Atmospheric exchanges of CO_2, CH_4 and N_2O of temperate forest soils under elevated CO_2 at BIFoR-FACE

UNIVERSITY OF BIRMINGHAM BIFOR BIRMINGHAM INSTITUTE OF FOREST RESEARCH

Alex Armstrong [1], Sami Ullah [1], Liz Hamilton [1], Elena Vanguelova [2], Mike Morecroft [3], Nathan Basiliko [4], Rob MacKenzie [1], Niall McNamara [5]

[1] University of Birmingham, [2] Forest Research, [3] Natural England, [4] Laurentian University, [5] UK Centre for Ecology and Hydrology

UKRI Natural Environment Research Council CENTA

Introduction

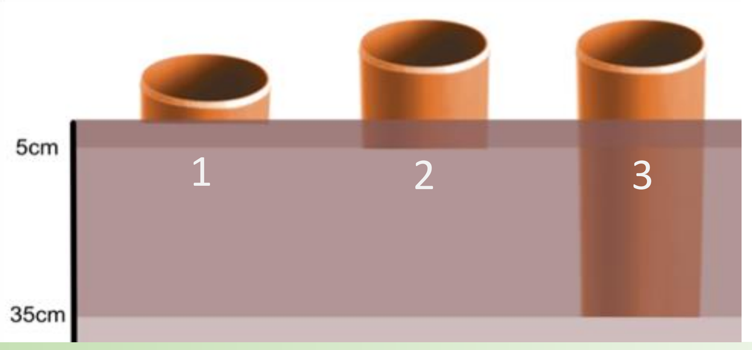
- Atmospheric exchanges of CO_2, CH_4 and N_2O of temperate forest soils are an important aspect of the net global warming potential and climate mitigation function of forests.
- However, it's unclear how these fluxes will respond to rising atmospheric CO_2 concentrations (eCO_2) in temperate forests. Increased carbon sequestration under eCO_2 and storage in biomass and soils can influence the activities of soil microbes responsible for greenhouse-gas (GHG) process dynamics and hence net emissions.
- Initial trends from 2017 - 2020 indicated that eCO_2 arrays had a higher efflux of CO_2 relative to aCO_2 arrays by +20%. However, during 2021 and 2022, eCO_2 arrays have seen a decline in the efflux of CO_2 by -27.5% relative to aCO_2
- Sink potential of CH_4 and efflux of N_2O are also significantly lower under eCO_2 arrays, by -72% and -109% respectively.

Aims

1. Determine inter and intra seasonal patterns in soil gas fluxes under eCO_2 and aCO_2
2. Partition the relative contribution of autotrophic and heterotrophic fluxes to net emissions.
3. Couple with wider available microclimatic and biotic data-streams to assess the key regulatory processes driving flux patterns.

Methodology

- CO_2 flux rates are determined through long-term LI-8100A continuous gas analyzer system.
- CH_4 & N_2O are measured through a coupled Picarro G2508 trace gas analyzer.
  - δ13C of CO2 efflux rates measured with loaned Picarro G2201-i (Aug – Nov 2023).
- Automated LI-8200-104 chambers are fitted to 9 collars in each Array, of which there are 3 collar depths.
  - 1 – Shallow collar = Net Emissions.
  - 2 – Medium collar = Net Emissions (minus lateral diffusion).
  - 3 – Deep collar = Pseudo-root exclusion collars.
- Two parallel systems exist, placed within paired eCO_2 and aCO_2 arrays and rotated fortnightly.
  - A1 -> A3
  - A4 -> A2
  - A6 -> A5



Conclusions

1. Efflux of CO_2, N_2O and the uptake of CH_4 have declined under eCO_2 during 2022 – 2023 by 40%, 109% and 72% respectively.
2. Lower VWC across a soil profile up to 1m was detected in eCO_2 arrays, which should stimulate microbially mediated gas flux process dynamics and increase the efflux of CO_2, N_2O and the uptake of CH_4.
3. Higher relative mean differences (Δ%) between pseudo-root exclusion and zero-exclusion chambers coupled with δ13C keeling plot R^2 values suggests reduced heterotrophic or enhanced autotrophic contribution to the efflux of CO2 under eCO_2.

