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Feedback of ambient air CO_2 concentration on soil CO_2 efflux

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Soil CO_2 flux (F_c) is driven primarily by the CO_2 concentration gradient across the soil surface. We show that under calm and warm night-time conditions, ecosystem respiration can lead to elevated ambient air CO_2 concentration (C_a) above the soil, which suppresses F_c, as expected from diffusion theory. We hypothesize that on warm and calm nights prolonged suppression of F_c has the effect of capping the soil, and leads to elevated soil CO_2 concentrations (C_s). When the atmosphere becomes unstable at sunrise, or when the friction velocity (U*) increases, this cap is removed by replacing air above the soil that has elevated C_a with ambient air characteristic of the well-mixed atmosphere. This can occur quite rapidly producing a large gradient between C_s and C_a, which leads to enhanced diffusion and elevated F_c, especially at sunrise. Elevated F_c can persist for one to two hours, apparently until the soil CO_2 concentration profile readjusts.

We conducted a series of experiments at two field sites with different soil and vegetation types, to investigate the impact of ambient CO_2 concentration on F_c. We used two kinds of closed chamber systems (LI-6400 and LI-8100) to measure F_c. The LI-6400 chamber used a draw-down approach and F_c was estimated when the chamber CO_2 concentration (C_c) was near the ambient CO_2 concentration (*Norman, et al., 1992. Soil surface CO_2 fluxes and the carbon budget of a grassland. J. Geophys. Res., 97*). The LI-8100 was a fully automated multiplexed system, and F_c was estimated using the initial slope $(dC_c/dt|_{t=0})$ of a fitted exponential function of C_c vs time, which we call the exponential approach. Both the draw-down and the exponential approaches were done to minimize the impact of altered CO_2 diffusion gradient inside the chamber on the flux measurements. Comparison of F_c measurements between these two

approaches yielded excellent agreement, suggesting the two approaches were equivalent.

Nearly continuous measurements of night-time F_c from the two field sites demonstrated that F_c was negatively correlated with changes in C_a,suggesting F_c was suppressed under high C_a due to the reduced CO_2 diffusion gradient. Also, at sunrise, increased turbulence caused a rapid drop in C_a and a concomitant increase in F_c that preceded any increase in soil temperature, and persisted for one to two hours, which was much longer than the time required to bring C_a to a well-mixed daytime value. We tested the hypothesis that the increased F_c was due to elevated C_s by capping the soil using the LI-6400, and allowing the headspace CO_2 concentration to rise to various levels above ambient, whereupon we scrubbed the chamber air quickly back to ambient and measured F_c. Measured F_c increased with increasing CO_2 concentration in the headspace prior to measurement, as predicted by a diffusion-based mechanism. Wind-induced pressure pumping was not involved.

This has important implications both for chamber measurements and for ecosystem respiration. Our results suggest that respired CO_2 can accumulate in the soil profile under calm conditions. The accumulated CO_2 in the soil can slowly flush out when C_a returns to the atmospheric background level as the atmosphere becomes unstable. It probably takes much longer to flush out CO_2 accumulated in the soil profile than to flush out CO_2 accumulated in the plant canopy. This might provide an explanation in addition to U*-dependent night-time flux, for the abnormally high ecosystem respiration rate at sunrise often observed by the carbon flux community. Flechard, et al., (,*2006. Temporal changes in soil pore space CO2 concentration and storage under permanent grassland. Agric. Forest Meterol. in press*) present a similar argument, although they suggest wind-induced pressure pumping as the primary mechanism moving CO_2 out of the soil and into the atmosphere.