

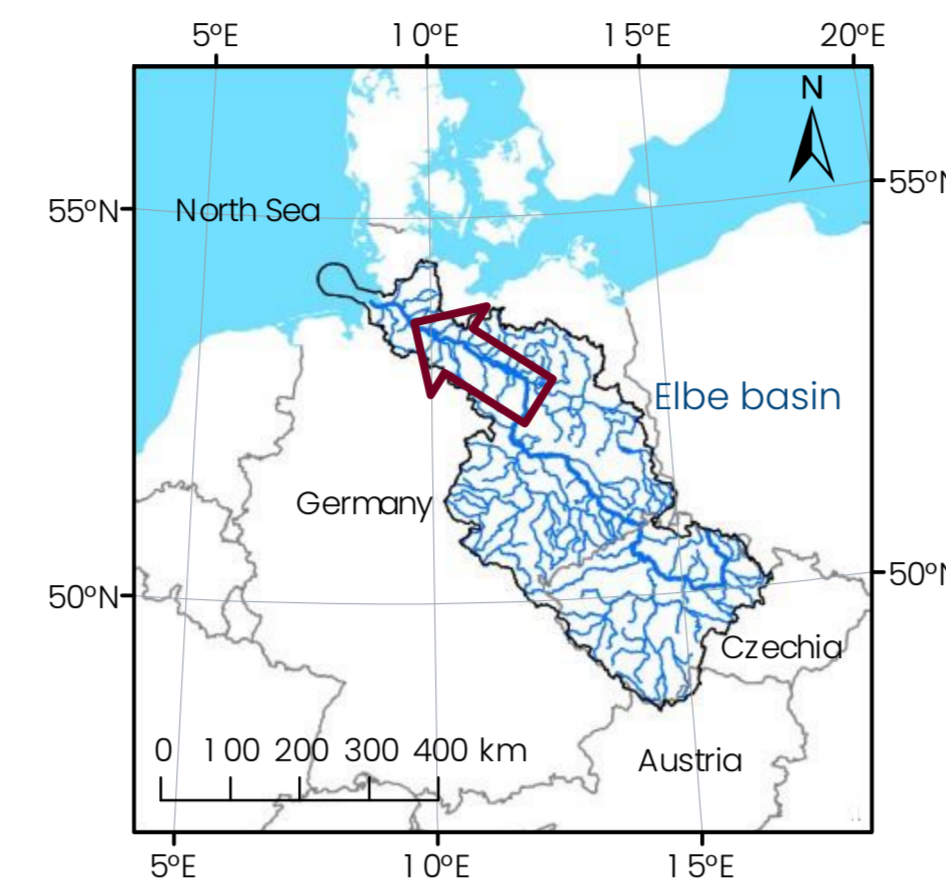
Influence of Suspended Particulate Matter on the Distribution and Transport of Metal and Organic Pollutants in the Elbe estuary, Germany



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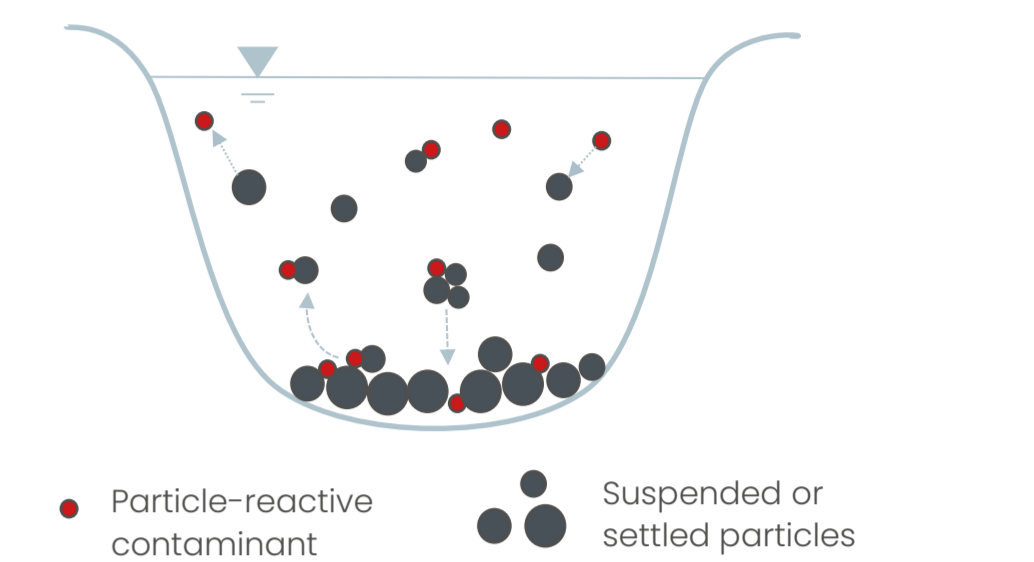
Motivation and relevance

