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Microbial community dynamics in soil aggregates shape biogeochemical gas fluxes from soil profiles

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Microbial communities inhabiting soil aggregates dynamically adjust their activity and composition in response to variations in hydration and other external conditions. These rapid dynamics shape signatures of biogeochemical activity and gas fluxes emitted from soil profiles. Mechanistic models of microbial processes in unsaturated aggregate pore networks revealed dynamic interplay between oxic and anoxic microsites that are jointly shaped by hydration and by aerobic and anaerobic microbial communities. The spatial extent of anoxic niches (hotspots) flicker in time (hot moments) and support significant anaerobic microbial activity even in aerated soil profiles. We employed an individual-based model for microbial community life in soil aggregate assemblies represented by 3-D angular pore networks with profiles of water, carbon, and oxygen that vary with soil depth as boundary conditions. The study integrates microbial activity within aggregates of different sizes and soil depth to obtain biogeochemical fluxes over the soil profile. The results quantify impacts of dynamic shifts in microbial community composition on CO_2 and N2O production rates in soil profiles in good agreement with experimental data. Aggregate size distribution and the shape of resource profiles in a soil determine how hydration dynamics shape denitrification and carbon utilization rates. Results from the mechanistic model for microbial activity in aggregates of different sizes were used to derive parameters for analytical representation of soil biogeochemical processes across large scales of interest for hydrological and climate models.