Detecting water-table–CO_2 coupling with scalable sensor arrays

Primary contact: *Mark Hopper, Technical Supervisor, CSX (mark.hopper@csxcarbon.com)*

Narrative brief

CSX helps landowners monetise their Natural Capital by evidencing changes in land management and gathering data around Natural Capital stocks. On peatlands, their workflow combines capturing drone imagery, applying machine learning models to detect erosion features, suggesting restoration plans based on these outputs, and monitoring changes in water table depth through IoT sensors. CSX has developed CO_2 sensors to measure atmospheric CO_2 at 20-minute intervals and relay this data semi-live. These CO_2 sensors are currently being deployed on peatlands alongside water table depth loggers. Sensor arrays must be scalable and cost-effective for landowners to see them as an effective solution for monitoring their peatlands.

This challenge asks: to what extent do changes in the water table affect peatland CO_2 flux, and is that influence detectable in near-surface atmospheric CO_2 concentration time series from CSX sensors? The 2021 Nature study by Evans et al. reports overriding water-table control on managed peatland greenhouse-gas emissions; we will explore how far that relationship can be recovered from concentration data rather than flux measurements, and how site characteristics modulate detectability.

Two outcomes are targeted. First, a statistically defensible linkage between water table depth (WTD) and observed CO_2 concentration dynamics at the sensor scale, controlling for confounders (temperature, wind/mixing, vegetation activity, sensor drift). Second, a design insight: how many sensors, at what heights and spacing, and with what processing, are required for reliable detection so arrays remain affordable while still informative.

Possible sub-problems:

- Does the expected proportion of CO_2 to CH_4 emissions change with WTD?
- Is the change in CO_2 concentration from changes in WTD measurable within atmospheric concentration data?
- Can the linkage between CO_2 concentration and WTD be compared to the work of Evans et al.[1,] and to what extent does it agree with these outputs?
- Are these dynamics dependent on the bulk density of peat, vegetation, total peat depth, etc?
- Can a carbon density of peat be inferred from these relationships?

MATHGEO–MATHPEAT KE Study Group, University of Dundee, 10-12 September 2025

Data and assets available

Data is available from two sensor clusters at one site covering the period March through August 2025. Each cluster has a WTD logger surrounded by three or four CO_2 sensors (some at different heights). Group 1 sits within metres of restored grips on relatively flat, heather/grass-dominated ground with a peat depth of 1.2m; Group 2 is heather-dominated, on a slight hill with a vegetated gully approximately 30 m away and a peat depth of 2.3m. WTD is recorded twice daily, and CO_2 is measured every 20 minutes. Drone imagery from December 2024 covers both clusters. Sensor drift is a known problem and may vary by unit.

Further available datasets include two clusters on a different site to above. These clusters each have a WTD logger and one CO_2 sensor mounted 30cm above the ground. These CO_2 sensors are from a different company but use the same CO_2 sensing board. One group is on 3m deep peat, heather dominated with blocked grips nearby. The dataset extends from March 2024 to August 2025 with CO_2 recorded every 15mins and WTD twice a day. The other group is on shallower peat, grass dominated with blocked grips. This dataset is from July 2024 to August 2025 with CO_2 recorded every 15mins and WTD every two hours. Drone imagery of both these locations are also available.

What success looks like

- Preliminary link between WTD and CO_2: interpretable model estimating effect size and lag, controlling for basic confounders, plus simple robustness checks.
- Early design insight for scalable arrays: a proposed minimal sensor configuration (count, heights, spacing, logging cadence, duration) that would achieve a detectable signal under current noise levels, supported by a back-of-the-envelope power/sensitivity analysis and explicit assumptions.

[1] Evans, C.D., Peacock, M., Baird, A.J. *et al.* Overriding water table control on managed peatland greenhouse gas emissions. *Nature* **593**, 548–552 (2021).