Supplement of Biogeosciences, 21, 1867–1886, 2024
https://doi.org/10.5194/bg-21-1867-2024-supplement
© Author(s) 2024. CC BY 4.0 License.

Biogeosciences
Open Access

Supplement of

Exploring temporal and spatial variation of nitrous oxide flux using several years of peatland forest automatic chamber data

Helena Rautakoski et al.

Correspondence to: Helena Rautakoski (helena.rautakoski@fmi.fi)

The copyright of individual parts of the supplement might differ from the article licence.

S1. Chamber characteristics

Table S1: Vegetation and distance to nearest trees and ditches. Only living trees growing within 5 m from each chamber are included.

Chamber	Species	Trees (< 5m from chamber)	Distance to ditch
1	*Vaccinium vitis-idea, Carex globularis, Pleurozium schreberi, Hylocomium splendens, Dicranum polysetum*	2.6 m Picea abies, 3.1 m Betula pubescens, 4.8 m Picea Abies	12 m
2	*Vaccinum myrtillus, Dryopteris carthusiana, Dicranum polysetum, Pleurozium schreberi*	Picea abies 3.7 m	10 m
3	*Sphagnum spp., Trientalis europaea*	3.2 m Picea abies, 4.2 m Betula pubescens, 2.4 m Picea abies, 2.2 m Betula pubescens, 3 m Picea abies, 4.2 m Betula pubescens, 4.4 m Picea abies	20 m
4	*Pleurozium schreberi, Dicranum polysetum*	2.9 m Picea abies, 2.5 m Betula pubescens, 3.3 m Picea abies, 3.5 m Betula pubescens, 2.4 m Betula pubescens, 2.4 m Picea abies, 2.8 m Picea abies	5 m
5	*Dryopteris carthusiana, Vaccinum vitis-idae, Vaccinum myrtillus, Pleurozium schreberi, Dicranum polysetum, Hylocomium splendens*	1.9 m Picea abies, 1.6 m Picea abies, 1.2 m Pinus sylvestris, 4.8 m Betula pubescens, 4.5 m Picea abies	5 m
6	*Trientalis europaea, Pleurozium schreberi, Dicranum polysetum, Hylocomium splendens*	2.8 m Picea abies, 3.4 m Betula pubescens, 4.9 m Picea abies, 1.9 m Picea abies, 3.4 m Betula pubescens, 3.8 m Picea abies, 5 m Picea abies, 3.2 m Picea abies, 2.1 m Picea abies, 2.3 m Betula pubescens, 2.7 m Picea abies	20 m

S2. N_2O flux histograms

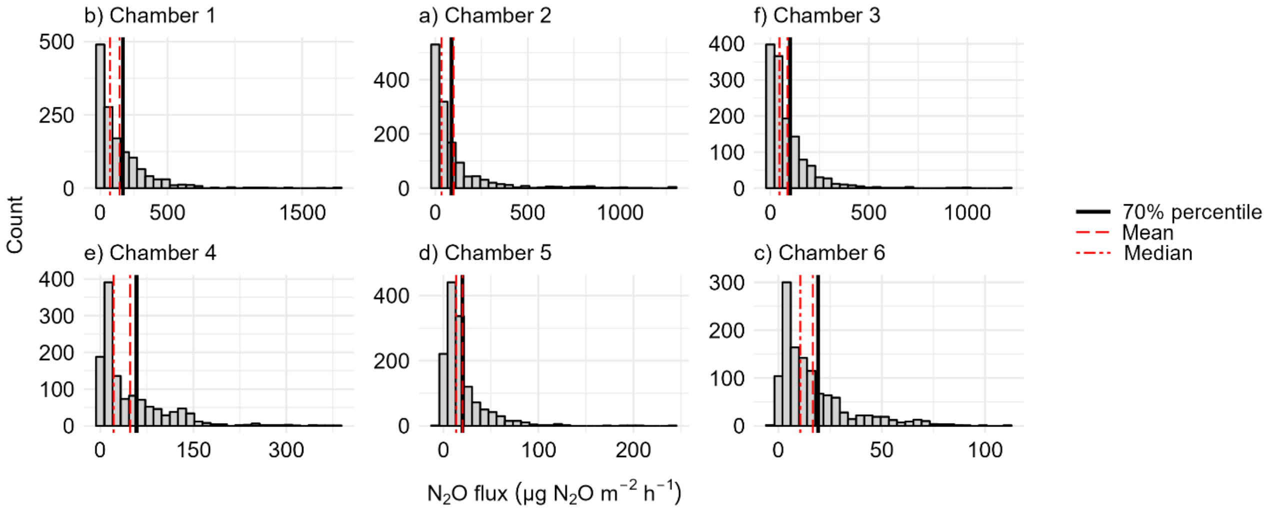

Figure S1: Distribution of daily mean N_2O flux in Chambers 1–6. The chamber-specific mean, median and 70 % percentile that was used to define high-flux days, are shown as vertical lines.

S3. Spatio-temporal variation of N_2O fluxes

Table S2: Mean, minimum and maximum N_2O fluxes in different measurement years. Unit of the N_2O flux is µg N_2O m^{-2} h^{-1}. Years 2015 and 2019 include only part of the year (*). Measurements in Chamber 6 ended six months earlier in 2019 than in other chambers.

	2015*			2016			2017			2018			2019*		
Chamber	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1	77	2	467	215	26	1266	233	–1	1761	43	0.1	322	131	0.5	717
2	63	4	359	189	6	1272	145	–1	1282	24	0.4	198	48	0	294
3	61	–12	476	151	15	1192	130	7	937	30	0.5	227	50	0	333
4	27	2	85	71	9	228	89	7	381	21	1	110	18	–1	87
5	16	0	54	24	3	118	27	–1	244	12	–5	201	21	–2	103
6	16	1	71	24	–1	111	23	–1	74	7	–3	31	7	–3	25

Table S3: Mean, minimum and maximum N_2O fluxes (μg N_2O m^{-2} h^{-1}) in different thermal seasons. All years are included.

	Spring			Summer			Autumn			Winter		
Chamber	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1	122	0	621	199	0	1761	86	2	717	117	–1	1266
2	55	–1	298	173	0	1282	45	6	211	49	0	339
3	57	1	228	96	3	937	44	–12	220	117	0	1192
4	71	1	306	47	–1	381	14	1	72	62	1	184
5	15	0	52	20	–5	244	11	–1	54	30	–3	201
6	9	–3	41	20	–1	77	8	–3	42	21	–1	112

S4. Time series correlations

Table S4: Correlation of N_2O time series between each pair of chambers. Correlations were statistically significant ($p < 0.05$).

