

A cross-site comparison of ecosystem- and plot-scale methane fluxes across multiple sites

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45 **Abstract.** Wetland and upland ecosystems play significant but opposing roles in the global methane (CH₄) budget, acting as
natural sources and sinks, respectively. Two of the most common approaches for measuring CH₄ fluxes (FCH₄) are chambers,
which capture temporally intermittent, fine-scale spatial heterogeneity (ca. 1 m²), and eddy covariance (EC) towers, which
cover a larger area (ca. 100-10000 m²) at a longer term. Although chamber and EC observations have been combined in various
syntheses and databases to estimate CH₄ budgets, a unified cross-site evaluation of FCH₄ estimates at plot and ecosystem
50 scales is lacking. As a first step toward a systematic spatiotemporal scaling of EC tower and chamber footprints, we quantified
the differences between site-level aggregate FCH₄ (EC vs chamber; ΔFCH_4) from ten wetland and upland sites at half-hourly,
hourly, daily, weekly, monthly, and annual timescales. We found that ecosystem-scale median FCH₄ was consistently higher
than plot-scale FCH₄ at all temporal scales, with the smallest difference at daily timescale (multi-site median ΔFCH_4 : 1.36
nmol m⁻² s⁻¹; median ecosystem-scale FCH₄ = 1.56 nmol m⁻² s⁻¹, median plot-scale FCH₄ = 0.06 nmol m⁻² s⁻¹) and largest at
55 annual scales (2.58 nmol m⁻² s⁻¹; median ecosystem-scale FCH₄ = 25.91 nmol m⁻² s⁻¹, median plot-scale FCH₄ = 6.55 nmol m⁻²
s⁻¹). In general, the agreement between ecosystem- and plot-scale FCH₄ decreased with finer temporal resolution (from
Spearman $\rho=0.95$ at annual scale to $\rho=0.65$ at half-hourly scale), while ΔFCH_4 variation was greatest at daily-to-annual scales.
Key environmental predictors of ΔFCH_4 at the ten sites included plot-scale spatial heterogeneity, dominant vegetation type,
vapor pressure deficit, atmospheric pressure, and friction velocity at the daily and monthly scales. Wind direction was a
60 significant predictor only at the monthly scale, suggesting EC footprint effects at these sites. These findings suggest accounting
for variation in EC footprint extent, chamber measurement placement and artifacts is key to reconciling multi-scale FCH₄
observations in diverse ecosystems and refining CH₄ budgets.

1 Introduction

Methane (CH₄), a potent greenhouse gas, is produced in wetlands and consumed in upland soils- respectively the largest natural
65 CH₄ sources and sinks globally. However, the magnitude of these fluxes remains highly uncertain (IPCC, 2023; Saunio et al.,
2024). Field measurements of CH₄ fluxes (FCH₄) are often conducted using enclosed chamber systems or eddy covariance
(EC) towers (Bansal et al., 2023b). Chambers are typically deployed at point scale (<1 m²) to capture plot-scale spatial
heterogeneity in CH₄ source-sink dynamics within the study area (Livingston and Hutchinson, 1995; Morin et al., 2017;
Virkkala et al., 2018). Chamber measurements can be manual or automated, the former is more labor-intensive and thus, results
70 in a temporally sporadic sampling pattern (typically few per month), while the latter offers more consistent and long term
temporal sampling (typically half hourly over seasons) but can be more spatially limited due to high instrumentation cost.
Thus, chambers generally represent a lower fraction of the ecosystem (Barba et al., 2018; McGuire et al., 2012; Morin et al.,
2014, 2017).

In contrast, EC towers continuously measure FCH₄ with high temporal resolution, typically half hourly, over seasons and years
75 (Morin, 2019; Morin et al., 2017). The EC technique is based on the principle that the measured FCH₄ that originates from the
tower footprint area (100-10000 m²) is carried upwards and outward toward the sensor by turbulent diffusion (Aubinet et al.,

2012; Morin et al., 2014). Therefore, a single half-hourly EC measurement represents a mixed observation at the ecosystem scale located over a somewhat uncertain footprint area, which changes from one observation to the other, and may include a mixture of distinctly different ecosystem and hydrological patches (Chu et al., 2021; Xu et al., 2018). At the ecosystem subtype scale (i.e., “plot scale”), chamber measurements represent fixed sampling points with well-defined spatial location but limited areal extent. Averaging multiple chamber observations in the same plot (defined as “spatial replicates”) increases the area representation of the chamber observation, but it is still several orders of magnitude smaller than EC measurements. While both approaches provide complementary perspectives on ecosystem FCH₄, the data provided by each method pose different challenges for model parameterization or evaluation of relevant ecosystem FCH₄ processes across spatial and temporal scales.

85 Many global and regional FCH₄ models are parameterized using EC FCH₄ data because of its consistent temporal sampling and because the EC reporting standard include environmental covariates (e.g., McNicol et al., 2023; Oikawa et al., 2024; Peltola et al., 2019; Ueyama et al., 2023b). Community-contributed datasets, such as FLUXNET-CH₄ (Delwiche et al., 2021; Knox et al., 2019), offer unprecedented opportunity to access EC FCH₄ data from around the globe. However, even large collaborations such as FLUXNET-CH₄ only cover a relatively small number of locations, from a global perspective, and is missing important coverage in key ecosystems (e.g., tropics; Delwiche et al., 2021; Zhu et al., 2024). Chamber FCH₄ data are cheaper and simpler to deploy and are therefore implemented in a larger number of sites globally. Thus, sites with chambers provide a greater global measurement coverage than EC sites and are needed to fill the missing data gaps. As a result, data from EC and chamber methods are sometimes compiled to augment syntheses and budget estimations (Hill and Vargas, 2022b; Kuhn et al., 2021; Yuan et al., 2024). Integration of plot-scale chamber FCH₄ data into ecosystem-scale EC datasets poses several challenges due to methodological differences (Hill and Vargas, 2022b). These challenges also apply to carbon dioxide (CO₂) measurements, with studies noting significant discrepancy between the two, partly due to manual chambers (and sometimes EC) often lacking nighttime measurements, biasing flux estimates (Barba et al., 2018; Phillips et al., 2017). Chamber and EC FCH₄ measurements also contain different uncertainties due to varying methods for measuring gas concentration in the chamber measurement techniques (e.g., gas chromatography vs high-precision CH₄ analyzers) and different EC and chamber instrument makes and models (Christiansen et al., 2015; Peltola et al., 2014; Pihlatie et al., 2013). To our knowledge, a systematic comparison of FCH₄ from these different scales across multiple sites, has not been conducted (but see Davidson et al. 2017).

Plot and ecosystem-scale FCH₄ can differ due to the different FCH₄ source areas, measurement artifacts and uncertainties of the chamber and EC methods, and differences in their response to environmental FCH₄ drivers. In many comparison studies conducted in wetland and upland ecosystems, chamber FCH₄ is higher than EC FCH₄ (Chaichana et al., 2018; Clement et al., 1995; Davidson et al., 2017; Krauss et al., 2016; Marushchak et al., 2016; Meijide et al., 2011; Morin et al., 2017; Riutta et al., 2007), although some studies report the opposite (Budishchev et al., 2014; Forbrich et al., 2011; Hill and Vargas, 2022b; Schrier-Uijl et al., 2010; Wang et al., 2013) and others find that the direction of the difference varies between years (Korrensalo et al., 2018). Since the attribution of surface cover type and location is better defined in chamber measurements, chamber FCH₄

110 sampling can offer more representative estimates of FCH₄ variability within a site (Bansal et al., 2023a). However, chambers
capture a small portion of the landscape, are often placed in high-emitting hotspots, do not sample over tall vegetation patches,
and may incorporate sampling location biases (Bansal et al., 2023b), leading to higher observed fluxes at the individual sampled
plots, than the mean ecosystem-scale FCH₄ as measured by EC (but see Voigt et al., 2023). For example, placing chambers
over CH₄-emitting hollows in a peatland could bias ecosystem FCH₄ estimates, as the lower FCH₄ in other peatland
115 microtopographic forms and margins may not be captured (e.g., Bubier 1993; 1995; Juselius-Rajamäki et al., 2025;
Waddington and Roulet, 2000). The EC method integrates FCH₄ over the constantly moving and often spatially heterogeneous
footprint, and the surface cover types within the footprint differ substantially in FCH₄ and, in wetlands, may include non-
flooded areas where FCH₄ is expected to be near zero (Kutzbach et al., 2004; Riutta et al., 2007; Sha et al., 2011), which can
also introduce significant bias (Morin et al., 2017). Environmental variables that influence FCH₄ variability, such as soil
120 temperature, water table level (or water elevation in flooded sites), and net ecosystem CO₂ exchange, could also predict cross-
scale FCH₄ differences given the different processes influencing FCH₄ at different spatial and temporal scales (Knox et al.,
2021; Morin et al., 2014; Turetsky et al., 2014). EC observations are sensitive to environmental variables, such as wind speed
and direction, that affect the extent and location of the observation footprint, while chamber measurements should be unaffected
by these (Wang et al., 2013). While some studies have evaluated EC-chamber FCH₄ differences with spatially explicit FCH₄
125 upscaling or downscaling with the help of EC footprint modeling, many of these studies have been conducted in individual
sites (e.g., Budishchev et al., 2014; Marushchak et al., 2016; Morin et al., 2017; Schrier-Uijl et al., 2010). Thus, an exploration
of bulk-scale FCH₄ differences between ecosystem- and plot-scale FCH₄ (based on spatiotemporal aggregations) and their
controls across multiple sites can help in directing future research efforts utilizing EC footprint modeling to reconcile cross-
scale FCH₄ differences.

130 To explore the differences between ecosystem and plot-scale FCH₄ (Δ FCH₄) measured by EC and chamber systems,
respectively, and to identify the time scales and environmental conditions at which the two data types agree best, we 1)
compared co-located and contemporaneous EC and chamber FCH₄ rates across multiple sites and examined how the
differences ranged across temporal scales (half-hourly to annual), and 2) investigated the potential predictors of Δ FCH₄ at
these sites. To achieve this, we utilized FCH₄ data commonly used by the FCH₄ community, i.e., gap-filled EC data and
135 chamber data quality-controlled in different ways by data providers (ebullition events were removed in some datasets as is
common for chamber FCH₄ data; Jentsch et al., 2025) (see 2.2.1 and Table C2). We hypothesized that plot-scale FCH₄ would
be higher than ecosystem-scale FCH₄ as chambers often selectively target FCH₄ hotspots and manual chamber measurements
are often conducted at warmer daytime conditions. We expected that Δ FCH₄ is highest during daytime when most chamber
measurements are conducted and plant activity is high, the latter of which is fully captured by towers but not always by manual

140 chambers (Knox et al., 2021; Yu et al., 2013). This comparison of bulk FCH₄ rates is a key first step toward standardized harmonization of EC tower and chamber footprints to account for spatiotemporal heterogeneity across multiple sites.

We hypothesized that larger variance (suggesting higher spatio-temporal heterogeneity) observed in chambers and EC measurements would increase Δ FCH₄, and that the different temporal resolutions of manual and automated chambers would further contribute to Δ FCH₄. Finally, we expected that the temporal scale of data aggregation could influence the magnitude
145 of Δ FCH₄, and we hypothesized that Δ FCH₄ would be lower at coarser (seasonal to annual) than at finer (hourly to daily) temporal aggregations.

2 Methods

2.1 Study sites

We compiled ecosystem-scale (EC) and plot-scale (chamber) FCH₄ data from ten sites, representing different climatic
150 conditions and ecosystem types (two uplands and eight wetlands; Fig. 1, Table 1). Each site differed in the number of days with both chamber and EC measurements (n=5-759), the number of chambers used (n=3-18), the year of observations (range across sites: 2012-2020), and whether the chambers were automated or manual (Table C1 and Fig. B1). The site selection was based on the availability of coincident EC and chamber FCH₄ data. EC data were obtained from the FLUXNET-CH₄ database (Delwiche et al., 2021; Knox et al., 2019) and chamber data were provided by site principal investigators in response to a call
155 for data via the FLUXNET-CH₄ network. The sites are located in China, Finland, Sweden and the USA. Most sites have a humid continental (n=3) or subarctic climate (n=3), with others located in humid subtropical (n=3) and cold subtropical highland (n=1) regions (Table 1).

