Methane dynamics in a temperate forest revealed by plot-scale and ecosystem-scale flux measurements

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Soils play important roles as CH$_4$ sources and sinks. CH$_4$ is produced in anoxic environments, including submerged soils, by methanogenic bacteria. On the contrary, CH$_4$ is oxidized by methanotrophic bacteria in upland soils. In general, forest soils are recognized as the efficient sinks for atmospheric CH$_4$, because of their CH$_4$ oxidation capacity in water-unsaturated soil (Le Mer and Roger, 2001). However, we hypothesized that forest ecosystems, especially in wet warm climates such as Asian monsoon climate, are not always CH$_4$ sink. In this study, we examined the CH$_4$ dynamics in a temperate Asian monsoon forest (Kiryu Experimental Watershed: 35°N, 136°E), which included wet areas along riparian zones within the watershed. In order to reveal the spatio-temporal variations of CH$_4$ fluxes, we combined multi-point plot-scale CH$_4$ flux measurements using chamber methods and ecosystem-scale CH$_4$ flux measurements using a micrometeorological method, relaxed eddy accumulation (REA) method (Businger and Oncley, 1990; Hamotani et al., 1996, 2001).

Intensive manual chamber measurements of CH$_4$ fluxes at 60 points in the wet areas and within the water-unsaturated forest floor, respectively, showed that the wet areas had a greater spatial and temporal variability of CH$_4$ fluxes than the forest floor. This indicates that accurate consideration of CH$_4$ fluxes from any wet areas is important in order to evaluate the CH$_4$ budget within the forests. From biweekly continuous manual chamber measurements of CH$_4$ fluxes at 9 points in the wet areas and the forest floor, respectively, hotspots of CH$_4$ emissions were observed during summer and fall immediately after intensive precipitation in the wet areas. On the other hand, in the forest floor, seasonal variations of CH$_4$ fluxes were not simply associated with temperature variations. In contrast, CH$_4$ absorption increased at some measurement plots in spring before intensive summer rainfall. In addition to the manual chamber measurements, we observed the environmental responses of CH$_4$ fluxes at a half-hourly time resolution, by using automated chamber measurements at three plots on the water-unsaturated forest floor. We found that the CH$_4$ absorption flux was greatly weakened by summer intensive rainfall, but recovered and peaked after rainfall as the soil water content decreased. The responses of CH$_4$ fluxes to rainfall were different for each plot. In a dry soil plot with a thick humus layer, CH$_4$ fluxes decreased abruptly at the peak of rainfall intensity, and it increased gradually after rainfall. In a wet soil plot and a dry soil plot with a thinner humus layer, such abrupt decreases in CH$_4$ fluxes were not observed, and CH$_4$ fluxes gradually switched from a sink to neutral following rainfall. Simultaneous measurements of CO$_2$ fluxes provided useful information when considering the controlling factors affecting complex CH$_4$ fluxes in terms of gas diffusivity and microbial activity.

The ecosystem-scale CH$_4$ flux measurements revealed that the Japanese cypress forest switched seasonally between being a sink and source of CH$_4$, and the pattern differed year by year. CH$_4$ fluxes tended to be a source during summer and fall, and switched to a sink during dry period. At hourly to daily timescales, the CH$_4$ fluxes were sensitive to rainfall; rain events increased CH$_4$ emission, decreased CH$_4$ absorption, or shifted CH$_4$ absorption to CH$_4$ emission. The results show that the temperate forest containing riparian zone acted as a CH$_4$ source seasonally, through the increased CH$_4$ emission in the wet areas and/or the decreased CH$_4$ absorption on the water-unsaturated forest floor in response to changing soil temperatures and/or the soil water status. The Asian monsoon rainfall was found to strongly influence temporal variations in CH$_4$ fluxes at both plot-scale and ecosystem-scales.