	Chamber 1	Chamber 2	Chamber 3	Chamber 4	Chamber 5	Chamber 6
Chamber 1	1.00	0.79	0.64	0.65	0.36	0.40
Chamber 2	0.79	1.00	0.75	0.55	0.29	0.47
Chamber 3	0.64	0.75	1.00	0.69	0.41	0.53
Chamber 4	0.65	0.55	0.69	1.00	0.46	0.48
Chamber 5	0.36	0.29	0.41	0.46	1.00	0.49
Chamber 6	0.40	0.47	0.53	0.48	0.49	1.00

S5. Temporal variation of N_2O within a year

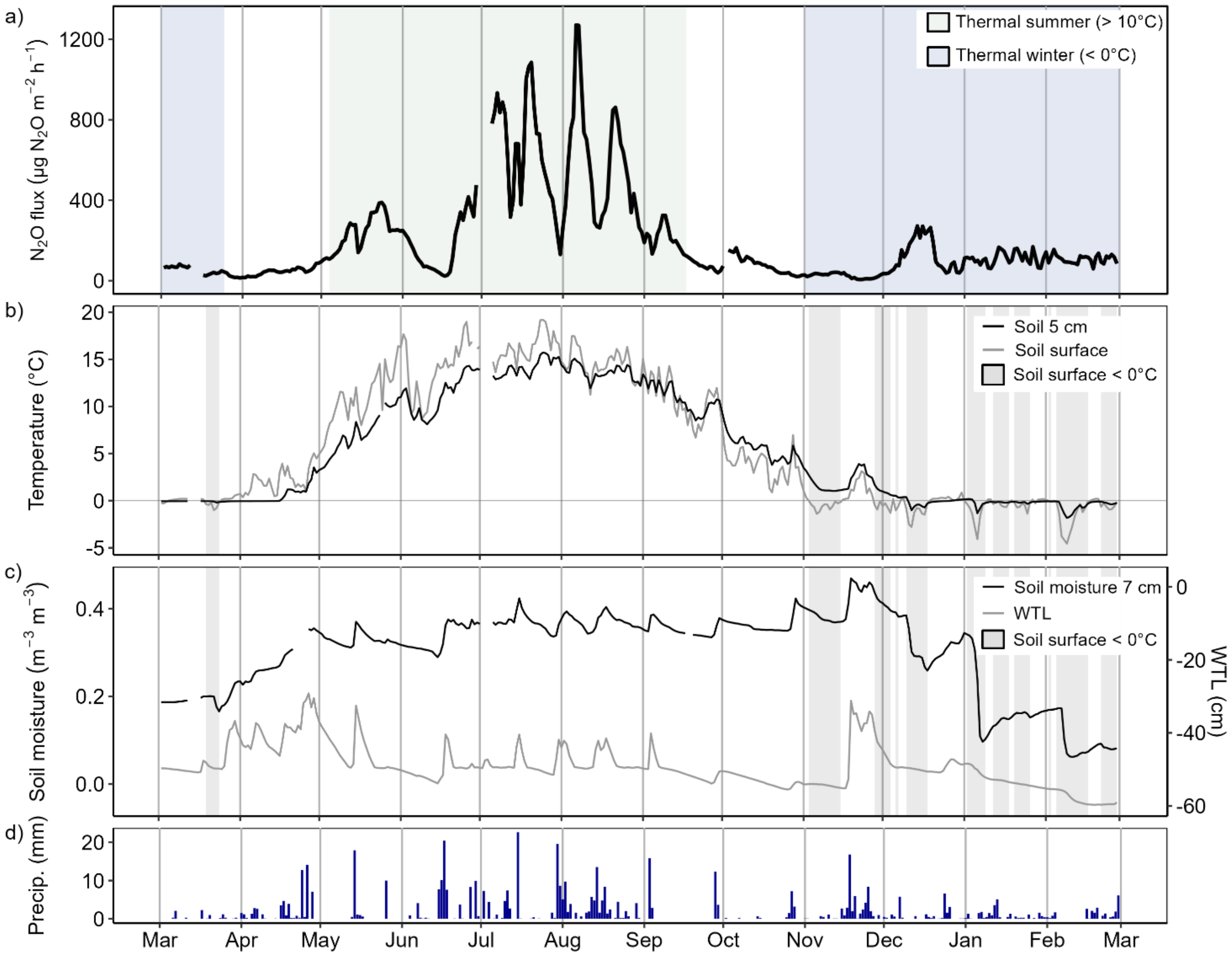

Figure S2: a) Daily mean N_2O flux, b) soil surface temperature and temperature at 5 cm depth with highlighted freezing periods (soil surface temperature < 0 °C), c) soil moisture and water table level (WTL), and (d) daily precipitation from March 2016 to March 2017 in Chamber 2. The shown temporal dynamics of N_2O flux were measured in a year with relatively wet summer and warm winter. Data are not gap-filled. Figure for Chamber 1 is presented in the manuscript (Fig. 6).

