Recent Path Changes of the Kuroshio and Kuroshio Extension and Their Impacts on the Ocean–Atmosphere around Japan

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Since the summer of 2017, the Kuroshio has persisted in a Large Meander (LM) state south of Japan, representing one of the longest LM events in the historical record. Concurrently, since 2023, the Kuroshio Extension (KE) has exhibited an extreme northward shift, with its axis reaching nearly 40˚N during the winter of 2024. These unprecedented paths of Kuroshio/KE provide a unique opportunity to understand how ocean current paths modify the oceanic and atmospheric conditions surrounding Japan.
Along the Pacific coast south of Japan, the LM-induced branch current has advected anomalously warm water into coastal regions, producing sea surface temperature (SST) anomalies exceeding +3 ˚C. Satellite observations reveal recurrent and persistent coastal marine heatwave conditions during summer. Regional atmospheric model experiments further demonstrate that this coastal warming enhances near-surface humidity and increases downward longwave radiation, leading to additional surface warming through a local greenhouse feedback and significantly intensified precipitation along the Japanese coast. These results highlight the role of western boundary current variability in directly modulating regional atmospheric conditions.
East of Japan, the extreme northward KE meander has generated even more pronounced warming. Satellite data show SST anomalies reaching +4.9 ˚C between April 2023 and August 2024, with marine heatwave conditions occurring almost continuously. Hydrographic observations in May 2024 reveal that thick warm–salty subtropical water replaced the climatological cold–fresh subarctic water mass, with temperatures at 50–400 dbar exceeding past decades by up to 10 ˚C. This indicates not only surface marine heatwaves but also substantial subsurface heat accumulation associated with a regime-scale circulation shift. These observations demonstrate that KE path variability can induce vertically coherent thermal anomalies extending from the surface into the subsurface ocean.
Together, these anomalies suggest that recent Kuroshio and KE path changes represent a large-scale reorganization of the western boundary current system around Japan, affecting both horizontal heat transport and vertical ocean structure. The resulting marine heatwaves and enhanced air–sea interaction have significant implications for regional atmospheric variability, extreme precipitation, marine ecosystems, and coastal biological communities. This presentation synthesizes satellite observations, hydrographic measurements, and numerical model experiments to elucidate the physical mechanisms, vertical structure, and atmospheric impacts of these unprecedented events, and discusses their implications for climate variability and ongoing ocean warming.

Keywords: Kuroshio Large Meander Path, Extreme Northward Meander of Kuroshio Extension Path, Intense Marine Heat Wave, Japan Climate

