ANNUAL REPORT ON GEOTRACES ACTIVITIES IN CHINA

May 1st, 2024 to April 30th, 2025

New GEOTRACES or GEOTRACES relevant scientific results

- **The First Dataset of Size-Fractionated Biogenic Particle Concentrations**

  Particulate C:N:P:Si ratios and their variations in the upper ocean are crucial for understanding carbon export and its coupling with nutrient dynamics and phytoplankton community composition associated with nutrient limitation. This study present the first dataset of size-fractionated biogenic particle concentrations and their elemental ratios, including particulate organic carbon (POC), particulate nitrogen (PN), particulate phosphorus (PP), and biogenic silica (BSi), in the upper 500 m of the water column in the subtropical western North Pacific. The highest POC, PN, and PP concentrations consistently occurred in surface water and then decreased with increasing depth, whereas BSi concentration was frequently highest in the subsurface chlorophyll maximum layer at ~ 120 m. The small size fraction (SSF, 0.8 or 1–51 μm) dominated the total pool of POC, PN, and PP but contributed less to the total BSi pool than the large size fraction (LSF, >51 μm). This feature was accompanied by lower C:N, C:P, and N:P ratios and higher C:Si ratios in the SSF than in the LSF. In the euphotic zone, total particulate C:N, C:P, N:P, and C:Si ratios averaged 8 ± 1, 146 ± 30, 17 ± 3, and 120 ± 48 mol:mol respectively, and exceeded the canonical Redfield and Brzezinski ratio. The three former ratios aligned with cellular C:N:P ratios of *Prochlorococcus* and *Synechococcus*. Moreover, these ratios exhibited observable latitudinal gradients; they were generally higher in the gyre center than in its southern boundary occupied by the North Equatorial Current. Below the euphotic zone down to 500 m, there was a distinct increase in SSF molar C:N, C:P, and N:P ratios with depth, while total particulate molar C:Si ratios remained relatively constant. Combined with data collected in the subtropical eastern South Pacific and North Atlantic, our results demonstrate that the composition of the phytoplankton community primarily controls particulate molar C:N:P:Si stoichiometry in the euphotic zone of ocean gyres, in particular in the SSF, below which preferential remineralization of various bioelements plays an important role.

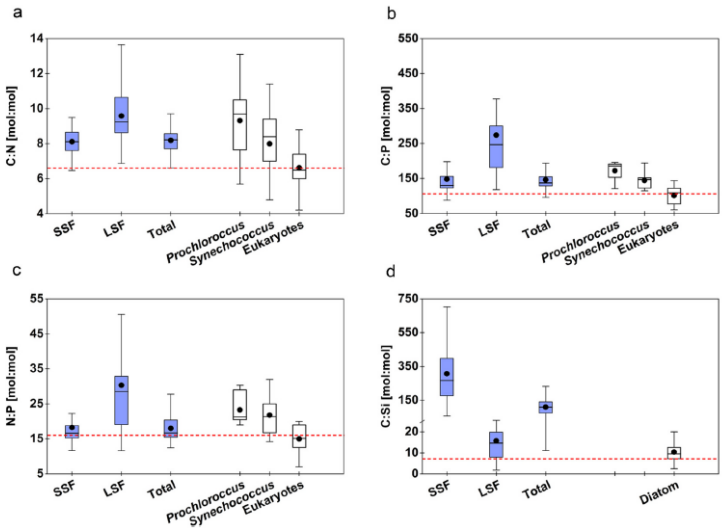

Figure 1. (a) C:N, (b) C:P, (c) N:P, and (d) C:Si ratios for the small size fraction (SSF, 0.8 or 1–51 μm), large size fraction (LSF, >51 μm), and total particulates (Total, >0.8 or 1 μm) in the euphotic zone in the subtropical western North Pacific.