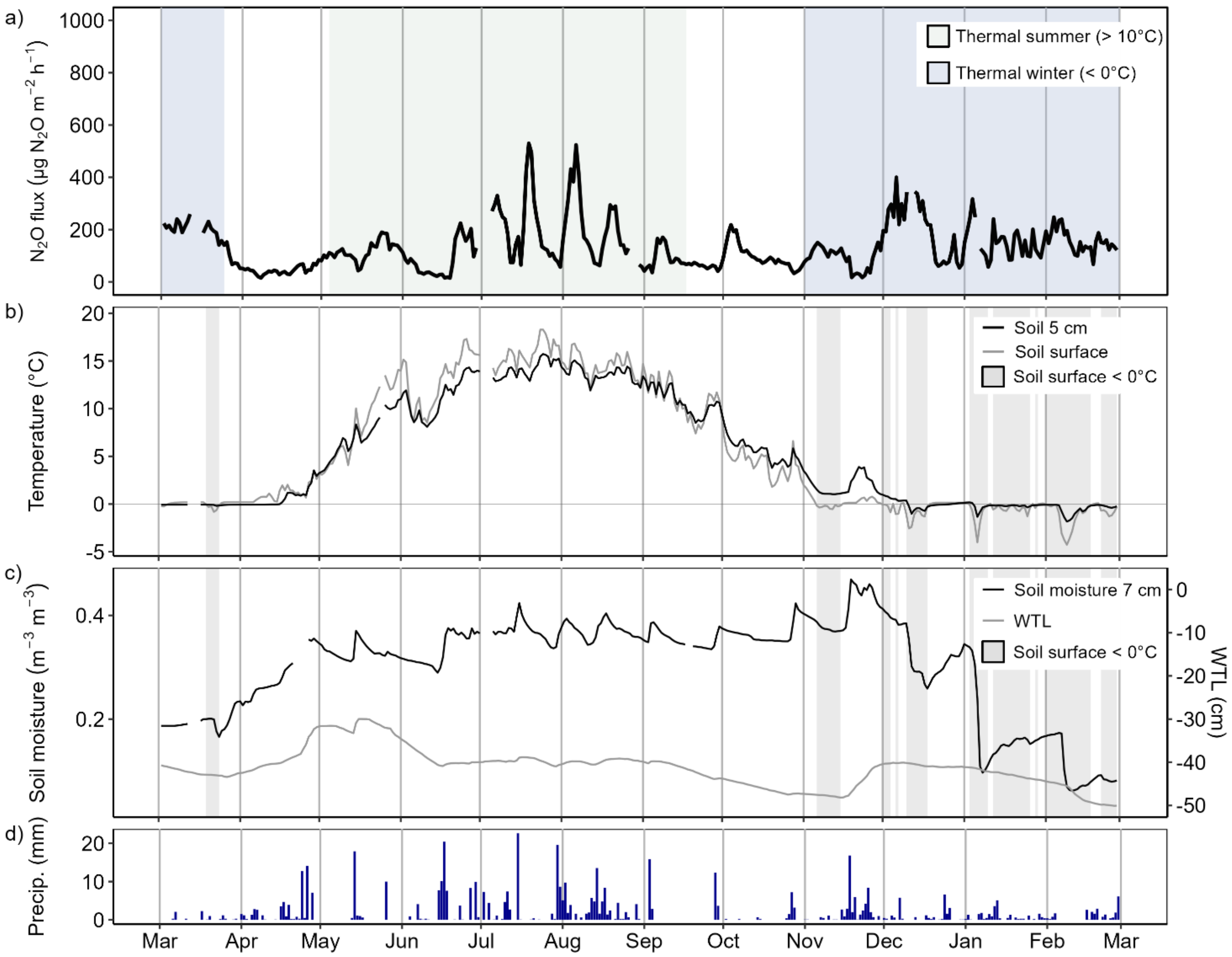

Figure S3: a) Daily mean N_2O flux, b) soil surface temperature and temperature at 5 cm depth with highlighted freezing periods (soil surface temperature < 0 °C), c) soil moisture and water table level (WTL), and (d) daily precipitation from March 2016 to March 2017 in Chamber 3. The shown temporal dynamics of N_2O flux were measured in a year with relatively wet summer and warm winter. Data are not gap-filled. Figure for Chamber 1 is presented in the manuscript (Fig. 6).

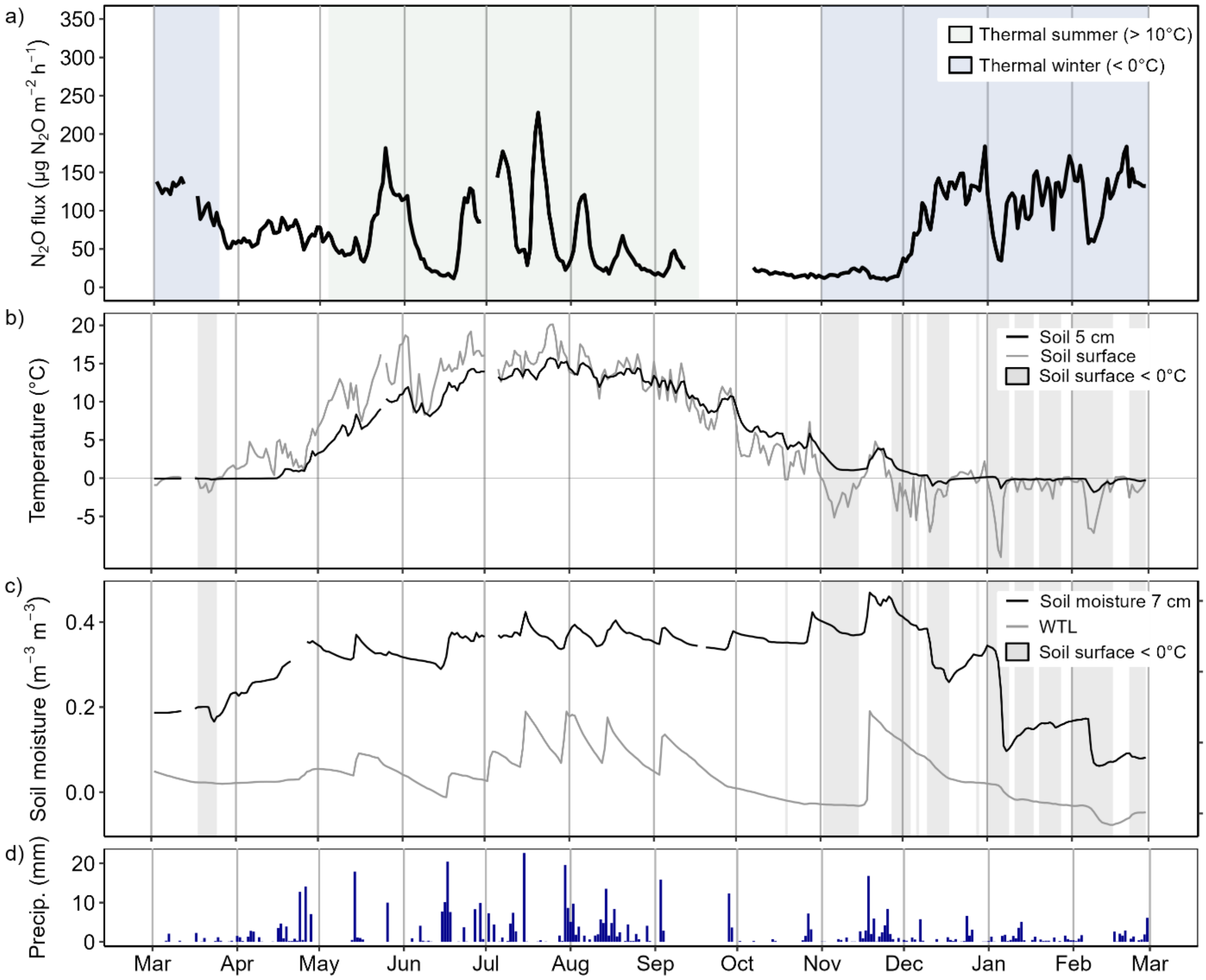

Figure S4: a) Daily mean N_2O flux, b) soil surface temperature and temperature at 5 cm depth with highlighted freezing periods (soil surface temperature < 0 °C), c) soil moisture and water table level (WTL), and (d) daily precipitation from March 2016 to March 2017 in Chamber 4. The shown temporal dynamics of N_2O flux were measured in a year with relatively wet summer and warm winter. Data are not gap-filled. Figure for Chamber 1 is presented in the manuscript (Fig. 6).

