Mitigating the impact of slow sensor response times on NEON soil CO_2 data

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INTRODUCTION

The National Ecological Observatory Network (NEON) is measuring vertical profiles of soil CO_2 concentration in 5 soil plots at each of 47 sites throughout the US to estimate soil CO_2 fluxes using the gradient method. NEON designed a soil CO_2 assembly that allows soil air to diffuse to the CO_2 sensor (Vaisala GMP343), while protecting it from the soil environment and allowing removal for calibration without disturbing the surrounding soil (Fig. 1). However, the assembly's relatively large headspace volume (~500 cm^3) is expected to slow the sensor's response time. We quantify:

1. the response time of CO_2 sensors in these assemblies at different pressures and temperatures; and
2. the response time's impact on estimated soil CO_2 fluxes in the field.

Fig. 1. Soil CO_2 assemblies measuring CO_2 concentrations at 3 different depths at Ordway-Swisher Biological Station, FL.

TECHNICAL APPROACH - LAB

Contractors at Eosense Inc. (Dartmouth, NS, Canada) designed and built an enclosure where CO_2 concentrations could be rapidly changed to determine the response time (Fig. 2). Because temperature and pressure influence diffusivity rates, the enclosure was placed in a controlled environment chamber to measure the response times at 5 temperature (-29, -10, 10, 30, & 50 °C) and 5 pressure (72, 79, 86, 93, & 101 kPa) combinations. These combinations represent conditions expected at NEON sites.

Fig. 2. Response time testing enclosure.

TECHNICAL APPROACH – FIELD DATA

Soil CO_2 sensors were directly buried in a non-irrigated peanut field in Georgia at 2 & 5 cm using the Vaisala soil adapter cap (75% response time: 17 mins) to create a time series with minimal response time impacts. Data were collected every 5 mins. The NEON assembly time series was estimated as: $C_{A_{t=i+1}} = C_{A_{t=i}} + R_5\left(C_{F_{t=i+1}} - C_{A_{t=i}}\right)$ where, C is the CO_2 concentration in the NEON assembly (A) or field data (F) at time t, and R_5 is the NEON assembly 5-min response. CO_2 concentrations were assumed to be identical at t=0.

RESULTS - LAB

The 75% response time was slow (e.g., 2.0 ±0.3 hrs at 10 °C & 101 kPa; Fig. 3a). Response times increased with increasing pressure ($p < 0.01$) and decreasing temperature ($p < 0.01$; Fig. 3b & c).

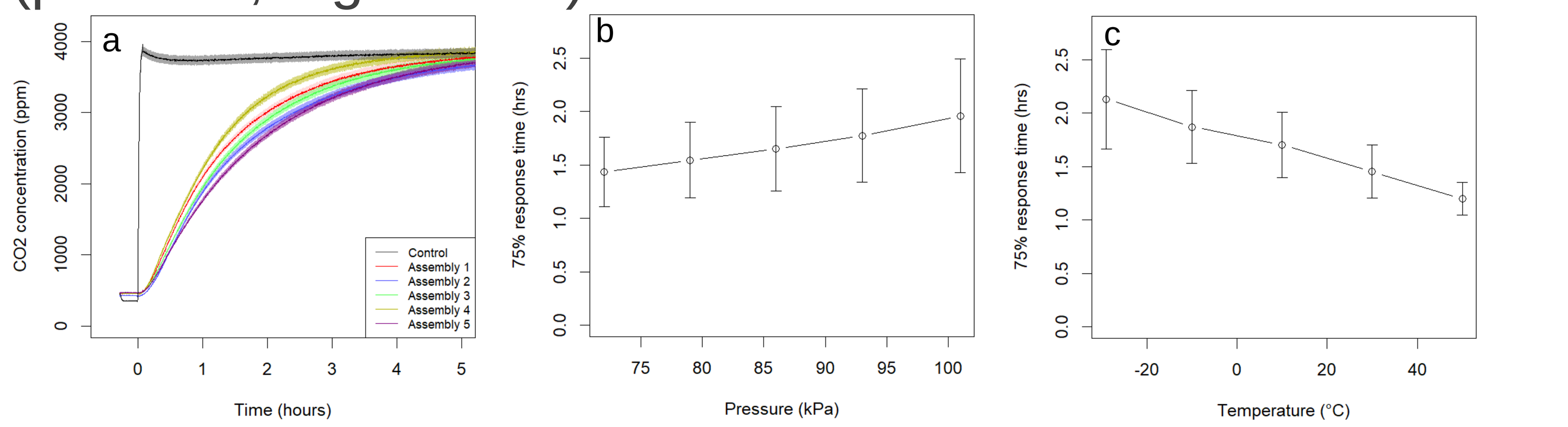

Fig. 3. Sensor response at 10 °C & 101 kPa (a), and relationship between 75% response time and pressure (b) and temperature (c).

