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Effect of water and heat transport processes on methane emissions from paddy soils: a process-based model analysis

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High CH_4 fluxes are emitted from paddy fields worldwide and represent a considerable issue for the rice production eco-sustainability. Water and heat transport fluxes are known to strongly influence biogeochemical cycles in wetland environments, and therefore also CH4 emissions from paddy soils. Water percolation affects the dynamics of many compounds (e.g. DOC, O_2) influencing CH_4 fate. On the other hand, heat fluxes strongly influence CH_4 production in submerged rice crops, and lowering ponding water temperature (LPWT) can reduce microbial activities and consequently decrease CH_4 emissions. Moreover, as long as the optimal temperature range for rice growth is maintained, LPWT can lower CH_4 emissions without rice yield limitation. Hence, a process-based model is proposed and applied to investigate the role of water flow on CH_4 emissions, and to analyse the efficiency of LPWT as mitigation strategy for CH_4 production and release. The process-based model relies on a system of partial differential mass balance equations to describe the vertical dynamics of the chemical compounds leading to CH_4 production. Many physico-chemical processes and features characteristic of paddy soil are included: paddy soil stratigraphy; spatio-temporal variations of plant-root compartment; water and heat transport; SOC decomposition; heterotrophic reactions in both aerobic and anaerobic conditions; root radial oxygen loss; root solute uptake; DOC root exudation; plant-mediated, ebullition, and diffusion gas exchange pathways. LPWT is included as a temperature shift subtracted directly to the ponding water temperature. Model results confirm the importance of water flow on CH_4 emission, since simulations that do not include water fluxes show a considerable overestimation of CH_4 emissions due to a different DOC spatio-temporal dynamics. Particularly, when water fluxes are not modeled the overestimation can reach 67 % of the total CH_4 emission over the whole growing season. Moreover, model results also suggest that roots influence CH_4 dynamics principally due to their solute uptake, while root effect on advective flow plays a minor role. In addition, the analysis of CH_4 transport fluxes show the limiting effect of upward dispersive transport fluxes on the downward CH_4 percolation. Finally, LPWT is confirmed to be a valid mitigation strategy for CH4 emissions from paddy soils, since the reduction of CH_4 emission reach about -50 % with a LPWT equal to only 2°C over the whole growing season.