

Continuous measurements of methane exchange at a temperate secondary forest by the modified gradient method

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Methane (CH₄) budget in upland forests is highly uncertain. In this study, we measured CH₄ exchange at an upland forest using the modified gradient (GR) method. We present the applicability of the GR method, comparing to CO₂ fluxes measured by the eddy covariance (EC) method and CH₄ fluxes by the hyperbolic relayed eddy accumulation (HREA) method. Our aim is to show a consistency in CH₄ fluxes by different methods for reinforcing knowledge of CH₄ budget in forest ecosystems and reducing uncertainties.

We measured fluxes at the Yamashiro forest hydrology research site in Kyoto, Japan during 2016.

Turbulent fluxes of momentum, sensible heat, latent heat, and CO₂ were measured by the eddy covariance method. We developed a measurement system that the HREA and GR methods could be applied simultaneously. CO₂ and CH₄ concentration at two height (35, and 25 m) were measured above the canopy. Horizontal wind speed measured at 35, 25, and 22 m for estimating the displacement height. We also examined two diffusion coefficients based on site-specific universal functions for temperature (Φ_h) and CO₂ (Φ_c). Based on the specification of the available gas analyzer (FGGR-24r-EP, Los Gatos Research, USA), CH₄ concentration gradient was expected to be near a detectable limit of the analyzer. Thus, we examined the applicability of nighttime data for the GR method under stable conditions when vertical CH₄ concentration was expected to be large.

CO₂ fluxes by the EC and GR methods were reasonably agreed for stable and unstable conditions ($R^2 = 0.66 - 0.68$, RMSE = 5.66 - 6.66 gCO₂ m⁻² d⁻¹); but, no consistency was found in CH₄ fluxes from the HREA and GR methods. Using data under stable conditions, CO₂ fluxes by the GR method using Φ_h was 50% overestimated in comparison with those by the EC method. On the other hand, overestimation was not found in CO₂ fluxes using Φ_c . For stable conditions, the value of R^2 among CO₂ fluxes by two methods increased with integration times; by averaging over 30 days or more, CO₂ fluxes by two methods showed a consistency ($R^2 = 0.86 - 0.91$, RMSE = 5.73 - 6.42 gCO₂ m⁻² d⁻¹). This results suggests that the random errors associated with eddy diffusivity were reduced at the monthly time scale.

Monthly CH₄ fluxes by the GR method (0.63 - 1.79 mgCH₄ m⁻² d⁻¹) and the HREA method (0.58 - 1.96 mgCH₄ m⁻² d⁻¹) showed similar seasonal variations during the period from June to October and December. A disagreement during the period from January to March was caused by long-term missing data of the EC or the HREA method. The disagreement in April and May was caused by short integration time for determining vertical concentration differences. The consistent seasonal variations among two methods indicates that the GR method under stable conditions could be applicable for measuring CH₄ fluxes at this forest.

Based on the GR and HREA measurements, the forest acted as a net annual CH₄ source (GR; 172 mgCH₄ m⁻² yr⁻¹, HREA; 237 mg CH₄ m⁻² yr⁻¹). Monthly CH₄ fluxes by the GR and HREA methods delayed one month to the monthly precipitation during the period from June to October ($R^2 = 0.97$, $p < 0.01$). This was probably because rainfall turned soils anaerobic conditions gradually, and activations of methanogenic bacteria took time.

Keywords: Methane flux, Modified gradient method, Upland forest