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Hidden sinks: the role of subsurface environments in greenhouse gas dynamics

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In recent years, greenhouse gases (GHGs) have received increasing attention due to their role in global warming. However, several ecosystems remain understudied, including subsurface natural ecosystems (caves, lava tubes) leading to large uncertainties in future projections. Although these ecosystems have been documented to actively remove atmospheric methane and microbial methanotrophy has been reported in caves, their carbon dynamics remain poorly constrained.

In this study, subsurface air samples for CO_2 and CH_4 concentrations and isotopic analyses were collected in different caves across contrasting climatic and geological settings and in their overlying soils, while sediment–air exchange fluxes were measured in situ. Measurements encompassed both ventilated areas (ecotone and entrance zones) and isolated sectors, covering a total of 41 sampling zones (12 from the overlying soil, and 29 from the subsurface).

Despite the environmental heterogeneity among sites, carbon dynamics were broadly consistent between underground sediments and their overlying soils. Overall, the cave subsurface exhibited comparable CH_4 uptake rates but significant lower CO_2 emissions. Flux magnitudes varied among systems, with the highest rates observed in the humid carbonate karst system, lower values in the semi-arid Mediterranean gypsum karst, and the lowest rates in the arid subtropical volcanic system. Pronounced within-cave spatial variability was observed, with no consistent pattern across systems, with significant differences in exchange fluxes among sediment zones. Notably, CH_4 uptake rates reached -12.3 nmol m^{-2} s^{-1} in the most isolated zone of the humid carbonate karst cave.

These findings underscore the need for further investigation and inclusion of the subsurface carbon dynamics in global warming predictions, as well as the consideration of their spatial heterogeneity in order to improve their representation in global greenhouse gas budgets and climate projections.