

Supplement of Enhanced CO₂ Emissions Driven by Flooding in a Simulation of Palsa Degradation

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S1 Study site

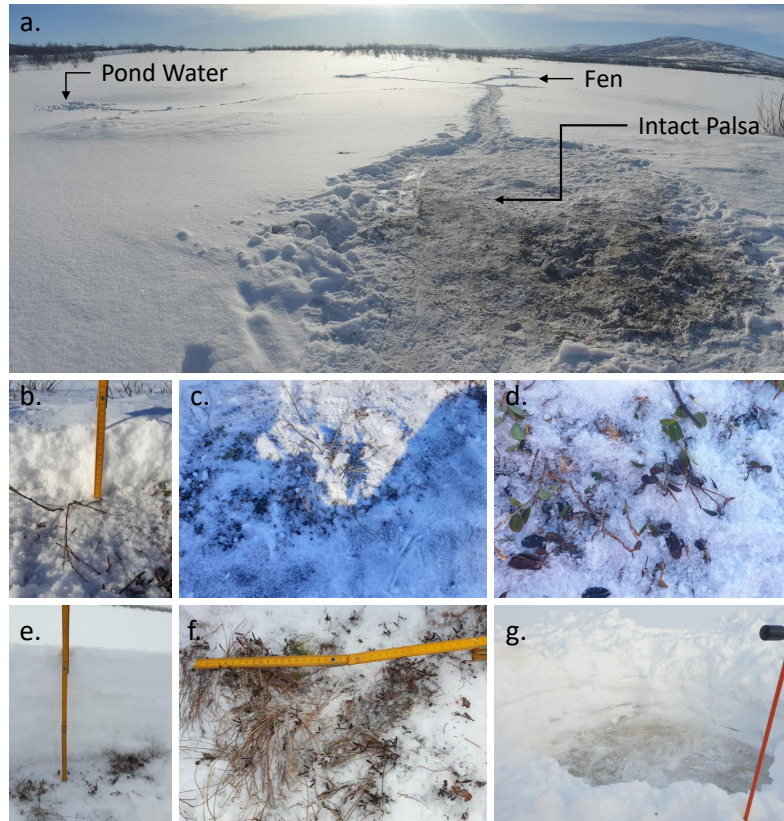


Figure S1. Sampling sites and dead vegetation still on site. Panorama of the three sampling locations: the intact palsa, the fen and the pond water (a.); Snow thickness of 16 cm at the palsa site (b.); Dominant vegetation at the palsa: dwarf shrubs (c.) and *Vaccinium ssp* (d.); Snow thickness of 46 cm at the fen site (e.); Dominant vegetation at the fen site: Sedge and Eriophorum (f.); frozen pond where the water used to inoculate part of the cores was collected (g.)

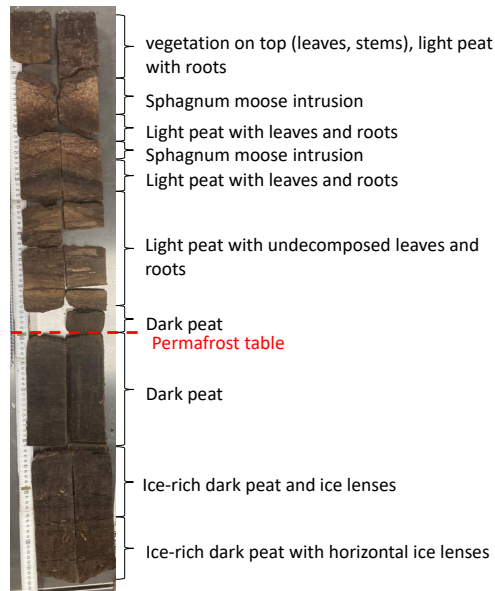


Figure S2. Core description of the palsa. The description covers the first meter and was done in the climate chamber at Alfred-Wegener-Institute. The same core was used for the geochemical analyses.

The mesocosms were incubated at the Leibniz-Zentrum für Agrarlandschaftsforschung, Müncheberg (Germany).

S2 Experimental Design

S2.0.1 Incubation chamber

- 5 The incubation chamber was made of two compartments stacked on top of each other. The bottom part was a freezer where we set the temperature at -5 °C. On top of it, we placed a styrofoam chamber, fitted to the dimension of the freezer. The styrofoam chamber was equipped with a peltier element and a ventilation system to ensure a homogeneous temperature inside the incubator. We used a resistance to set the temperature of the styrofoam chamber at 10°C. The two compartments were separated by a 6 mm styrofoam log. Holes were drilled through the separation log to insert the mesocosm tubes. To avoid
- 10 air circulation between the tubes and the styrofoam log, we used foam. The tubes were held by clamps positioned inside the styrofoam chamber. We gradually thawed the mesocosms by uplifting the tubes with the clamps (Fig. S4b). We tested the incubation chamber before the incubation to ensure the temperature was stable in both compartments. During the incubation, we continuously monitored the temperature in the two compartments with HoBo Sensors (Fig. S7).

S2.0.2 Tube preparation

- 15 We incubated the cores in PVC tubes (PCV-Welt, Germany) of 1.20 m. 1 m was allocated for the cores and the remaining 0.20 m were used for the headspace (Fig. S4). Before putting the cores into the tubes, we pre-drilled the tubes where the probes would be later inserted. To avoid any contamination, we cleaned the tubes in a hydrogen peroxide bath and rinsed them with milli-Q water. Finally, we dried them in an oven.

S2.0.3 Sample preparation

- 20 The samples were transported from Kilpisjärvi to AWI Potsdam via a refrigerator truck and kept at -20 °C. Once in Potsdam, we did all the core preparation at -8 °C. For each core we scratched the outer part to remove potential contamination due to the coring. Afterward, we weighed and measured the cores before introducing them into the mesocosm tube. Then, we pushed the cores inside the tubes. Because of the coring, the cores were split into several core pieces. Therefore, we took care to match the core pieces when we inserted the cores inside the tube. We measured the headspace for each mesocosm, weighed them
25 and remeasured the length of the core after insertion. We closed the tubes with rubber flexible pipe caps and sealed them with silicone. Finally, we pre-drilled the cores where we previously drilled the tubes. Between each core, the tools were cleaned with isopropanol. We closed the wholes with sealing tape to avoid contamination during the transport to Müncheberg. We kept the samples frozen during the transport to Müncheberg by wrapping them in aluminium foil and ice-packs.

S2.0.4 Start of the incubation

- 30 Before starting the incubation, we inserted the probes for the first 60 cm and sealed them with silicone. We fixed the samples in the incubation chamber by using clamps. We limited the air circulation between the two chambers from the holes in the styrofoam log by adding foam. We let the samples thaw overnight and then inoculated them with the different water treatments.