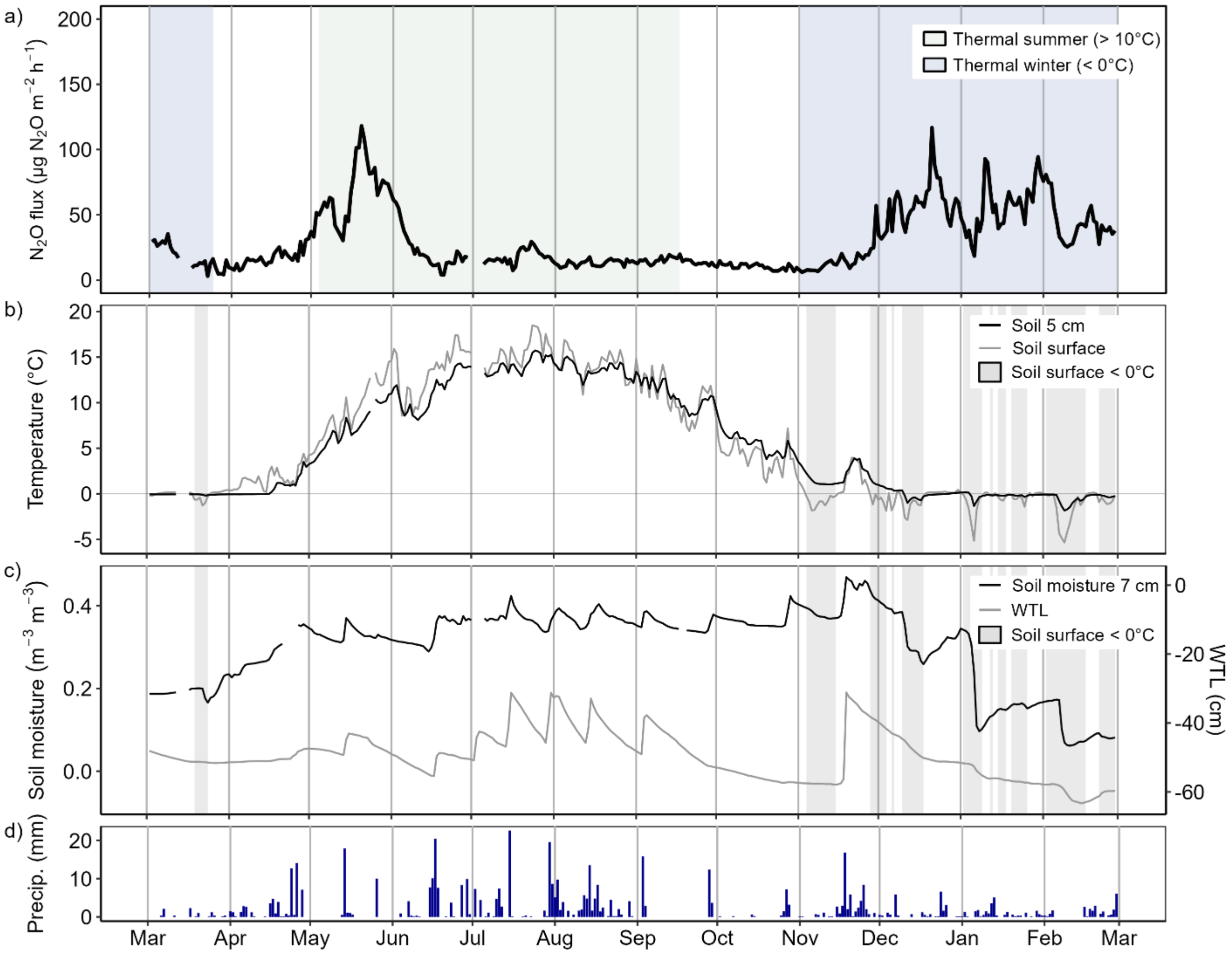

Figure S5: a) Daily mean N_2O flux, b) soil surface temperature and temperature at 5 cm depth with highlighted freezing periods (soil surface temperature < 0 °C), c) soil moisture and water table level (WTL), and (d) daily precipitation from March 2016 to March 2017 in Chamber 5. The shown temporal dynamics of N_2O flux were measured in a year with relatively wet summer and warm winter. Data are not gap-filled. Figure for Chamber 1 is presented in the manuscript (Fig. 6).