- **Cd-P Decoupling in the North Pacific Subtropical Gyre**

  This study examined the spatial variation in size-fractionated (0.8–51 and > 51 μm) particulate Cd and phosphorus (P) based on a large dataset collected during a GEOTRACES Section cruise (GP09) in the NPSG to better understand the interrelationship between Cd and P biogeochemical cycles. Concentrations of particulate Cd (0.06–2.15 pmol L^{-1}) and P (0.33–10.19 nmol L^{-1}) showed an initial increase with depth followed by a decrease, and were among the lowest observed in the global ocean. Bulk particulate Cd: P ratios in the euphotic zone, indicative of phytoplankton Cd assimilation, showed strong geographic variability averaging 0.05 ± 0.02 within the NPSG interior vs. 0.14 ± 0.04 pmol $nmol^{-1}$ at the southern boundary. Cadmium to P remineralization ratio in the mesopelagic zone had a roughly similar stoichiometry as what was produced in the euphotic zone, being ~ 0.05 ± 0.01 in the NPSG interior vs. 0.21 ± 0.04 pmol $nmol^{-1}$ at the southern boundary. Cd–P decoupling was reflected in the elements' vertical distribution, showing unsynchronized changes through the water column, consistent with Cd–P differential remineralization resulting from multiple Cd and P pools. The Cd–P relationship also differed between small and large particles, suggesting differences in Cd assimilation among phytoplankton assemblages as well as particle dynamic processes. Our results highlight complex processes fractionating Cd from P in the oligotrophic ocean and complicate the use of Cd as a palaeophosphate proxy.

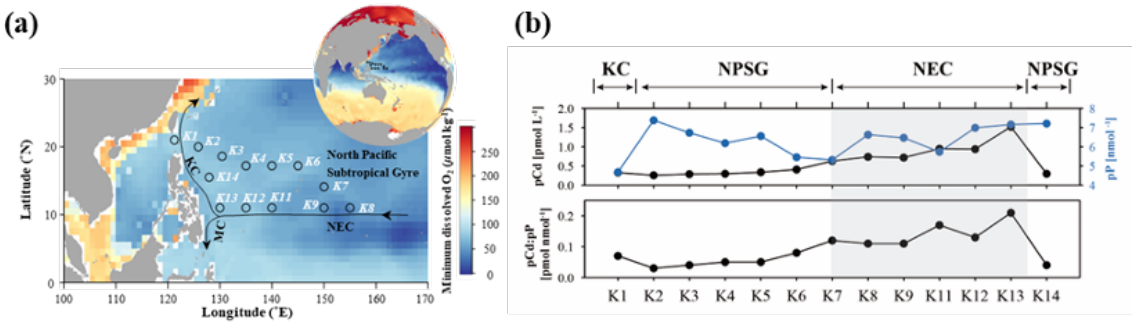

Figure 2. (a) Location of sampling stations (K1–K14) along the GP09 Northwestern Pacific Transect. (b) Particulate Cd, phosphorus P and pCd: pP ratio each station during the GP09 cruise. The gray shaded area indicates North Equatorial Current (NEC) affected stations.

- **Deep-Sea Arsenic Removal Mechanisms**

  This study observed distinct decreases in total dissolved inorganic arsenic (DAs) concentration in deep waters around hydrothermal vents, seamounts, and island sediments in the subtropical western North Pacific. DAs removal corresponds to elevated dissolved and total dissolvable particulate Fe concentrations, indicating a major control of particle adsorption on As behavior in specific deep-ocean regions. Particle scavenging effect varied among the three deep-sea regions, mainly ascribed to varying particulate elemental compositions and environmental factors. Newly estimated DAs removal fluxes associated with particles around hydrothermal or seamount systems are comparable to the individual input flux from rivers, atmosphere, and hydrothermal vents, thus helping to balance the global oceanic As budget.

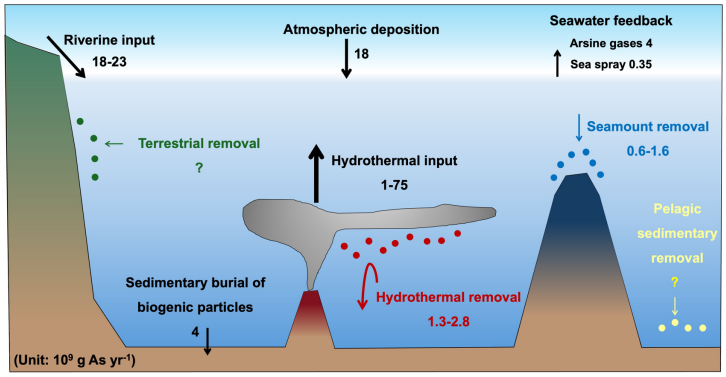

Figure 3. Schematic of the global oceanic arsenic (As) budget with updated DAs removal fluxes around hydrothermal vents and seamounts.