S2.0.5 Thawing steps

- For each thawing step event the samples were manually lifted up. Following the same procedure as for the beginning of the
35 incubation, we inserted the probes and sealed them with silicone. We inoculated the samples a day after increasing the thawed depth.

S2.0.6 Water preparation and water addition

We prepared the water treatments before each water addition.

- Autoclaved tap water: we autoclaved tap water from AWI Potsdam at ZALF, Müncheberg. The water was autoclaved to
40 avoid microbial contamination.

- Non-filtered water: we stored the thermokarst pond water at -20°C. Before each water addition, we subsampled the water in the climate chamber using a sterilized chisel and hammer. The subsampled water was therefore put into 500mL sterile glass bottles and melted at 4°C.
- Filtered water: we used half of the melted water from the thermokarst pond for the filtered treatment. The water was filtered using a vacuum filtration system (Nalgene, Germany) with a 0.2 μm filter and stored in clean 500 mL sterile glass bottles.

We added water at four different depths: 0, 25, 50 and 75 cm. Water at 75cm was only added when the permafrost was thawed (Thaw step 0-80 cm).

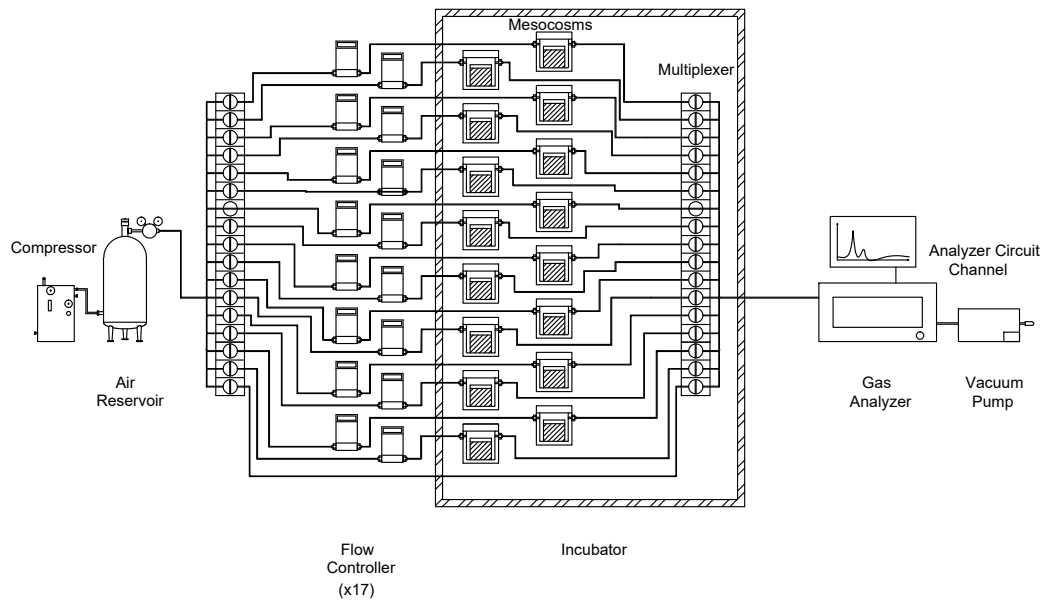


Figure S3. Schematic of the incubation setup from the Compressor to the Gas analyzer.



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Figure S4. Incubation setup of the mesocosms. Picture of the core from the fen after removing the oven pipe (a.); Incubation chamber with the 15 mesocosms. Here, only the first 60cm were thawed and incubated at 10°C. The bottom part represents the freezer (b.); Zoom in on the mesocosm tubes and the different probes: the 3-way valves, the rhizons and the temperature sensors. The blue cables are connected to the mesocosm headspace and to the Picarro (c.); Water sampling with syringes connected to the rhizons (d.).

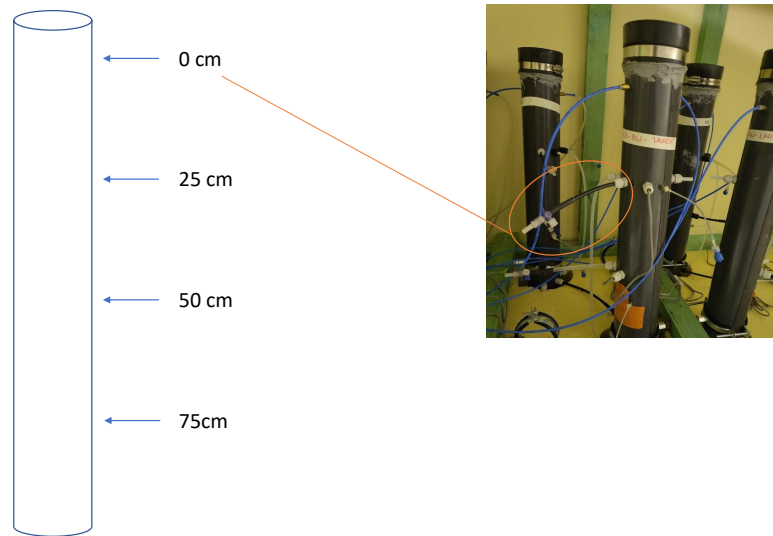


Figure S5. Depths at which the water treatments were added.

S3 Quality control prior to incubation

50 Prior to flux calculations we filtered out CO₂ and CH₄ measurements identified as not reliable due to the saturation of the C sensor. The Picarro Gas analyzer uses a single C sensor for CO₂ and CH₄ emissions. The high CO₂ emissions (> 5,000 ppm) from the cores were above the detection limit of the gas analyzer, leading to a saturation of the C sensor. Because of the saturation, the C sensor was likely not able to measure both CO₂ and CH₄ emissions. We identified measurements as abnormal when we measured an increase in CO₂ and a drop in CH₄ emissions simultaneously (Fig. S6). We manually reported

55 the beginning and the end of each anomaly for every channel. Finally, we filtered out the measurements belonging to those timestamps (TableS1). The timestamps used for the quality control can be found in the data associated with the paper Laurent et al. (2025).

