



Physical-biogeochemical Dynamics and their impacts on Climate and Fisheries in the Kuroshio-Oyashio Extension Regions (PacifiKER)

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I. Background

The Kuroshio and Oyashio are the major western boundary currents in the North Pacific Ocean. As they flow eastward after separating from Japan at approximately 35°N and 42°N, the Kuroshio and Oyashio Extensions (KOE) have been recognized as “hotspots” for various oceanic processes, including fronts, eddies, and meanders. These processes significantly influence ocean dynamics, air-sea interactions, climate system, and marine ecosystems. Notably, the KOE region contributes over a quarter of the global fish catch, offering substantial potential for nearby countries to expand their distant-water fisheries.

Despite its importance, current understanding of the KOE region has primarily concentrated on multi-scale physical processes, while our knowledge of biogeochemical cycles and their interactions with physical dynamics remains limited. This knowledge gap often leads to numerical models that struggle to accurately represent these complex interactions. Additionally, the specific oceanographic and biological factors that drive changes in fish stock productivity within the KOE region are still not well understood, which hinders our ability to accurately simulate and predict future environmental changes affecting local ecosystems and fishing grounds.

To address these challenges, this project aims to establish a comprehensive, long-term, multidisciplinary observation system in the KOE region. By conducting extensive data collection and fostering interdisciplinary research, we seek to deepen our understanding of both physical and biogeochemical processes and their impacts on climate and fisheries. Ultimately, this initiative will provide a solid scientific foundation for climate prediction efforts and the development of effective fishery management strategies.

II. Timeframe and Objectives

Year	Observations		Understandings	Data sharing
2023	Multidiscipline cruises carried by RV DongFangHong3; Building up KOE Observing System	Fishery study fleets carried by RV SongHang	International Workshop	A preliminary version of Observation Data Access for Kuroshio-Oyashio Extension Region (ODA-KOER) online;
2024				Website about PacifiKER



2025		/	A special collection of related studies in JGR-Oceans or other journals	
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Objectives

- 1) **Observation.** To establish a systematic and long-term observational network in the KOE region focusing on both physical and biogeochemical processes, including Kuroshio Extension Mooring System (KEMS), BGC-Argo/Deep Argo arrays and repeated hydrological transects.
- 2) **Understanding.** To enhance our current understanding of physical and biogeochemical processes in the KOE region through interdisciplinary studies. This goal includes identifying the primary drivers of variability affecting both the climate system and fishery resources within the KOE.
- 3) **Application.** To evaluate the impacts of physical and biogeochemical processes in the KOE on regional climate and fisheries, providing a scientific foundation for improved climate prediction and fishery management in the Northwestern Pacific.

III. Major Activities in 2024

- 1) Two Cruises were successfully conducted, one was Northwest Pacific Comprehensive Scientific Research Cruise, and another one was Fishery study cruise in the Northwestern Pacific.
- 2) The website of this project was established for its beta version.
- 3) Ten XUANWU floats were successfully deployed in the KOE region, forming a preliminary regional network of Deep Argo in this region, and the data had been updated to OceanOPS.

IV. Data Site

<http://oda-koer.com>

V. Outputs & Outcomes

1) Northwest Pacific Comprehensive Scientific Research Cruise

From August 25 to October 11, 2024, Ocean University of China conducted the 2024 Northwest Pacific Comprehensive Scientific Research Cruise, with two primary objectives. The first was to maintain the Kuroshio Extension Mooring System (KEMS) by recovering, servicing, and redeploying two air-sea mooring buoys and five subsurface moorings. The second objective was to carry out intensive networked observations of mesoscale eddies in the Kuroshio Extension. Based on satellite altimeter data, underway ADCP measurements, and

surface drifting buoys, a preliminary survey was conducted on a cyclonic eddy south of the Kuroshio jet, identifying its position, structure, intensity, and evolution characteristics. Intensified observation of the eddy were carried out, including two zonal transects, one radial transect, one edge-focused transect, and three continuous stations. Satellite remote sensing and on-site observational data were used to continuously update and adjust the eddy's shape and location in real-time, dynamically refining the station layout.

During the cruise, including underwater gliders, wave gliders, BGC-Argo floats, and the XUANWU autonomous platform were deployed for networked observations, capturing high-resolution data of the air-sea interface and upper ocean layers within the mesoscale eddy. Notably, this cruise marked the first real-time networked deployment of underwater gliders in the Kuroshio Extension. By integrating data assimilation and optimal pathfinding techniques, the mission dynamically adjusted the target waypoints and observational strategies of the gliders, significantly enhancing the efficiency of reconstructing the eddy's three-dimensional structure.

