eddy interacts with Kuroshio, the pycnocline tilt was increased/decreased resulting in a strengthening/weakening of the Kuroshio current speed. Based on CPIES observations in the Kuroshio Extension region, a cold eddy with maximum temperature anomaly (-9.1°C) was captured (Zhang et al.). Its three-dimensional structure and energy budget were investigated. Observational results provide a better understanding on the processes and dynamics of eddy-current interactions.

The state-of-the-art numerical ocean model is a powerful tool for investigating eddy-current interactions in the ocean, as it can provide high-resolution and comprehensive information that is difficult or impossible to obtain by *in-situ* field observations or remote sensing (Zhu et al., 2015; Cao et al., 2021). Especially, physical-ecological coupled dynamical models are fitted for studying how eddy-currents interactions impact on marine ecology and biology, influencing the primary productivity, plankton community, fishery resources and carbon cycle (Ji et al., 2022). Chen et al. indicated that there was plentiful sub-mesoscale energy in the Kuroshio current along the continental slope of the East China Sea (ECS), and found that a closely connected system with multi-scale dynamical processes, by employing a high-resolution ocean circulation numerical model. Lin et al. investigated the responding of the typhoon-induced upper ocean to the oceanic eddies by using a coupled ocean-atmosphere model, and indicated that both the vertical mixing and horizontal advection of eddy-related currents can enhance sea surface cooling. Xu et al. employed a hydrodynamic ocean model with cyclonic and anticyclonic eddies to reveal the response of the phosphate transportation from the cross-shelf Kuroshio to the ECS. The phosphate transportation could be reduced (increased) by cyclonic (anticyclonic) eddy due to the strong interaction with the Kuroshio Current. Guo et al. compared and evaluated global and regional operational oceanography forecasting systems by focusing on the effect of native typhoons Cempaka and Lupit in 2021 on the oceanic and ecological processes. It is found that typhoon could induce different chlorophyll-a bloom processes from coastal waters to the continental shelf, and river discharge could bring extra nutrients to stimulate chlorophyll-a bloom in coastal waters and its impact could extend to the continental shelf.

Impacts of eddy-current interactions on climate change

Both observations and model simulations have indicated that energetic eddies and their interactions with large-scale ocean currents could greatly affect sea-air interactions and oceanic heat transports in both the horizontal and vertical directions, which further modulated the spatial patterns of interannual-decadal climate variabilities and long-term warming (Ma et al., 2015; Ma et al., 2016; Beech et al., 2022; Guo et al., 2022; Li et al., 2022; Wang et al., 2022; Zhang et al., 2023). Despite significant progress, characteristics and the underlying dynamics of ocean eddies and eddy-current interactions influencing the global and regional climate change and variabilities are still not well understood. This Research Topic presents several detailed studies on the impacts of eddies and eddy-current interactions on regional circulation and climate variabilities. Interannual variations in the Kuroshio Extension in the North Pacific Ocean could remotely cause significant changes of the middle and upper troposphere trough over the Mediterranean and eastern Europe in winter through both Rossby wave propagations and eddy activities in the atmosphere (Jiang et al.). In the tropical Northwestern Pacific Ocean, eddies acted to influence climate change and variabilities in different ways in different regions. In two belts in the tropical Pacific warm pool, short-lived cyclonic and anticyclonic eddies were widespread and regulated variations in sea surface temperature and mixed layer depth, which could influence tropical cyclone formation and sea-air interactions (Liu et al.). East of the Luzon Strait, cyclonic eddies enhanced sea surface cooling during the passage of Typhoon Soulik in July 2013 through changing the three-dimensional temperature structure and generating anomalous horizontal currents (Lin et al.). In the western boundary region, anticyclonic (cyclonic) eddies strengthened (weakened) the Kuroshio current (Ren et al.), which is one of the strongest currents on Earth and brings heat from the tropics to mid-latitudes. The intraseasonal signals induced by eddies resulted an insignificant seasonal variability of the Kuroshio current in 2018 based on mooring observations (Wang, F. et al.). In the subthermocline (>26.5 σ_θ) eddies enhanced diapycnal diffusivity up to $O(10^{-4})$ m^2 s^{-1}, which was approximately one order larger than the background value and was also larger than diapycnal diffusivity generated by tides and near-inertial oscillations (Nan et al.). This finding implied that diapycnal mixing caused by subthermocline eddies may be important in closing the global ocean energy budget (Nan et al.). In addition, anticyclonic eddies could relay low potential vorticity of North Pacific Subtropical Mode Water from regions east of the Luzon Strait and transport them over long distances in the South China Sea, conveying large-scale sea-air interaction signals in the North Pacific Ocean to marginal seas (Wang, R. et al.).

Impacts of eddy-current interactions on marine ecology and biology

The interaction between ocean eddies and currents can significantly modify the physical environment such as temperature, salinity and ocean water movement that marine ecosystem heavily depends on. It also affects biological conditions such as the nutrient concentration and light availability (Babin et al., 2004; Walker et al., 2014). Chen and Tang (2012) presented a clear evidence of a phytoplankton bloom with an eddy-shape happened in South China sea in 2009, which could be directly linked to a cold ocean eddy that was caused by tropical cyclone Linfa. Babin et al. (2004) examined the enhanced chlorophyll concentrations within the cool wakes of hurricanes occurred in Sargasso Sea region, North Atlantic Ocean during the period between 1991 to 2001, and showed that the ocean eddy caused by hurricane can push down the mixed layer depth along with lower sea surface temperature, and bring deep nutrients upward that fuel the phytoplankton growth. Gierach and Subrahmanyam (2008) further studied the biophysical responses of the upper ocean water to several hurricanes occurred in Gulf of Mexico in 2005, and reported a maximum temperature about 4-7 °C and chlorophyll-a increase about 2-4 μg/L. Based on these recent progresses about phytoplankton bloom related to ocean eddies, more studies about the ecosystem processes related to eddy-current interaction in South and East China Sea have been conducted. As phytoplankton is crucial to ocean ecosystem, and abundant variety of phytoplankton species co-exists, it is necessary to understand the phytoplankton community that contribute the chlorophyll enhancement. Gong et al. incubated seawater samples that were collected at surface and deep chlorophyll maximum depths, and found that diatom tend to dominate after 72-hour incubation with good light condition and nutrient supplies, which help us to understand the changes of phytoplankton when ocean eddy events happens. Xu et al. found that the anticyclonic eddies can significantly increase the phosphate transport in the ECS.

Contribution and perspectives

In this Research Topic, we introduce the Research Topic to study the eddy-current interactions in the ocean and their impacts on climate, marine ecology and biology. Totally, 15 papers are published in this Research Topic. Usually, eddy-current interactions are highly complex and nonlinear, which involve multiple physical processes and spatiotemporal scales, such as turbulence, mixing, diffusion, mesoscale/submesoscale eddy, internal waves, etc. In order to well represent the eddy-current interactions, all these processes should be included into the numerical/conceptual models. Especially, the coupled three-dimensional atmosphere-ocean and physical-biogeochemical model should be developed to simulate the eddy-current interactions' impacts on marine ecology and biology. Results from *in-situ* observations and/or physical-ecosystem coupled models can significantly improve our knowledge and provide a better understanding of the eddy-current interactions and their influences. More targeted observations on eddy-current interactions are strongly recommended to be conducted in the future. The studies included in our Research Topic brought new knowledge about the impact of eddy-current interaction on the ocean ecosystem, which is useful for marine researchers to understanding the phytoplankton blooms that increasingly occur in many regions of the world ocean.

Author contributions

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of interest

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