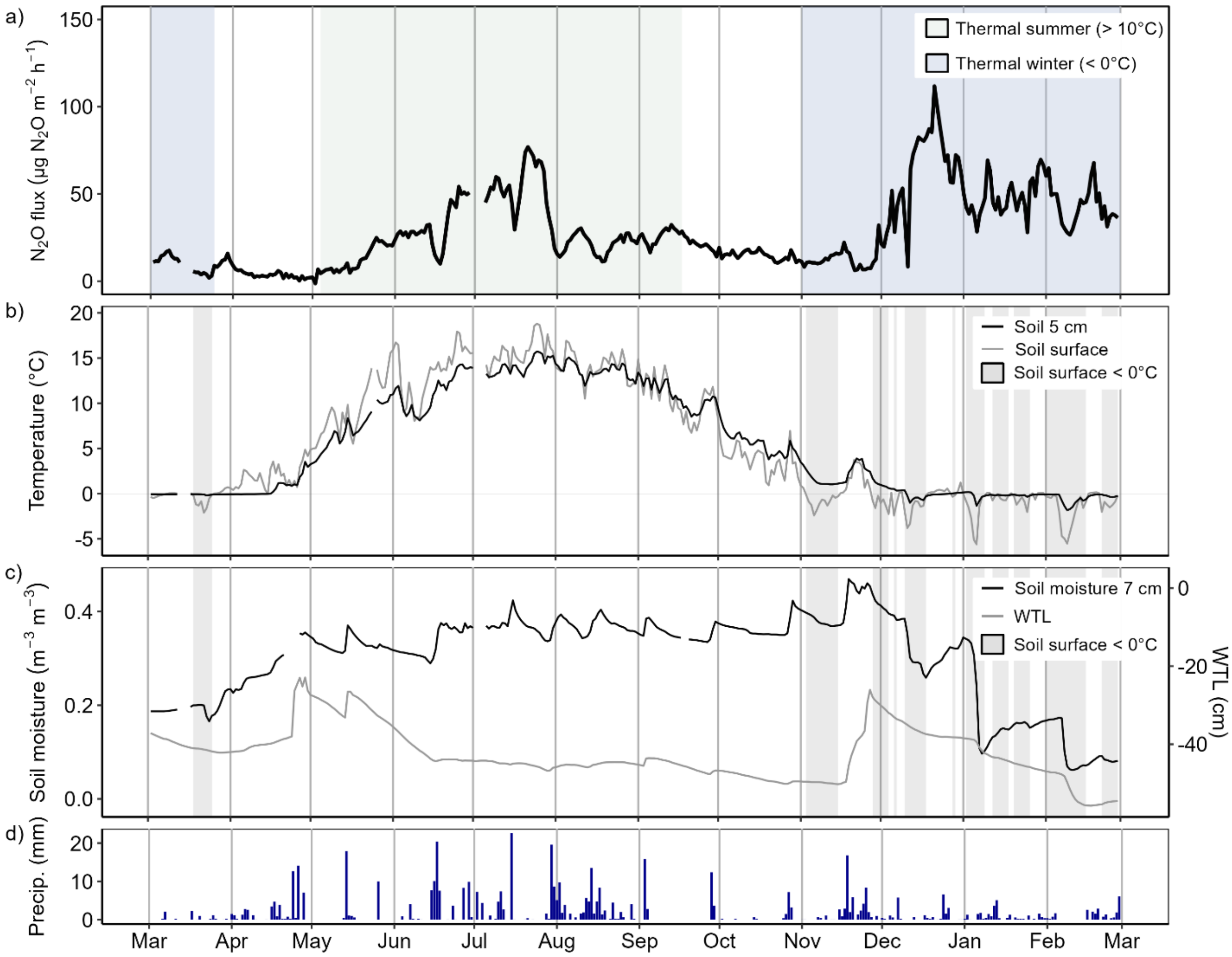

Figure S6: a) Daily mean N_2O flux, b) soil surface temperature and temperature at 5 cm depth with highlighted freezing periods (soil surface temperature < 0 °C), c) soil moisture and water table level (WTL), and (d) daily precipitation from March 2016 to March 2017 in Chamber 6. The shown temporal dynamics of N_2O flux were measured in a year with relatively wet summer and warm winter. Data are not gap-filled. Figure for Chamber 1 is presented in the manuscript (Fig. 6).

S6. Lag-specific variable importance

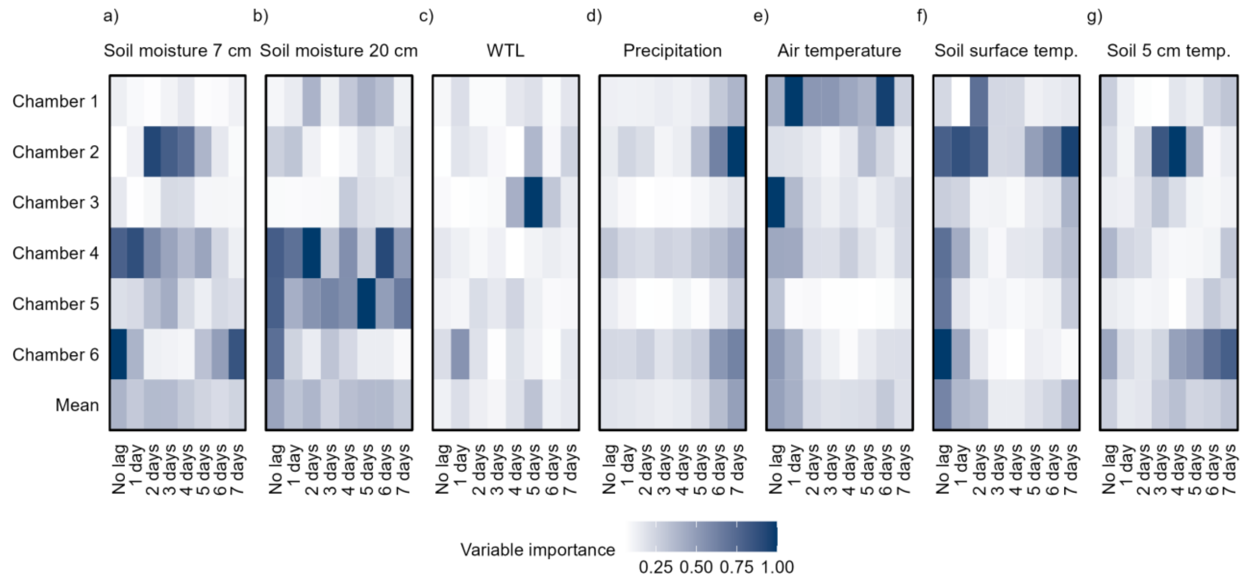

Figure S7: Variable importance (VI) scores of different environmental variables and their lagged versions in explaining the temporal variation of N_2O. The matrix plot shows VI values separately for different chambers (Chambers 1–6) as well as the mean VI across all the chambers (Mean row). VI values are means across 10 runs of Random forest with conditional inference trees. VI scores are scaled between 0 and 1 (0 = lowest importance, 1 = highest importance) per chamber to make VI scores comparable across chambers. Total VIs of each environmental variable are presented in the manuscript (Fig. 8). Comparing VIs of individual lags and unlagged versions of the variables, should be done with care to avoid very data-specific conclusions.

