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Constraining the stable carbon isotopic signature of inland water surface methane globally

TONYA DELSONTRO AND PAULA REIS
University of Waterloo

Inland waters occupy a small fraction of Earth's surface yet contribute disproportionately to global methane (CH4) emissions. While spatial patterns in CH4 concentrations have been explored through meta-analyses, globally consistent datasets that include the stable carbon isotopic composition of methane (δ13C-CH4) remain scarce. This isotopic signature provides critical constraints on methane sources and sinks, enabling improved attribution of natural versus anthropogenic contributions and refinement of global methane budgets. Here, we present a globally standardized assessment of surface-water CH4 concentrations and δ13C-CH4 across 76 lakes and reservoirs spanning five continents and 24 countries. Each system was sampled along littoral-to-pelagic transects during the stratified season and analyzed using a unified protocol. All systems were supersaturated in methane, with concentrations spanning three orders of magnitude among and within waterbodies. δ13C-CH4 ranged from -87‰ to +4‰, revealing substantial isotopic heterogeneity at the global scale. Trophic state emerged as a key regulator of this variability: eutrophic and mesotrophic systems exhibited higher surface CH4 concentrations and isotopically enriched CH4 relative to oligotrophic systems. There was a significant interaction between waterbody type (i.e., reservoir or lake) and trophic state in the stable isotopic signature of CH4, meaning that the effect of trophic state on δ13C-CH4 depends on the waterbody type. While a weak but positive relationship was found between δ13C-CH4, the concentration-isotope coupling differed systematically across trophic categories. These findings indicate that CH4 isotopic signatures in surface waters are not solely a function of concentration but reflect system-specific balances among production, oxidation, and physical transport processes. The strong lake-to-lake variability underscores the importance of ecosystem context, including productivity and waterbody type, in modulating CH4 cycling. By providing one of the first globally consistent datasets of δ13C-CH4 from inland waters, this study advances isotopic constraints on freshwater methane emissions which can help improve global methane source attribution under ongoing climate change and eutrophication pressures.