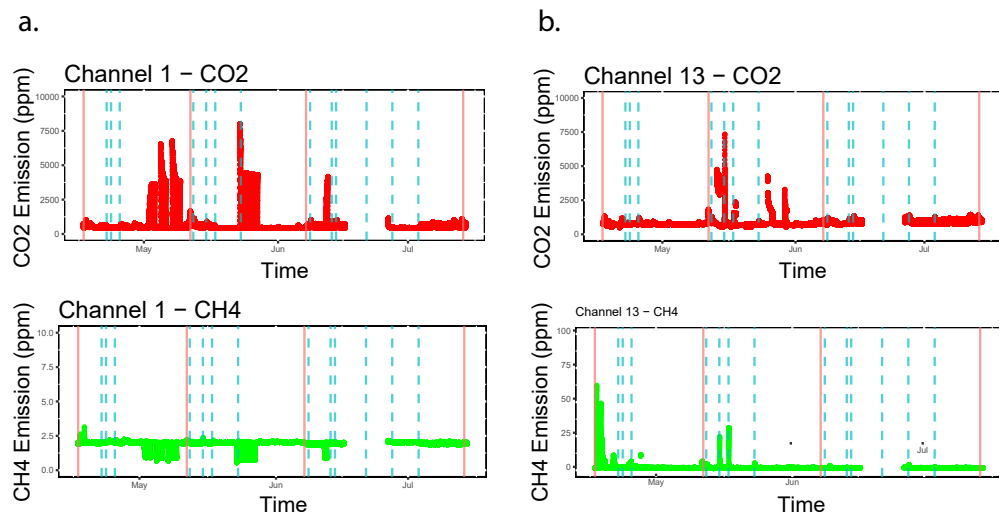


Figure S6. Comparison between abnormal measurements and measurements without the saturation effect. Example of a time series of CO₂ and CH₄ concentrations in ppm with saturation effect for specific time windows. The saturation effect is detected by inverse behavior between CO₂ and CH₄ (a.) Example of a time series of CO₂ and CH₄ emissions in ppm without saturation effect (b.)

S4 Supplementary Figures Results

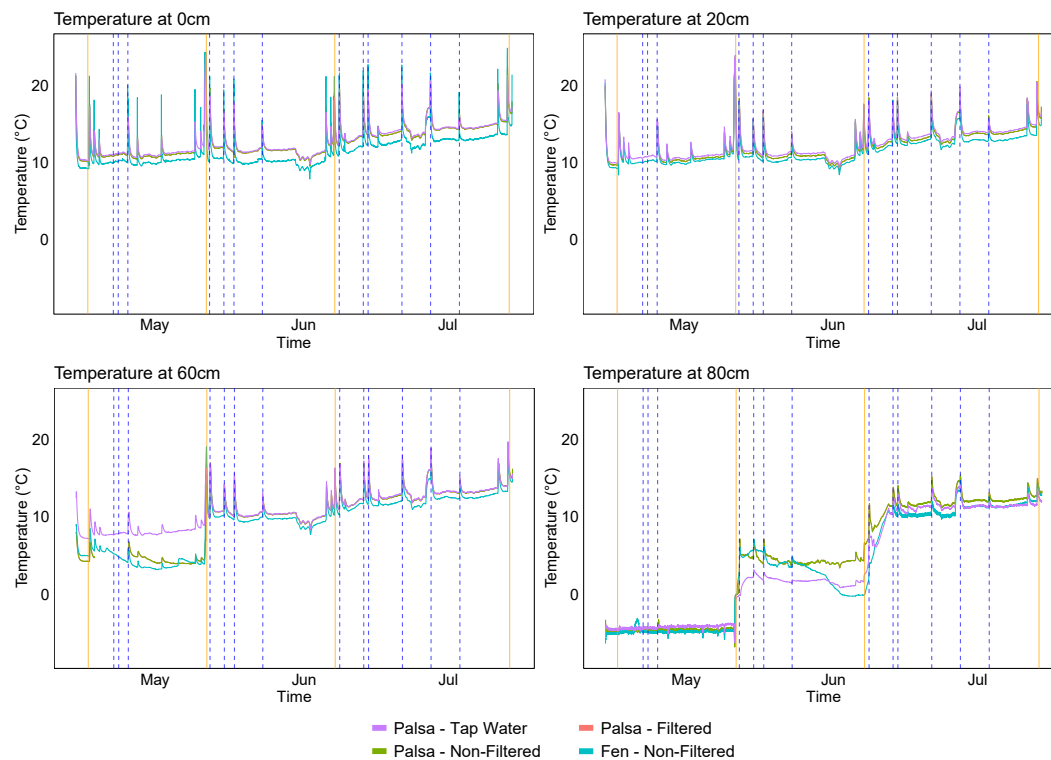


Figure S7. Monitoring of the temperature at four depths along the mesocosm tubes. Each panel shows the temperature for four out of the five treatments. The orange lines represent the thaw stage, while the blue-dashed lines indicate water addition times.

