DETERMINING SOIL CO\textsubscript{2} EFFLUX FROM SOIL AIR CO\textsubscript{2} CONCENTRATION PROFILES

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ABSTRACT
In this study, soil CO\textsubscript{2} effluxes determined from CO\textsubscript{2} concentration gradients were compared to effluxes obtained with automated chamber measurements. The CO\textsubscript{2} concentrations showed a diurnal pattern following the soil temperature the concentrations increasing with increasing soil depth. Both methods gave comparable CO\textsubscript{2} effluxes indicating that the gradient method provides an alternative method for monitoring soil CO\textsubscript{2} effluxes.

INTRODUCTION
Soil CO\textsubscript{2} efflux is usually monitored by different kinds of chambers attached on the soil surface. However, chamber measurements have been shown to disturb the natural soil CO\textsubscript{2} concentration gradient [Davidson et al. 2002]. Chambers may also change the environmental conditions both above and below the ground, which in turn may affect the biological processes underlying soil CO\textsubscript{2} efflux. According to Fick’s first law, the gas flux is dependent on the concentration gradient and the diffusivity of the soil. Because, the concentration in the soil is higher than that in the atmosphere, the CO\textsubscript{2} flux in the soil is usually upwards resulting in a CO\textsubscript{2} efflux out of the soil. Thus, the soil CO\textsubscript{2} efflux and the respiratory activity of individual soil layers can be calculated directly from concentration gradients. In this study, we compared CO\textsubscript{2} effluxes determined from automated concentration gradient measurements to those measured by automated soil respiration chambers.

MATERIALS AND METHODS
All measurements were carried out at SMEAR II station (Station for Measuring Forest Ecosystem-Atmosphere Relations) in a 45-year-old boreal coniferous forest stand in Southern Finland. Soil CO\textsubscript{2} concentrations in the soil profile were monitored by Vaisala GMP343 probes (Vaisala Oyj., Vantaa, Finland) installed permanently in the mineral soil at 0, 12, and 22 cm depths and on the humus layer. The GMP343 probe (55 mm in diameter and 194 mm in length) was covered with a sintered PTFE filter and a cap with a diffusion slot enabling gas exchange between the soil and the probe and protecting the probe from water. Soil temperature and soil water content were recorded at respective depths at hourly intervals. Atmospheric CO\textsubscript{2} concentration was measured at 0.1m height above the soil surface with an IRGA (URAS 4, Hartmann & Braun, Frankfurt am Main, Germany). Soil CO\textsubscript{2} efflux nearby was also monitored at hourly intervals with automated open dynamic chamber system [Pumpanen et al., 2001].

Soil CO\textsubscript{2} efflux was calculated with a dynamic model [Pumpanen et al., 2003] where soil is described as a layered structure, which is divided into distinct horizons. The CO\textsubscript{2} movement between layers and from soil to the atmosphere is mediated by diffusion, which is dependent on the total porosity of subsequent soil layers, soil water content, the distance and the concentration gradient between the layers. As an example, we present here the flux calculation between the humus layer and the atmosphere:

\[
J_H = -D_H \frac{C_{ATM} - C_H}{l_H/2}
\]

where \(J_H\) is the flux from humus layer to the atmosphere (g CO\textsubscript{2} m\textsuperscript{-2} s\textsuperscript{-1}), \(D_H\) is the diffusion coefficient of CO\textsubscript{2} in humus layer (m\textsuperscript{2} s\textsuperscript{-1}), \(C_{ATM}\) and \(C_H\) is the CO\textsubscript{2} concentration (g CO\textsubscript{2} m\textsuperscript{-3}) of atmosphere and humus layer, respectively and \(l_H\) is the thickness of the humus layer. The diffusion coefficient of CO\textsubscript{2} \((D)\) in a soil layer is a fraction of the diffusion coefficient of CO\textsubscript{2} in air \(D_o\) (m\textsuperscript{2} s\textsuperscript{-1}) according to a model developed by Troeh et al. [1982]:
\[
\frac{D}{D_0} = \left( \frac{E_g - u}{1 - u} \right)^h
\]

(2)

where \(E_g\) is the air filled porosity of soil (m\(^3\) m\(^{-3}\)) and \(u\) and \(h\) are empirical parameters obtained from the literature [Glinski and Stepniewski, 1985]. For the temperature response of \(D_0\) we used a non-linear empirical function.

**RESULTS AND DISCUSSION**

There was a vertical gradient in the \(\text{CO}_2\) concentrations of the soil air, the concentrations being highest in the deepest soil horizons and following the diurnal temperature pattern of the soil temperature. Based on the \(\text{CO}_2\) concentrations, most of the \(\text{CO}_2\) efflux was originating from the humus and the first mineral soil horizon, A-horizon, probably because most of the readily decomposable organic matter and fine roots were concentrated in the surface horizons of the soil. The \(\text{CO}_2\) efflux determined from the concentration gradients was in good agreement with the \(\text{CO}_2\) efflux measured by the chamber method.

The gradient based efflux was very sensitive to the fluctuation in the ambient \(\text{CO}_2\) concentration just above the soil surface due to the nature of the flux calculation. Thus, accurate concentration measurements are the presupposition for correct flux estimates. The spatial variation in soil \(\text{CO}_2\) concentration, soil porosity, roots and stones may also affect the \(\text{CO}_2\) efflux just like in the chamber measurements.

One great advantage of the gradient method is that it provides a good opportunity for studying the processes underlying soil \(\text{CO}_2\) efflux without disturbing the processes involved. As soon as the system has been stabilized after the installation, the measurement itself does not disturb the \(\text{CO}_2\) fluxes significantly. The \(\text{CO}_2\) gradient method has also good potential for wintertime measurements, because the difficulties related to installation of soil chambers on the snow pack can be avoided.

**REFERENCES**


