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Spatial and seasonal variation of dissolved nitrous oxide along the Elbe estuary

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Nitrous oxide (N_2O) is a greenhouse gas contributing to global warming. Estuaries are a potential source for N_2O. We aimed to identify seasonal and spatial variations of N_2O production and emission along the Elbe estuary in Germany.

Between 2015 and 2021, we performed nine research cruises along the Elbe estuary. Most of the cruises took place in growing seasons (April – September), while one cruise was conducted in winter (early March). We continuously measured the dissolved N_2O dry mole fraction 2 m below the surface using a laser-based analyzer coupled with an equilibrator. Based on these profiles, we calculated N_2O concentration, saturation and emissions.

During all cruises, the Elbe estuary was supersaturated in N_2O. Highest N_2O concentration occurred in the Hamburg port region, a hotspot of N_2O production by nitrification in the water column and denitrification in the sediments. The maximum concentration in this region was 158 nmol L^{-1} in March 2021. Nitrification in the maximum turbidity zone (MTZ) produced a second local N_2O maximum. Average N_2O emissions were 0.19 Gg a^{-1}(0.52 Mg d^{-1}) during the growing season. The N_2O emission was highest in winter with 0.64 Gg a^{-1} (1.76 Mg d^{-1}).

During growing seasons emissions were strongly correlated with pH (R^2 = 0.73) and suspended particulate matter concentration (R^2 = 0.55). A trend toward higher N_2O saturations and emissions during cruises in summer is evident. We presume that N_2O saturation and emission were likely driven by temperature-dependent turnover processes in high turbidity areas of the Elbe estuary, such as nitrification and denitrification.

However, the maximum N_2O concentrations in winter (March 2021) cannot be explained that way, because water temperature was low. N_2O production may be driven by the dissolved inorganic nutrient (DIN) load, which is more than doubled in comparison to all other cruises. Two other possible explanations come to mind: First, N_2O production in this case may be less sensitive to water temperature, possibly due to sedimentary sources. Second, a sink for N_2O in the water column may exist, which is more active during higher temperatures. These two scenarios may both apply and might interact over the course of the year.

Overall, seasonality affects N_2O production in the Hamburg port region more than in the

maximum turbidity zone. In late spring/summer, N_2O production is driven mainly by enhanced microbial productivity. High N_2O concentrations in colder seasons may result from high DIN concentration, but further research on the controls on N_2O production, and possibly consumption, is clearly needed.