- **Rare Earth Elements in the North Pacific Subtropical Gyre**

  This study presents the spatiotemporal distributions of dissolved rare earth element (REE) concentrations based on two GEOTRACES-CHINA process study cruises (GPpr15) conducted in summer and winter, along with published results from a GEOTRACES-CHINA cruise (GP09) during spring. Above the depth of chlorophyll maxima (DCM), REE levels were lowest in winter compared to summer, reflecting enhanced scavenging of REEs by particulate matter, primarily driven by increased chlorophyll-α during winter. In subsurface to intermediate waters (150–1000 m), release efficiencies (~0.04 pmol Nd/μmol apparent oxygen utilization) exhibited no seasonal variations in the North Pacific Subtropical Gyre (NPSG). These efficiencies were consistent with those in the North Atlantic Gyre at similar latitudes, but differed from those at higher latitudes (~0.15), which may be attributed to variations in the plankton community structure across regions. Furthermore, inputs of slope sediments to intermediate waters (500–1000 m) off the Philippine Islands were identified using Ce anomalies and Yb/Nd ratios. These inputs peaked during winter, with Nd contribution from slope sediment accounting for 15 –43 % of the total Nd concentration. In deep waters (>4500 m) of the Philippine Basin (stations K2/K2b, K3, K13/13a, and K14), elevated REE concentrations indicated extra inputs from the seafloor and lateral transport from the Philippine Islands, contributing 17 ± 6 % of Nd. The contributions of Nd from settled particles and water mass mixing were estimated at 10 ± 5 % and 73 ± 3 %, respectively. Additionally, Yb reliably traced the distribution of lower circumpolar deep water in the Philippine Basin. In summary, these findings highlight the significant influence of biogeochemical processes on seasonal variations of REEs above the DCM and underscore the potential of REE in tracking deep water transport.

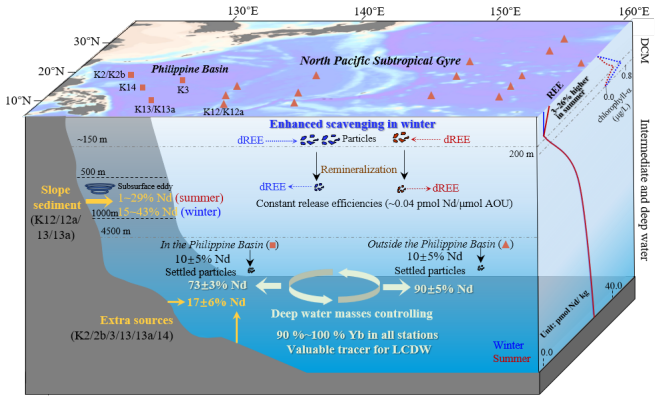

Figure 4. Graphical Abstract of REE cycling.

- **Trans-Oceanic Aerosol Trace Elements**

  Aerosol samples were collected along a 50,000 km transect spanning the Northwest Pacific marginal seas, Indian Ocean, Southern Ocean, Drake Passage, and South Pacific to investigate the large-scale distribution and sources of aerosol-borne trace elements (TEs). This study found that TE concentrations exhibited strong spatial heterogeneity, with elevated levels in coastal seas and the Indian Ocean, moderate levels over the Southern Ocean, and the lowest values in the South Pacific. Crustal-derived elements (Al, Ti, V, Mn, Fe, and Co) dominated over remote oceans, whereas anthropogenic elements (Cr, Ni, Cu, Zn, Cd, As, Pb) were widely enriched along the cruise track. Source-specific analysis indicated that Cr and Ni were primarily associated with vehicle emissions. The estimated deposition fluxes also showed regional variability, with the highest Fe deposition in the Northwest Pacific marginal seas, followed by the Drake Passage and sectors of the Southern Ocean and South Pacific. These results highlight the uneven distribution and diverse sources of aerosol TEs across ocean basins, and emphasize their important role in regulating marine biogeochemical cycles and ocean productivity on a global scale.

