DETERMINING SOIL CO_2 EFFLUX FROM SOIL AIR CO_2 CONCENTRATION PROFILES

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ABSTRACT
In this study, soil CO_2 effluxes determined from CO_2 concentration gradients were compared to effluxes obtained with automated chamber measurements. The CO_2 concentrations showed a diurnal pattern following the soil temperature the concentrations increasing with increasing soil depth. Both methods gave comparable CO_2 effluxes indicating that the gradient method provides an alternative method for monitoring soil CO_2 effluxes.

INTRODUCTION
Soil CO_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_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_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_2 flux in the soil is usually upwards resulting in a CO_2 efflux out of the soil. Thus, the soil CO_2 efflux and the respiratory activity of individual soil layers can be calculated directly from concentration gradients. In this study, we compared CO_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_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_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_2 efflux nearby was also monitored at hourly intervals with automated open dynamic chamber system [*Pumpanen et al.*, 2001].

Soil CO_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_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 humus layer and atmosphere:

$$J_H = -D_H \frac{C_{ATM} - C_H}{l_H / 2} \tag{1}$$

where J_H is the flux from humus layer to the atmosphere (g CO_2 m^{-2} s^{-1}), D_H is the diffusion coefficient of CO_2 in humus layer (m^2 s^{-1}), C_{ATM} and C_H is the CO_2 concentration (g CO_2 m^{-3}) of atmosphere and humus layer, respectively and l_H is the thickness of the humus layer. The diffusion coefficient of CO_2 (D) in a soil layer is a fraction of the diffusion coefficient of CO_2 in air D_o (m^2 s^{-1}) according to a model developed by *Troeh et al*. [1982]:

$$\frac{D}{D_o} = \left(\frac{E_g - u}{1 - u} \right) h \qquad (2)$$

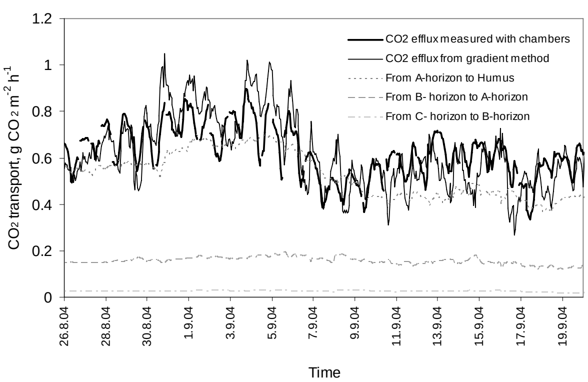
where E_g is the air filled porosity of soil (m^3 m^{-3}) and u and h are empirical parameters obtained from the literature [*Glinski and Stepniewski*, 1985]. For the temperature response of D_o we used a non-linear empirical function.

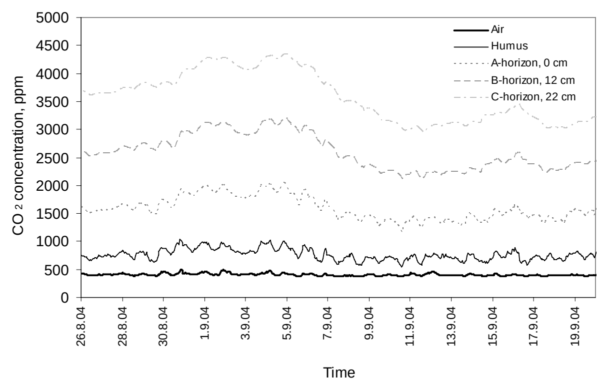
RESULTS AND DISCUSSION

There was a vertical gradient in the 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 CO_2 concentrations, most of the 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 CO_2 efflux determined from the concentration gradients was in good agreement with the CO_2 efflux measured by the chamber method.

The gradient based efflux was very sensitive to the fluctuation in the ambient 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 CO_2 concentration, soil porosity, roots and stones may also affect the 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 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 CO_2 fluxes significantly. The 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.





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