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Spatial changes in nitrogen inputs drive short- and long-term variability in global N_2O emissions

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Anthropogenic activities, particularly fertilisation, have resulted in significant increases in nitrogen in soils globally, leading to negative environmental impacts including eutrophication, acidification, poor air quality, and emissions of the important greenhouse gas N_2O. Potential changes in terrestrial N loss pathways driven by global change and spatial redistribution of N inputs are highly uncertain. We present a novel coupled soil-atmosphere isotope model (IsoTONE; **ISO**topic **T**racing **O**f **N**itrogen in the **E**nvironment) to quantify terrestrial N losses and N_2O emissions and emission factors for the period 1850-2020. The soil module is initialised using a global isoscape of natural soil $\delta^{15}N$ values generated from measurement data using an artificial neural network. The model is optimized within a Bayesian framework using a high precision tropospheric time series of N_2O isotopic composition as well as emission factor measurements from many sites across the globe.

N inputs from atmospheric deposition caused the majority (51%; 3.6±0.3 Tg N_2O-N a^{-1}) of total anthropogenic N_2O emissions from soils (7.1±0.9 Tg N_2O-N a^{-1}) in 2020. Growth in total and anthropogenic soil N_2O emissions over the past century was driven by both fertilization and deposition, however N inputs from biological fixation were responsible for subdecadal variability

in emissions. N_2O emission factors show large spatial variability due to climate and soil parameters. The mean global EF for N_2O weighted by N inputs was 4.3±0.3% in 2020, much higher than the land surface area-weighted mean of 1.1±0.1%, as a large proportion of N inputs were in regions with relatively high emission factors. Climate warming as well as redistribution of fertilisation inputs have led to an increase in global EF for N_2O over the past century; these additional emissions account for 18% of the total anthropogenic soil flux in 2020. Predicted increases in fertilisation in emerging economies will accelerate N_2O-driven climate warming in the coming decades, unless targeted mitigation measures focussing on fertiliser management in developing regions are introduced.