Modeling seasonal variations of subsurface gas dynamics and soil gas composition in the context of inert gas tracer applications

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The composition of the subsurface gas phase is of central interest for inert gas tracer studies in groundwater hydrology, as the last equilibration of percolating water happens with soil air. An understanding of the underlying processes requires a detailed and sophisticated model approach. This is the first study providing a seasonal treatment of relevant transport mechanisms in the subsurface gas phase. An iterative method for including seasonally varying boundary conditions in simulations with the software MIN3P yields a successful reproduction of measured data under diverse climatic conditions and thus enables general conclusions. A validation of this model approach is provided by an extensive set of soil gas data sampled under diverse climatic conditions. The model outcomes confirm the dominating impact of O_2+CO_2 on inert gas mixing ratios in soil air as experimentally found by previous studies. The amount of precipitation is identified as key driving factor for seasonal variations of the depth-dependent profile of the occurring gas fluxes. This study identifies O_2+CO_2 induced diffusive fluxes as the origin of a slight mass dependent fractionation of the soil gas composition. Advective transport induced by varying soil moisture conditions is identified as dominant transport process determining top boundary fluxes of inert gases between soil air and atmosphere. The findings of this study are of particular relevance for inert gas tracer applications such as noble gas thermometry, but also for a treatment of soil contamination as well as for reliable estimations of greenhouse gas fluxes from the soil into the atmosphere.