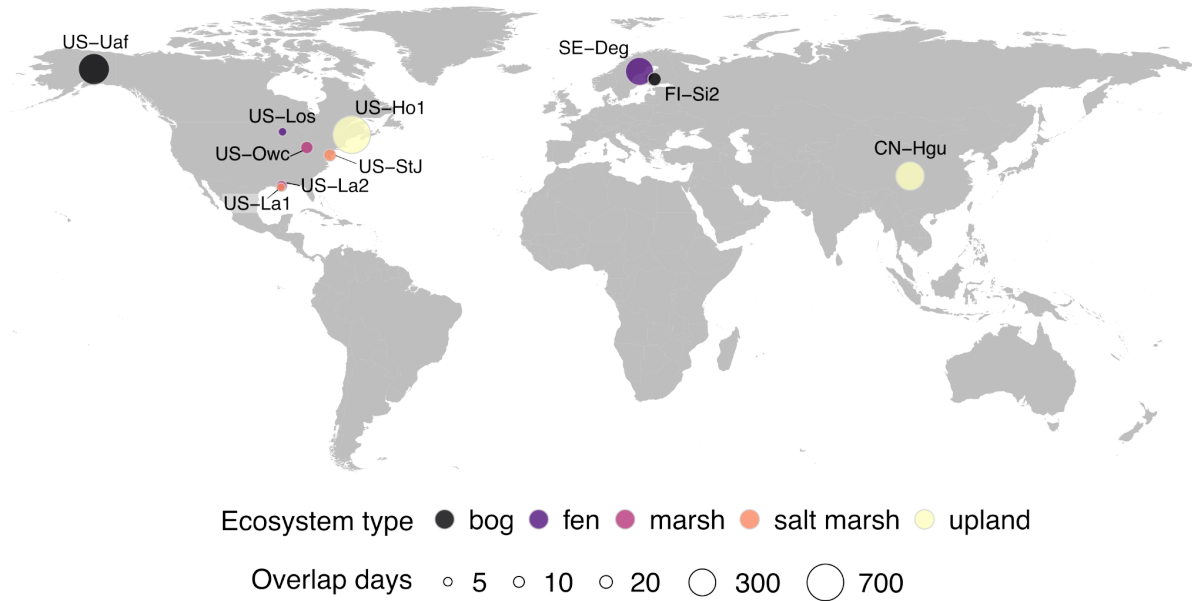


Figure 1. Map of study sites. Point colors indicate ecosystem type and point size reflects the number of overlap days between eddy covariance and chamber measurements (details in Table C1). Ecosystem type follows the site classification in the FLUXNET-CH₄ database (Delwiche et al., 2021; Knox et al., 2019). Base map: Natural Earth (1:50 m Cultural Vectors; naturalearthdata.com), created with R package *maps* (Becker et al., 2023).

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Table 1. Environmental characteristics of the study sites during the methane (CH₄) flux (FCH₄) observation periods. Site classification, dominant vegetation, air temperature, precipitation, and water table level data were obtained from half-hourly FLUXNET-CH₄ and chamber datasets (Delwiche et al., 2021; Knox et al., 2019). Mean air temperature, total precipitation, and mean water table level were calculated over the eddy covariance (EC)-chamber overlap periods used in the analyses. Negative water table level indicates that water table level was below the soil surface. Köppen climate abbreviations: Cwc = cold subtropical highland, Dfc = subarctic, Dfb = warm-summer humid continental, Cfa = humid subtropical, Dwc = monsoon-influenced subarctic climate. Column abbreviations: TA = air temperature, P = total precipitation, WTL = water table level, Vegetation = site dominant vegetation type, Overlap days = number of days with both EC and chamber FCH₄ observations. In Overlap days, values marked with and without asterisk (*) represent automated and manual chambers, respectively. Month coverage shows the range of months covered across years per site (see details in Fig. B1).

FLUXNET-CH ₄	ID	Site name	Climate (Köppen)	Site classification	TA (°C)	P (mm)	WTL		Vegetation	Overlap days	Month coverage	Chamber	
							(min, max; cm)					FCH ₄ data	ref.
CN-Hgu		Hongyuan	Cwc	upland (alpine meadow)	2.6	386	-	Aerenchymatous	363*	February-November	Wang et al. (2021)	Niu and Chen (2020)	
FI-S12		Siikaneva-2 Bog	Dfc	bog	14.6	14	-11.6 (-39, 15.2)	<i>Sphagnum</i> moss	26	May-October	Korrensalo et al. (2018)	Alekseychik et al. (2021); Vesala et al. (2020)	
SE-Deg		Degerö	Dfc	fen	4.7	394	-1.35 (-10.2, 0.8)	<i>Sphagnum</i> moss	338*	May-October	Bond-Lamberty et al. (2020); Järveoja et al. (2018)	Nilsson and Peichl (2020)	
US-Ho1		Howland Forest	Dfb	upland (needleleaf forest)	6.9	838	-53.6 (-112, 8.19)	Tree	759*	April-November	Richardson et al. (2019)	Richardson and Hollinger (2020)	
		Pointe-aux-Chenes					-0.99	Aerenchymatous		March-May, September	Krauss et al.	Holm et al.	

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FLUXNET-CH ₄ ID	Site name	Climate (Köppen)	Site		WTL (min, max; cm)	Vegetation	Overlap days	Month coverage	Chamber	
			classificat ion	TA (°C)					P (mm)	FCH ₄ data ref.
US-La1	Pointe-aux- Chenes	Cfa	salt marsh	24.7	9	Aerenchym atous	5	March-May, September- October	Krauss et al. (2016)	Holm et al. (2020a)
	Brackish Marsh									
	Salvador WMA Freshwater Marsh	Cfa	marsh	26	15	Aerenchym atous	10	January, March- October	Krauss et al. (2016)	Holm et al. (2020b)
US-Lo5	Lost Creek	Dfb	fen	18.4	92	Ericaceous shrub	5	June-August	Desai (2025b)	Desai (2025a); Desai and Thom (2020)
US-Owc	Old Woman Creek	Dfb	marsh	15.2	468	Aerenchym atous	18	June- October	Bohrer et al. (2019)	Bohrer et al. (2020)
	St Jones Reserve	Cfa	salt marsh	20	520	Aerenchym atous	16	May- December	Hill and Vargas (2022a)	Vargas (2022b); Vázquez-Lule and Vargas (2021)
US-Uaf	University of Alaska, Fairbanks	Dwc	bog	-0.2	262	<i>Sphagnum</i> moss	458*	May- October	Ueyama et al. (2022)	Iwata et al. (2020)

2.2 Datasets and data compilation

2.2.1 Chamber and EC CH₄ flux data

240 The FCH₄ data were selected based on coincident plot- and ecosystem-scale FCH₄ observations. The plot-scale chamber FCH₄
data for each site were obtained from the site principal investigators. Each dataset included FCH₄ (varying units) and additional
environmental variables, such as soil temperature and water table level. Chamber datasets comprised measurements from both
manual (n=6 sites; taken 1-3 times per month) and automated chamber methods (n=4 sites; taken at half-hourly or hourly
245 intervals, see Table C1; Subke et al., 2021). Chamber fluxes for all sites were calculated by the data providers using linear
regression of change in CH₄ concentration over time. None of the chamber FCH₄ data were gap-filled, and in some cases (n=4
sites), ebullition events had been filtered out by the data providers (Table C2). The decision to utilize chamber FCH₄ data with
differing ebullition removal protocols across data providers was intended to reflect the way ebullition data are typically dropped
in chamber studies, where FCH₄ measurements are excluded from analyses when linear regressions between timepoints fall
below a user-defined R² threshold (Jentsch et al., 2025), which may contribute to differences between bulk ecosystem- and
250 plot-scale FCH₄ estimates. We designated CH₄ emission with positive, and CH₄ uptake with negative signs.

The ecosystem-scale EC datasets for each site (except US-StJ, see below) were obtained from the FLUXNET-CH₄ database
(Delwiche et al., 2021; Knox et al., 2019), and include both gap-filled and non-gap-filled FCH₄ values (nmol m⁻² s⁻¹) at a half-
hourly resolution along with various meteorological and environmental variables. We used gap-filled EC FCH₄ in the analyses,
but excluded data during long data gaps (>2 months) when the gap-filled values may be a significant source of uncertainty
255 (Delwiche et al., 2021). Gap-filling was performed using artificial neural networks (ANN; Knox et al. 2019) which have shown
good performance for FCH₄ data gap-filling (Irvin et al., 2021; Knox et al., 2016, 2019).

CN-Hgu EC FCH₄ data showed anomalous extreme CH₄ uptake and isolated extreme positive FCH₄ spikes. Therefore, we
filtered out EC FCH₄ values where 1) CH₄ uptake exceeded -100 nmol m⁻² s⁻¹ (empirically determined threshold; Chen et al.,
2019, 2020), 2) nighttime (incoming shortwave radiation < 10 W m⁻²; Morin et al., 2014) friction velocity < 0.1 m s⁻¹ (Chen et
260 al., 2019, 2020), and 3) single extreme positive FCH₄ spikes occurred beyond the monthly 99.5th FCH₄ percentile where
nighttime air temperature was within 1 °C of its dew point (calculated with Magnus formula and Alduchov & Eskridge
constants; Alduchov and Eskridge, 1996; Lawrence, 2005) and the open-path gas analyzer may have had condensation
(Heusinkveld et al., 2008). Additional extreme FCH₄ (FCH₄ = 862 nmol m⁻² s⁻¹) associated with friction velocity = 0.93 m s⁻¹
and wind speed = 0.05 m s⁻¹ was removed as an outlier. After filtering, the CN-Hgu dataset was 70% of the original.

265 For US-StJ, we obtained EC FCH₄ data from the data providers (Hill and Vargas, 2022b; Vázquez-Lule and Vargas, 2021).
As ANN-gap-filled EC FCH₄ values were not available at US-StJ, we used only non-gap-filled EC FCH₄. EC FCH₄ were
processed by the data providers following AmeriFlux protocols (Chu et al., 2023; Hill and Vargas, 2022b; Vázquez-Lule and
Vargas, 2021).

2.2.2 Environmental data

270 For all sites (except US-StJ), environmental data were obtained from the FLUXNET-CH₄ EC data product, including ANN-gap-filled net ecosystem CO₂ exchange (NEE), friction velocity (u^*), wind direction (WD), gap-filled wind speed, gap-filled vapor pressure deficit (VPD), and gap-filled air pressure (PA) (Delwiche et al. 2021; Knox et al. 2019). Soil temperature (TS; topmost 2-10 cm depth) data was obtained from FLUXNET-CH₄ and site-specific chamber datasets when available. If a site had TS observations from both chamber and FLUXNET-CH₄ datasets, a mean of both was taken to obtain a site-level TS.

275 Similarly, site-level water table level (WTL) was obtained by utilizing either FLUXNET-CH₄ or chamber-associated WTL measurements, or by taking their mean.

Environmental data for US-StJ were obtained from the data providers (Hill and Vargas, 2022b; Vázquez-Lule and Vargas, 2021). PA, VPD, wind speed, WD, and u^* were not gap-filled, while TS and WTL were gap-filled based on their linear relationships with water temperature and water table level, respectively (Hill and Vargas, 2022b). NEE was gap-filled using

280 marginal distribution sampling moving look-up tables (Hill and Vargas, 2022b).

See a summary of environmental data in Table C3.

2.3 Data processing and harmonization

The chamber datasets were harmonized to a similar structure, and FCH₄ units were standardized to $\text{nmol m}^{-2} \text{s}^{-1}$, matching the units used in the FLUXNET-CH₄ EC FCH₄ data. Then, EC and chamber datasets were combined using common timestamps

285 (Fig. 2). To evaluate differences across temporal aggregations, we aggregated data at six temporal scales: 1. half-hourly (automated chamber data only; CN-Hgu, SE-Deg, US-Ho1, US-Uaf; n=4 sites), 2. hourly (CN-Hgu, SE-Deg, US-Ho1, US-Uaf; n=4 sites), 3. daily (all sites, n=10 sites), 4. weekly (n=10 sites), 5. monthly (n=10 sites), and 6. annual (n=10 sites) (Fig. 2). Note that most sites did not include snow-covered periods, and the datasets primarily represent the snow-free season.

The data were aggregated from the timestamp-aligned data by taking the median of FCH₄ measurements (non-normally

290 distributed), mean of NEE (normally distributed) and wind u and v components (see 2.4.2), and median of the rest of the environment and meteorological variables (non-normally distributed). Half-hourly aggregation was created by taking the median of chamber measurements for each EC timestamp. To check for robustness of our results from the median-based temporal aggregations, we also created temporal aggregations based on FCH₄ means. In addition, we calculated cumulative sums ($\text{mg CH}_4 \text{ m}^{-2}$) of chamber and EC FCH₄ at daily, weekly, monthly, and annual scales to see how EC-chamber differences

295 scale up to ecosystem CH₄ budgets. As the chamber FCH₄ data from FI-Si2, US-La1, and US-La2 lacked hourly timestamps, we estimated daily cumulative FCH₄ for these sites by using the daily median or mean chamber FCH₄ and multiplied it by 48 while EC cumulative FCH₄ was calculated based on half-hourly EC FCH₄ from FLUXNET-CH₄. As this is not an accurate estimate of daily cumulative chamber FCH₄ for EC-chamber FCH₄ comparisons, we included these sites only in site-specific analyses and excluded them from cross-site analyses.

