

Quantifying the Evaporative Kinetic Fractionation Using Triple Oxygen Isotopes in Closed-Basin Lakes

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Evaporative enrichment in terrestrial waters is a fundamental process that shapes the isotopic composition of natural water bodies, reflecting water–atmosphere interactions, hydrologic balance, and moisture dynamics. Therefore, precise quantification of evaporation-driven isotopic fractionation is essential, both for reconstructing modern hydrological processes and for an accurate interpretation of geological archives. While equilibrium and pure diffusion fractionation factors are well understood, the kinetic fractionation of water evaporating into the free atmosphere in natural conditions is not well characterized. Complexity in differentiating between diffusion, advection, and mixing processes occurring in the lower laminar and turbulent layers of the atmosphere, and differences in the forcing of evaporation processes (temperature, relative humidity, wind, etc.) result in poorly constrained kinetic fractionation factors.

Closed-basin lakes offer a unique opportunity to study evaporation processes since water entering the lakes leaves solely by evaporation, making them highly sensitive to isotopic evaporative enrichment. Still, there has not been an attempt to utilize the isotopic composition of closed-basin lakes, with an emphasis on $\Delta^{17}\text{O}$, to understand evaporative enrichment with respect to their source waters in a comparative manner. Here, we study 11 closed-basin lakes across three continents and diverse climatic regimes to assess the mechanistic links between the meteorological conditions driving evaporation and its isotopic signatures. We apply a novel method for high-precision $\Delta^{17}\text{O}$ measurements with a Picarro L2140-i isotopic water analyzer that achieves a high signal-to-noise ratio, adequate for studying evaporation processes. We measured the isotopic composition and chemistry of each lake, its inflow waters and feeding springs, and compiled published hydrological and meteorological properties of the basin. Using this data, we pair chemical, isotopic and hydrological modeling and assess the factors governing the isotopic signatures of these lakes.

Our results show a distinct correlation between $\Delta^{17}\text{O}$ evaporative enrichment and wind speed, while the correlation to relative humidity is not as pronounced. This work refines our understanding of the evaporative kinetic fractionation in natural settings and provides better constraints on the evaporation process, which can be implemented in paleoclimate reconstructions and hydrological models.