S7. N_2O flux responses to immediate and time-lagged environmental conditions

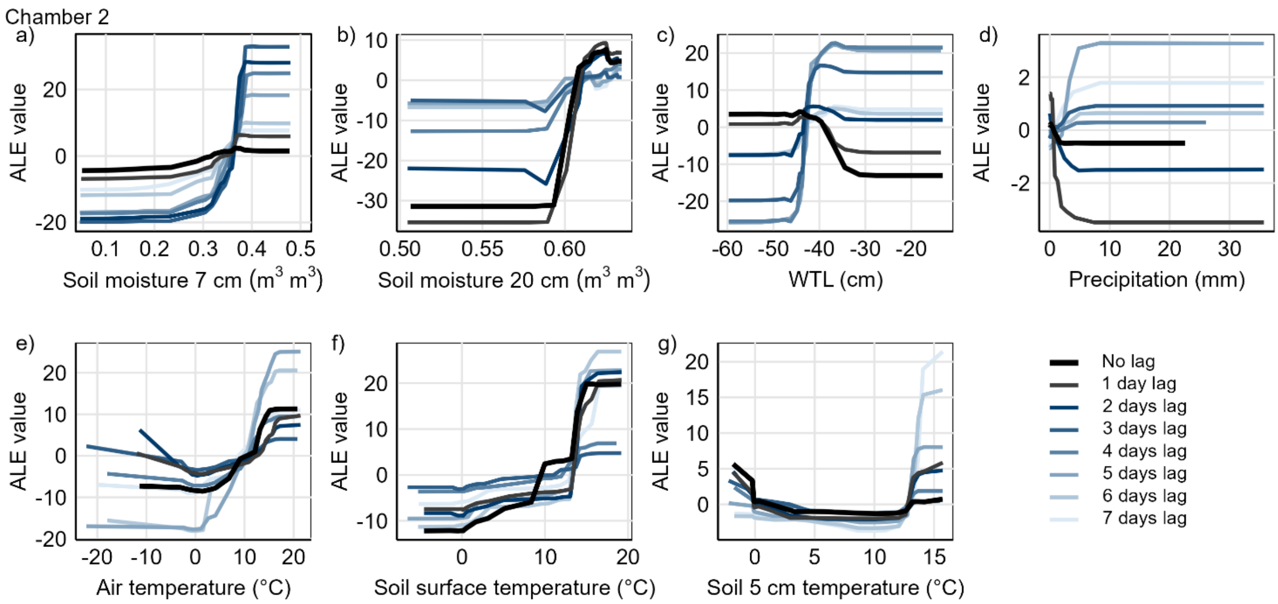

Figure S8: Response of predicted N_2O flux to different environmental conditions for Chamber 2 visualized using Accumulated Local Effects (ALE). Figures illustrate how the predicted N_2O flux values deviate from the mean predicted flux (ALE value = 0) along the gradients of a) soil moisture at 7 cm depth, b) soil moisture at 20 cm depth, c) water table level (WTL), d) precipitation, e) air temperature, f) soil surface temperature and g) soil temperature at 5 cm. ALE responses for unlagged and lagged variables (1–7 days) are included. Responses for chamber 1 are presented in the manuscript (Fig. 9).

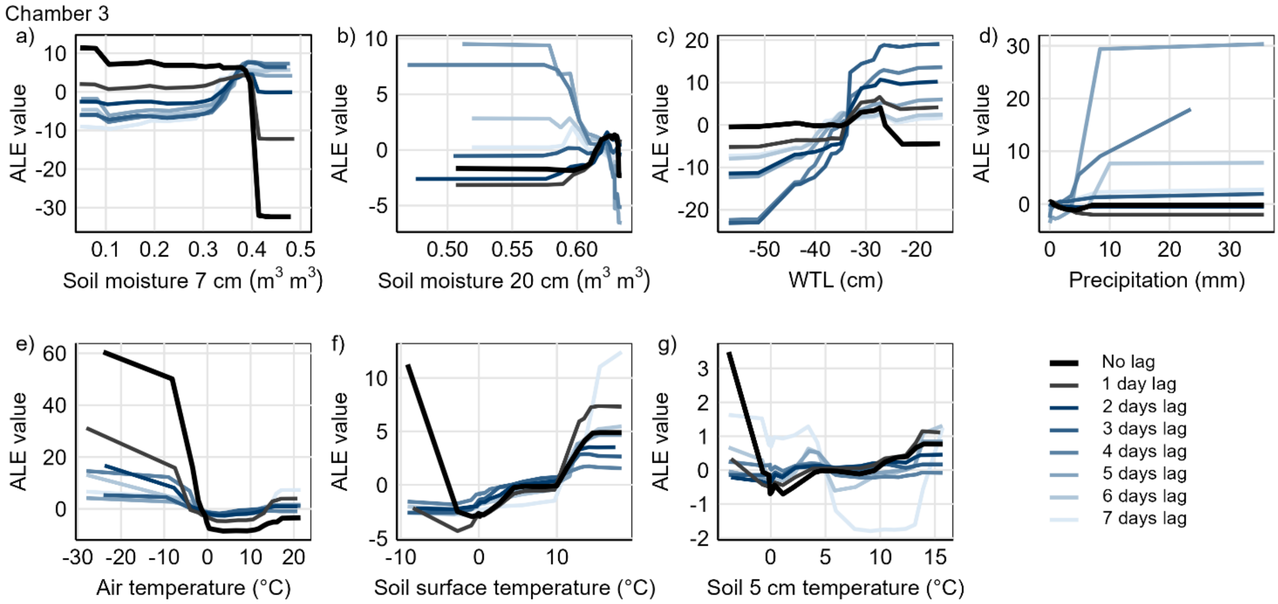

Figure S9: Response of predicted N_2O flux to different environmental conditions for Chamber 3 visualized using Accumulated Local Effects (ALE). Figures illustrate how the predicted N_2O flux values deviate from the mean predicted flux (ALE value= 0) along the gradients of a) soil moisture at 7 cm depth, b) soil moisture at 20 cm depth, c) water table level (WTL), d) precipitation, e) air temperature, f) soil surface temperature and g) soil temperature at 5 cm. ALE responses for unlagged and lagged variables (1–7 days) are included. Responses for chamber 1 are presented in the manuscript (Fig. 9).

