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A PROCESS-BASED MODEL OF METHANE CONSUMPTION BY UPLAND SOILS

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Introduction. In recent decades, the attention to methane (CH_4) budgets has been growing, as it was found that the radiative forcing of the atmospheric methane is second only to CO_2 (Curry, 2007). Over the recent years, estimation of methane emission from the Russian territory has been our general goal. Such an estimate cannot be deduced without having a methane sink model for upland soils. Existing methane sink models are largely empirical, particularly in regard to their treatment of biological oxidation, with rare exceptions. However, even those models do not account for certain specific features of methane sink in soils, such as methane consumption by microorganisms living on plant roots. Therefore, the model in development had to satisfy the two main requirements. First, the model must be a process-based so that it can well reproduce the process of methane sink by the land biomes based on the known biochemical and physical processes. Second, it must contain only those parameters that can be obtained for all types of soils and biomes over the Russian territory. Due to these requirements, we had to only use the average parameter values found for the respective biome types and soils in literature. This study presents an attempt to construct a process-based model of methane sink in upland soils including both the biological and physical aspects of this problem without any calibration of model parameters. Since we do not consider seasonally or permanently waterlogged soils, methane production is assumed to be negligible.

Sites description. The field experiments were carried out during the 2014 summer period at 3 sites in the south taiga zone of Western Siberia, in one forest and two grassland sites. The forest site (FS, 56.862°N, 83.070°E) is a coniferous spruce-pine-fir forest, the grasslands sites include a mesophilic grassland (G1, 56.872°N, 83.074°E) and a mesophilic grassland with sparse birch cover (G2, 56.883°N, 83.068°E).

Methods. The measurements of CH_4 and CO_2 flux were performed using the static chamber method. Fluxes were calculated from the linear regression for CO_2 emission and exponential regression for CH_4 uptake, with weights inverse to concentration measurement uncertainty for the chamber headspace concentration versus measurement time (Глаголев и др., 2010). Air and soil temperatures were measured during flux measurement by the temperature loggers TERMOCHRON iButton DS 1921–1922 (DALLAS Semiconductor, USA). Soil water content was measured gravimetrically by oven-drying at 105 °C. Soil samples for physical analyses 0.5 kg each were randomly picked from each soil horizon. For the comparison of modeled against measured fluxes, measurements on eight different chamber sites (six on FS site, one on G1 and one on G2) were provided. The total number of CH_4 flux measurements is 40, CO_2 flux - 38. For each chamber site (in the same point in space) 2 to 12 temporal replicates of methane flux and 2 to 10 temporal replicates of total ecosystem respiration were taken in a row (i.e., within several hours) were obtained. For further calculations and comparisons, we use the weighted median of methane flux (WM) and median of total ecosystem respiration across all replicates for each chamber site. Weights were assigned in inverse proportion to squares of individual flux uncertainty. The solution of partial differential equations, numerical integration for calculation of root biomass were performed with MATLAB v. 7.8.0 (MathWorks, USA).

Model description. The model is designed to couple the processes of consumption and transport of gaseous oxygen and methane in pore space of one-dimensional column of upland soils. Influence of the factors listed above was taken into account. The model assumes that methane is consumed by two groups of methanotrophs: those living on plant roots and those inhabiting the soil, but not associated with the rhizosphere (termed ‘rhizospheric’ and ‘soil’ methanotrophs from now on, correspondingly). The CH_4 consumption rate by both rhizospheric and soil methanotrophs follows Michaelis-Menten kinetics for both methane and oxygen, and is also a function of soil temperature and moisture. The model describes respiration of both the plant roots and the microorganisms inhabiting the soil. Soil respiration rate is the function of soil temperature and soil carbon content. Root respiration rate is the function of soil temperature and root biomass. Both soil and root respiration follows Michaelis-Menten kinetics for oxygen. Transport of both CH_4 and O_2 in soil is by molecular diffusion through the air-filled soil pore space. The model calculates methane fluxes to the atmosphere. Detailed description of the model is given in (Sabrekov et al., 2016). Input parameters include air temperature, CO_2 flux measured by dark chambers (total respiration, TR), soil profiles of temperature, moisture, bulk density, solid phase density, carbon content and clay content.

The model is formulated similarly to the other modern models or model blocks predicting methane consumption in wetlands and upland soils. However, there are notable differences between