300 The difference between ecosystem and plot-scale FCH₄ was calculated as the row-wise difference between instantaneous EC FCH₄ and chamber FCH₄ (Δ FCH₄) in each aggregated dataset by subtracting chamber FCH₄ from the corresponding EC FCH₄ on the same timestamp. For supplementary analyses, we calculated the difference between cumulative EC FCH₄ and chamber FCH₄ at daily, weekly, monthly, and annual scales.

2.4 Statistical analyses

305 2.4.1 Differences between ecosystem and plot-scale FCH₄ observations

We used non-parametric statistics to analyze the FCH₄ data (EC, chamber and Δ FCH₄), because the data were skewed and non-normal. To test the statistical significance ($\alpha = 0.05$) of Δ FCH₄ and to assess Δ FCH₄ differences between chamber types at different temporal scales, we used Wilcoxon-Mann-Whitney tests (*wilcox.test* from *stats*; R Core Team 2024). Since the mean-based temporal aggregations were used as a sensitivity check, only descriptive statistics and Wilcoxon-Mann-Whitney
310 tests were conducted for the mean-based aggregations (results in Table C4). Similarly, cumulative FCH₄ were analyzed with descriptive statistics and Wilcoxon-Mann-Whitney tests (results in Table C5). The rest of the methods described here were conducted on the median-based temporal aggregations of instantaneous FCH₄.

To estimate the slopes of the EC FCH₄ - chamber FCH₄ relationship, we also built simple linear mixed effects models with site as the random effect using function *lme* from package *nlme* (Pinheiro et al., 2000, 2023). For better interpretability of
315 model slopes (in contrast to Yeo-Johnson-transformed values, see 2.4.2) and to meet the residual normality assumptions of linear mixed modeling, we transformed EC FCH₄ with inverse hyperbolic sine (Table C6). Due to non-convergence and residual non-normality, half-hourly and hourly scales were not assessed for EC-chamber FCH₄ slopes. As the data were non-normally distributed and did not meet the assumptions of linear regression, we also used Spearman correlations together with normalized root mean square error (using the standard deviation of pooled EC and chamber FCH₄ as the denominator at each
320 temporal scale) to assess the direction and strength of the relationship between EC FCH₄ and chamber FCH₄, manual and automated chamber FCH₄, as well as FCH₄ magnitude (row-wise mean of EC and chamber FCH₄) and absolute Δ FCH₄.

We used Kruskal-Wallis tests (*kruskal.test* from *stats*; R Core Team 2024) to test for differences in Δ FCH₄ across hours and months (treated as categorical variables) within each temporal aggregation (half-hourly, hourly, daily, weekly, monthly, and annual). Then, we identified the significantly differing groups using the Conover-Iman post hoc test (function *conover.test*
325 from package *conover.test*; Dinno, 2024).

2.4.2 Predictors of FCH₄ differences between ecosystem and plot scales

We built linear mixed models to estimate the predictors of Δ FCH₄. The aim was to explore how the predictors influence the direction of Δ FCH₄ (i.e., more positive or negative Δ FCH₄ or, in other words, increase ecosystem-scale FCH₄ in relation to plot-scale FCH₄ or vice versa) at the ten sites. To meet the assumptions of linear mixed modeling and to improve residual

330 diagnostics (normality and homoscedasticity of residuals) for model inference, we applied Yeo-Johnson power transformation (Yeo and Johnson, 2000) to absolute ΔFCH_4 values using the function *yeojohnson* from *bestNormalize* (Peterson, 2021). This transformation can be applied to zero values, and it improved our residual diagnostics, which were important for model inference. Acknowledging the difficulty to interpret the precise effect sizes after this transformation, we used this model only to investigate the directionality of ΔFCH_4 . All models were built with the function *lme* from *nlme* (Pinheiro et al., 2000, 2023).

335 To evaluate potential predictors of ΔFCH_4 , we included environmental and temporal variables available in the FLUXNET-CH₄ and chamber datasets in the models. The predictor selection was based on literature. They included: TS (°C), WTL (cm), PA (kPa), u^* ($m\ s^{-1}$), WD (degrees), VPD (hPa), NEE ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$), month (categorical), site dominant vegetation (VEG; categorical; “tree”, “ericaceous shrub”, “aerenchymatous”, “brown moss”, and “*Sphagnum* moss”; taken from Delwiche et al., 2021), and hour (categorical; only with half-hourly and hourly datasets). We included EC-specific variables, such as u^* and

340 WD, as proxies for EC footprint to assess how variables contributing to the EC footprint may affect ΔFCH_4 . While two of the VEG classes (tree and ericaceous shrub) were only represented in one site, preliminary linear regression model comparisons showed that VEG explained a large proportion of the ΔFCH_4 variance ($R^2 = 0.4-0.7$), and its inclusion in linear mixed models substantially improved model fit. Therefore, we included VEG as a fixed effect, while acknowledging that for tree and ericaceous shrub classes, the estimated effect may be related to the site rather than vegetation.

345 For all models, the reference level in VEG was *Sphagnum* moss, 0 in Hour, and May in Month. As WD is a circular variable ($0^\circ=360^\circ$), we represented WD as a continuous function of wind direction and speed by separating WD into orthogonal u and v wind components (uWD and vWD , respectively), which were averaged from the half-hourly EC datasets in hourly, daily, weekly, monthly, and annual aggregations (Supplementary Methods A1). As a result, uWD represents the strength of west-east wind while vWD represents the strength of north-south wind. This representation avoided discontinuity at $360^\circ/0^\circ$ and

350 potential multicollinearity between model predictors.

For improved model convergence and β -coefficient calculations, Yeo-Johnson-transformed absolute ΔFCH_4 and all predictors were centered and scaled, except hour, month and VEG, which were categorical variables and were included without centering and scaling. To account for multicollinearity, we chose predictors based on Pearson correlation matrices (threshold $|r|<0.7$) and checked variance inflation factors (VIF; threshold ≤ 3) using the function *vif* from *car* (Fox and Weisberg, 2018). Due to

355 multicollinearity ($VIF>3$), we built two separate half-hourly models containing either month or TS, two weekly models without NEE or VPD, and a monthly model without VPD and TS. WTL data was not available for CN-Hgu, and thus, this site was excluded from the models.

After accounting for temporal autocorrelation and residual variance (Supplementary Methods A2), we used backward variable selection based on likelihood ratio tests (AIC and p -values) together with type I ANOVA tests to determine significant

360 predictors of Yeo-Johnson-transformed absolute ΔFCH_4 . During variable selection, the models were fitted with maximum likelihood, and the final models were refitted with restricted maximum likelihood for statistical inference. Model marginal and

conditional R^2 were calculated with the function *r.squaredGLMM* from package *MuMIn* (Bartoń, 2024). To test how well the models generalize to other sites, we validated the models with leave-one-site-out cross validation and evaluated model performance with R^2 , mean absolute error (MAE) and root mean square error (RMSE) between observed and predicted values.

365 To allow for predictions to new sites with the training data, the fixed effect VEG had to be removed from the models, as some of the VEG classes (tree and ericaceous shrub) were represented only by a single site and the effect of these classes cannot be estimated when they are withheld in the test data. Similarly, due to uneven temporal coverage across sites, observations (e.g., date or year-month) included in the test data but not present in the training data were excluded from evaluation.

We built linear mixed effects models to investigate the effect of spatio-temporal FCH₄ variation on Δ FCH₄. To represent the

370 FCH₄ variation between individual chambers within each site, we calculated the interquartile range (IQR) of chamber FCH₄ from an unaggregated dataset per each site and temporal scale unit (i.e., per day, week, month, or year). To see whether temporal variation within each temporal scale unit in EC FCH₄ may affect absolute Δ FCH₄, we also calculated EC FCH₄ IQR per each site and temporal scale unit. In the models, log-transformed absolute Δ FCH₄ was the response variable, and either log (+0.01)-transformed chamber IQR or log (+0.01)-transformed EC IQR was the explanatory variable, or both were included as

375 explanatory variables to assess their relative effects on absolute Δ FCH₄.

All data processing and statistical analyses were carried out using R v4.3.3 (R Core Team, 2024).

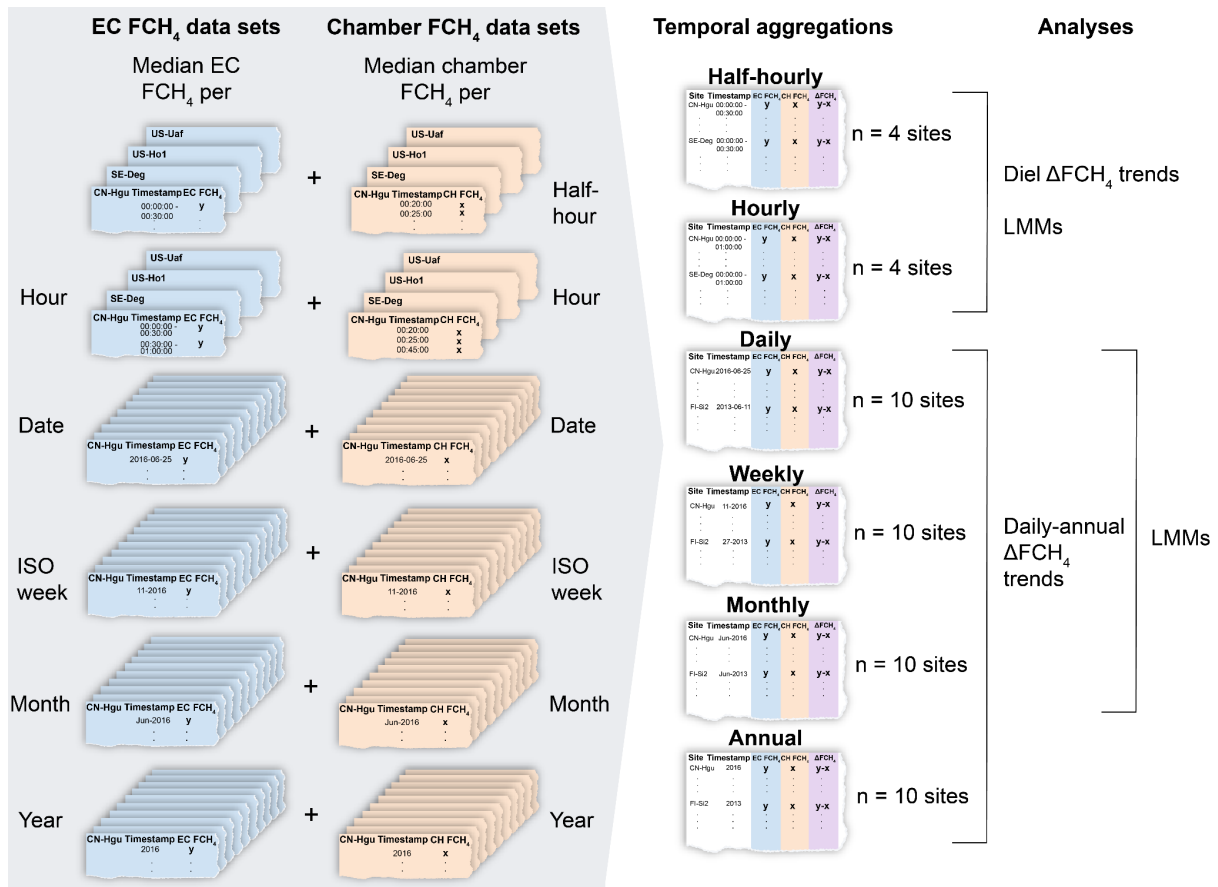


Figure 2. Overview of the main data aggregation workflow. Site-specific eddy covariance (EC) methane (CH₄) flux (FCH₄; 380 blue) and chamber FCH₄ (orange) datasets were combined by taking the median FCH₄ per timestamp (half-hour to annual scale). ISO week is the week number according to the ISO-8601 standard. Then, site-level datasets were combined into multi-site datasets at six temporal scales: half-hourly, hourly, daily, weekly, monthly, and annual. Half-hourly EC FCH₄ data was not aggregated as it was already in half-hourly scale. ΔFCH₄ (purple) was calculated by subtracting median chamber instantaneous FCH₄ from median EC instantaneous FCH₄ per timestamp per site, and this measure was used in all analyses 385 and linear mixed effects models (LMMs). Note that we also created temporal aggregations by taking the mean of EC and chamber FCH₄, and these data sets were used as a sensitivity check with descriptive statistics and pairwise comparisons.