Legacy and emerging pollutants pose significant ecological risks to coastal environments, particularly in estuaries of historically industrialized rivers such as the Elbe. Contaminants are transported from the river basin to the estuarine mouth, where they are subjected to intense physico-chemical processes driven by salinity and organic matter gradients.



The fate of particle-bound contaminants is closely linked to the dynamics of suspended particulate matter (SPM) and its interactions with organic matter. While chemical and physical binding mechanisms explain pollutant behavior at small spatial scales, incorporating these processes into predictive transport models at the estuarine scale remains a major challenge.

Helmholtz-Zentrum hereon

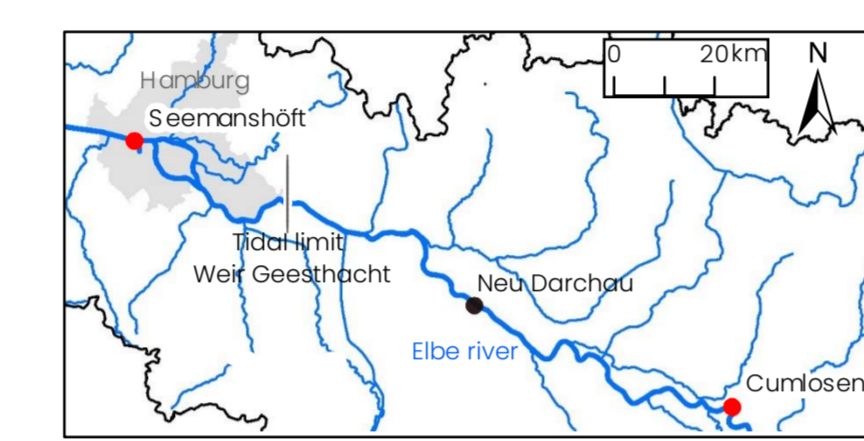
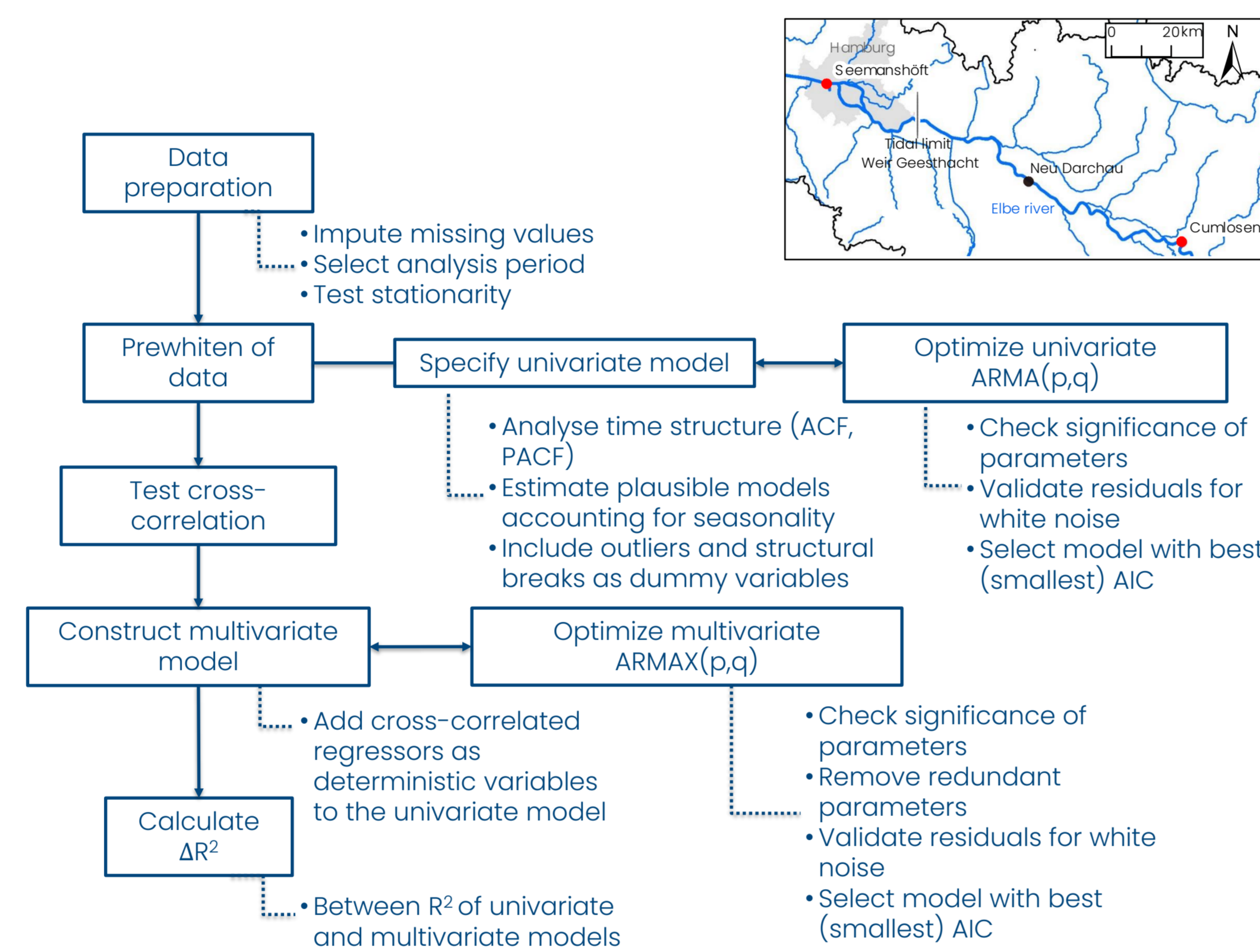


