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Atmospheric O2 and CO2 measurements at a single height provide weak constraint on the surface carbon exchange.

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The ratios of atmospheric tracers are often used to interpret the local CO2 budget, where measurements at a single height are assumed to represent local flux signatures. Alternatively, these signatures can be derived from direct flux measurements or using fluxes derived from measurements at multiple heights. In this study, we contrast interpretation of surface CO2 exchange from tracer ratio measurements at a single height versus measurements at multiple heights. Specifically, we analyse the ratio between atmospheric O2 and CO2 (exchange ratio, ER) above a forest canopy. We consider two alternative approaches: the exchange ratio of the forest (ERforest) obtained from the ratio of the surface fluxes of O2 and CO2, derived from their vertical gradients measured at multiple heights, and the exchange ratio of the atmosphere (ERatmos) obtained from changes in the O2 and CO2 mole fractions over time measured at a single measurement height. We investigate the diurnal cycle of both ER signals, with the goal to relate the ERatmos signal to the ERforest signal and to understand the biophysical meaning of the ERatmos signal. We combined CO2 and O2 measurements from Hyytiälä, Finland during spring and summer of 2018 and 2019 with a conceptual land-atmosphere model and a theoretical relationship between ERatmos and ERforest to investigate the behaviour of ERatmos and ERforest during different environmental conditions. We show that the ERatmos signal rarely directly represents the forest exchange, mainly because it is influenced by entrainment of air from the free troposphere into the atmospheric boundary layer. The resulting ERatmos signal is not the average of the contributing processes, but rather an indication of the influence of large scale processes such as entrainment or advection. We conclude that the ERatmos only provides a weak constraint on local scale surface CO2 exchange, because large scale processes confound the signal. Single height measurements therefore always require careful selection of the time of day and should be combined with atmospheric modelling to yield a meaningful representation of forest carbon exchange. More generally, we recommend to always measure at multiple heights when using multi-tracer measurements to study surface CO2 exchange.