2) Some findings on fishery studies in KOE region

In 2024, our findings on fish species in the Northwest Pacific Ocean focused on several key aspects. We analyzed the differences in feeding behavior of Japanese mackerel (*Scomber japonicus*), providing important theoretical support for understanding how feeding habits change during their developmental process. We also clarified the migration path differences and mechanisms for the winter-spring cohort of neon flying squid (*Ommastrephes bartramii*) in the Northwest Pacific. Additionally, we compared the abundance and characteristics of microplastics and artificial cellulose particles in the stomach and intestine of bigfin lanternfish (*Symbolophorus californiensis*), establishing an important baseline for contamination by these particles. Finally, we investigated the feeding and habitat changes of Japanese anchovy (*Engraulis japonicus*) at different growth stages, assessing how these changes affect Hg levels.

3) Biogeochemical studies in this region

We have quantitatively assessed the interplay between physical mixing and biogeochemical processes on trace elements, e.g. dissolved rare earth element (REE). Dissolved REE concentrations, measured along the P1 section during a cruise aboard the R/V Dongfanghong 3, revealed a high La/Yb ratio (>0.35) derived from the Aleutian Islands. This ratio, controlled by lateral transport, showed a strong correlation with salinity, indicating its utility as a tracer for low-salinity water from the subarctic region (Cao et al., 2023). In the Pacific, Yb/Nd ratios can differentiate North Pacific Intermediate Water (NPIW), Antarctic Intermediate Water (AAIW), and modified AAIW. Heavy REE, predominantly governed by water mass mixing ($93\% \pm 4\%$ for Yb), further demonstrate the effectiveness of Yb as a tracer for NPIW and modified AAIW in the northwest Pacific (Cao et al., 2024). Additionally, subsurface waters with high ^{137}Cs activities can be transported from the gyre to the Kuroshio source near the Luzon Strait. Quantification based on ^{137}Cs , REE, temperature, and salinity indicates that vertical mixing and advection enhance nutrient transport from deep waters to the euphotic layer (Zhu et al., 2023). These findings underscore the significant applicability of REEs and ^{137}Cs as tracers for basin-scale water mass mixing, providing valuable insights into ocean circulation.

Despite the insights gained, there remains a lack of detailed information on the biogeochemical processes and sources of trace metals in the northwest Pacific, particularly in the Kuroshio-Oyashio Extension (KOE) region. Using REE data obtained from the P1 section during a cruise aboard the R/V Dongfanghong 3, we reveal for the first time that REE release efficiency in the Oyashio and Kuroshio mixing region is about four times higher than in subtropical and tropical regions. This elevated efficiency is attributed to strong water mass mixing and distinct plankton communities (Cao et al., 2023). In the northwest Pacific, in intermediate and deep water (800~2000m), high Yb/Nd and low Dy/Er ratios indicate the scavenging of REEs by opal belts and Fe-Mn oxides formed in hydrothermal plumes (Cao et al., 2024). Additionally, lithogenic inputs from the Kuril Islands, Aleutian Islands, and the Sea of Okhotsk were identified by elevated REE concentrations and La/Yb ratios in the surface waters of the KOE (Cao et al., 2023). Taken together, these findings introduce valuable tracers for quantifying water mass mixing ratios on a basin-scale, while also enhancing our understanding of the biogeochemical processes governing REE in the Pacific.

4) Frontal-scale and eddy-scale air-sea exchanges

Submesoscale Fronts and Air-Sea Exchanges: Oceanic fronts at submesoscale (1–10 km) exhibit significant sea surface temperature (SST) gradients, which play a critical role in driving cloud formation, precipitation, and atmospheric storms. However, the effects of these small-scale fronts on the atmosphere have been challenging to quantify due to a lack of high-resolution observations and models. Using rare, high-resolution in situ observations in the Kuroshio Extension region, this study captures air-sea exchanges across a submesoscale front. The SST gradient across the front reaches 2.4°C/km, with turbulent heat flux gradients of up to 47 W/m²/km—much stronger than those typically observed in mesoscale-resolving data. These intense gradients significantly enhance air-sea fluxes and vertical mixing, promoting cloud formation. Idealized model simulations corroborate these intense exchanges at submesoscale fronts, though they remain unresolved in traditional mesoscale-resolving climate models. These findings highlight the need for improved model resolution to better capture the impacts of submesoscale features on atmospheric processes.

