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Temporal dynamics and controlling factors of CO_2 fluxes of the Asia's largest artificial freshwater lake

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Abstract: Reservoirs, while regulating runoff, profoundly alter the carbon flux and storage along river continua, playing a critical regulatory role in the global carbon cycle. Reservoirs can act as either net sources or sinks of carbon dioxide (CO_2). Reported reservoir CO_2 fluxes span wide ranges—for example, 1.86 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at the small eutrophic Falling Creek Reservoir (Hounshell et al., 2023), versus 0.31~0.36 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at larger, oligotrophic-to-mesotrophic drinking-water reservoirs such as Ross Barnett Reservoir (Liu et al., 2016) and Rappbode Reservoir (Spank et al., 2020). The carbon source–sink dynamics of reservoirs are influenced by various factors, including natural conditions, reservoir characteristics, and operational management. However, observations and studies on the dynamic changes in CO_2 fluxes at the water–air interface of reservoirs and the factors controlling these changes remain scarce, which severely limiting the accuracy of carbon budget assessments.

Using two years of high-frequency eddy covariance (EC) observations from a newly established flux site, this study investigated the temporal dynamics at various temporal scales of CO_2 fluxes at the water-air interface of the Danjiangkou (DJK) Reservoir, Asia's largest artificial freshwater lake. The results indicated that the water-air interface of the DJK reservoir was a slight carbon source, with an average annual CO_2 flux of 0.12 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Significant diel and seasonal variations in CO_2 fluxes were observed, with higher nighttime emissions and a transition from a net carbon source in spring, summer, and autumn to a carbon sink in winter.

To explore the key controlling factors of CO_2 exchange at the water-air interface, this study used XGBoost with gain-based feature importance and Accumulated Local Effects (ALE). The dataset was randomly split (70% training / 30% test) and tuned via 10-fold cross-validation; model skill was evaluated with R^2, RMSE, and NSE. Across seasons, the model captured CO_2 variability well (training set $R^2 > 0.77$; test set $R^2 > 0.65$), evidencing robust generalization. Machine learning-based feature importance analysis identified that temperature (both air and water), sensible heat fluxes, wind speed, and net radiation were the primary drivers of CO_2 fluxes, with the dominant factors varying between-season. During the flood season (June to October), hydrological factors such as inflow and water level exerted a pronounced influence. Compared to other reservoirs, the DJK reservoir exhibited moderate CO_2 emissions, likely due to its oligotrophic status and significant hydrological connectivity.

These findings underscored the necessity of high-frequency, long-term monitoring to accurately capture the temporal variability of CO_2 fluxes and provide valuable insights into the mechanisms governing reservoir carbon cycling.

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