Results

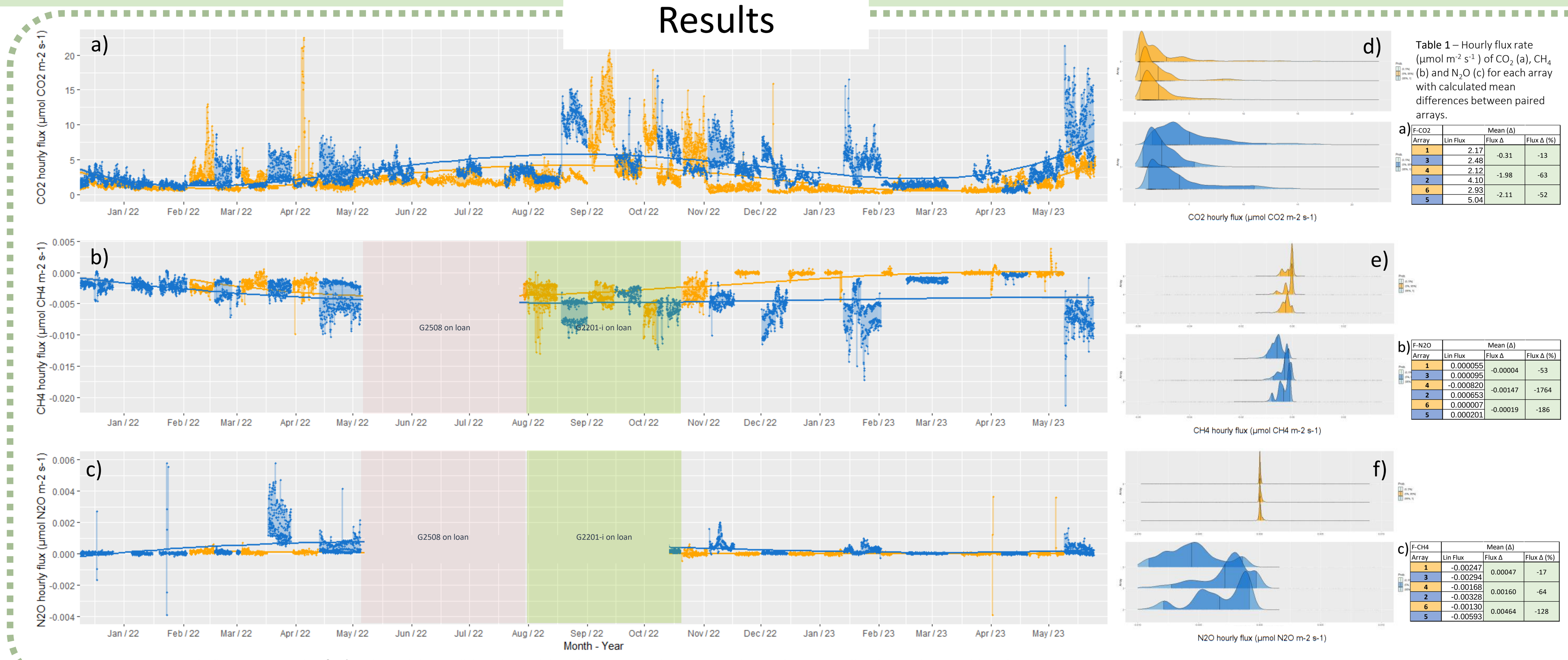


Figure 1 – Hourly flux rate (μmol m^{-2} s^{-1}) of CO_2 (a), CH_4 (b) and N_2O (c) with corresponding mean values of each gas flux for each array (d, e, f).

Figure 2 – Hourly flux rate (μmol m^{-2} s^{-1}) of CO_2 (a), CH_4 (b) and N_2O (c) against volumetric water content (%) and temperature (°C) across 7 soil depths for all Arrays. Corresponding tables contain correlations Sig 0.01, Sig 0.05, Not Sig.

