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N2O changes during Heinrich Stadials - Isotopic source deconvolution over HS0, HS1 and HS4 and its implication for the marine and terrestrial nitrogen cycle

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Using high precision and centennial resolution ice core information on atmospheric nitrous oxide concentrations and its stable nitrogen and oxygen isotopic composition enables us to quantitatively reconstruct changes in the terrestrial and marine N_2O emissions over the last 21,000 years as well as over Heinrich Stadial (HS) 4.

We show that over the deglaciation N_2O emissions from land and ocean increased in parallel by 1.8 ± 0.3 TgN yr^{-1} and 0.7 ± 0.3 TgN yr^{-1}, respectively. However, close to 50% of the terrestrial increase is accomplished within less than 200 years at the end of HS1 starting essentially in parallel with the co-occurring CH_4 increase. A similarly rapid but smaller increase is observed at the end of HS0 and suggested at the end of HS4, showing that terrestrial N_2O emissions respond strongly and rapidly to the northward shift in the Intertropical Convergence Zone connected to the resumption of the Atlantic Meridional Overturning Circulation (AMOC). However, little change in terrestrial N_2O emissions is observed during the onsets of Heinrich Stadials. Assuming that N_2O loss from terrestrial ecosystems is directly connected to nitrogen turnover in soils, the fast increase at the end of Heinrich Stadials suggests that terrestrial ecosystems did not become nitrogen-limited on this relatively short time scales, as also supported by model runs in our LPX-Bern dynamic vegetation/biogeochemical model. However, changes in number of moles of N_2O lost to the atmosphere per mole nitrogen turned over in soils (yield factor) may also contribute to the atmospheric N_2O changes.

Marine N_2O emissions also respond to Heinrich events and AMOC changes, however more gradually and less strongly compared to terrestrial emissions both in our data-based reconstruction and the Bern3D coupled ocean/biogeochemistry model. In fact, reconstructed

marine emissions start to slowly increase many centuries before the rapid warmings, connected to a re-equilibration of subsurface oxygen concentrations in response to previous AMOC changes. At the onset of HS1 marine emissions decreased by about 0.5 TgN yr^{-1}, concomitantly with changes in atmospheric CO_2 and $\delta^{13}C(CO_2)$, and started to re-increase after about 1500 years, when also rapid CO_2 and CH_4 jumps occurred, pointing to Southern Ocean and low-latitude circulation changes. A similar decrease as at the start of HS1 is found after the onset of HS0, but little N_2O emission change is suggested by N_2O concentrations and their isotopic signature at 39.5 kyr before present when Heinrich Event 4 presumably occurred, as suggested by a co-occurring intermittent CH_4 peak and a sudden increase in CO_2.