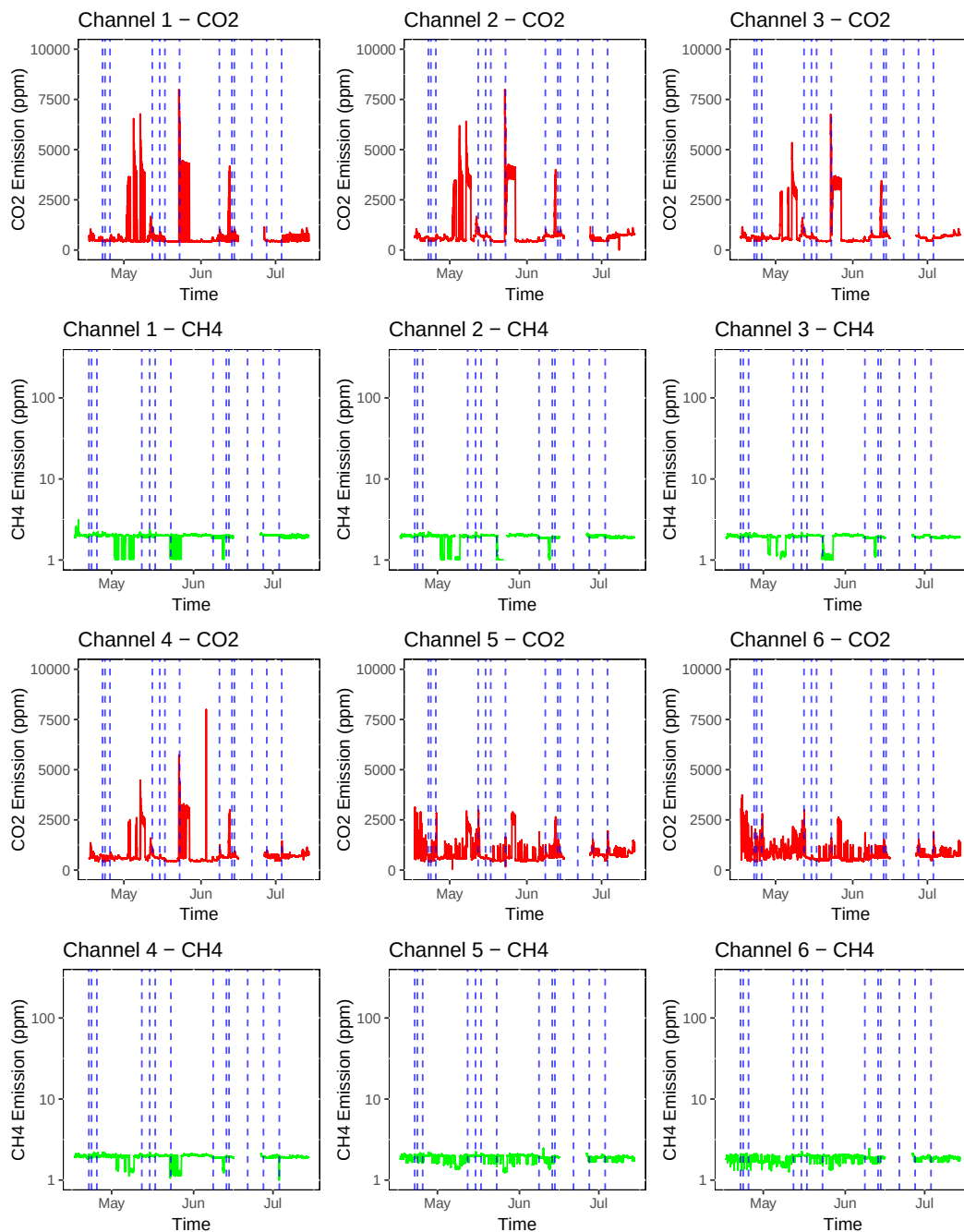


Figure S8. Raw data points of measured CO₂ and CH₄ concentrations (ppm) during the incubation. The blue-dashed lines indicate water addition times. Note that the y-axis is on a logarithmic scale. (Page 1)

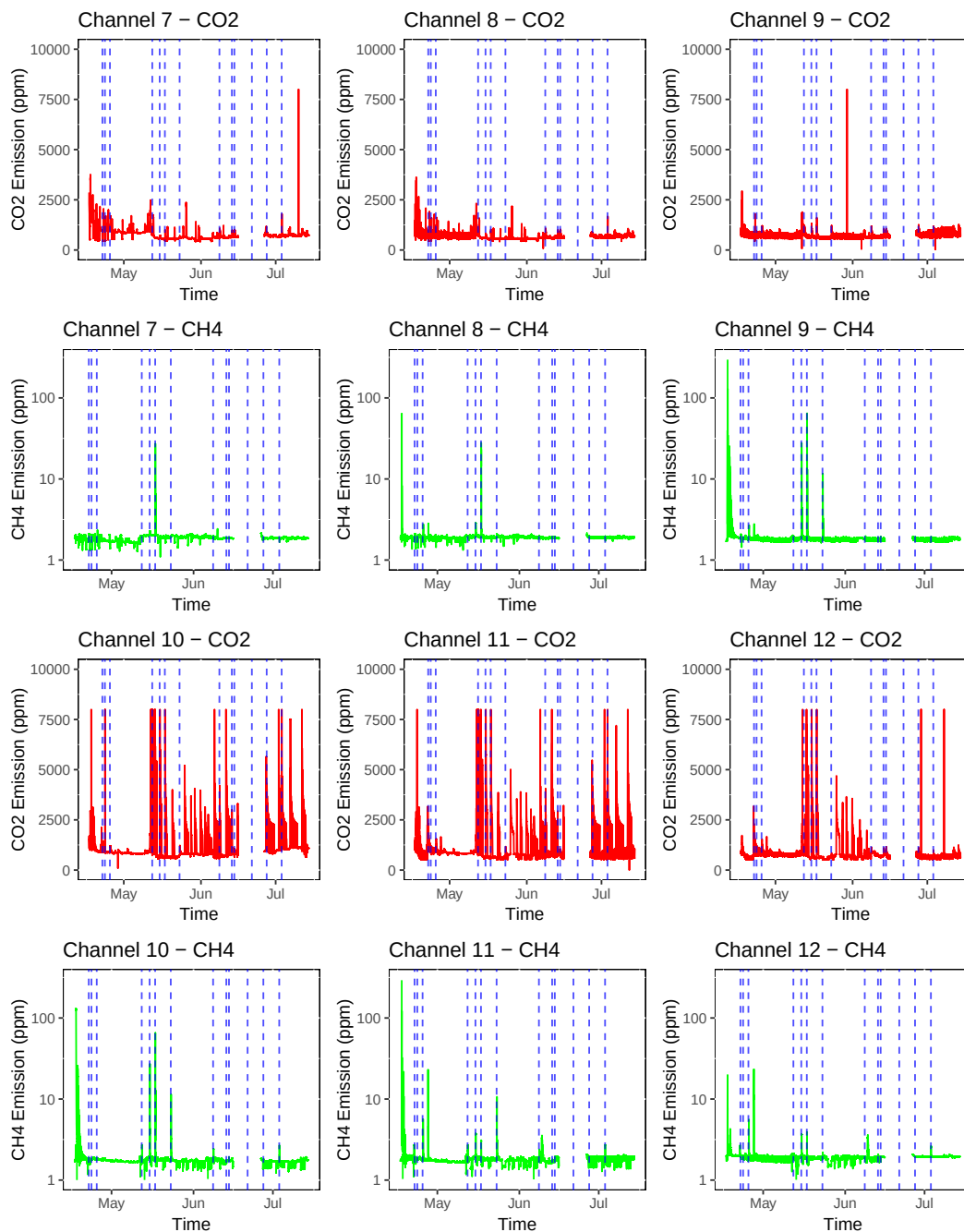


Figure S9. Raw data points of measured CO₂ and CH₄ concentrations (ppm) during the incubation. The blue-dashed lines indicate water addition times. Note that the y-axis is on a logarithmic scale. (Page 2)