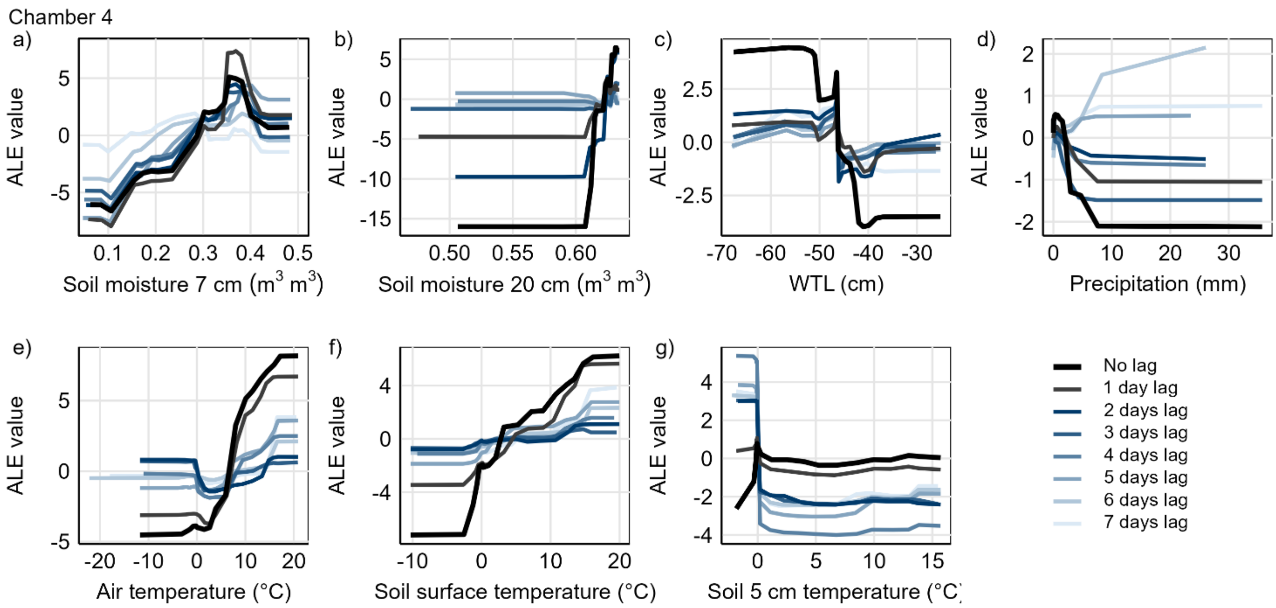

Figure S10: Response of predicted N_2O flux to different environmental conditions for Chamber 4 visualized using Accumulated Local Effects (ALE). Figures illustrate how the predicted N_2O flux values deviate from the mean predicted flux (ALE value = 0) along the gradients of a) soil moisture at 7 cm depth, b) soil moisture at 20 cm depth, c) water table level (WTL), d) precipitation, e) air temperature, f) soil surface temperature and g) soil temperature at 5 cm. ALE responses for unlagged and lagged variables (1–7 days) are included. Responses for chamber 1 are presented in the manuscript (Fig. 9).

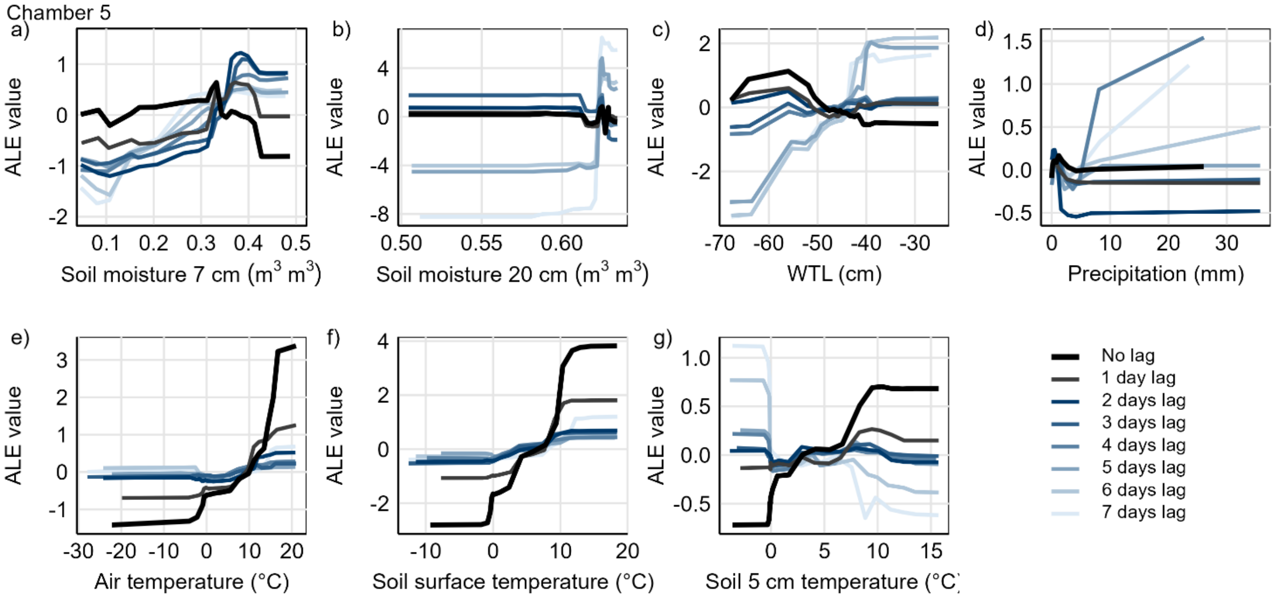

Figure S11: Response of predicted N_2O flux to different environmental conditions for Chamber 5 visualized using Accumulated Local Effects (ALE). Figures illustrate how the predicted N_2O flux values deviate from the mean predicted flux (ALE value = 0) along the gradients of a) soil moisture at 7 cm depth, b) soil moisture at 20 cm depth, c) water table level (WTL), d) precipitation, e) air temperature, f) soil surface temperature and g) soil temperature at 5 cm. ALE responses for unlagged and lagged variables (1–7 days) are included. Responses for chamber 1 are presented in the manuscript (Fig. 9).

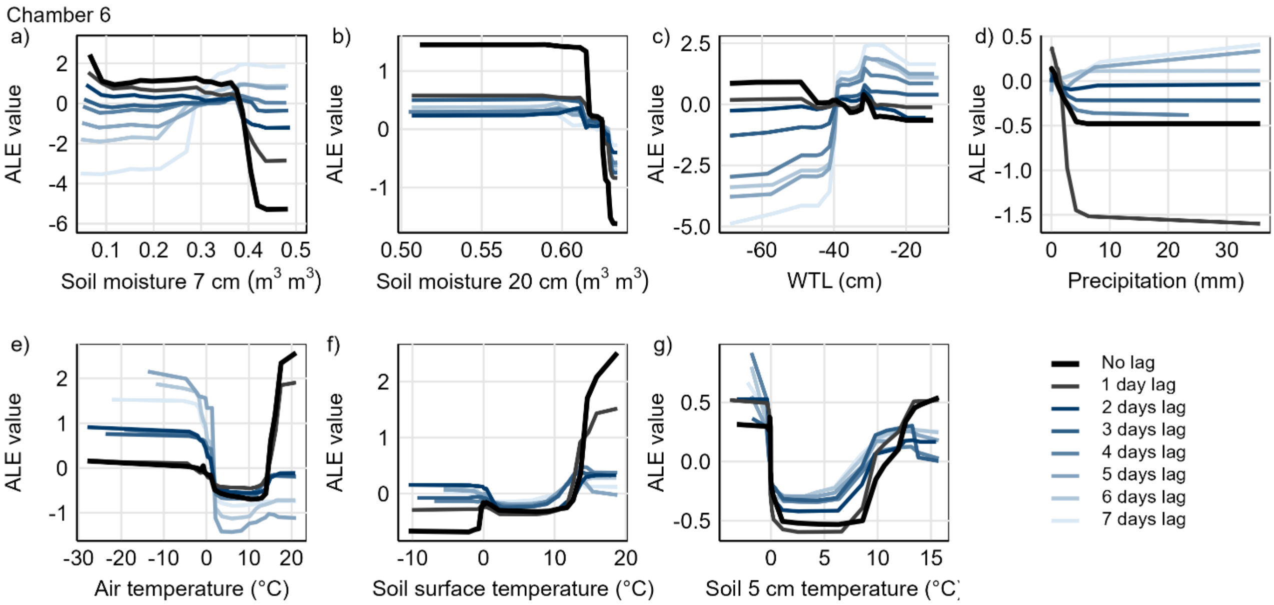

Figure S12: Response of predicted N_2O flux to different environmental conditions for Chamber 6 visualized using Accumulated Local Effects (ALE). Figures illustrate how the predicted N_2O flux values deviate from the mean predicted flux (ALE value = 0) along the gradients of a) soil moisture at 7 cm depth, b) soil moisture at 20 cm depth, c) water table level (WTL), d) precipitation, e) air temperature, f) soil surface temperature and g) soil temperature at 5 cm. ALE responses for unlagged and lagged variables (1–7 days) are included. Responses for chamber 1 are presented in the manuscript (Fig. 9).

