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Probabilistic inversion of temperature dependency of soil carbon turnover model with long-term experiment data on arable land soil

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Large amount of organic carbon accumulate in the soil in terrestrial ecosystems. There is about twice as much carbon in soils as in vegetation and three times as much as in the atmosphere. The response of soil organic carbon (SOC) to long-term environmental changes such as global warming is the most concern for projecting the future carbon cycling in terrestrial ecosystems. In order to diagnose and predict the carbon cycle in the soil, we generally use the soil carbon turnover model describing decomposition processes of SOC. Most of the current soil carbon turnover models include several compartments. The compartment structure conceptualizes decomposition as the transformation of organic materials into inorganic materials by heterotrophs. While the model structure differs in the definition of compartment in terms of formulation of the decomposition processes, the temperature dependency has been generally given as a positive response form to temperature rise, e.g. Q_{10}-like power function with a unique constant for all the compartments.

In this study, we tried to determine the temperature dependency of compartments included in a carbon turnover model based on the Rothamsted carbon model (RothC), from observed data on long-term changes in total SOC of arable land soils in Japan. We applied a probabilistic inversion method to long-term data on SOC content in arable land in Japan for estimating the temperature dependency of a soil carbon turnover model RothC. Bayesian inference was used to construct posterior probability density functions (PDF) of parameters on temperature dependency for each carbon compartment included in the model, assuming them to be random variables with given prior information.

The RothC consists of five compartments: decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO), humified organic matter (HUM) and inert organic matter (IOM). Time changes in carbon content of each compartment, Y, is governed by the following equation:

$$\frac{dY}{dt} = I(t) - a(T)b(W)c(P)k_0Y$$

On the basis of first-order kinetics, the decomposition rate is given as a multiplication of specific decomposition rates, soil moisture and temperature dependent factors. I is the amount of incoming carbon per unit time, $a(T)$ is the rate modifying factor for air temperature; T is the monthly average temperature, $b(W)$ is the rate modifying factor for moisture; W is the monthly average soil moisture deficit, $c(P)$ is the soil cover rate modifying factor; P indicates whether the plant cover exists or not. The soil moisture deficit W is calculated from precipitation and potential evapotranspiration. k_0 represents the nominal decomposition rate, which reflects the decomposability of each compartment (DPM: 10.0year^{-1}; RPM: 0.3year^{-1}; BIO: 0.66year^{-1}; HUM: 0.02year^{-1}), while the rate modifying factors depending on environment have common parameters for all the compartment in the original RothC. In particular, the modifying factor for temperature, $a(T)$, may vary with decomposability of each compartment and influence the decomposition process more intensively than the other factors. In order to determine the temperature dependency of each compartment from the long-term experiment data, we replaced the original RothC temperature function with a modified Arrhenius-type function widely used in studies (Lloyd and Taylor, 1994):

$$a(T) = \exp\left[E_0\left(\frac{1}{T_{\text{ref}} - T_0} - \frac{1}{T - T_0}\right)\right]$$

The parameter E_0 indicates the temperature dependency. We estimated the values for each compartment using

probabilistic inversion method and examine how the temperature dependencies vary with the decomposability of carbon pool.

The constructed posterior PDFs of the parameters show that the temperature dependencies of the compartments with slow turnover rates are well constrained compared to those with fast turnover rates. The parameter values of temperature dependency tend to decrease with an increasing the fertility of soil nutrient conditions due to priming effects. But there is no consistent association of the temperature sensitivity with the potential decomposition rate of each compartment. The probabilistic inversion is an effective method of determining the temperature dependency of SOC compartment with long turnover time of the model using temporal changes in total SOC, and also providing information on uncertainties in such as climate change projection.