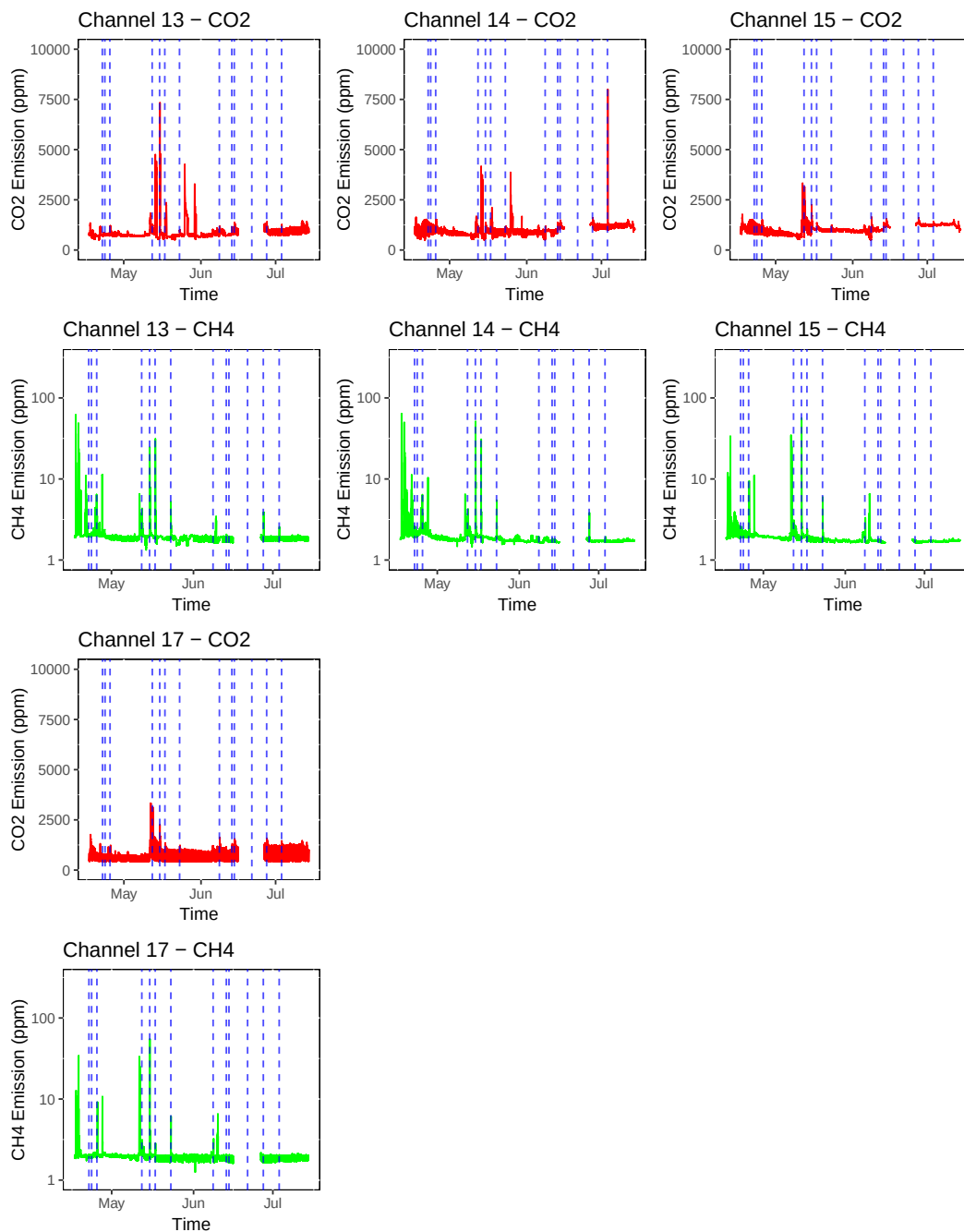


Figure S10. Raw data points of measured CO₂ and CH₄ concentrations (ppm) during the incubation. The blue-dashed lines indicate water addition times. Note that the y-axis is on a logarithmic scale. (Page 3)

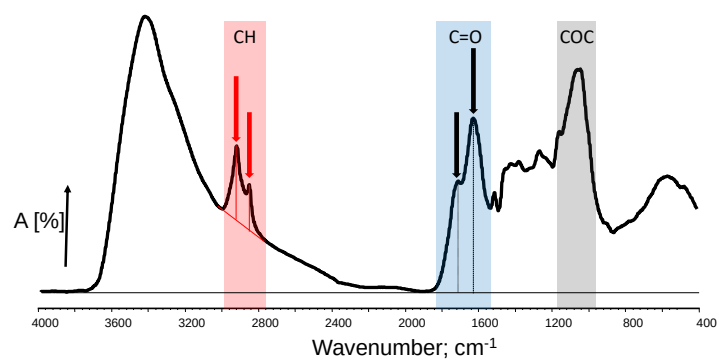


Figure S11. References for wavenumber in a FTIR spectrum. Coloured columns indicate the absorption bands of alkyl (C–H), carboxyl (C=O) and polysaccharide (COC).

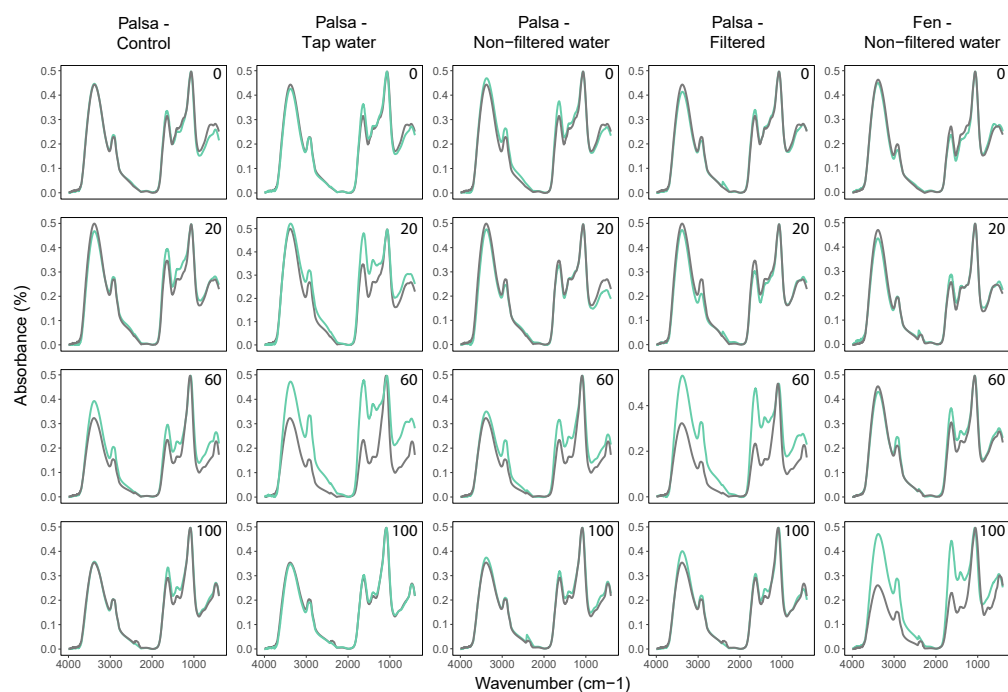


Figure S12. Peat quality along the the soil profile of the Palsa and the fen for each treatment before (grey line) and after (green line) the incubation. FTIR spectra of peat samples collected at the Palsa and fen site from 0 to 2 cm (0), 18 to 22 cm (20), 58 to 62 cm (60), and 96 to 100 cm (100).

