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Explaining the vertical soil organic matter distribution with lead-210 measurements and Bayesian calibration

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Since most conditions that control decomposition (e.g. soil organic matter (SOM) quantity and quality, temperature and moisture, microbial dynamics) vary strongly with depth, the vertical distribution of organic matter in the soil profile and surface organic layers plays an important role for soil organic carbon cycling. Therefore, soil carbon models need to move towards a more vertically explicit representation of the soil in order to be robust over different soils and ecosystems, and under changing environmental conditions. Unfortunately, the processes that determine the vertical distribution of SOM in the soil are still poorly understood and quantified. In general three processes contribute to carbon deposition in the profile: rhizodeposition, mixing due to bioturbation, and movement with the liquid phase as dissolved organic matter. Due to the convolution of these processes, the source of organic matter at a given depth cannot be determined simply from the local concentration. Hence, the vertical SOM distribution alone is not sufficient to parameterize a process-oriented model of SOM profile dynamics; additional information is needed.

The profile of the radioactive isotope lead-210 may offer this information. $^{210}\mathrm{Pb}$ is a cosmogenic isotope, produced both in the soil and in the atmosphere. Deposition of atmospheric $^{210}\mathrm{Pb}$ causes surface enrichment in the soil in excess to the in situ produced lead-210. The surface enrichment ($^{210}\mathrm{Pb}_{\mathrm{ex}}$) is reduced by vertical transport and decay. Since $^{210}\mathrm{Pb}$ is input only at the soil surface and binds strongly to organic matter, $^{210}\mathrm{Pb}_{\mathrm{ex}}$ can be used as a tracer for soil organic matter transport.

We performed a Bayesian parameter estimation of the previously developed mechanistic SOM profile model SOMPROF that includes the three above mentioned processes. Using a Markov Chain Monte Carlo algorithm, 13 parameters, related to decomposition and transport of organic matter, were calibrated for two sites: a coniferous forest (Loobos, the Netherlands) on a poor sandy soil, and a deciduous forest with a rich clay soil (Hainich, Germany). We used measurements of organic carbon stocks and concentrations, and turnover rate measurements. Furthermore, we performed a series of optimizations in which we stepwise added $^{210}\mathrm{Pb}_{\mathrm{ex}}$ data and prior knowledge of the parameters, to determine the value of the different sources of information.

The results of the initial optimizations, in which $^{210}\mathrm{Pb}_{\mathrm{ex}}$ and/or priors were omitted, reveal the existence of several regions in the parameter space that lead to reasonable fits to the measurements. These regions are characterized by the dominant mechanism for soil carbon input: root litter production, bioturbation or liquid phase transport. However, when additional information is included, one clearly favorite region in parameter space can be identified for each site. This shows that the $^{210}\mathrm{Pb}_{\mathrm{ex}}$ measurements as well as prior knowledge about the parameter values are very useful for parameterizing the model, allowing the rates of the different processes to be estimated.

The results of the final optimization suggest that for both sites advective transport (movement as dissolved organic matter) is a dominant mechanism for organic matter input in the mineral soil. However, for Hainich diffusion (bioturbation) plays a greater role than for Loobos, which has much stronger advection. These results are in good agreement with the differences between the two sites in terms of texture and biological activity.