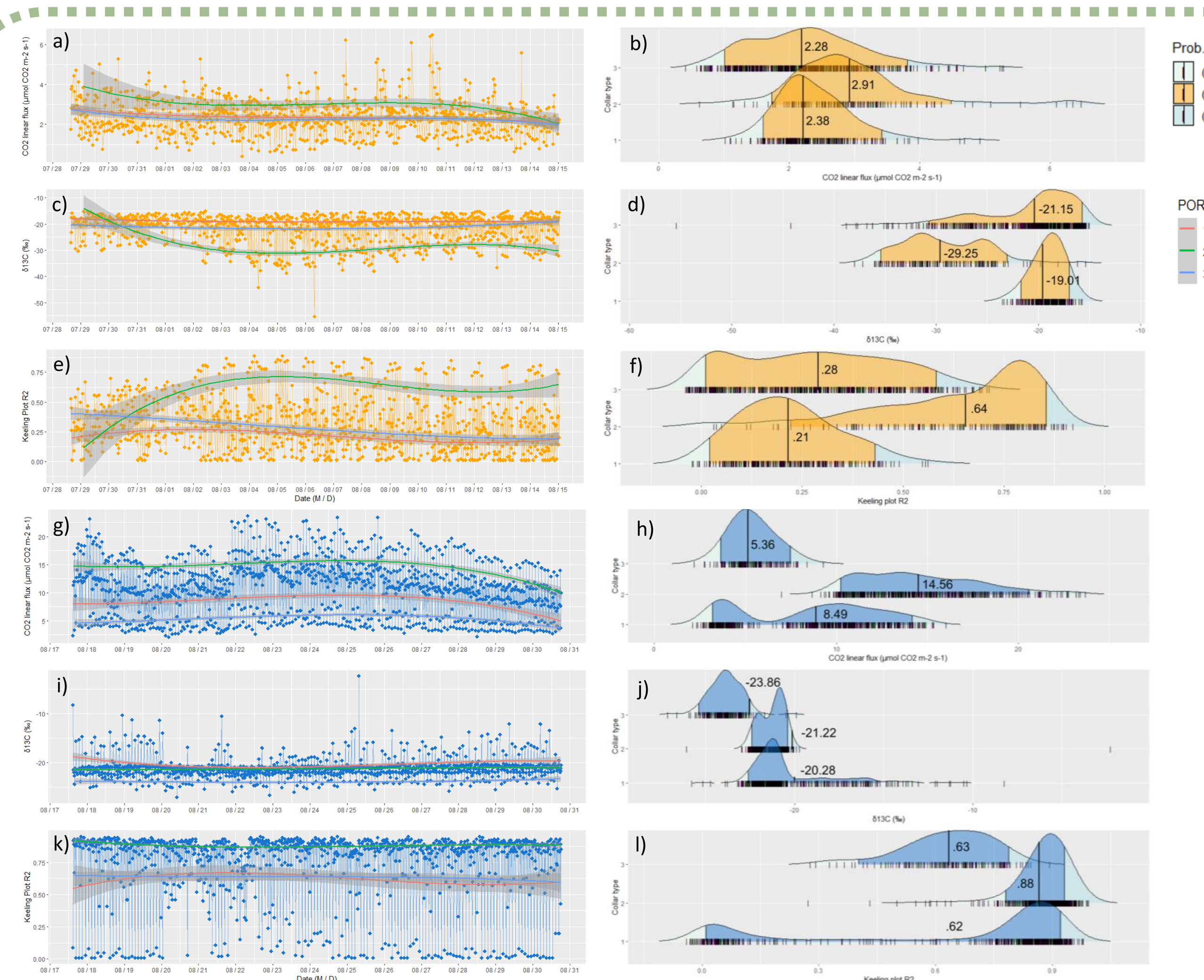


Figure 3 – CO2 flux rates (a, g) and mean collar values (b, h) with corresponding δ13C values derived from linear flux rates (c, d, i, j), with keeling plot derived R2 values for each observation (e, k) alongside mean R^2 values for each collar type (d, l).