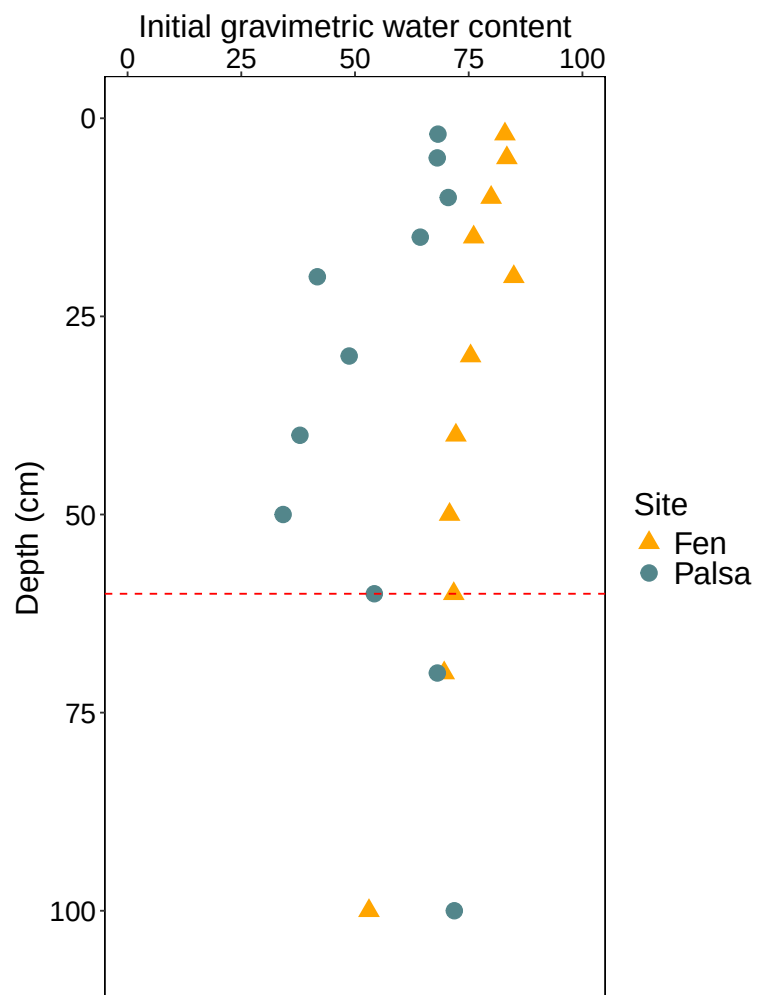


Figure S13. Initial gravimetric soil water content for the first meter of the palsa and the fen prior to incubation. The green circles indicate the values measured from the Palsa and the yellow triangle, those from the fen. The red dashed line represents the permafrost table of the Palsa.

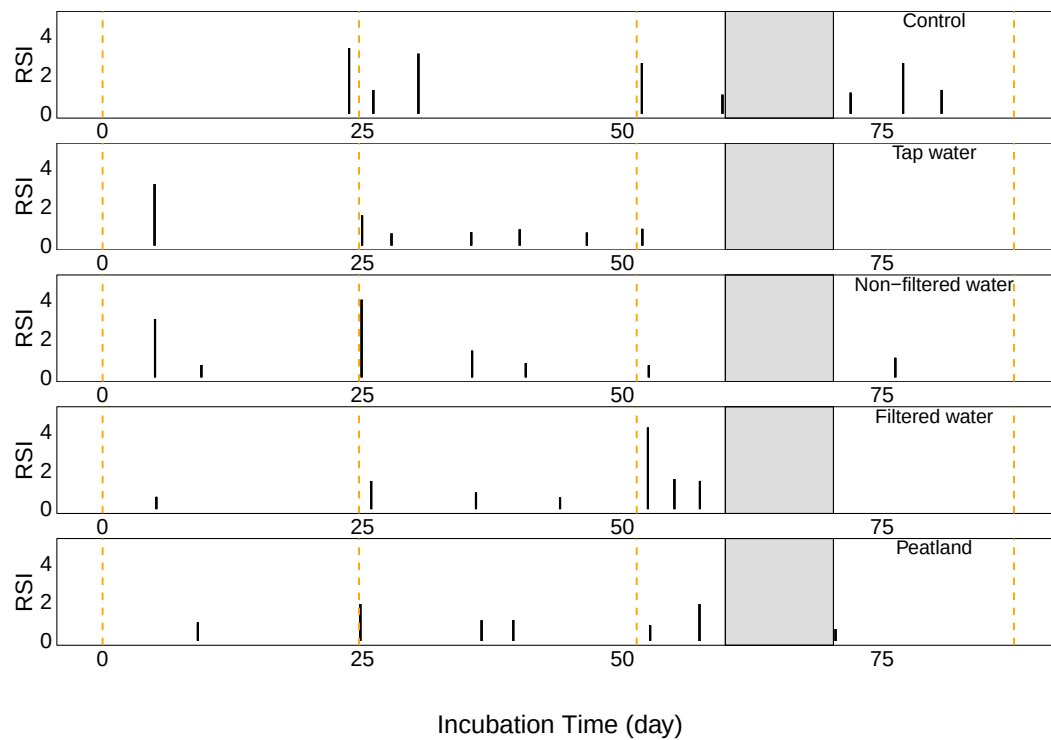


Figure S14. Detection of regime shifts in the average CO₂ emission rates for each treatment. The y-axis shows the Regime Shift Index, that indicates the strength of the regime shift event. The dashed orange lines indicate the thawing steps, while the grey area shows the time window when we had a measurement issue.

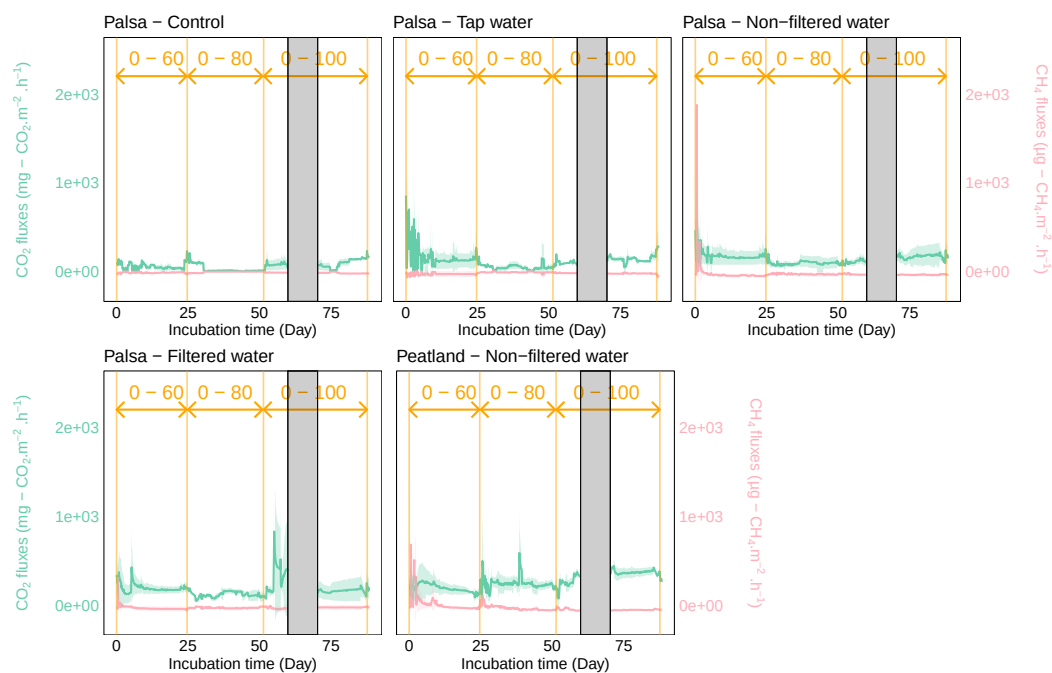


Figure S15. Average CO₂ (in green) and CH₄ (in pink) emission rates for each treatment over the course of the incubation. The orange vertical lines indicate the thawing step events. The depth of the core thawed throughout the incubation period is indicated by the numbers displayed above the arrows.