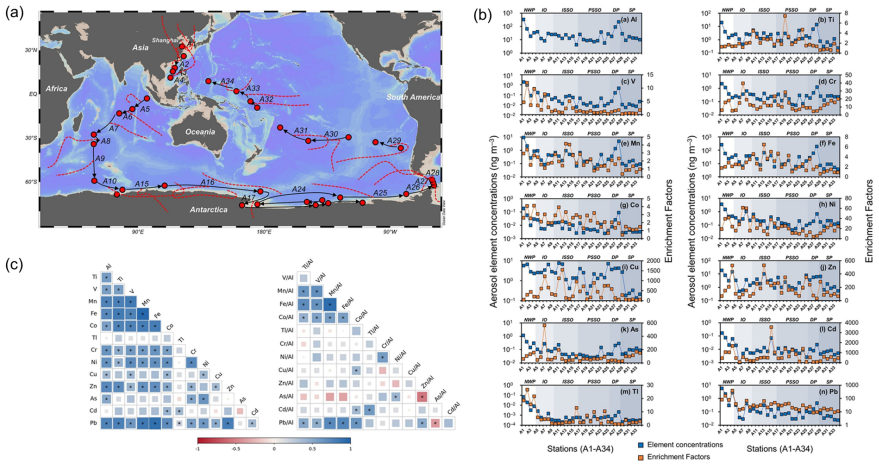

Figure 5. The cruise track with aerosol sample deployment locations (black lines); (a) the entire cruise track; Red dashed lines are 168–hr air mass back trajectories during the sampling period; (b) Aerosol trace element concentrations (primary vertical axis) and enrichment factors (secondary vertical axis); (c) Spearman correlation analysis was used to examine the relationships between the trace element concentrations and ratios normalized to aluminum (Trace Elements/Al) in four remote oceans.

- **Machine Learning Model for Global dCd**

  A global dataset of dCd was reconstructed using five machine learning models, with the random forest algorithm achieving the best performance ($R^2 = 0.99$, RMSE = 0.035 nmol kg^{-1}). Compared to previous approaches, it reduced estimation bias by 25%. The model identified key controls on dCd distributions at different depths, including surface biological uptake, deep-sea remineralization, and vertical stratification. The global Cd–PO_4 relationship was found to vary with regional biogeochemical conditions, particularly between high-nutrient, low-chlorophyll (HNLC) and non-HNLC regions. Over 80% of Cd–PO_4 variability was attributed to biological fractionation and particle remineralization in HNLC zones. These findings demonstrate the capability of machine learning in

resolving global-scale trace metal distributions and provide novel insights into cadmium cycling mechanisms in the ocean.