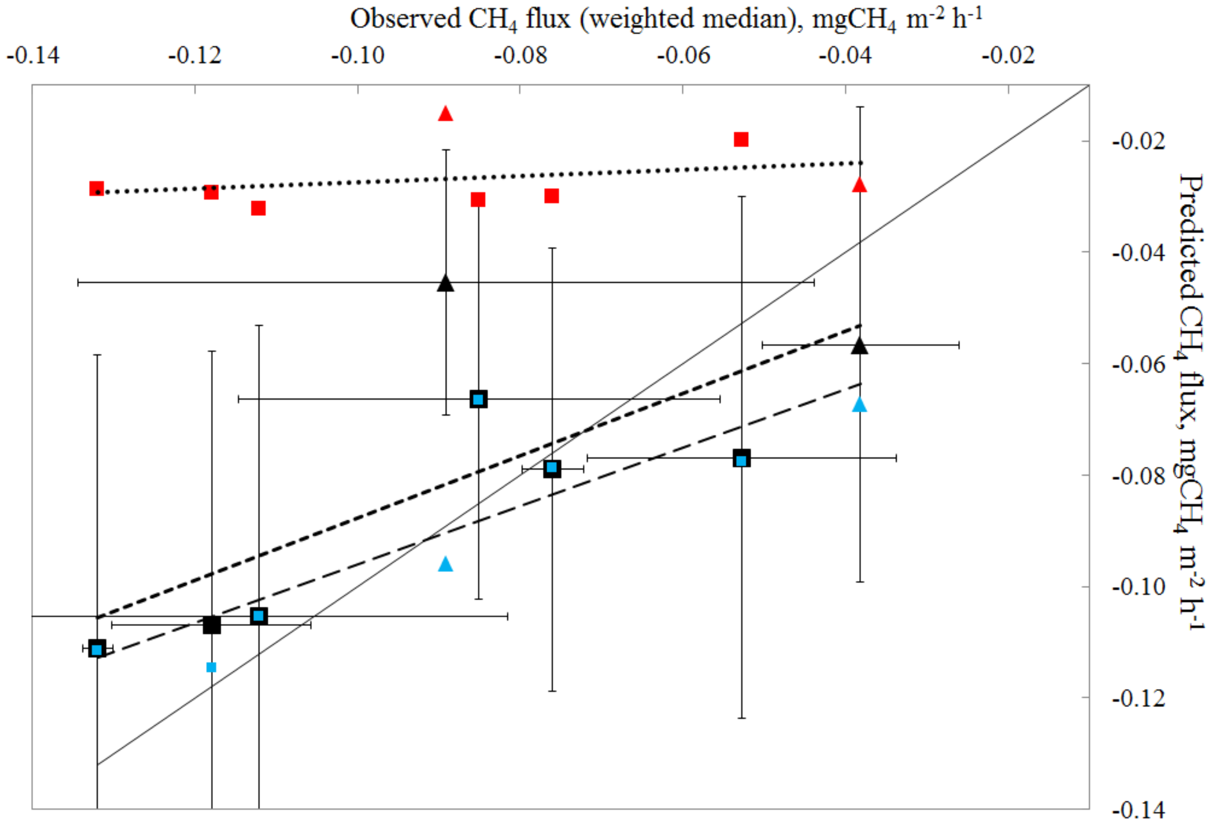

Fig. *Observed (WM) versus predicted values of* CH_4 *fluxes for study sites. Triangles indicate grassland chamber sites, squares indicate forest chamber sites. Black symbols denote situation when both methanotrophy components taken into account, red symbols – when rhizospheric methanotrophs excluded, cyan symbols – when both methanotrophy components taken into account, rhizospheric methanotrophs live at an optimal soil moisture conditions. The solid line gives a 1:1 slope. The other lines indicate linear fits for corresponding model experiments. The horizontal and vertical error bars indicate ±1 SD with respect to the weighted median value and modeled flux respectively.*

those prototype models. First, all the necessary parameters were obtained from literature for appropriate climate zone (if it was possible) and averaged across all sources. The model parameters were not calibrated, as the aim was to examine how modern knowledge of methane consumption in upland soils can reproduce the values of methane fluxes observed in chamber measurements. Second, in the above-mentioned models, rhizospheric methane consumption was not considered. Current model introduces that process, taking into account root biomass and root density distribution in the soil profile (see Sabrekov et al., 2016 for details). In order to estimate root biomass, the balance approach was used. Since total respiration is a sum of soil, below-ground and above-ground plant biomass respiration, root biomass can be estimated from their difference. Soil, root and shoot respiration rates per unit soil/plant mass and root-to-shoot ratio required for these calculations were borrowed from literature (see Sabrekov et al., 2016 for details).

Results and Discussion. The results of model runs are presented in figure. The simulated methane uptake was generally in good agreement with the chamber flux data, although underestimation did occur in two of the chamber sites. We conducted a quantitative examination of the importance of rhizospheric methane consumption components. It appeared that the assumption of zero activity of the rhizospheric methanotrophs significantly reduces the match between the model and the observations. Thus without rhizospheric methanotrophy it is impossible to explain local spatial variability of methane flux into the soil. Of course, the relative contributions of the rhizospheric and soil methanotrophs to methane consumption cannot be reliably partitioned based solely on the present data. But numerical experiments show that improvement effect due to taking rhizospheric methanotrophy into account does not depend on values of microbiological parameters used in the model.

A model simulation was conducted to determine the effect of soil temperature on methane fluxes. Numerical tests have shown that a 10°C increase in soil temperature leads to a 18-40% increase in methane sink (in other words, the flux becomes more negative). This result is in good agreement with the data from experimental studies on temperature sensitivity of CH_4 sink in soils and confirm the idea that during growing season methane consumption is mostly limited not by temperature but by diffusivity of CH_4 in soil pore space. It is also noteworthy that the temperature increase produced a greater effect when the soil moisture was lower, just as expected. Modeled oxygen concentrations were high enough in the soil even at the highest possible soil moisture contents (i.e. the lowest diffusivity), implying that oxygen did not limit methanotrophy. It is confirmed by the numerical experiments: a twofold increase of both root and soil respiration reduced the CH_4 flux by <0.1%.

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