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Iron supply pathways to the iron-limited Oyashio region: Contributions from the Kuroshio-Oyashio transition zone revealed by numerical simulations

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The Oyashio region in the western North Pacific is characterized by iron-limited conditions that constrain phytoplankton productivity despite abundant macronutrients. While previous studies have identified atmospheric deposition and sedimentary sources as key iron suppliers, the specific transport pathways and relative contributions from different source regions remain poorly understood. We conducted high-resolution biogeochemical modeling using a 1/12° ocean model with source-tagging simulations to quantify iron transport pathways. Iron from different origins was tracked separately: atmospheric deposition, Japanese coastal sediments, Okhotsk Sea sediments, Bering Sea sediments, and other regional sources. Additionally, iron transported more than 500 km offshore was tagged separately to identify potential return pathways from offshore regions back to the iron-limited Oyashio waters. Our simulations reveal that the Oyashio region receives iron from multiple sources, with Japanese coastal sediments, Okhotsk Sea sediments, and offshore oceanic waters being the dominant contributors. Remarkably, offshore-origin iron accounts for approximately one-quarter of the total iron supply to the Oyashio region, challenging the conventional paradigm of predominantly coastal-to-offshore iron transport.

Detailed analysis of seasonal and interannual variability shows that iron concentrations increase from summer to winter, reflecting reduced biological uptake and enhanced supply processes. Importantly, the source composition of iron within phytoplankton cells during spring blooms varies dramatically between years. In some years, iron originating from the offshore mixed water region dominates phytoplankton iron content, suggesting that mesoscale eddies efficiently transport iron-rich waters from the Kuroshio-Oyashio transition zone to fuel spring productivity. These results demonstrate that iron supply to the Oyashio region involves complex bidirectional transport processes, with the iron-rich mixed water region serving as a crucial but variable source for supporting biological productivity in iron-limited waters.