Spatial changes in nitrogen inputs drive short- and long-term variability in global nitrous oxide emissions

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Anthropogenic activities, particularly fertilisation, have resulted in significant increases in reactive nitrogen (rN) in soils globally, leading to eutrophication, acidification, poor air quality, and emissions of the important greenhouse gas N₂O. Understanding the partitioning of rN losses into different environmental compartments is critical to mitigate negative impacts, however, loss pathways are poorly quantified, and potential changes driven by climate warming and societal shifts are highly uncertain. We present a coupled soil-atmosphere isotope model (IsoTONE; ISOtopic Tracing Of Nitrogen in the Environment) to partition rN losses into leaching, harvest, NH₃ volatilization, and production of NO, N₂ and N₂O based on a global dataset of soil δ¹⁵N, as well as numerous other geoclimatic and experimental datasets. The model was optimized in a Bayesian framework using a time series of N₂O mixing ratios and isotopic compositions since the preindustrial era, as well as a global dataset of N₂O emission factors (EF). The posterior model results showed that the total anthropogenic flux in 2020 (7.8 Tg N₂O-N a⁻¹) was dominated by indirect emissions resulting from N deposition, while the growth rate and trend in anthropogenic N₂O was driven by both direct N fertilisation and deposition inputs. In contrast, inputs from fixation N drive natural N₂O emissions, and were responsible for subdecadal interannual variability in total emissions.

Total N gas (N₂O + NO + N₂) production and N₂O losses were strongly dependent on geoclimate and thus spatially variable, therefore the spatial pattern of N inputs strongly impacted resulting
EFs and total N\textsubscript{2}O emissions. The area-weighted global EF for N\textsubscript{2}O was 1% of anthropogenic N inputs in 2020, similar to the current IPCC default of 1.4%, however the N input-weighted global EF was 4.3%. Shifts in fertilisation inputs from the temperate Northern hemisphere towards warmer regions with higher EFs such as India and China have led to accelerating N\textsubscript{2}O emissions (1.02±0.7 Tg N\textsubscript{2}O-N a\textsuperscript{-1}). In addition, N\textsubscript{2}O emissions have increased over the past decades due to climate warming (0.76±0.4 Tg N\textsubscript{2}O-N a\textsuperscript{-1}). Predicted increases in fertilisation in India and Africa in the coming decades could further accelerate N\textsubscript{2}O-driven climate warming, unless mitigation measures are implemented to increase fertiliser N use efficiency and reduce N\textsubscript{2}O emission factors.