Eddy-Scale Energetics and Air-Sea Interactions: Utilizing eddy-resolving simulations from the Community Earth System Model (CESM), this study examines the energy dynamics of mesoscale eddies, specifically anticyclonic (AEs) and cyclonic eddies (CEs), in the Kuroshio Extension region. The energy balance analysis reveals that both AEs and CEs exhibit similar energy generation mechanisms, with eddy kinetic energy (EKE) primarily fueled by barotropic instability, vertical buoyancy flux, and energy transported from the upstream Kuroshio. Temperature variance, linked to eddy potential energy, is largely sustained by baroclinic instability. Air-sea interactions, particularly heat flux and wind stress, serve as significant mechanisms for dissipating eddy energy. For both AEs and CEs, air-sea heat exchange accounts for the dissipation of 60% and 72% of the temperature variance, respectively, while wind stress plays a smaller role, contributing to only 14% and 5% of EKE dissipation for AEs and CEs, respectively. These insights underscore the influence of air-sea fluxes on eddy

dynamics, particularly in their role in dissipating temperature variance and regulating ocean-atmosphere energy exchanges.

References:

- Cao, A., Liu, Q., Zhang, J., Shiller, A.M., Cai, Y., Zhang, R., Gilbert, M., Guo, X., and Liu, Z (2024), Dissolved rare earth elements in the North Pacific Subtropical Gyre: Lithogenic sources and water mass mixing control. *Geochimica et Cosmochimica Acta*, 372, 42-61. <https://doi.org/10.1016/j.gca.2024.02.018>.
- Cao, A., Zhang, J., Zhang, H., Chen, Z., Cui, G., Liu, Z., Li, Y., Liu, Q (2023), Dissolved rare earth elements in the Northwest Pacific: Sources, water mass tracing, and cross-shelf fluxes. *Frontiers in Marine Science*, 10:1135113. doi: 10.3389/fmars.2023.1135113.
- Zhu, S. J., Zhang, J., Matsuno, T., Tsutsumi, E., Kambayashi, S., Horikawa, K., et al. (2023), Quantifying the water contribution of subtropical mode water and related isopycnal/diapycnal water mixing in the western Pacific boundary current area using radiocesium: A significant nutrient contribution from subtropical Pacific gyre to the marginal region. *Journal of Geophysical Research: Oceans*, 128, e2022JC018975. <https://doi.org/10.1029/2022JC018975>.
- Yingcong Chen, Guanyu Hu, Zhenfang Zhao, Xinjun Chen, Bilin Liu. (2024) “Feeding Habits of Scomber japonicus Inferred by Stable Isotope and Fatty Acid Analyses”, *Journal of Marine Science and Engineering*, 12(8), 1335.
- Gong, Yi, Qian Wang, Yan Xiang, Bilin Liu. (2024) ‘Invisible threat to mesopelagic fish: Microplastics and artificial cellulose particles in bigfin lanternfish *Symbolophorus californiensis* from the Northwest Pacific Ocean’, *Regional Studies in Marine Science*, 78, 103799.
- Fang Z*, Han P W, Wang Y, Li J H, Hu G Y, Liu B L, Chen X J. Environmental fluctuation influences the ontogenetic dispersal and distribution of two ommastrephid squids in the Pacific Ocean[J]. *Reviews in Fish Biology and Fisheries*, 2024, 34: 337–352.
- Long Chen, Guanyu Hu, Zhenfang Zhao, Bilin Liu, Xinjun Chen, Liling Zhang. (2024) “Effects of diet and habitat on Hg levels in Japanese anchovy in the high seas of the northwestern Pacific Ocean”, *Marine Pollution Bulletin*, 208, 116976.
- Cai, J., M. Li, H. Yang* and Z. Chen*, 2024: Role of Air - Sea Interaction in the Energy Balance of Anticyclonic and Cyclonic Eddies in the Kuroshio Extension, *Journal of Geophysical Research: Oceans*, 129, e2023JC020682. <https://doi.org/10.1029/2023JC020682>.
- Yang, H., Z. Chen*, S. Sun*, M. Li, W. Cai, L. Wu, J. Cai, B. Sun, K. Ma, X. Ma, Z. Jing and B. Gan, 2024: Observations reveal intense air-sea exchanges over submesoscale ocean front, *Geophysical Research Letters*, 51, e2023GL106840. <https://doi.org/10.1029/2023GL106840>.

VI. Future Plan for 2025 and beyond

- 1) Cruise 2025 to be prepared
- 2) Finish the website testing as well as the data update
- 3) Hold a workshop in Qingdao