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From above the forest canopy into the soil – wind-induced pressure-pumping affects soil gas transport

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Gas exchange between soil and atmosphere is important for the biogeochemistry of soils and is commonly assumed to be governed by molecular diffusion. Besides other advective gas transport processes, the pressure-pumping effect (PPE) have been identified to enhance soil-atmosphere fluxes. However, the PPE has only been detected indirectly and the underlying effective mechanisms remain unclear. In this study we wanted to correlate the PPE to atmospheric phenomena.

We monitored soil gas transport in situ by injecting continuously helium (He) as a tracer gas into the soil. The resulting He concentration profile was monitored during a field campaign lasting three months in a well-aerated forest soil. 3D wind speed and air pressure were simultaneously measured above and below the forest canopy and air pressure was also measured in the topsoil. The effective soil diffusivity profile was determined using inverse modelling of the He concentration profile.

During periods of low above-canopy wind speed, the He concentration profile showed a steady-state and soil gas transport was assumed to be driven by molecular diffusion. During periods of high above-canopy wind speed, the previously steady diffusive He concentration profile showed temporary concentration decreases in the topsoil, indicating an increase of the effective gas transport rate in the topsoil up to 40 %. We attributed these increases in gas transport rates to the PPE. Furthermore, during these periods, air pressure fluctuations with periods between 10 and 100 s and amplitudes of up to 10 Pa were observed in the below-canopy space and in the soil. The enhancement of the effective topsoil gas diffusivity was more closely related to these air pressure fluctuations than to the mean above-ground wind speed. Moreover, the wind speed profile decreased significantly from above the canopy to the soil surface, while the air pressure fluctuations showed no significant attenuation from below the canopy into the soil. Considering all these points, we hypothesized that it is the fluctuating pressure field rather than the wind speed at soil surface which is responsible for the PPE.

For the first time, we directly detected and quantified the PPE on gas transport in soil in a field study, and could thus validate the importance of this non-diffusive gas transport process. Our in situ monitoring method of soil gas transport provides the opportunity to study further non-diffusive gas transport processes occurring in soil and snow related or not to atmospheric phenomena, and their possible feedbacks or interactions with biogeochemical processes.