3 Results

390 3.1 Ecosystem and plot-scale FCH₄ differ most at finer temporal aggregations

Ecosystem- (EC) and plot-scale (chamber) FCH₄ differed significantly at all the temporal aggregations shorter than monthly scale (Table 2). Median ecosystem FCH₄ was higher than plot-scale FCH₄ at all temporal aggregations (half-hourly to annual: 102%, 109%, 104%, 90%, 58%, and 87% higher, respectively). However, the coefficient of variation (CV, %) for Δ FCH₄ was large, particularly in daily (674%) and weekly (467%) aggregations (Table 2). Across temporal aggregations and site-years, 395 CH₄ emissions (FCH₄>0) above the 90th percentile contributed a larger share of total plot-scale FCH₄ than ecosystem-scale FCH₄ (Table 2, Fig. B2), possibly indicating more CH₄ emission hot spots and hot moments at the plot scale. Our observed trend persisted when we aggregated chamber and EC FCH₄ data with means instead of medians (Table C4 and C5), where median Δ FCH₄ ranged between 0.28 nmol m⁻² s⁻¹ (annual) and 1.23 nmol m⁻² s⁻¹ (half-hourly) but mean Δ FCH₄ turned increasingly negative from daily (-1.16 nmol m⁻² s⁻¹) to annual (-70.94 nmol m⁻² s⁻¹) scales, highlighting plot-scale CH₄ emission 400 hotspots and hot moments as possible Δ FCH₄ drivers which may have been more attenuated in the median-based aggregations. Ecosystem- and plot-scale FCH₄ were positively correlated across temporal aggregations, with annual aggregation having the best agreement, while the worst agreements were in half-hourly and hourly aggregations (Fig. 3). In linear mixed models, a 1 nmol m⁻² s⁻¹ increase in plot-scale FCH₄ was associated with an ecosystem-scale FCH₄ increase of 0.007 nmol m⁻² s⁻¹ ($p=0.03$) at daily plot-scale FCH₄ median (0.06 nmol m⁻² s⁻¹), 0.01 nmol m⁻² s⁻¹ ($p=0.066$) at weekly plot-scale FCH₄ median (0.51 nmol m⁻² s⁻¹), 0.009 nmol m⁻² s⁻¹ ($p=0.183$) at monthly plot-scale FCH₄ median (4.07 nmol m⁻² s⁻¹), and 0.019 ($p=0.044$) at annual 405 plot-scale FCH₄ median (6.55 nmol m⁻² s⁻¹; see Table C6 for details).

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Table 2. Ecosystem- (eddy covariance; EC) and plot-scale (chamber) methane (CH₄) flux (FCH₄) difference (Δ FCH₄) at different temporal aggregations. A positive Δ FCH₄ indicates higher ecosystem than plot-scale FCH₄ and vice versa. The EC and chamber data sample sizes in Wilcoxon-Mann-Whitney tests are reported as n_{EC} and n_{CH} , respectively. The 90th percentiles (p90, without parentheses) and proportion (% in parentheses) of chamber and EC CH₄ emission observations (where FCH₄>p90 and FCH₄>0) of the total chamber or EC FCH₄ sum show the contribution of high CH₄ emissions to total CH₄ emissions (see site-specific trends in the unaggregated dataset in Fig. B2). Abbreviations: IQR = interquartile range, SD = standard deviation, CV = coefficient of variation.

Aggregation	Δ FCH ₄			Chamber	EC	Chamber	EC	Chamber	EC	Wilcoxon-Mann-Whitney test
	median (IQR), $nmol\ m^{-2}\ s^{-1}$	Δ FCH ₄ mean (SD), $nmol\ m^{-2}\ s^{-1}$	Δ FCH ₄ CV (%)	FCH ₄ median (IQR), $nmol\ m^{-2}\ s^{-1}$	FCH ₄ median (IQR), $nmol\ m^{-2}\ s^{-1}$	FCH ₄ mean (SD), $nmol\ m^{-2}\ s^{-1}$	FCH ₄ mean (SD), $nmol\ m^{-2}\ s^{-1}$	FCH ₄ p90, $nmol\ m^2\ s^{-1}$ (% of total FCH ₄)	EC FCH ₄ p90, $nmol\ m^2\ s^{-1}$ (% of total FCH ₄)	
Half-hourly	1.4 (5.67)	5.61 (17.71)	196	0.27 (5.79)	1.55 (6.97)	5.88 (14.07)	11.49 (24.25)	33.44 (46)	64.31 (44)	$p < 0.001$ ($n_{EC}=74482$, $n_{CH}=74482$)
Hourly	1.41 (5.28)	6.08 (15.34)	191	0.15 (4.07)	1.39 (6.68)	4.98 (12.36)	11.05 (23.59)	45.76 (47)	63.92 (44)	$p < 0.001$ ($n_{EC}=40072$, $n_{CH}=40072$)
Daily	1.36 (4.27)	4.01 (81.49)	674	0.06 (4.79)	1.53 (6.27)	13.98 (106.34)	18.0 (69.09)	43.18 (75)	68.5 (60)	$p < 0.001$ ($n_{EC}=1879$, $n_{CH}=1879$)
Weekly	1.44 (5.29)	-0.62 (105.8)	467	0.51 (11.9)	3.0 (31.19)	34.28 (155.8)	33.66 (103.49)	112.64 (76)	78.08 (63)	$p < 0.001$ ($n_{EC}=349$, $n_{CH}=349$)
Monthly	1.46 (14.82)	-8.14 (151.18)	350	4.07 (46.41)	5.88 (60.3)	75.55 (223.01)	67.42 (161.75)	247.77 (69)	219.98 (64)	$p = 0.082$ ($n_{EC}=121$, $n_{CH}=121$)
Annual	2.58 (24.59)	-1.37 (63.6)	194	6.55 (67.22)	25.91 (53.29)	76.84 (185.83)	75.47 (145.95)	220.35 (64)	250.78 (57)	$p = 0.507$ ($n_{EC}=22$, $n_{CH}=22$)

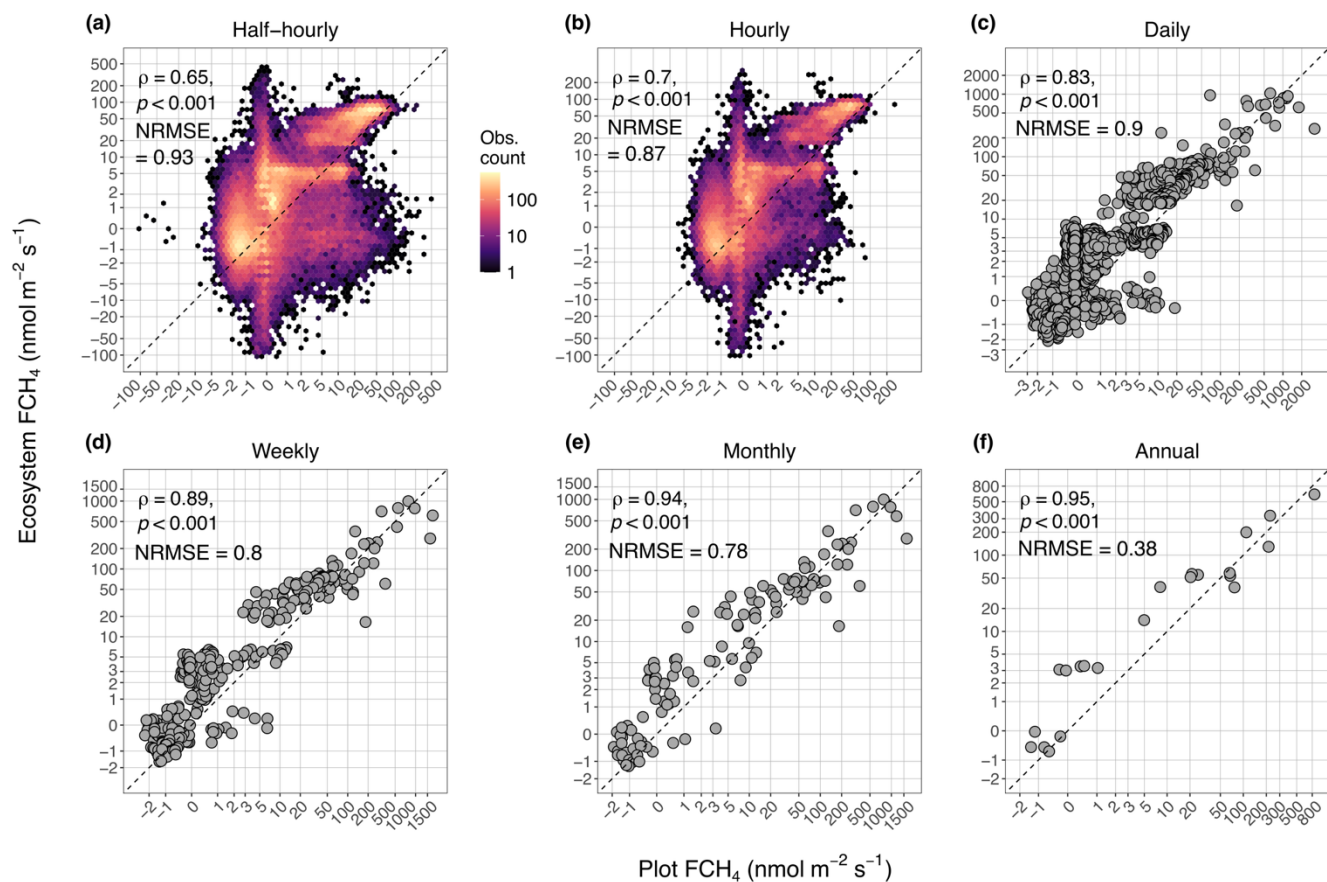


Figure 3. Results of correlation test (Spearman rank correlation coefficient, ρ , its significance level, p , and the normalized root mean square error, NRMSE) between plot-scale (chamber) methane (CH₄) flux (FCH₄) and ecosystem-scale (eddy covariance; EC) FCH₄ at half hourly (a), hourly (b), daily (c), weekly (d), monthly (e), and annual scales (f). For visualization, the plot axes (a-f) were transformed with inverse hyperbolic sine to spread out points in the low FCH₄ range and retain negative values (see untransformed plots in Fig. B3). Spearman ρ was calculated with untransformed data. NRMSE was calculated by dividing RMSE by the standard deviation of untransformed ecosystem- and plot-scale FCH₄ at each temporal aggregation. In a) and b) the points for half-hourly ($n=74482$) and hourly ($n=40072$) aggregations are shown in hexagonal density clouds with log10-

transformed color range to highlight trends in high point density areas (colors represent number of observations per hexagon).
445 Agreement between chamber and EC FCH₄ improves from finer to coarser temporal aggregations (a-f), as indicated by ρ . The high observation densities in a) and b) reveal site-specific trends in the discrepancy between ecosystem and plot scales (e.g., at $x=0$ and $y=5$). For daily (c), weekly (d), monthly (e), and annual (f) aggregations, sample sizes were $n = 1879, 349, 121,$ and 22, respectively. The dashed line represents 1:1 line.

Ecosystem and plot-scale FCH₄ differed between hours, months, and sites. In support of our hypotheses, the highest Δ FCH₄
450 occurred between 5 AM and 3 PM ($p<0.001$; Fig. B4-B7), with maximum median Δ FCH₄ at 9 AM (2.01 nmol m⁻² s⁻¹, IQR: 6.16; half-hourly scale) and minimum at 8 PM (0.9 nmol m⁻² s⁻¹, IQR: 4.16; half-hourly scale). However, the diel Δ FCH₄ trends varied between sites and months ($p<0.001$; Fig. B8-B12). The highest absolute Δ FCH₄ (with observations from all sites) was in August, September, and October (half-hourly to daily $p<0.001$; Fig. B13). In addition, Δ FCH₄ varied in both magnitude and direction within and between sites (Kruskal-Wallis $p<0.001$; half-hourly to monthly scale), with most medians being positive
455 (Tables C6-C11 and B14-B15). The difference between cumulative sums of ecosystem and plot-scale FCH₄ increased from daily to annual scales but the seasonal and inter-annual trends varied between sites (Table B4, Fig. B16). The largest absolute Δ FCH₄ medians and CVs were consistently found in US-Owc (median: -108.22 nmol m⁻² s⁻¹, CV: 169%; daily scale), while the lowest absolute Δ FCH₄ and FCH₄ were consistently found in US-Ho1 (median Δ FCH₄ <1 nmol m⁻² s⁻¹; Tables C6-C11).

Flux magnitude, measured as the mean between EC and chamber FCH₄ (FCH_{4_mean}), was generally positively related to Δ FCH₄
460 but negative relationships existed when FCH_{4_mean}<0 (i.e., net uptake). The positive FCH₄ magnitude and absolute Δ FCH₄ relationship became stronger at coarser temporal resolutions (Spearman $p<0.001$; Fig. 4). In all aggregations, the higher Δ FCH₄ came from higher ecosystem than plot-scale FCH₄ ($\geq 70\%$ of all observations when FCH_{4_mean}>0; result not shown). In half-hourly and hourly aggregations, Δ FCH₄ and FCH_{4_mean} were negatively or positively related when FCH_{4_mean} suggested net uptake or emission, respectively (Fig. 4a and b). When FCH_{4_mean}<0, ecosystem-scale FCH₄ was generally higher than plot-
465 scale FCH₄ (57% and 58% of all observations when FCH_{4_mean}<0 in half-hourly and hourly aggregations, respectively; result not shown). However, most of the highest observations originate from CN-Hgu. Sites also differed in whether the trends in negative FCH₄ came from higher plot or ecosystem-scale FCH₄: for example, at US-Uaf and CN-Hgu, 100% and 91% of Δ FCH₄ observations at FCH_{4_mean}<0, respectively, consisted of higher plot-scale FCH₄ while ca. 66% of hourly and half-hourly observations (FCH_{4_mean}<0) in US-Ho1 came from higher ecosystem-scale FCH₄.