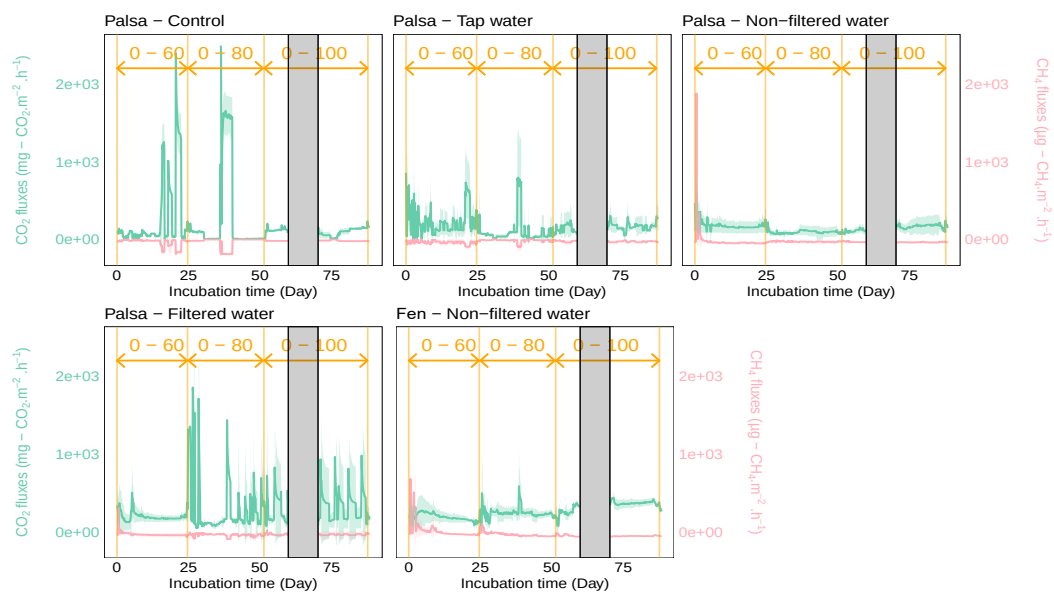


Figure S16. Average CO₂ (in green) and CH₄ (in pink) emission rates without quality control for each treatment over the course of the incubation. The orange vertical lines indicate the thawing step events. The depth of the core thawed throughout the incubation period is indicated by the numbers displayed above the arrows.

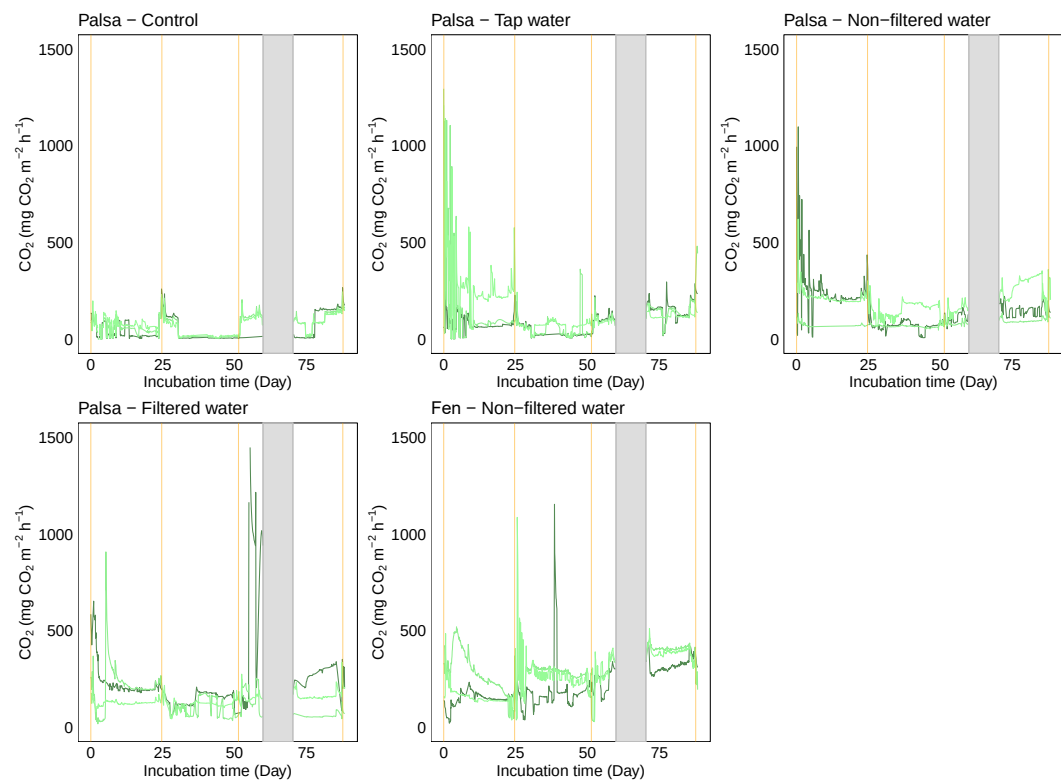


Figure S17. Continuous CO₂ emission rates for each treatment during the incubation period. The green lines in each panel represent the CO₂ emission rates for each individual replicate and the vertical orange lines indicate the thaw stages.