Methods

1. Long-term statistical analysis of seasonal pollutants dynamics

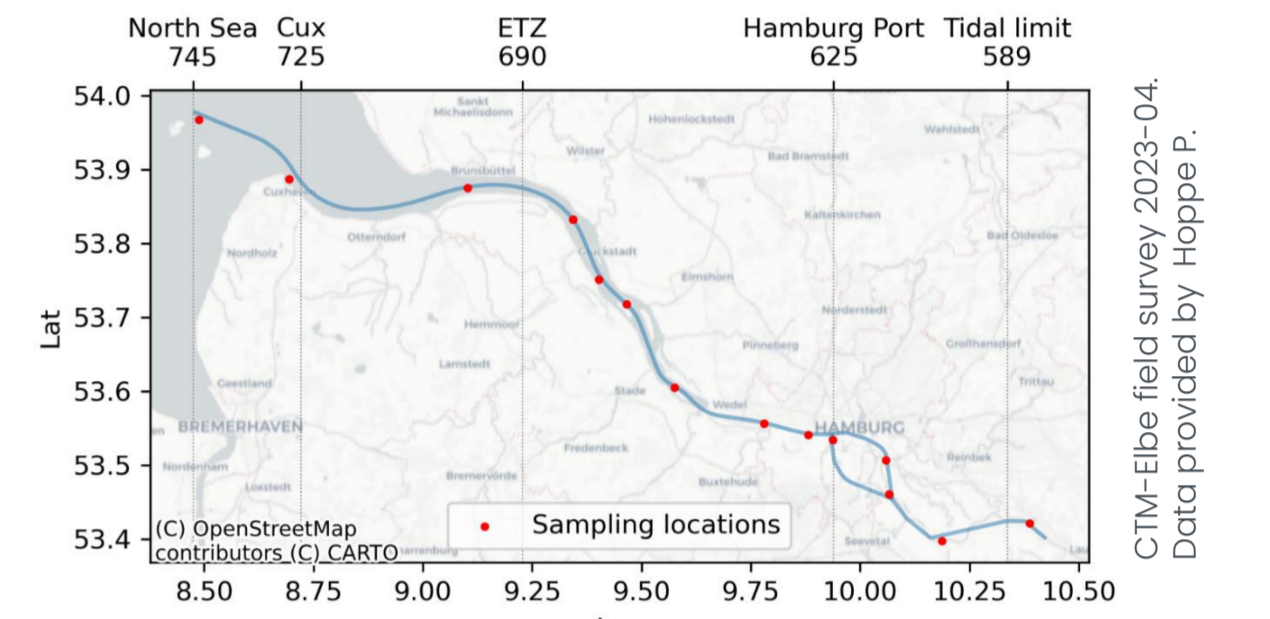
Long-term statistical analysis of seasonal pollutant dynamics using time-series data from tidal and non-tidal stations along the Elbe.