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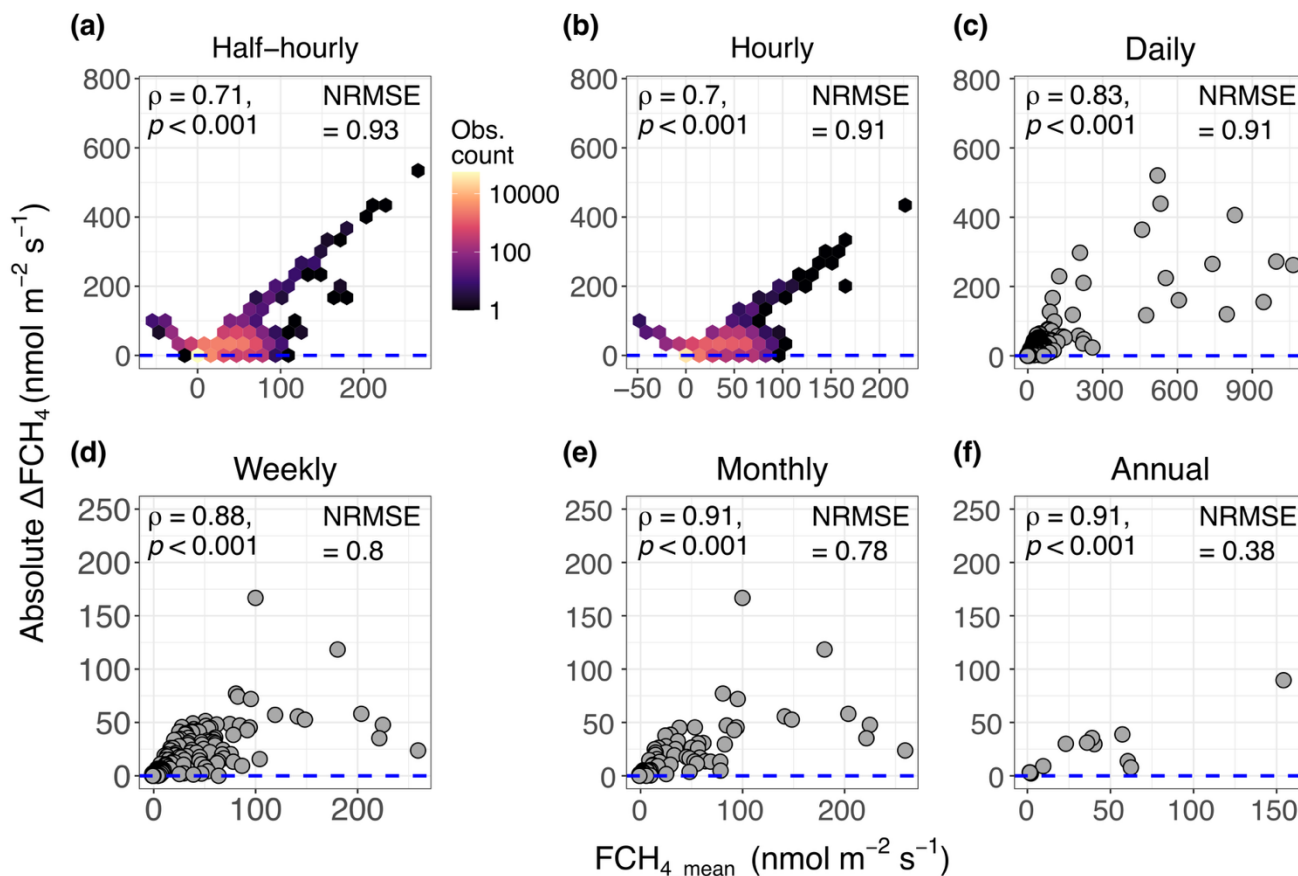


Figure 4. The relationship between methane (CH_4) flux (FCH_4) magnitude (FCH_{4_mean}) and absolute difference between ecosystem-scale (eddy covariance; EC) and plot-scale FCH_4 (ΔFCH_4) from half-hourly (a) to annual (f) scales, represented by Spearman correlation coefficient, (ρ), its significance, (p), and normalized root mean square error of ΔFCH_4 (NRMSE). FCH_{4_mean} is the row-wise mean of EC FCH_4 and chamber FCH_4 . In a) and b) half-hourly and hourly points are shown in hexagonal density clouds with a log-transformed color range to highlight trends in high point density areas (colors represent number of observations per hexagon). Plots c-f show daily, weekly, monthly and annual aggregations, respectively. The blue dashed line represents $\Delta\text{FCH}_4=0$ meaning complete agreement between ecosystem and plot-scale FCH_4 . Higher Spearman correlation coefficient ($\alpha=0.05$) represents stronger deviation from $\Delta\text{FCH}_4=0$. NRMSE was calculated by dividing RMSE (of ΔFCH_4) by the standard deviation of ecosystem- and plot-scale FCH_4 at each temporal aggregation. For visualization, outliers were removed from daily ($n=3$), weekly ($n=10$), monthly ($n=8$) and annual ($n=1$) plots but the Spearman correlations and NRMSE are based on original data. See plots with outliers in Fig. B17 and a figure showing how high CH_4 emissions from ecosystem and plot scales contribute to annual CH_4 emissions per site in Fig. B2.

3.2 Predictors of ecosystem and plot-scale FCH₄ differences

485 3.2.1 Atmospheric pressure, friction velocity and wind direction drive daily-to-monthly FCH₄ differences between ecosystem and plot scales

The significance and effect size of Δ FCH₄ predictors varied across temporal aggregations, with site-dominant vegetation type having the highest effect sizes at the daily-to-monthly scale (Table 3). Dominance of aerenchymatous vegetation had relatively high effect sizes ($|\beta$ -coefficient >0.68). However, only one site was classified as tree-dominated (US-Ho1) and ericaceous
490 shrub-dominated (US-Los), while three were aerenchymatous and two were *Sphagnum*-moss dominated. Thus, we were unable to separate true vegetation-related effects from site effects.

PA and u^* were significant Δ FCH₄ predictors at the daily and monthly scales (but weekly PA $p=0.057$), while VPD was significant only at the daily scale. However, the effect sizes were relatively low (β -coefficient ≤ 0.25 ; Table 3). Wind direction (uWD) was a significant Δ FCH₄ predictor only in the monthly scale. Month was a significant predictor only in the final half-
495 hourly-daily models, where August and July had the highest effect sizes (β -coefficient >0.41), while morning hours, particularly 5 AM, were most important in the half-hourly models (5 AM β -coefficient >0.08). However, the fixed effects in the final half-hourly and hourly models explained a very small proportion of the total variation (marginal $R^2 < 0.05$, Tables S12-S13). In addition, the high conditional R^2 and high negative LOOCV R^2 , high MAE and RMSE showed that the Δ FCH₄ predictors are specific to the sites included in this study (Table 3).

500 **Table 3.** Linear mixed effects model results identifying environmental predictors of ecosystem- and plot-scale methane (CH₄) flux (FCH₄) difference (Δ FCH₄) at different temporal scales. Fixed effects are listed in decreasing order based on their β -coefficients. Significant predictors are highlighted in bold. Half-hourly and hourly models had very low marginal R^2 (< 0.05) and were excluded from this table. See half-hourly and hourly models in Table C14 and full models in Table C15. Abbreviations: SE = standard error, Df = degrees of freedom, LOOCV = leave-one-out cross validation, MAE = mean absolute
505 error, RMSE = root mean square error, VEG = site dominant vegetation, PA = air pressure (kPa), u^* = friction velocity ($m s^{-1}$), WTL = water table level (cm), TS = soil temperature ($^{\circ}C$), NEE = net ecosystem CO₂ exchange ($\mu mol CO_2 m^{-2} s^{-1}$), VPD = vapor pressure deficit (hPa), vWD = v wind component ($m s^{-1}$), uWD = u wind component ($m s^{-1}$).

Dataset	Predictors	β -coefficient	SE	p -value (t-test)	Marginal R^2	Conditional R^2	Df	Random effect variation explained, %	LOOCV		
									R^2	MAE	RMSE
Daily (n=9 sites)	Intercept	0.4867	0.361	0.1779	0.5346	0.9265	1363	-1.65	1.48	1.76	
	Fixed effects										
	VEG										
	- Tree	-1.4718	0.6767	0.0816			5				
	- Aerenchymatous	1.0111	0.4723	0.0852			5				
	Month										

- Jul	0.4939	0.1685	0.0043	87
- Aug	0.4577	0.1696	0.0084	87
VEG				
-Ericaceous shrub	0.4333	0.7104	0.5686	5
Month				
- Sep	0.2851	0.1656	0.0886	87
- Apr	0.234	0.3683	0.5269	87
- Dec	0.2281	0.5059	0.6533	87
- Oct	0.1884	0.1689	0.2677	87
- Jun	0.1595	0.1658	0.3389	87
- Nov	0.1118	0.2356	0.6363	87
- Mar	-0.0735	0.5003	0.8835	87
TS	-0.0525	0.0269	0.051	1371
VPD	-0.0457	0.0109	0	1371
u*	0.0342	0.0076	0	1371
PA	-0.0259	0.0072	0	1371
uWD	0.0052	0.0066	0.4305	1371
vWD	0.0043	0.007	0.5423	1371
NEE	0.0017	0.0104	0.8679	1371
WTL	0.0012	0.0376	0.9745	1371

Random effects

Site	59.59
Year-month	24.62

Weekly	Intercept	0.5066	0.3402	0.1381	0.5554	0.8351	178	-0.82	1.25	1.46
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Fixed effects

(n=9 sites)	VEG									
	- Tree	-1.3455	0.6772	0.1036			3			
	- Aerenchymatous	0.8552	0.4642	0.1248			3			
	-Ericaceous shrub	0.5256	0.6837	0.4767			3			
	PA	-0.0716	0.0374	0.0572			178			

Random effects

Site	62.91
Year-month	1.03e ⁻⁰⁵

Monthly	Intercept	-0.2243	0.3145	0.4778	0.6599	0.8788	80	-0.57	1.04	1.25
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Fixed effects

(n=9 sites)	Month									
	- Mar	1.4967	1.4236	0.2962			80			
	VEG									
	-Aerenchymatous	1.2901	0.4307	0.0303			5			
	-Ericaceous shrub	0.7673	0.6684	0.3029			5			

Month				
- Apr	0.6774	0.2947	0.0241	80
VEG				
- Tree	-0.5482	0.5955	0.3995	5
PA	-0.2535	0.1046	0.0177	80
uWD	0.2322	0.0666	0.0008	80
u*	-0.1875	0.0774	0.0176	80
Month				
- Oct	-0.1805	0.1432	0.2111	80
WTL	0.1375	0.0809	0.0931	80
Month				
- Dec	0.1258	0.3948	0.7509	80
NEE	0.1069	0.0664	0.1114	80
Month				
- Sep	0.0963	0.1475	0.5158	80
vWD	0.0686	0.0501	0.1747	80
Month				
- Jul	0.0608	0.1465	0.6789	80
- Jun	0.0461	0.1408	0.7442	80
- Nov	-0.0404	0.2062	0.8453	80
- Aug	0.021	0.1456	0.8857	80

Random effects

Site

64.35

3.2.2 Spatial FCH₄ variation increases ecosystem and plot-scale FCH₄ difference

510 Spatial variation between FCH₄ measurements by individual chambers increased absolute Δ FCH₄ (Fig. 5). The increasing trend between chamber IQR (log +0.01) and absolute Δ FCH₄ (log) became clearer in coarser temporal scales, where a unit (*e*-fold; ca. 2.7x) increase in monthly and annual chamber FCH₄ variation (IQR +0.01) was associated with ca. 51% and 63% increase in absolute Δ FCH₄, respectively (marginal $R^2 \geq 0.31$, $p \leq 0.01$). Temporal EC FCH₄ variation (e.g., within date in daily scale) did not lead to strong increases in absolute Δ FCH₄ at daily-to-monthly aggregations (marginal $R^2 < 0.01$), but the annual mixed effects model showed a ca. 198% increase in absolute Δ FCH₄ with a unit increase in EC FCH₄ IQR (+0.01; marginal $R^2 = 0.82$). Models with both chamber and EC IQR (log +0.01) as explanatory variables showed significant chamber IQR at daily-to-monthly aggregations ($p < 0.001$, marginal $R^2 = 0.06$ -0.31) and significant EC IQR at daily scale ($p = 0.005$). In contrast, the annual model had a nonsignificant chamber IQR and significant EC IQR ($p = 0.001$, marginal $R^2 = 0.81$). The sites also differed in the strength and direction of the relationship between chamber and EC FCH₄ variation and Δ FCH₄ (Fig. 5).