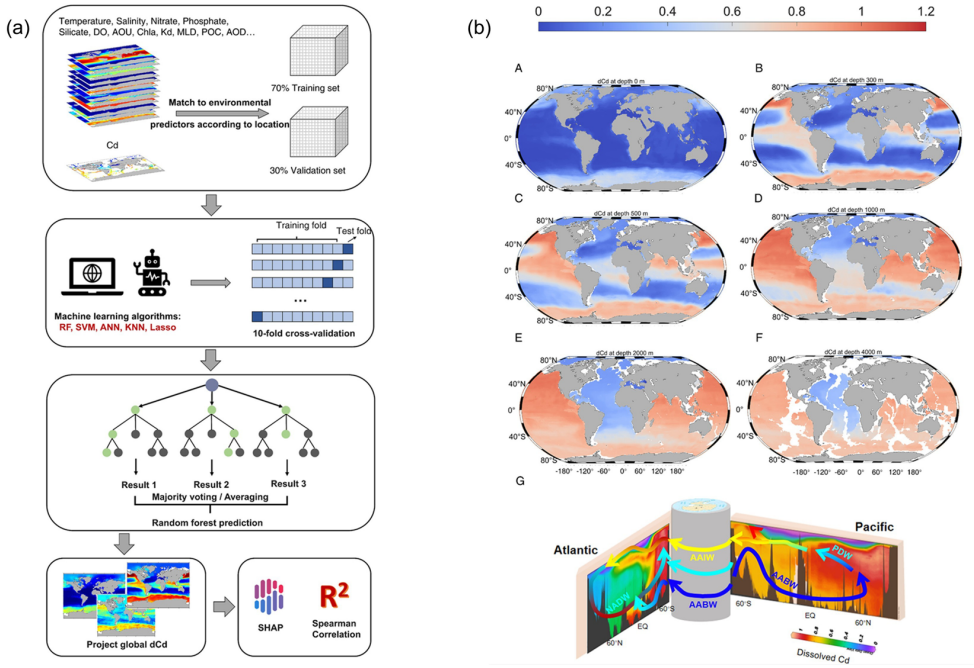

Figure 6. (a) Workflow for the data processing, model construction, and statistical analyses; (b) Global modeled dCd using the random forest approach. (A–F) Global maps of the modelled dCd at various depth horizons; (G) corresponding dCd transects across the Atlantic and Pacific. The water masses shown are North Atlantic Deep Water (NADW), Antarctic Bottom Water (AABW), Antarctic Intermediate Water (AAIW), and Pacific Deep Water (PDW).

- **Glacial Iron Transport in Kongsfjorden (Arctic)**

  Dissolved iron, dissolved aluminum, and iron isotopes ($\delta^{56}Fe$) were measured in Kongsfjorden, an Arctic fjord system, to investigate the transport of glacially derived iron from land to ocean. This study found that dFe concentrations were low in the southern inflow region of the outer fjord (5.23 ± 0.43 nM), but significantly higher in the inner and middle fjord (10.74 ± 5.22 nM), and in the northern outflow of the outer fjord (9.37 ± 2.85 nM). This spatial pattern, along with the observed correlation between dFe and salinity, indicates that both glacial meltwater input and fjord circulation jointly regulate dFe distribution in surface waters. Endmember concentrations of dFe and dAl from glacial meltwater were estimated at 82 ± 21 nM and 1089 ± 200.7 nM, respectively, with corresponding summer fluxes of 4.6–19 Mg and 29 ± 5.4 Mg. A short residence time of dFe (days to a week) contrasts with the nearly conservative behavior of dAl, supporting its use as a tracer of glacial input. The $\delta^{56}Fe$ values in surface water averaged 0.08 ± 0.19‰, and the inferred glacial input ranged from 0.1‰ to 0.3‰. These results highlight the importance of Arctic fjords as efficient conduits of glacial iron to the ocean, and demonstrate the coupled influence of meltwater input and physical circulation on iron fate in polar coastal systems.

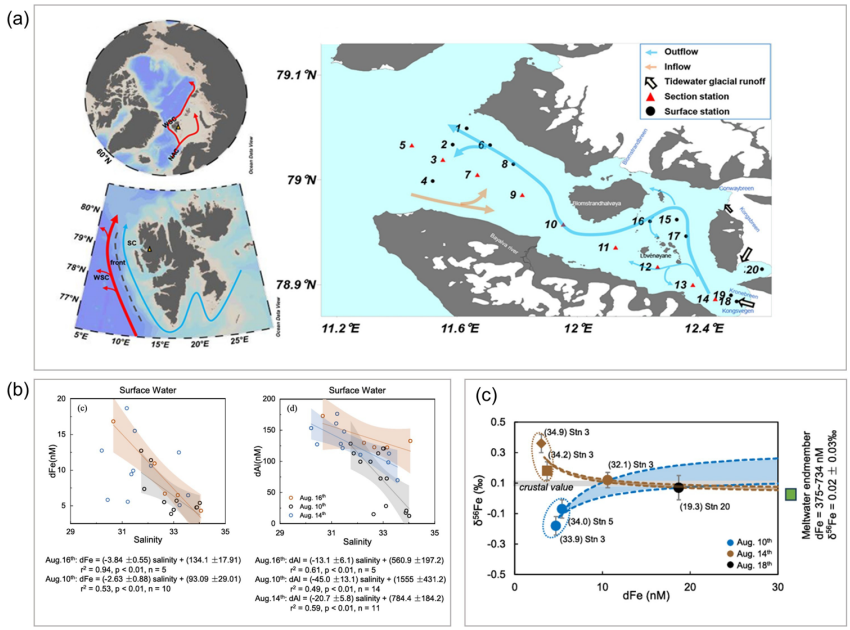

Figure 7. (a) Station locations in Kongsfjorden; (b) Relationships between dissolved metals (Fe and Al) and salinity in surface waters; (c) Plot of δ^{56}Fe (‰) values versus dFe concentration in Kongsfjorden.

