

Precessional and Millennial Intensification of the Kuroshio Current in the Okinawa Trough Revealed by Foraminifera-Bound Nitrogen Isotopes

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The Kuroshio Current is the principal western boundary current of the North Pacific and a major conduit of heat and salt to the Northern Hemisphere, exerting strong influence on regional hydroclimate and the Okinawa Trough. Variations in its strength affect East Asian monsoon dynamics, marginal-sea stratification, and nutrient supply to the continental shelf. Yet reconstructing past Kuroshio transport remains challenging because conventional proxies—such as faunal assemblages, SST, or grain size—cannot uniquely distinguish transport intensity from pathway shifts or local hydrographic changes. Here we apply foraminifera-bound nitrogen isotopes (FB- $\delta^{15}\text{N}$) as a circulation-sensitive tracer. Nitrogen isotopes provide a distinctive fingerprint for Kuroshio waters because Kuroshio Tropical Water carries characteristically low $\delta^{15}\text{N}$ nitrate values, reflecting basin-wide N_2 fixation in the western subtropical Pacific. We generate two FB- $\delta^{15}\text{N}$ records spanning the past 100 kyr: one from the upstream Kuroshio in the open western North Pacific and one from the Okinawa Trough. The upstream record exhibits persistently low $\delta^{15}\text{N}$ values, indicating a stable tropical N_2 -fixation imprint in source waters. In contrast, the Okinawa Trough record shows pronounced oscillations paced by precession and amplified during Northern Hemisphere cold events.

Lower $\delta^{15}\text{N}$ values in the Okinawa Trough—indicating enhanced penetration of low- $\delta^{15}\text{N}$ Kuroshio Tropical Water—occur when Northern Hemisphere summer insolation is reduced at precessional maxima. This pacing is punctuated by additional low- $\delta^{15}\text{N}$ excursions that coincide with millennial-scale Northern Hemisphere cooling events, suggesting transient intensification of Kuroshio transport during stadials. The Okinawa Trough $\delta^{15}\text{N}$ variability closely parallels Chinese speleothem $\delta^{18}\text{O}$ records of the East Asian Summer Monsoon, highlighting a coherent link between boundary current dynamics and large-scale atmospheric circulation.

Together, these results demonstrate that Kuroshio intensification in the Okinawa Trough during precession maxima and Northern Hemisphere cold events was driven primarily by large-scale wind reorganization. By exploiting the low- $\delta^{15}\text{N}$ signature imparted by subtropical N_2 fixation, foraminifera-bound nitrogen isotopes provide a robust circulation-specific proxy that reveals wind-forced modulation of western boundary current strength on orbital and millennial timescales.

Keywords: Kuroshio Current, Okinawa Trough, Foraminifera-bound nitrogen isotopes, Precessional forcing, Northern Hemisphere cold events, East Asian Summer Monsoon