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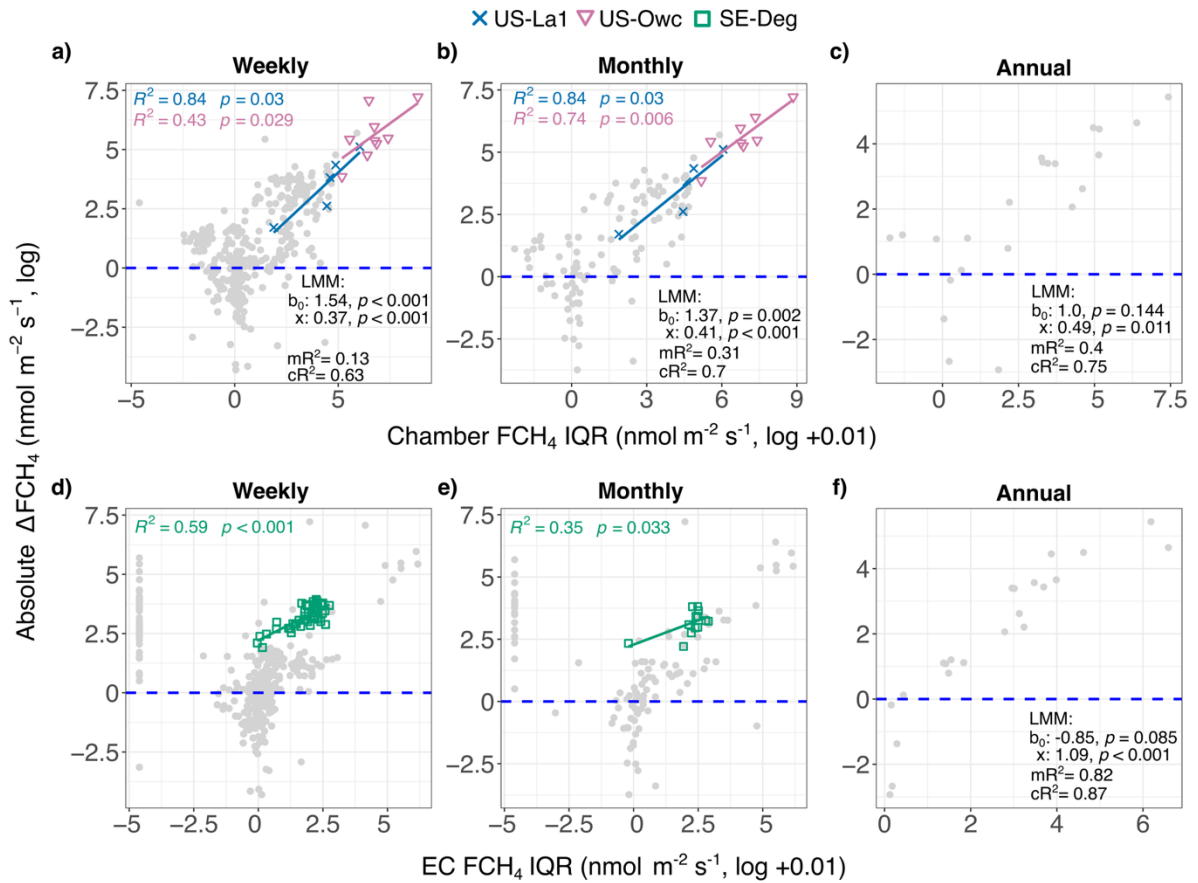


Figure 5. Variation in methane (CH_4) flux (FCH_4) between individual chambers and eddy covariance (EC) timestamps increases absolute ΔFCH_4 . a-c) Relationship between chamber FCH_4 variation (variation between individual chambers per aggregation timestamp, represented by interquartile range; IQR) and absolute ΔFCH_4 at weekly (a), monthly (b) and annual (c) scales. d-f) Relationship between EC timestamp FCH_4 variation (represented by IQR) and absolute ΔFCH_4 at weekly (d), monthly (e) and annual (f) scales. Linear mixed effects model (LMM) results: b_0 = model intercept, x = predictor (chamber or EC FCH_4 log IQR +0.01) of log absolute ΔFCH_4 , p = predictor significance (preceded by model coefficient estimates), mR^2 and cR^2 = marginal and conditional R^2 , respectively. In d) and e) LMM results are not shown due to low marginal R^2 ($mR^2 \leq 0.06$). In e) linear regression results for SE-Deg without data point where $x < 0$: $R^2 = 0.62, p = 0.002$. Daily scale is not shown due to the low number ($n=1$) of sites with significant relationships and low marginal R^2 ($mR^2 \leq 0.06$). Linear regressions, R^2 s and p -values are only shown for sites with significant IQR predictor and $R^2 > 0.2$ and are shown in different colors and shapes (gray points: nonsignificant and $R^2 \leq 0.2$ sites). The dashed blue line indicates $\Delta FCH_4 = 0$. See version with untransformed data in Fig. B18.

3.2.3 Ecosystem and plot-scale FCH₄ difference does not significantly vary among chamber types

We did not find significant differences in Δ FCH₄ between automated and manual chambers at all aggregations (Wilcoxon-Mann-Whitney; daily $p=0.948$, weekly $p=0.361$, monthly $p=0.565$, annual $p=0.722$). However, Δ FCH₄ in manual chambers had higher variation than automated chambers in daily ($CV_{\text{manual}}=284\%$, $CV_{\text{automated}}=181\%$), weekly ($CV_{\text{manual}}=262\%$, $CV_{\text{automated}}=181\%$), and monthly ($CV_{\text{manual}}=240\%$, $CV_{\text{automated}}=182\%$) aggregations. The correlations between chamber FCH₄ and EC FCH₄ for both automated and manual chambers were strong at daily-to-annual aggregations ($\rho>0.7$, Fig. B19).

4 Discussion

4.1 Ecosystem-scale FCH₄ is higher than plot-scale FCH₄ at all temporal scales

As a first step to reconcile the discrepancies in FCH₄ data obtained from ecosystem-scale EC and plot-scale chamber measurements used increasingly in combination in various syntheses and FCH₄ modeling, we explored the cross-scale differences across ten sites and six temporal aggregations. Across all temporal scales, ecosystem-scale (EC) FCH₄ was higher than at the plot scale (chamber). Supporting these results, higher EC FCH₄ than chamber FCH₄ have been observed in an arctic peatland with area-weighted chamber FCH₄ (Budishchev et al., 2014), a managed peat meadow with upscaled chamber FCH₄ (Schrier-Uijl et al., 2010), a peatland with down-scaled EC FCH₄ (Forbrich et al., 2011), a temperate forest with spatial chamber FCH₄ averages (Wang et al., 2013), and a temperate salt marsh with spatio-temporal chamber and EC FCH₄ averages (Hill and Vargas, 2022b). Other studies at individual sites have observed higher chamber FCH₄ (upscaled to ecosystem-level with different methods) than EC FCH₄ (Chaichana et al., 2018; Clement et al., 1995; Davidson et al., 2017; Krauss et al., 2016; Marushchak et al., 2016; Meijide et al., 2011; Morin et al., 2017; Riutta et al., 2007). Nonetheless, the median difference was relatively low across sites and temporal aggregations (min 1.36 daily, max 2.58 nmol m⁻² s⁻¹ annual), with CV ranging from a minimum of 191% (hourly) to a maximum of 674% (daily; Table 2), indicating relatively good agreement between ecosystem and plot-scale FCH₄ across sites but with large variation around perfect agreement. While our higher ecosystem- than plot-scale FCH₄ trend was robust across temporal scales, due to the limited data availability (n=10 sites), our results reflect site differences and generalizations should be tested when more data become available.

We found the best general agreement between instantaneous ecosystem- and plot-scale FCH₄ in the monthly and annual aggregations, with the agreement improving from fine to coarse temporal resolutions, as expected. The improved agreement is likely a result of the data aggregation, which reduces the influence of inter-daily FCH₄ variability and inflates correlation coefficients (e.g., Clark and Avery, 1976; Pollet et al., 2015). In addition, mean Δ FCH₄ in weekly, monthly and annual aggregations was negative (Table 1), indicating higher plot-scale than ecosystem-scale FCH₄, and the CV for the weekly aggregation in particular was large (467%) (Table 1). Our results suggest that high CH₄ emissions and FCH₄ variability in plot-scale measurements are associated with higher Δ FCH₄, particularly at time scales longer than daily (Table 2 and Fig. B2);

suggesting that combining plot- and ecosystem-scale bulk FCH₄ at heterogeneous sites is particularly problematic at coarse temporal scales. However, footprint-aware comparisons between upscaled chamber or downscaled EC FCH₄ could show better agreement between ecosystem and plot scales (e.g., Schrier-Uijl et al., 2010) (see 4.6). Nonetheless, this highlights the practice of selective chamber placement on high-emitting locations and time periods within the study sites (Hill and Vargas 2022b; Vargas and Le 2023). However, our results based on cumulative FCH₄ (Table C5) also show that ecosystem-scale cumulative FCH₄ are generally higher than at plot scale. Therefore, site-level CH₄ budgets calculated with ecosystem-scale FCH₄ data can exceed plot-scale estimates despite localized plot-scale CH₄ emission peaks (with site-specific variation; Fig. B16).

In general, mismatches in capturing site FCH₄ heterogeneity between EC and chambers, and chamber measurement artifacts may have contributed to the higher ecosystem-scale FCH₄ and Δ FCH₄ variation. Chamber measurements are challenged by tall vegetation, and ebullition events are often discarded, while EC footprints may have covered high-CH₄-emitting areas (i.e., CH₄ emission hot spots), such as CH₄-transporting vegetation patches, and ebullition events (i.e., CH₄ emission hot moments) more often than chambers, increasing ecosystem-scale FCH₄. Ebullition can also be triggered by chamber placement onto water or waterlogged soil surface, or by soil disturbance around the chamber (e.g., Jentzsch et al., 2025), but as ebullition events were removed from some of the chamber FCH₄ data (see 2.2.1 and Table C2), this was unlikely to contribute to the general Δ FCH₄ trends. This has been demonstrated in spatially heterogeneous areas, where CH₄ emission hot spots within EC footprints may be important Δ FCH₄ drivers (Desai et al., 2015; Rey-Sanchez et al., 2025; Xu et al., 2018), and at least in some sites, the majority of FCH₄ is contributed through ebullition with variation across and within sites (Männistö et al., 2019; Ueyama et al., 2023b; Villa et al., 2021). FCH₄ hot spots and hot moments can also vary in space and time, which manual chamber FCH₄ measurements (n=6 sites) may not capture due to sporadic daytime measurements in weekly or monthly intervals (Anthony and Silver, 2021, 2023; Vargas and Le, 2023). This may result in uncertainties in spatio-temporal FCH₄ and Δ FCH₄ variation across temporal scales (Anthony and Silver, 2021, 2023; Vargas and Le, 2023). The EC footprint effects could be further highlighted by the increasing Δ FCH₄ with greater FCH₄ (Fig. 4), and similar trends were observed in a rice paddy where plot-scale FCH₄ was higher than at ecosystem scale (Meijide et al., 2011). In addition, high CH₄ uptake at the plot scale increased Δ FCH₄ particularly at CN-Hgu (see 3.1), highlighting selective chamber placement on CH₄-consuming areas (Table C2). These and Meijide et al. (2011) results highlight the need to account for the increasing disagreement between ecosystem- and plot-scale FCH₄ when combining cross-scale data at high FCH₄ sites or periods. However, Δ FCH₄ in low FCH₄ is uncertain due to EC and chamber detection limits, the reported ranges of which cover the minimum absolute Δ FCH₄ of 0-0.05 nmol m⁻² s⁻¹ (Desai et al., 2015; Erkkilä et al., 2018; Kroon et al., 2007, 2010; Richardson et al., 2019; Smeets et al., 2009). Thus, the Δ FCH₄ trends in low FCH₄ (Fig. 4) and possibly low-emitting uplands (e.g., part of US-Ho1) should be interpreted with caution. Altogether, the mismatch in EC footprint and chamber measurement coverage, as well as chamber CH₄ ebullition removal, could be important Δ FCH₄ drivers, as FCH₄ can vary strongly between surface cover types and within them even during the same growing season (Voigt et al., 2023). This highlights the need to account for EC and chamber

footprint representativeness as well as chamber data quality control when combining plot- and ecosystem-scale FCH₄ data, particularly at high-FCH₄ sites and periods (Fig. 4).

