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Predictions of riverine gas exchange rates may be biased towards low-submergence rivers

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The exchange of gas across the interface between rivers and the atmosphere is a key control of oxygen and carbon fluxes (in the form of carbon dioxide and/or methane) in rivers and streams. The intensity of gas exchange is measured by the gas transfer velocity, k , a parameter expressing the efficiency of sub-surface mixing driven by turbulence in water. Scaled experiments and theoretical analysis both suggest a significant shift in the drivers of k depending on the relative submergence, i.e., the ratio between water depth H and the characteristic bed roughness scale, D : In high-submergence (deep) rivers, turbulent mixing is dominated by viscous forces, while in low-submergence (shallow) rivers by form drag due to protruding bed roughness elements. However, the bed roughness scale is not usually reported in field gas transfer datasets and the effects of submergence are neglected by existing models.

We conducted a meta-analysis of the largest known dataset of gas transfer velocity and hydraulic flow parameters to investigate the potential role of submergence on gas transfer in the field, estimating the relative submergence according to the observed flow resistance through an established semi-empirical variable-power relation. Then, we used the same model to partition the gas transfer velocity into its friction (high submergence) and macro-roughness (low submergence) constituents. The results indicate that 93% of data was recorded in low-submergence streams and rivers (partition coefficient > 0.5). Such skewness in the data distribution is explained by the difficulty in measuring the gas transfer velocity in large rivers using existing methods. Due to the different physical mechanisms governing gas exchange, widely used semi-empirical models calibrated in shallow rivers may overestimate k in deep rivers. Since large rivers contribute around 50% of global riverine CO₂ emissions, the impact on global emissions uncertainties may be significant. Ultimately, our results highlight the urgent need for improved measurement approaches to characterise the gas transfer velocities in large rivers, and the importance of introducing systematic quantitative riverbed surveying into gas exchange measurement protocols.