Dynamic autoregressive moving-average models with exogenous variables (ARMAX) were applied to quantify the influence of SPM-related parameters (Ortiz Gutierrez et al., 2025).



2. Estimation of metal partitioning based on field measurements

Sensitivity analysis of particle-reactive metals transport based on Turner's formulation (1996). It describes metal partitioning between aqueous and particulate phases (K_D) as a function of salinity and the relative contribution of two particle types: a permanent and a temporary fraction with higher and lower sorptive capacity. We modified Turner's approach to evaluate the influence of fluvial SPM and organic matter on K_D variability. Fluvial particles are expected to exhibit a higher sorptive potential and their content decreases toward the North Sea due to mixing, degradation, and deposition.



K_D (permanent SPM)

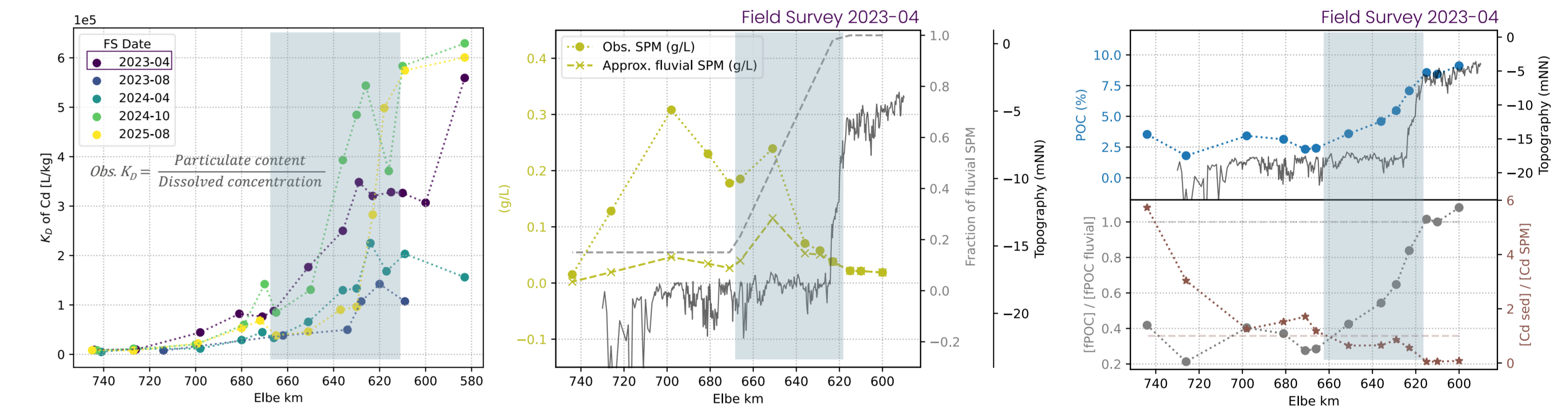
$$K_D = kd0 (S + 1)^b \left\{ \beta + \left(\frac{SPM^{PS}}{SPM} \right) (1 - \beta) \right\}$$

K_D (approx. fluvial SPM (%))

$$K_D = kd0 (S + 1)^b \left\{ \beta + \left(\frac{\text{approx. fluvial SPM}}{SPM} \right) (1 - \beta) \right\}$$

K_D (rate of change of POC (%))