S8. N_2O budgets and seasonal contributions

Table S5: Annual N_2O budgets in different chambers. Unit of N_2O budget is mg N_2O m^{-2} y^{-1}. The annual N_2O budget includes only part of the year in 2015 (summer and autumn) and 2019 (spring and summer) (*). Measurements in Chamber 6 ended in early 2019 and the annual budget was not calculated for that year.

Chamber	2015*	2016	2017	2018	2019*
1	469	1886	2114	399	790
2	360	1613	1367	222	283
3	350	1340	1116	281	284
4	141	613	743	214	112
5	88	210	246	112	155
6	87	214	200	59	-
Mean	249	979	964	215	325

Table S6: Contributions of spring fluxes to annual N_2O budgets. Contributions are expressed as percentage (%) of the annual budget. The annual N_2O budget includes only part of the year in 2015 and 2019 (*). Measurements in Chamber 6 ended in early 2019 and the annual N_2O budget was not calculated for that year.

Chamber	2015*	2016	2017	2018	2019*
1	-	5	12	9	24
2	-	3	11	6	19
3	-	4	14	9	26
4	-	11	27	13	45
5	-	8	6	8	21
6	-	2	12	9	-
Mean	-	6	14	9	27

Table S7: Contributions of summer fluxes to annual N_2O budgets. Contributions are expressed as percentage (%) of the annual budget. The annual N_2O budget includes only part of the year in 2015 and 2019 (*). Measurements in Chamber 6 ended in early 2019 and the annual N_2O budget was not calculated for that year.

Chamber	2015*	2016	2017	2018	2019*
1	77	52	61	64	48
2	53	79	67	59	64
3	63	36	48	41	63

4	66	35	39	36	34
5	52	44	48	28	15
6	66	45	42	42	-
Mean	63	49	51	45	45

Table S8: Contributions of autumn fluxes to annual N_2O budgets. Contributions are expressed as percentage (%) of the annual budget. The annual N_2O budget includes only part of the year in 2015 and 2019 (*).

Chamber	2015*	2016	2017	2018	2019*
1	18	5	14	7	-
2	37	5	9	12	-
3	24	7	14	13	-
4	30	5	6	5	-
5	41	6	16	8	-
6	25	8	12	6	-
Mean	29	6	12	9	-

Table S9: Contributions of winter fluxes to annual N_2O budgets. Contributions are expressed as percentage (%) of the annual budget. The annual N_2O budget includes only part of the year in 2015 and 2019 (*).

Chamber	2015*	2016	2017	2018	2019*
1	-	37	14	20	-
2	-	13	24	23	-
3	-	53	27	36	-
4	-	49	30	45	-
5	-	43	34	56	-
6	-	44	20	43	-
Mean	-	40	25	37	-

S9. Model performance

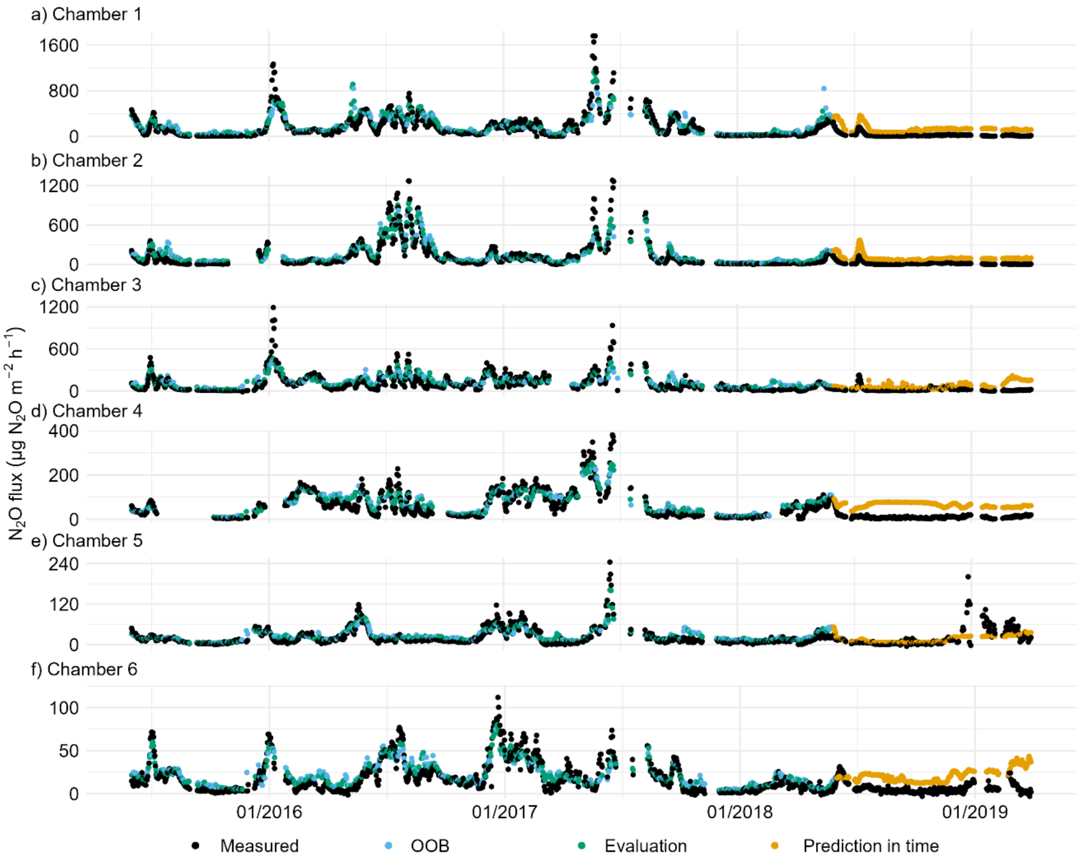

Figure S13: Measured and predicted N_2O fluxes plotted against time. Figures (a–f) show predicted values from random forest with conditional inference trees separately for six chambers. Points are colored by the used data with out-of-bag (OOB) data, evaluation data within training period (30 % of first three years of data) and prediction in time data (outside model training period, fourth year of data) different types of evaluation datasets, and daily means of measured fluxes.