Master Thesis:

The role of local river morphology on the magnitude of air-water gas exchanges: numerical modelling and comparison of existing approaches

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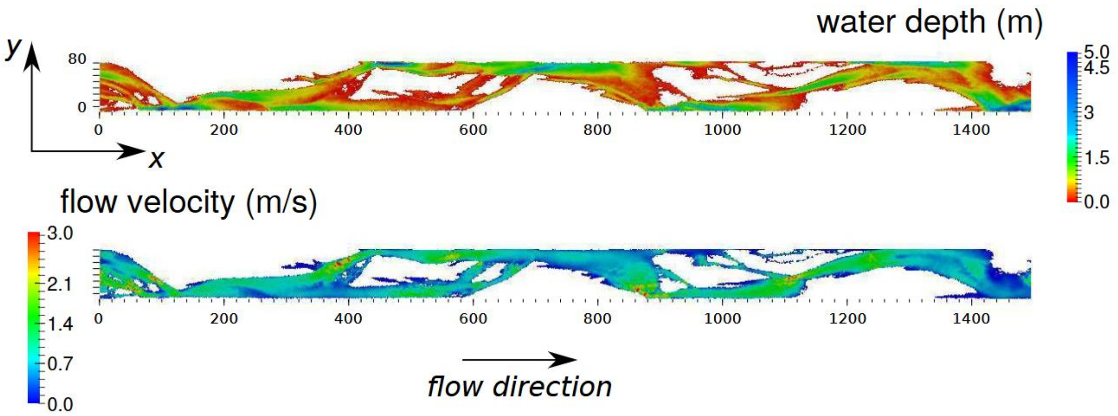

Fig. 1: Distribution of simulated water depth and flow velocity in a wandering river morphology

Motivation

Gas exchange at the air–water interface of streams and rivers is a cornerstone of freshwater biogeochemical processes. Understanding and quantifying these exchanges is paramount, as they influence multiple processes—from the cycling of nutrients to the regulation of greenhouse gases (e.g. Calamita et al 2021). The dynamics of gas transfer are governed mainly by the flow conditions and water temperature of the river (e.g. Ulseth et al 2019), both of which are susceptible to human activities and the overarching effects of climate change. While empirical models provide a framework to estimate gas exchange based on average river conditions, the subtle yet potentially significant impact of local river morphology remains elusive (e.g. Duvert et al 2018).

Research objective

The main objective of this thesis is to investigate the influence of river morphology in the estimation of gas exchange rates when using different existing empirical models. In particular, we intend the student to:

1. Compare different empirical models for gas exchange and evaluate their sensitivity to relevant hydraulic parameters (Moog and Jirka 1999a, 1999b; Raymond et al 2012).

2. Based on 2D (depth-averaged) hydrodynamic simulations, quantify the spatial variability of gas exchange rate depending on the type of river morphology (e.g. single channel vs braiding).

3. Compare the gas exchange rates obtained from empirical reach-scale models (of point 1) with the one integrated from the local-morphology analysis (point 2).

Methods

The thesis involves model application, data analysis and evaluation of existing 2D hydrodynamics numerical simulation results. If possible, the student can run further hydrodynamic simulations to explore further scenarios (in terms of flow conditions and morphologies).

Remarks

The intermediated meetings and the report are in English. The thesis will develop in collaboration with the University of Tübingen (Dr. Elisa Calamita). The project requires an affinity for evaluation/execution of numerical simulations and data analysis. General scripting skills are helpful.

References

Calamita, E., Siviglia, A., Gettel, G. M., Franca, M. J., Winton, R. S., Teodoru, C. R., ... & Wehrli, B. (2021). Unaccounted CO2 leaks downstream of a large tropical hydroelectric reservoir. Proceedings of the National Academy of Sciences, 118(25), e2026004118.

Duvert, C., Butman, D. E., Marx, A., Ribolzi, O., & Hutley, L. B. (2018). CO2 evasion along streams driven by groundwater inputs and geomorphic controls. *Nature geoscience*, *11*(11), 813-818.

Moog, D. B., & Jirka, G. H. (1999a). Air-water gas transfer in uniform channel flow. Journal of hydraulic engineering, 125(1), 3-10.

Moog, D. B., & Jirka, G. H. (1999b). Stream reaeration in nonuniform flow: Macroroughness enhancement. Journal of Hydraulic Engineering, 125(1), 11-16.

Raymond, P. A., Zappa, C. J., Butman, D., Bott, T. L., Potter, J., Mulholland, P., ... & Newbold, D. (2012). Scaling the gas transfer velocity and hydraulic geometry in streams and small rivers. Limnology and Oceanography: Fluids and Environments, 2(1), 41-53.

Ulseth, A. J., Hall Jr, R. O., Boix Canadell, M., Madinger, H. L., Niayifar, A., & Battin, T. J. (2019). Distinct air–water gas exchange regimes in low-and high-energy streams. Nature Geoscience, 12(4), 259-263.