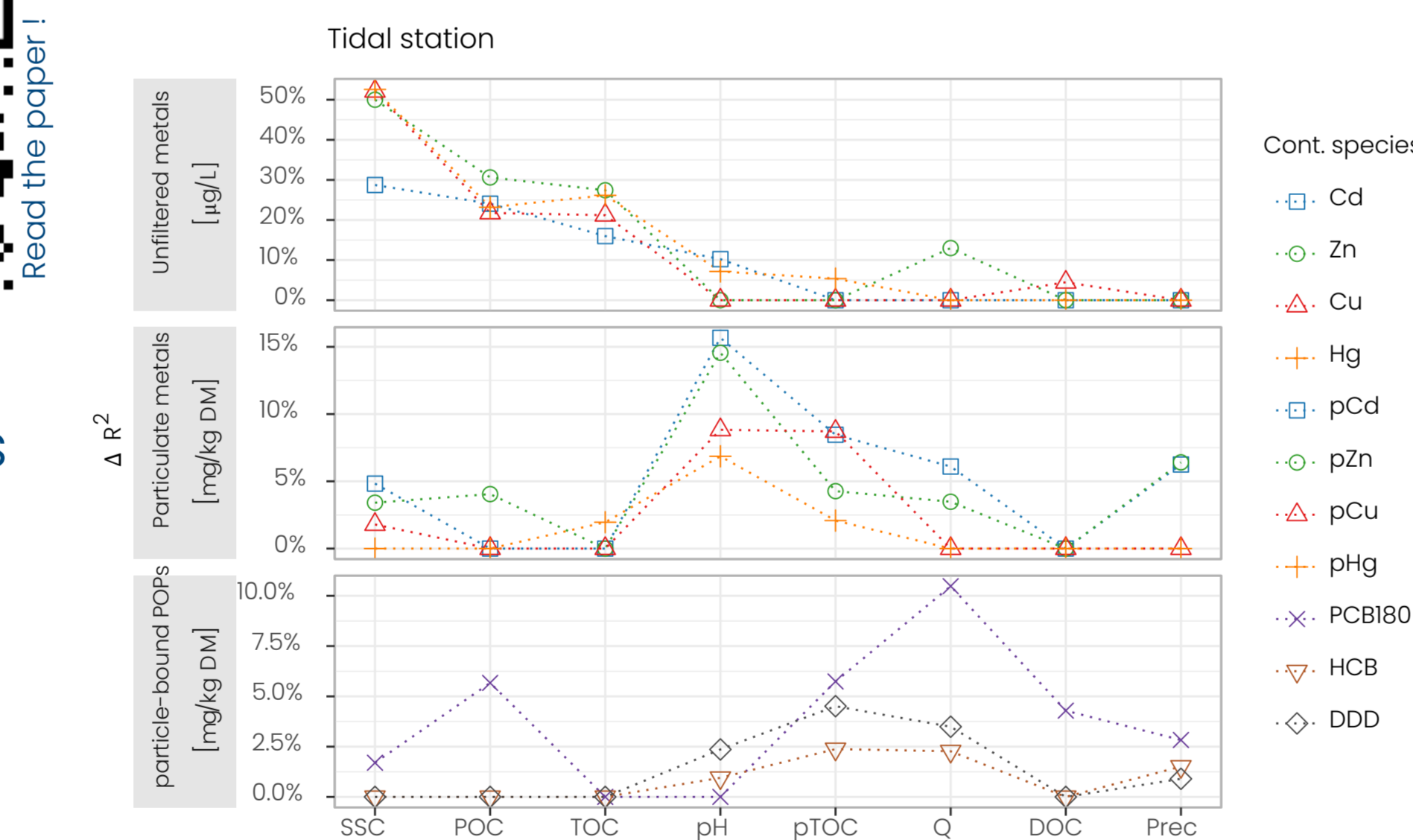
$$K_D = kd0 (S + 1)^b \left\{ \beta + \left(\frac{POC}{SPM * POC_f(\%)} \right) (1 - \beta) \right\}$$