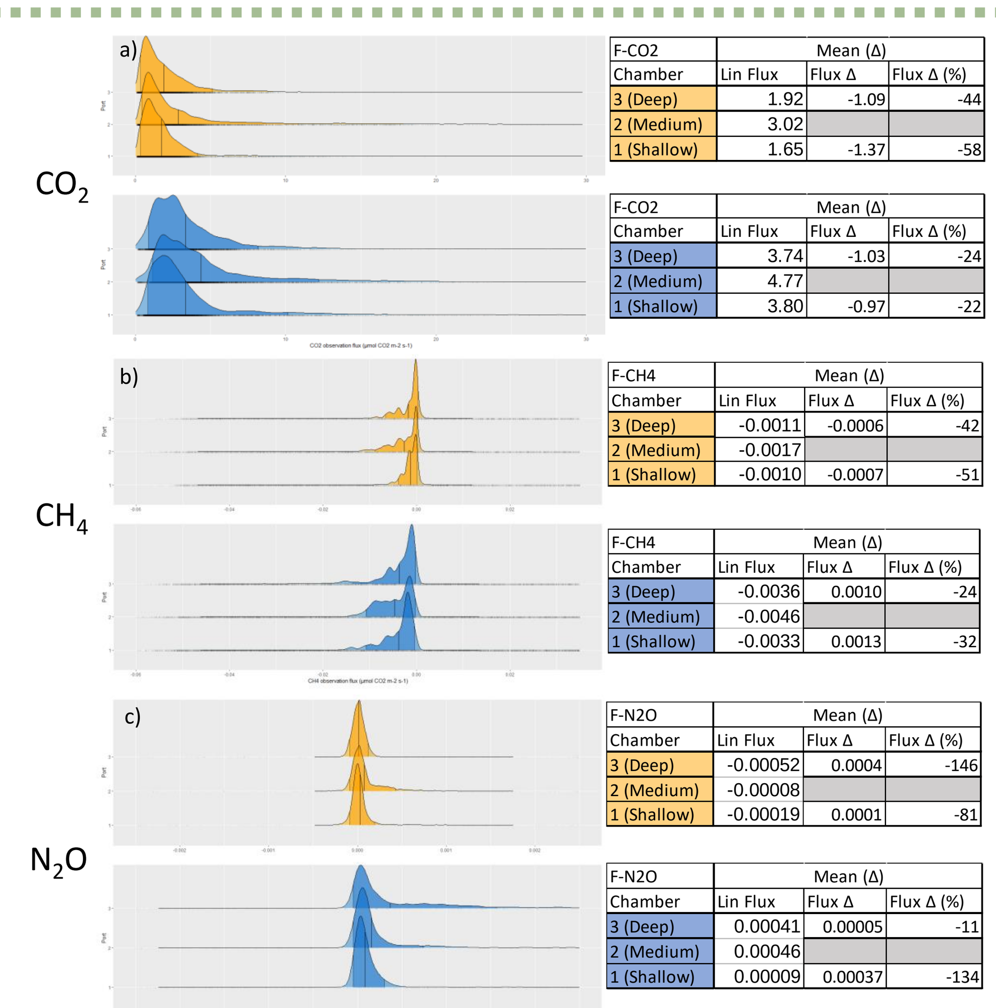


Figure 4 – Mean gas flux rates for CO_2 (a), CH_4 (b) and N_2O (c) with corresponding tables for mean values and Δ% between shallow, deep and medium collar types.

Discussion

Soil gas flux patterns, differences between and within eCO_2 & aCO_2 Arrays.

- Flux of CO_2 is significantly lower under eCO_2 ~-40% ($p<.001$)*
  - ~ 1.2 μmol m^{-2} s^{-1} lower efflux.
  - Stochastic episodes of high efflux in Spring and Autumn.
- Uptake of CH_4 is significantly lower under eCO_2 ~ -72% ($p<.001$)*
  - ~ 0.0021 μmol m^{-2} s^{-1} lower uptake rate.
  - Even under significantly drier soil conditions under eCO_2
- Efflux of N_2O is significantly lower under eCO_2 ~109% ($p<.001$)*
  - ~ -0.0000567 μmol m^{-2} s^{-1} lower efflux.
  - Difference driven by A4, low emissions and episodes of uptake possibly driven by significantly lower soil moisture across all soil depths relative to A2 (-14.3% VWC).

Discussion

Soil moisture and temperature; key regulatory drivers of gas fluxes.

- VWC is significantly different between eCO_2 and aCO_2 ($p<.001$)*
  - Highly variable across soil profile, equivalent mean difference ~-4.69%.
    - A1 -> A3 = eCO_2 -4.4%
    - A4 -> A2 = eCO_2 -14.3%
    - A6 -> A5 = eCO_2 +4.6%
- Temperature shows more homogeneity across both Arrays and depth.
  - A1 -> A3 = eCO_2 +0.17°C
  - A4 -> A2 = eCO_2 +0.03°C
  - A6 -> A5 = eCO_2 +0.27°C

CO_2	Strong significantly negative correlation with VWC (eCO2 = -.44, aCO2 = -.44) and a strong significantly positive correlation with temperature (eCO2 = .48, aCO2 = .48) across all depths and Arrays.
CH_4	Strong significantly positive correlation with VWC (eCO2 = .67, aCO2 = .42) and a strong significantly negative correlation with temperature (eCO2 = -.64, aCO2 = -.32) across all depths and Arrays.
N_2O	Varied response across both Arrays and depth, showing weak significant correlations with VWC (eCO2 = .06, aCO2 = .06), but converse responses to temperature (eCO2 = -.05, aCO2 = .09).

Discussion

Disseminating gas fluxes and their relative sources; collar type & δ13C analysis.

- Higher mean differences (Δ%) between pseudo-root exclusion (3) and zero-exclusion chambers (2) within the eCO_2 arrays suggests a potential decline in the heterotrophic or an increase in the autotrophic contribution to CO_2 effluxes.
  - Coupled with significantly lower δ13C keeling plot R^2 values from CO_2 efflux rates, this further suggests a potential shift in source contributions.
  - Potential increased reliance on N-obtaining ectomycorrhizal fungi under ECO2 driving an enhanced Gadgil effect; effective competitive exclusion of other microbial groups.
- CH_4 & N_2O shows no significant difference between shallow (1) and pseudo-root exclusion chambers (3) under eCO_2.
  - Uptake of CH_4 and efflux of N_2O are significantly lower under eCO_2, across all Chamber types.