GEOTRACES or GEOTRACES relevant cruises

- 2024 Northwest Pacific Ocean Multidisciplinary Cruise, water samples were collected to analyze monomethylmercury and dimethylmercury during this cruise.
- 2025 Northwest Pacific Ocean Multidisciplinary Cruise, water samples were collected to analyze dissolved and particulate trace metals (e.g. Fe) during this cruise.

New projects and/or funding

- Trace metal iron sources and sinks in the Southwest Pacific (National Key Research and Development Program, 2023–2025, leading PI: Ruifeng Zhang)
- Integrated study on the multiscale material cycling at the sea-air interface in the West Pacific (Integrated Project of the NSFC Major Research Plan Program, 2023-2025, leading PI: Zhimian Cao)
- Refined eddy network observation in the countercurrent region of the subtropical western North Pacific (Technology Innovation Project of Laoshan Laboratory, 2024-2027, leading PI: Honghai Zhang)
- Marine metabolism and element cycles (NSFC Innovation Research Group Project, 2025-2029, leading PI: Dalin Shi)
- Marine biogeochemistry and global change (NSFC Youth Science Fund (Category A continuation fund), 2025-2029, leading PI: Dalin Shi)

GEOTRACES workshops and meetings organised

- We organized a session titled *Advances in Understanding Nutrient Cycles and the Biological Pump in the Western Pacific under Past, Present, and Future Climates at the*

AGU Annual Meeting 2024 in Washington, D.C., USA, from December 9 to 13. The conveners were Prof. Zhimian Cao (Xiamen University), Prof. Tian-Yu Chen (Nanjing University), Prof. Dalin Shi (Xiamen University), Prof. Thomas Browning (GEOMAR Helmholtz Centre for Ocean Research Kiel), and Dr. Zuozhu Wen (Xiamen University). This session focused on regulatory factors of past, present, and future nutrient and trace metal cycles in the Western Pacific, as well as their role in modulating biological pump structure and function under climate change.

- We organized *the 2024 Scoping Workshop on Synergy of Ocean Observations and Biogeochemical Models*, held from May 21-23, brought together 40 renowned marine scientists from 8 countries under the joint moderation of Prof. CHAI Fei from Xiamen University and Dr. Veronique Garçon from CNRS France. The workshop focused on enhancing the integration of observational data into biogeochemical models through improved strategies for data assimilation and forecasting, while exploring innovative approaches involving autonomous platforms like BGC Argo and remote sensing techniques. Discussions centered on key topics including the use of biogeochemical data for emergent climate constraints and model validation, the development of ocean digital twins incorporating AI and omics data, and the operational assimilation of biogeochemical observations into predictive systems to advance marine ecosystem forecasting capabilities.

Outreach activities conducted (please list any outreach/educational material available that could be shared through the GEOTRACES web site) *(We are particularly interested in recordings from webinars from GEOTRACES research)*

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Other GEOTRACES activities

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New GEOTRACES or GEOTRACES-relevant publications (published or in press) *(If possible, please identify those publications acknowledging SCOR funding)*