Results

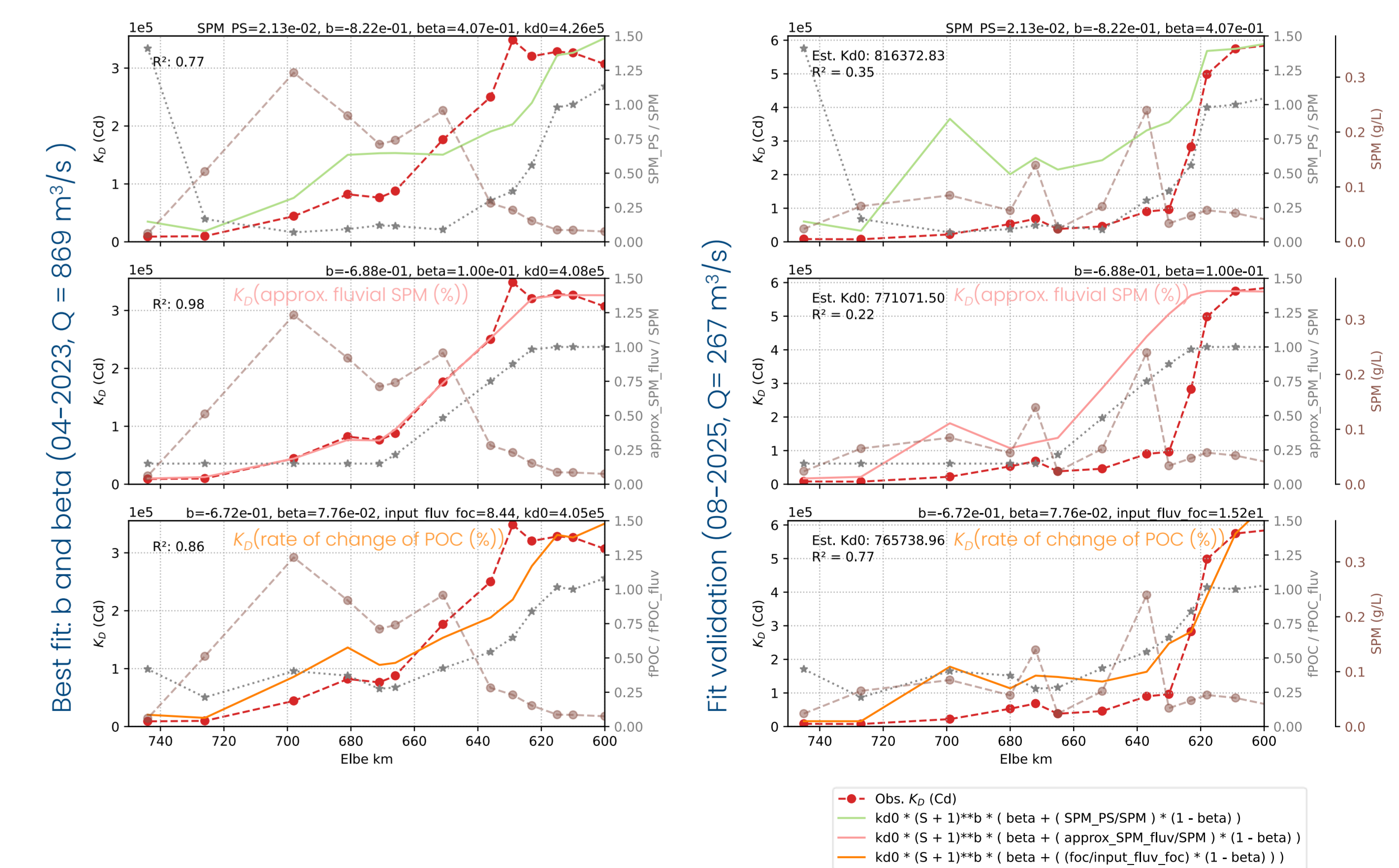
1. Explanatory content

Long-term statistical modeling of measured time series affirms previous experimental observations that heavy metals (Cd, Zn, Cu, Hg) preferentially sorb to organic surfaces under environmental conditions.



2. Results of empirical model for metal partitioning (Cd)

The modified K_D formulation performed well and scaled with the decrease in POC (%). Variability in K_D for Cd, Zn, and Cu was well approximated as a function of salinity and POC (%). The results also reveal the influence of estuary geometry and freshwater discharge magnitude on the seaward flushing of particle-bound pollutants by controlling location and slope of the highest rate of change of K_D .



Conclusions and Outlook

- Seasonal metal behavior links to suspended organic matter in river and estuary waters.
- The modified K_D formulation performed well and scaled with the decrease in POC (%), used as a proxy for particulate constituents carrying sorbed metals (here Cd).
- These results will be integrated into a 3D hydrodynamic sediment transport model (UnTRIM2-SediMorph) to improve predictions of particle-bound contaminant transport under estuarine conditions.

References

- Ortiz Gutierrez, V.; Fricke, B.; Kelln, J.; Zimmermann, T.; Pröfrock, D. (2025): Seasonal influence of suspended particulate matter on metal and organic pollutant distribution under fluvial and tidal conditions in the Elbe River. Water Research 291. DOI: 10.1016/j.watres.2025.125177.
- Turner, A. (1996): Trace-metal partitioning in estuaries: importance of salinity and particle concentration. Marine Chemistry 54 (1-2). DOI: 10.1016/0304-4203(96)00025-4.