600 **4.2 Atmospheric pressure, friction velocity and vapor pressure deficit predict daily and weekly FCH₄ difference between ecosystem and plot scales**

PA, u* and VPD were important daily and weekly-scale Δ FCH₄ predictors. PA is a strong predictor of daily and multiday (ca. 3-21 days) FCH₄ (Knox et al., 2021), and Δ FCH₄ decreased with higher PA (Table 3). As drops in PA have been associated with ebullitive FCH₄ in wetlands (Knox et al., 2021; Nadeau et al., 2013; Sachs et al., 2008; Tokida et al., 2007) and as
605 unvented closed chambers can alter chamber air pressure (Jentzsch et al., 2025) and ebullition events were filtered out from some of the chamber FCH₄ data (Table C2), EC may have captured FCH₄ pulses during falling PA that chamber data did not include. As ebullition events are often removed from chamber FCH₄ data, these results highlight that the large variation in chamber FCH₄ data processing protocols between researchers could also increase Δ FCH₄ and thus uncertainty in multi-site syntheses combining cross-scale FCH₄ data, at least in the sites included in this study (e.g., Jentzsch et al., 2025; Levy et al.,
610 2011). Friction velocity likely increased Δ FCH₄ mainly via effects on CH₄ ebullition in open water (Wille et al., 2008), which EC detected but chambers excluded. While EC FCH₄ can be underestimated in low u*, leading to decreased Δ FCH₄, EC FCH₄ under low u* were filtered out by the FLUXNET-CH₄ team, so low u* was unlikely to influence the observed Δ FCH₄ trends (Aubinet, 2008; Baldocchi, 2003; Knox et al., 2019; Delwiche et al., 2021). The strong effect size of site dominant vegetation and the negative VPD effect can reflect species- and site-specific stomatal conductance and CH₄ transport (Cernusak et al.,
615 2018; Grossiord et al., 2020). For example, at US-Owc (dominated by aerenchymatous vegetation), plant CH₄ conductance varies spatially and temporally between *Nelumbo lutea*, *Nymphaeae odorata*, and *Typha angustifolia*, which may have been covered differently by chamber and EC FCH₄ footprints (Villa et al., 2020). The importance of plant activity is further supported by the marginally-significant TS (Table 3), a possible proxy for increased plant activity in the peak growing season months in the northern hemisphere (July and August; Table 3). Chamber artifacts could have also contributed to the u* and
620 VPD effects: short chamber deployments in high u* and low WTL can underestimate chamber FCH₄ (Lai et al., 2012), while longer measurements (e.g. FI-Si2, US-La1 and US-La2: >30 min) in high WTL can keep stomata open and increase CH₄ transport and chamber FCH₄ (Knapp and Yavitt, 1992; Langensiepen et al., 2012). However, given the limited sample size in the models (n=9 sites) and the low model performance based on leave-one-site-out analyses (Table 3), these results are influenced by site selection and generalizations to other sites are not possible.

625 As hypothesized, greater variation in FCH₄ between chambers led to higher Δ FCH₄ especially at the weekly to annual scales. Chamber FCH₄ can vary strongly between individual chambers (Davidson et al., 2002) but FCH₄ variation can be even stronger between chamber patches (due to differences in vegetation and microtopography) than within them (Stewart et al., 2024), a factor which was not included in our analyses. Similar to CH₄, spatial variation in soil CO₂ respiration measurements has been an important driver of the discrepancies between ecosystem and soil CO₂ respiration observations and their varying directions,
630 indicating that chambers may capture soil respiration hot spots and moments that EC does not (Phillips et al., 2017). While

CH₄ cycling is driven by different controls than CO₂, chambers capturing CH₄ emission hot spots and hot moments may have similarly led to the large ΔFCH_4 CVs and negative mean ΔFCH_4 , particularly in the daily and weekly aggregations in both median and mean-based temporal aggregations (Table 2 and Table C4). The spatial variation between chambers could have also contributed to chamber FCH₄ random errors and ΔFCH_4 patterns in Fig. 4 (Levy et al., 2011). Nevertheless, despite the possible importance of chamber CH₄ emission hot spots and moments in driving ΔFCH_4 , cumulative plot-scale FCH₄ is increasingly exceeded by higher ecosystem-scale FCH₄ at coarser temporal scales, but with site-specific trends (Table C5, Fig. B16).

The FCH₄ variation between chambers and its influence on ΔFCH_4 differed between sites. Between-chamber variation explained ΔFCH_4 best at US-La1 (but n=5) and US-Owc where plot-scale FCH₄ were also higher (Table C9-C12), which is likely related to spatial FCH₄ heterogeneity: in US-Owc, daily mean FCH₄ ranges from 500 nmol m⁻² s⁻¹ in open water areas to 21 000 nmol m⁻² s⁻¹ in mud flats, but CH₄ ebullition and diffusion rates are highest at the *Nelumbo lutea* and *Typha angustifolia*-dominated vegetation patches, where plant-mediated CH₄ transport also varies between species (Rey-Sanchez et al., 2018; Villa et al., 2020, 2021). In contrast, SE-Deg has a relatively homogeneous vegetation composition dominated by *Sphagnum* spp. mosses, *Eriophorum vaginatum*, and *Andromeda polifolia* (Järveoja et al., 2018), which is probably the reason why EC FCH₄ variation had a better fit than between-chamber FCH₄ variation (Fig. 5). Across sites, the increasing absolute ΔFCH_4 with between-chamber FCH₄ variation may result from the EC footprint capturing patches that only a portion of the chamber measurements may represent. This may be highlighted in sites with manual chamber measurements which were conducted 1-3 times a month and during daytime when FCH₄ are often higher than at nighttime (Koebsch et al., 2015; Long et al., 2010; Parmentier et al., 2011) (e.g., US-La1; Fig. 5). However, at some sites median plot-scale FCH₄ was higher than at the ecosystem scale and very high plot-scale FCH₄ contributed more to annual FCH₄ than ecosystem-scale FCH₄, (e.g., US-Owc), highlighting the ability of chambers to capture fine-scale spatial FCH₄ heterogeneity as a ΔFCH_4 driver in some sites (Tables C9-C12). Therefore, using representative chamber patches and measurement times to upscale chamber FCH₄ to the EC footprint could potentially decrease ΔFCH_4 (Schrier-Uijl et al., 2010; Vargas and Le, 2023). This could be achieved for example by utilizing statistical optimization for temporal sampling (Vargas and Le, 2023) and matching the chamber, EC and site spatial heterogeneity by surveying the vegetation, hydrological and edaphic properties of the study site, EC footprint, and the surrounding area/region that the footprint represents (e.g., Chu et al., 2021; Schrier-Uijl et al., 2010, Riutta et al., 2007) (see also 4.6).

4.3 Wind direction, atmospheric pressure and friction velocity drive monthly ecosystem- and plot-scale FCH₄ differences

At the monthly scale ΔFCH_4 was best explained by wind direction (uWD), PA and u*. Wind direction has been an important EC FCH₄ predictor in wetlands similar to the sites of this study in multiday (ca. 3-21 days) and seasonal (ca. 43-341 days) scales (Knox et al., 2021). In general, the significant effect of uWD may indicate monthly-scale variation in EC footprint and the possibly systematically different land cover coverage than that of chambers within the study sites, but footprint-aware

analyses with a larger sample size are required to confirm these hypotheses. PA and u^* are considered to be more influential
665 FCH₄ drivers in the diel to multiday scales, so, together with u_{WD} , they may instead represent seasonality in ΔFCH_4 , driven
by continental-scale air pressure systems or regional land-sea winds (Griebel et al., 2016; Montaldo and Oren, 2016; Rebmann
et al., 2005). The significant and positive effect of aerenchymatous vegetation may further suggest a role of seasonal plant
activity with higher CH₄-emitting or -consuming aerenchymatous plant biomass in growing season months (Knox et al., 2021;
Niu et al., 2011), but this could also be related to site-specificity in monthly ΔFCH_4 patterns (conditional $R^2=0.88$). The
670 significant effect of April in the monthly model (Table 3) was likely influenced by site-specificity, as only three out of ten
sites had observations in that month (Fig. B1, Table 1). Thus, more sites with year-round FCH₄ observations are needed to
confirm the significance of, and the possible ΔFCH_4 drivers in, April.

Monthly and annual ΔFCH_4 trends may have also reflected seasonal snow and ice thaw dynamics, as well as changes in the
chamber measurement system. The higher ecosystem-scale FCH₄ at CN-Hgu in cooler months (February-April, Fig. B15) may
675 have resulted from spring snowmelt releasing stored CH₄ below the ice and snow cover (Hargreaves et al., 2001; Morin et al.,
2017; Rinne et al., 2007; Zhang et al., 2012) which could have been captured by the EC footprint but not by the smaller
chamber footprints, especially since chamber placement in frozen conditions tends to be located further from ice cracks and
fissures. Indeed, snowmelt and ice thawing period occurred between February and April in a peatland close to CN-Hgu (ca.
30 km distance) in 2015 and 2016 (Liu et al., 2021). However, only four sites had data from November, December and March
680 (Fig. B1, Table 1). Therefore, sites with full year co-occurring chamber and EC FCH₄ coverage are needed to investigate the
seasonal ΔFCH_4 dynamics further. Changes in the chamber measurement system also likely contributed to monthly and
interannual ΔFCH_4 . In US-Ho1 and US-Uaf, the number of chambers per chamber surface cover class varied between years
and months: due to instrument malfunction or chamber replacements, in some timestamps spatial chamber medians did not
include CH₄-emitting or -consuming patches while EC did, leading to a large monthly- and annual-scale ΔFCH_4 variation
685 (Richardson et al., 2019; Ueyama et al., 2023a). These variations in chamber footprints likely influenced ΔFCH_4 strongly
particularly at US-Ho1, where the EC footprint often covers both dry, CH₄-consuming or low-emission upland forest and
water-saturated, CH₄-emitting wetland areas, the latter of which was not always included in chamber FCH₄ measurements
(Richardson et al., 2019). This further highlights the influence of selective site-specific chamber and EC tower placement and
the development of methods for plot selection over time on ΔFCH_4 .

690 **4.4 FCH₄ difference between ecosystem and plot scales is highest in the morning and at noon**

Our diel analyses revealed higher ΔFCH_4 and ecosystem-scale FCH₄ from morning to noon (max ΔFCH_4 at 9 AM) and lower
in the evening and at night (min ΔFCH_4 at 8 PM), but the trends varied strongly between sites and months. Higher daytime
FCH₄ has been observed particularly during growing seasons (Koebisch et al., 2015; Long et al., 2010; Parmentier et al., 2011),
and higher daytime EC FCH₄ than chamber FCH₄ also by Yu et al. (2013). Ecosystem FCH₄ seemed to be driving the monthly
695 diel ΔFCH_4 fluctuations particularly in July with noon and August with morning FCH₄ peaks, while plot scale showed less

diel fluctuation (Fig. B8-B12), possibly as a result of the spatial aggregation of chamber measurements across ecohydrological patches that differ in FCH₄ (e.g., from wet *Carex* sp. to dry lichen in US-Uaf; Ueyama et al., 2023a). Our findings of increasing absolute Δ FCH₄ with FCH₄ (Fig. 4) may reflect these differences, as EC and chamber FCH₄ random error can increase with flux magnitude (Hollinger and Richardson, 2005; Knox et al., 2019; Richardson et al., 2006, 2008), and may also be associated with diel variation in turbulence, EC footprint, and spatial FCH₄ heterogeneity (Hollinger & Richardson, 2005; Knox et al., 2021; Levy et al., 2011), and vary between sites (Delwiche et al., 2021; Richardson et al., 2006). However, further investigations into the exact mechanisms behind these trends are needed. In addition, the diel-scale mixed models had very low explanatory power and high site-specificity (conditional R²>0.79), making it difficult to identify drivers for the observed Δ FCH₄ trends. Thus, more sites with hourly chamber FCH₄ measurements are needed to disentangle the diel Δ FCH₄ predictors.