- Cao, AX; Liu, Q; Zhang, J; Liu, ZS; Ren, JL; Cai, YH; Zhou, KB; Guo, XH; Liu, X. 2025. Spatiotemporal variation of dissolved rare earth elements in the North Pacific Subtropical Gyre: Influence of biogeochemical cycling and application in tracing deep water. *Global and Planetary Change*. 246, 104719.
- Dai, RB; Wen, ZZ; Hong, HZ; Browning, TJ; Hu, XH; Chen, Z; Liu, X; Dai, MH; Morel, FMM*; Shi, DL*. 2025. Eukaryotic phytoplankton drive a decrease in primary production in response to elevated CO_2 in the tropical and subtropical ocean. *Proceedings of the National Academy of Sciences of the United States of America*. 122: e2423680122.
- Ge, YC; Guan, WK*; Wong, KH; Zhang, RF*. 2024. Spatial variability and source identification of trace elements in aerosols from Northwest Pacific marginal sea, Indian Ocean and South Pacific to Antarctica. *Global Biogeochemical Cycles*. 38, e2024GB008235.
- Ge, YC; Zhang, RF*; Zhu, ZY; Zhao, J; Zhu, Z; Li, Z; Li, BR; Zhang, ZR; Zhang, Y; Zhou, M; John, S; Smith, WO. 2024. Distributions of nutrients, trace metals, phytoplankton composition, and elemental consumption in the Ross and Amundsen Seas. *Marine Chemistry*. 265–266, 104436.

- Jiang, ZY; Liao, EH*; Li, ZA; Zhang, RF*. 2025. Modeling the global ocean distribution of dissolved cadmium based on machine learning—SHAP algorithm. *Science of the Total Environment*. 958, 177951.
- Li, DY; Cui, GH; Chen, SS; Qiao, YF; Liu, Q; Zhang, J; He, Q. 2024. Sensitive determination of neodymium isotope in seawater by multi-collector inductively coupled plasma mass spectrometry with ultrasound nebulization-dielectric barrier discharge vapor generation as sample introduction. *Journal of Analytical Atomic Spectrometry*. 39: 2395–2401.
- Li, YB; Zhang, HM; Guan, YJ; Cheng, GY; Li, ZH; Li, Z; Cao, MX; Yin, YG; Hu, LG; Shi, JB; Chen, BW. 2024. Functional genes and microorganisms controlling *in situ* methylmercury production and degradation in marine sediments: A case study in the Eastern China Coastal Seas. *Journal of Hazardous Materials*. 476, 134965
- Li, YC; Bo, GY; Cai, YH; Zhang, K; Zhou, KB; Zhang, PP; Yang, CJ; Chen TY; Dai, MH; Ma, J*; Cao, ZM*. 2025. Removal of dissolved arsenic from deep seawater around hydrothermal vents and seamounts, *Earth and Planetary Science Letters*. 660, 119351.
- Ruan, YQ; Zhang, RF*; Yang, SC; Jiang, ZY; Chen, S; Conway, TM; Huang, KF; Boyle, EA; Zhou, M; John, SG. 2024. Iron, Nickel, Copper, Zinc, and their stable isotopes along a salinity gradient in the Pearl River Estuary, southeastern China. *Chemical Geology*. 645, 121893.
- Shen, Z; Ge, YC; Liu, JH; Guan, WK; Hu, WF; Zhang, RF*. 2024. A bulk extraction method to determine the stable isotope ratios of iron, nickel, copper, zinc, and cadmium in seawater using multi-collector inductively coupled plasma mass spectrometry. *Acta Oceanologica Sinica*. 43: 125-137.
- Shen, Z; Zhang, RF*; Ren, JL; Marsay, C; Zhu, ZY; Wu, Y; Zhang, J; John, S. 2024. Distribution of dissolved aluminum and dissolved iron in Kongsfjorden: a glacial fjord in the Arctic. *Marine Chemistry*. 263, 104399.
- Wang, CY; Zhang, K; Cao, ZM*; Zhou, KB*; Yuan, ZW; Chen, JH; Ma, YF; Zhou, B; Liu, X; Cai, YH; Shi, DL; Dai, MH. 2025. Size-fractionated C:N:P:Si stoichiometry of particulate matter in the subtropical Western North Pacific. *Global and Planetary Change*, 246, 104732.
- Wang, X; Zhang, XR; Yang, WF; Shi, DL; Chen, M; Cheng, H; Lin, QY; Cai, PH; Cai, YH*. 2025. Dust deposition and iron cycling in the tropical western North Pacific based on thorium supply. *Global and Planetary Change*. 247, 104740.
- Xie, TX; Cao, ZM; Hamzah, F; Schlosser, P; Dai, MH*. 2024. Nutrient Vertical Flux in the Indonesian Seas as Constrained by Non-Atmospheric Helium-3. *Geophysical Research Letters*. 51, e2024GL111420.
- Yu, XR; Wen, ZZ; Jiang, RT; Yang, JY; Cao, ZM; Hong, HZ; Zhou, YT*; Shi DL*. 2024. Assessing N_2 fixation flux and its controlling factors in the (sub)tropical western North Pacific through high-resolution observations. *Limnology and Oceanography Letters*. 9: 716-724.
- Yuan, ZW; Achterberg, EP; Engel, A; Dai, MH; Browning, TJ*. 2024. Switches between nitrogen limitation and nitrogen–phosphorus co-limitation in the subtropical North Atlantic Ocean. *Limnology and Oceanography*. 69: 1005-1013.
- Zhang, K; Zhou, KB; Cai, YH; Yuan, ZW; Chen, YJ; Xu, FP; Liu, X; Cao, ZM; Dai, MH*. 2024. Decoupled cycling of particulate cadmium and phosphorus in the subtropical