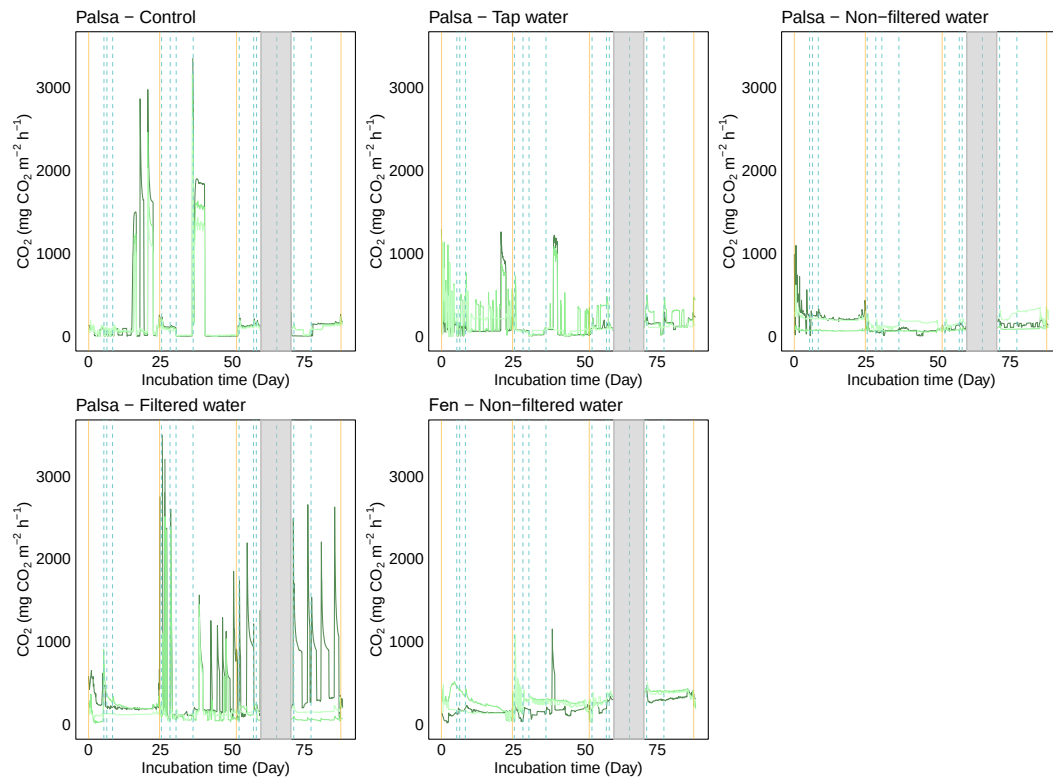


Figure S18. Continuous CO₂ emission rates without quality control for each treatment during the incubation period. The green lines in each panel represent the CO₂ emission rates for each individual replicate, the vertical orange lines indicate the thaw stages and the dashed blue lines indicate the water addition times.

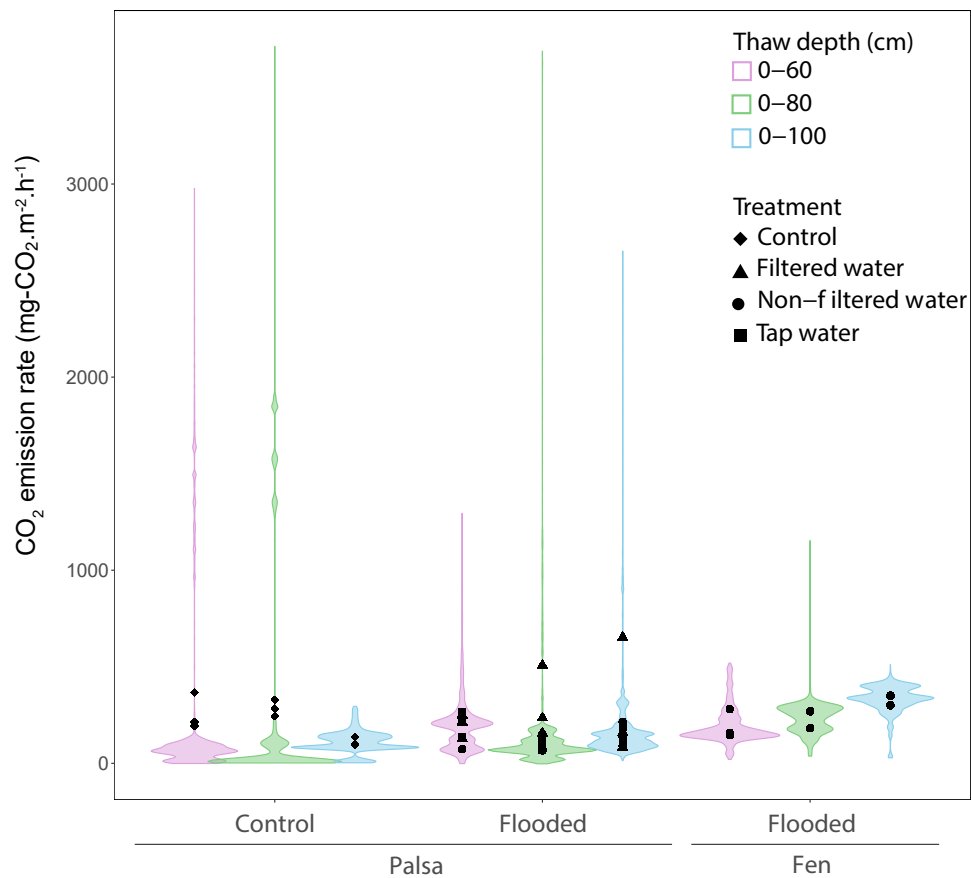


Figure S19. CO₂ emissions rates for each thaw stages under flooded or control conditions without the quality control applied. The distribution uses the time series data of CO₂ emissions from each thaw stage, under conditions (control vs. flooded) and across sites (Palsa vs. fen) to create the violin plots with the points indicating the average CO₂ emission rates for each treatment. The colors show the different thaw stage events.

S5 Supplementary Table Results

Table S1. Data Loss for individual channel due to the CO₂ sensor saturation during the experiment.

Site	Channel	Treatment	Total Data Points	Filtered Data Points	Data Loss (%)
Palsa	1	Control	86000	18326	21.54
	2	Control	86006	10846	12.61
	3	Control	85949	8352	9.72
	4	Tap water	85910	8159	9.50
	5	Tap water	85855	30117	35.08
	6	Tap water	85850	0	0.00
	7	Unfiltered water	85845	3814	4.44
	8	Unfiltered water	85840	21569	25.13
	9	Unfiltered water	85832	480	0.56
	10	Filtered water	85874	27785	32.35
	11	Filtered water	85918	25149	29.27
	12	Filtered water	85934	6815	7.91
Fen	13	Unfiltered water	85930	0	0.00
	14	Unfiltered water	85839	0	0.00
	15	Unfiltered water	85706	0	0.00
No Site	17	Zero Channel	85960	0	0.00

Table S2. Summary of the thawing step stages during the incubation (Depth and duration). The Permafrost thawed column only applies to the cores from the Palsa.

Week of incubation	Thaw depth (cm)	Permafrost thawed	Duration (week)
1-5	0-60	0	4
5-8	0-80	20	4
9-12	0-100	40	4

Table S3. pH and conductivity values of the thermokarst water used for the Non-filtered and Filtered treatments.

Sample	pH	Conductivity ($\mu\text{S.cm}^{-1}$)	DOC (mg.L ⁻¹)
Thermokarst water	4.2	300	9.68

Laurent, M., Lück, M., and Treat, C. C.: Initial soil parameters of a palsa and a peatland core used in a mesocosm incubation, <https://doi.pangaea.de/10.1594/PANGAEA.974304>, dataset in review, 2025.