RESULTS – FIELD DATA

Estimated CO_2 concentration

The NEON assembly's slow response time caused a slight smoothing of the data and lag in the time series relative to the original field data (Fig. 4), but descriptive statistics were very similar. For example, the original and NEON-approximated mean ±SD concentration at 2 cm were 1353 ±222 & 1365 ±230 ppm, respectively, and max-min were 2183-1061 & 2172-1118 ppm.

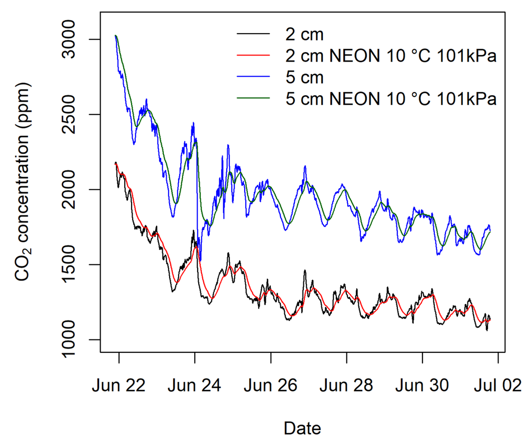

Fig. 4. Time series of CO_2 concentrations. NEON estimated values are based on the 10 °C 101 kPa response time.

RESULTS – FIELD DATA (cont.)

Temperature & pressure effects

Response times for different pressures and temperatures had little impact on the estimated CO_2 concentration, even during the rapid decrease on 24 Jun (Fig. 5). As a result, all subsequent analyses used the 10 °C 101 kPa response time.

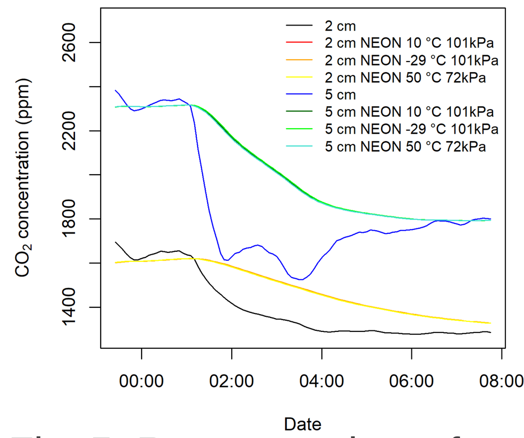

Fig. 5. Response times for different pressures and temperatures had little impact.

Lag correction

The RMSE of the NEON data versus the original field data was minimized when the NEON data were shifted 110 mins earlier for both depths (Fig.6).

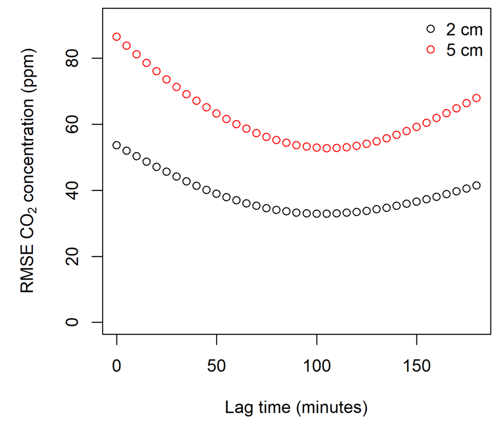

Fig. 6. RMSE of NEON CO_2 concentrations versus field data for various lag times.

Impact on soil CO_2 flux

CO_2 fluxes based on NEON estimated data had a similar pattern to the original data, but were smoothed and had a lag (Fig. 7). Fluxes calculated with the lag-corrected concentration data improved the RMSE from 0.21 to 0.14 µmol m^{-2} s^{-1}. The mean lag-corrected NEON flux and the original field data flux were almost identical (mean ±SD: 2.30 ±0.30 and 2.29 ±0.36 µmol m^{-2} s^{-1}, respectively).

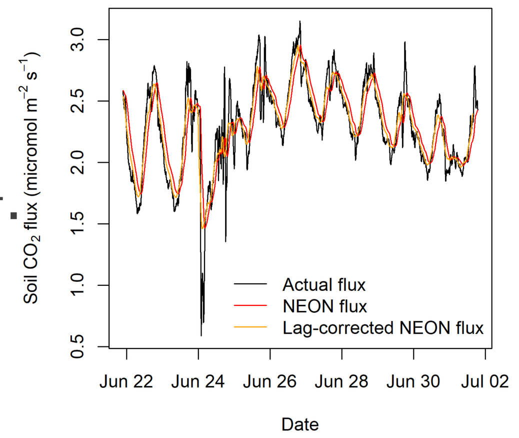

Fig. 7. Actual and estimated soil CO_2 fluxes.

CONCLUSIONS

1. CO_2 concentration data from the NEON assembly can be used to calculate accurate mean fluxes for time intervals of ≥9 days (±0.01 µmol m^{-2} s^{-1} in this study).
2. Instantaneous fluxes were usually accurate, but underestimated minimum and maximum flux rates.
3. Accounting for the lag time improved flux estimates.
4. Impacts of pressure and temperature on response time are negligible for most use cases.

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