Northwest Pacific. *Limnology and Oceanography*. 69: 1941-1954.

Please indicate if there is any forthcoming or planned GEOTRACES special issue publication

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Completed GEOTRACES PhD or Master theses *(please include the URL link to the pdf file of the thesis, if available)*

- Guanghao Cui. A new analytical method of rare earth elements and neodymium isotopes in seawater: Study based on InertSep ME-2 resin and Ultrasonic Nebulizer Dielectric Barrier Discharge Technology. Master thesis. Ocean University of China, 2024.
- Huiling Wang. Distribution of various species of mercury and their influencing factors in the South China Sea and Northwest Pacific Ocean. Master thesis. Ocean University of China, 2024.
- Luqi Ma. Geochemical Behavior of Th-Pa in the South China Sea Basin. Master thesis. Xiamen University, 2024.
- Pingping Zhang. Biogeochemical Behaviors of Dissolved Biogenic Trace Metals (cadmium copper nickel zinc) in the Western North Pacific. Master thesis. Xiamen University, 2024.
- Yalin Zhang. The Geochemical Behaviors of ^{210}Po and ^{210}Pb in the South China Sea Basin and Their Tracer Applications. Master thesis. Xiamen University, 2024.
- Yuncong Ge. The biogeochemistry of trace metals in the Ross and Amundsen Seas, Antarctica. PhD thesis. Shanghai Jiao Tong University, 2024.
- Xinran Yu. The Responses of N_2 Fixation to Environmental Changes and Its Regulation Mechanisms. PhD thesis. Xiamen University, 2024.
- Xin Zhang. Effects of Iron Concentration, Light Intensity and Ocean Acidification on *Prochlorococcus*. PhD thesis. Xiamen University, 2024.

GEOTRACES presentations in international conferences

- Chaoyong Wang. Poster Presenter for American Geophysical Union Annual Meeting: “Size-fractionated C:N:P:Si stoichiometry of particulate matter in the subtropical Western North Pacific”. December 10, 2024, Washington, America (online)
- Ruotong Jiang. Poster Presenter for 2025 Xiamen Symposium on Marine Environmental Sciences: “Biological N_2 fixation and its nutrient controls in the North Pacific Subtropical Gyre”, January 14, 2025, Xiamen, China
- Xinran Yu. Poster Presenter for 2025 Xiamen Symposium on Marine Environmental Sciences: “Assessing N_2 Fixation Flux and Its Controlling Factors in the (Sub)tropical Western North Pacific through High-density Observations”, January 16, 2025, Xiamen, China
- Yanbin Li. Oral Presenter for 18th International Symposium on Persistent Toxic Substances and Health: “Sources of mercury varied in the Mariana trench during Last Glacial Maximum to Holocene”, September 14 to 19, 2024, Chania, Greece

- Yuanchen Li. Poster Presenter for Xiamen Symposium on Marine Environmental Sciences: “Missing dissolved arsenic in the deep seawater around various abyssal systems”. January 16, 2025, Xiamen China

Submitted by Dalin Shi (dshi@xmu.edu.cn)