The high daytime Δ FCH₄ (CN-Hgu, SE-Deg, US-Ho1) could have resulted from diel variation in u* and VPD. High daytime u* can enhance ebullition, CH₄ volatilization and release of stored CH₄ from nocturnal boundary layer (Baldocchi, 2003; Long et al., 2010; Morin et al., 2014; Sachs et al., 2008; Wille et al., 2008). Related to VPD, pressurized plant-mediated CH₄ transport typically peaks in the late morning to afternoon, as temperature and humidity gradients between cooler belowground tissues and warmer, drier aboveground air enhance internal-external pressure differences that drive gas flow through aerenchyma (van den Berg et al., 2020; Knox et al., 2021; Morin et al., 2014; Vroom et al., 2022; Whiting and Chanton, 1996). However, very high VPD can induce stomatal closure, thereby reducing CH₄ transport (Grossiord et al., 2020). Enhanced stomatal conductance under high solar radiation may have also increased diffusive plant-mediated CH₄ transport (van der Nat et al., 1998), leading to higher daytime ecosystem-scale FCH₄ than plot-scale FCH₄ as dark chambers possibly closed the stomata. However, longer chamber deployment can decrease VPD within the chamber, and re-open the stomata (Knapp and Yavitt, 1992; Langensiepen et al., 2012). In addition, the lower plot- than ecosystem-scale diel FCH₄ at CN-Hgu (e.g., Fig. B9) likely reflected the selective chamber placement at CH₄-consuming areas whereas the EC footprint captured CH₄ emission events more often (Table C2). The high nighttime Δ FCH₄ (US-Uaf) could have been driven by u*: the nighttime EC footprint may have covered high-CH₄-emitting areas when u* was low and EC footprint larger (Baldocchi et al., 2012; Chu et al., 2021; Vesala et al., 2008). Deeply-rooted aerenchymatous vegetation (e.g., *Carex* sp.) may have also decreased daytime ecosystem-scale FCH₄ by increasing rhizospheric oxidation and CH₄ consumption under high solar radiation, VPD, and soil temperature (Cho et al., 2012; Zhao et al., 2021, Ueyama et al., 2023a). However, further footprint-aware research on diel Δ FCH₄ patterns is needed to explore these hypotheses.

4.5 Plot-scale FCH₄ may have been underestimated

EC and chamber techniques fundamentally differ in how ecosystem FCH₄ is measured, which could influence Δ FCH₄. Gas analyzers used for EC can be divided into open- and closed-path analyzers, the former of which is more sensitive to weather conditions, while the latter is influenced by the choice of the air pump and time lags between sonic anemometer and the gas analyzer (Baldocchi, 2003; Detto et al., 2011). The specific EC CH₄ analyzers can also differ in signal noise (Peltola et al.

2014). However, the random and systematic errors associated with open- and closed-path EC gas analyzers do not contribute significantly to the total EC FCH₄ random error, which may be more affected by the movement of EC footprint and turbulence (Deventer et al., 2019; Knox et al., 2019; Peltola et al., 2014). Thus, the two analyzers should agree relatively well in practice and they can be combined in multi-site syntheses (Detto et al., 2011; Deventer et al., 2019; Peltola et al., 2014). However, detecting upland CH₄ uptake rates accurately with open-path analyzers is challenging due to uptake rates often falling within the instrument's detection limits (Chamberlain et al., 2017; Iwata et al., 2014). Of the two upland sites included in this study, these artifacts may have affected the results from CN-Hgu where EC FCH₄ were measured with an open-path gas analyzer.

As manual and automated chambers differ in temporal representation, the nonsignificant differences between automated and manual chambers in Δ FCH₄ were surprising. The nonsignificant differences are also reflected in the strong correlations between automated and manual chamber FCH₄ and EC FCH₄ (Fig. B19), and similar nonsignificant differences between automated and manual chambers were found in a Tibetan wetland (Yu et al., 2013). While manual chambers allow researchers to capture higher spatial FCH₄ variation than automated chambers (e.g., Vargas and Le, 2023), the use of spatial medians for chamber FCH₄ may have reduced manual chamber FCH₄ variation so that the resulting median FCH₄ was similar to the FCH₄ measured by automated chambers. However, the higher Δ FCH₄ variation of manual chambers could have also resulted from chamber measurements being conducted 1-3 times a month leading to data gaps (Morin et al., 2014, 2017). Thus, care should be taken when combining manual chamber FCH₄ data with EC FCH₄ data in multi-site syntheses.

Chamber FCH₄ measurement and calculation methodology may have contributed to the generally lower plot-scale FCH₄. As previously discussed (see 4.1 and 4.2), plot-scale FCH₄ could have been generally underestimated due to the removal of ebullition events from some of the chamber FCH₄ data (Table C2), calling for standardization of chamber-based ebullition measurements and data processing (Jentzsch et al., 2025). In addition, all chamber FCH₄ data was calculated using linear regression which may underestimate FCH₄ (Forbrich et al., 2010; Korriakoski et al., 2017; Levy et al., 2011; Nakano, 2004; Pihlatie et al., 2013). High-precision CH₄ analyzers, such as cavity ring-down spectrometers and near-infrared laser gas analyzers, could capture nonlinear CH₄ concentration gradients which linear regression fails to do (Forbrich et al., 2010). With gas chromatography, the underestimation and related uncertainties may become even greater due to smaller sample sizes and difficulty in detecting low-quality FCH₄ measurements during chamber measurements (Christiansen et al., 2015; Levy et al., 2011). In sites which used gas chromatography, the number of samples was 4-7 per chamber deployment (e.g., FI-Si2, US-Owc), while sites that used high-precision CH₄ analyzers (CN-Hgu, SE-Deg, US-Ho1, US-Uaf) had ca. 1 Hz sampling interval, resulting in vastly different sample sizes per chamber deployment between sites, and thus higher uncertainties in chamber FCH₄. However, linear regression can be statistically more robust for comparing chamber FCH₄ from different sites with varying soil properties (Venterea et al., 2009). Furthermore, depending on chamber design, chambers can alter soil conditions (e.g., soil moisture) which may also contribute to Δ FCH₄ (Bansal et al., 2023b; Subke et al., 2021). It may be valuable to compare chamber and EC FCH₄ using both linear and exponential fits for chamber FCH₄ (from both high-precision CH₄ analyzers and gas chromatography) to better understand Δ FCH₄ trends across sites.

4.6 Limitations and uncertainties

As we were able to include only ten sites in the analyses, our results are limited by the site-specific climate, vegetation, and methodology. Thus, in order to produce results that would be better generalizable to other sites and regions (e.g., tropics), future studies could include more sites from a variety of climates, ecosystem types, dominant vegetation types, and chamber measurement systems (i.e., automated and manual, gas chromatography and high-precision CH₄ analyzers) (n>3 sites per group to allow statistical inference). In addition, year-round FCH₄ observations were lacking, which introduced uncertainty, particularly into the annual Δ FCH₄ trends. While challenging to measure, nongrowing season FCH₄ can be significant (Treat et al., 2018). Thus, future syntheses could include nongrowing season FCH₄ observations to improve annual Δ FCH₄ estimates and investigate the possible effects of ice thaw and snowmelt on Δ FCH₄.

Another source of uncertainty in our study arose from the EC and chamber FCH₄ footprints. Since we used spatial medians of chamber FCH₄ measurements instead of upscaled chamber FCH₄ in the analyses to investigate cross-scale FCH₄ differences, the results should not be taken as indication of systematic methodological differences between EC and chamber FCH₄. Thus, the next steps could include comparing EC and chamber methods by upscaling chamber FCH₄ to the EC footprint level, or downscaling EC FCH₄ to chamber level, using footprint models and indices of footprint spatial heterogeneity based on fine-scale land cover classification (Hartley et al., 2015; Metzger, 2018; Räsänen et al., 2021; Tuovinen et al., 2019; Xu et al., 2018). Future studies could apply high-resolution (e.g., 1-2 m) remotely-sensed data together with field surveys to determine chamber patch classes which could be used in upscaling chamber FCH₄ to the EC footprint level (Davidson et al., 2017; Forbrich et al., 2011; Morin et al., 2017; Rey-Sanchez et al., 2018; Schrier-Uijl et al., 2010; Stewart et al., 2024; Tuovinen et al., 2019), or downscaling EC FCH₄ to land cover classes (Forbrich et al., 2011; Rößger et al., 2019). By comparing footprint- and patch-weighted chamber FCH₄ to EC FCH₄, we would expect Δ FCH₄ to decrease or chamber FCH₄ exceed EC FCH₄ due to the incorporation of footprint FCH₄ heterogeneity (Budishchev et al., 2014; Schrier-Uijl et al., 2010). As our results may indicate FCH₄ hot spots and moments within the study sites as a possible Δ FCH₄ driver, identifying FCH₄ hot spots within the EC footprint with the aid of footprint-weighted FCH₄ maps (Rey-Sanchez et al., 2022) could also assist in finding representative chamber FCH₄ locations to reconcile the ecosystem and plot-scale FCH₄ differences.

In addition, our cross-scale FCH₄ comparisons may contain large uncertainties due to differences in chamber FCH₄ outlier removal (Table C2), design and the gas analyzer used (Table C1) (Jentzsch et al., 2025; Levy et al., 2011; Pihlatie et al., 2013; Pumpanen et al., 2004). To minimize these uncertainties in future comparison studies, it is therefore recommended to use chamber FCH₄ data that has been processed in as standardized a way as possible. Given that our results indicated ebullition removal from some of the chamber FCH₄ data as one potential driver of Δ FCH₄, future studies could also conduct cross-scale FCH₄ comparisons based on chamber FCH₄ data with ebullition events both included and excluded from a variety of wetland types. Ebullition events are sometimes also removed from EC FCH₄ data following the standard data quality protocols and further standardization of EC-based ebullition measurements are needed.

5 Conclusions

We explored the differences between ecosystem-scale (eddy covariance, EC) and plot-scale (chamber, spatially-aggregated median) instantaneous CH₄ flux (FCH₄) across ten sites and in different temporal aggregations. Contrary to our expectations, we observed significantly higher median ecosystem FCH₄ than plot-scale FCH₄ across all temporal scales. However, the median FCH₄ difference between ecosystem- and plot-scales (Δ FCH₄) remained relatively low. Ecosystem- and plot-scale FCH₄ correlated strongly from daily to annual scales, which indicates that ecosystem- and plot-scale FCH₄ observations could be combined in multi-site analyses at coarse temporal scales. However, care must be taken when combining cross-scale FCH₄ data, as variation in (based on instantaneous FCH₄) and magnitude of Δ FCH₄ (based on cumulative FCH₄) was large at daily to annual scales, and the agreement was worst at the half-hourly to hourly scales. In addition, Δ FCH₄ increased with FCH₄ magnitude at all temporal scales, suggesting that combining ecosystem- and plot-scale FCH₄ in high CH₄-emission ecosystems, such as wetlands, could lead to large FCH₄ uncertainties.

We attribute the higher ecosystem-scale FCH₄ than plot-scale FCH₄ mainly to the combination of selective chamber placement, ebullition removal from chamber FCH₄ data, and the spatio-temporal dynamics of the EC footprint which may have captured CH₄ emission events that were not detected by chambers. Our results highlight the importance of monthly and seasonal variation in variables related to plant activity, atmospheric pressure, wind direction, and friction velocity as drivers of Δ FCH₄ at the ten sites. Between-chamber FCH₄ variation also led to higher Δ FCH₄, which highlights the mismatch of chamber and EC footprint coverage of the study sites as a Δ FCH₄ driver. Nevertheless, Δ FCH₄ varied strongly between sites and the models' ability to predict to other sites was limited by the low sample size, warranting further research on Δ FCH₄ controls within and across ecosystem types. Based on our findings, we recommend the following:

- Cross-site efforts to upscale chamber FCH₄ to EC footprint level, or conversely, to downscale EC FCH₄ to chamber scale, using chamber measurements stratified by surface cover classes which take into account for vegetation and soil characteristics
- Further investigation of diel Δ FCH₄ dynamics from a higher number of sites with automated chamber measurements, particularly related to the spatial representativeness of the chamber measurements in relation to the EC footprint and chamber artifacts on the observed FCH₄
- Standardized protocols for chamber FCH₄ data quality control, especially related to ebullition removal (see Jentzsch et al., 2025 for recent recommendations for chamber FCH₄ data processing), and accounting for these differences when combining chamber and EC FCH₄ data
- More widely adopted, standardized methods for examining heterogeneity of FCH₄ in EC footprints, which can inform representative chamber and EC tower placement within the study sites (e.g., EC footprint modeling and targeted manual chamber sampling; Rey-Sanchez et al., 2022, Barba et al., 2018)
- Systematic bias and uncertainty of chamber and EC FCH₄ observations should be incorporated into model evaluation and parameterization studies

As syntheses and databases are increasingly utilizing both plot- and ecosystem-scale FCH₄ measurements, it is important to understand their differences across multiple sites. Taking these differences into account in future studies will improve ecosystem CH₄ budget estimates.

Appendices

830 Appendix A: Supplementary methods (Supplementary Methods A1-A2)

Supplementary Methods A1.

Wind u and v component calculation.

835 Wind direction was separated into u (calculated with sine; equation 1) and v (calculated with cosine; equation 2) component vectors which combine both wind speed and direction for each half-hour measurement period.

$$u = -WS * \sin\left[\frac{2\pi * WD}{360}\right] \quad (1)$$

$$v = -WS * \cos\left[\frac{2\pi * WD}{360}\right], \quad (2)$$

840 where WS is wind speed (m s⁻¹) and WD is wind direction in decimal degrees.

The u and v component averages were then calculated by taking the mean over the temporal unit in each aggregation (e.g. hour or day), resulting in temporally-aggregated u and v components in m s⁻¹.

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Supplementary Methods A2.

Details of linear mixed effects models.

Temporal autocorrelation and residual variance structures were examined and chosen based on Akaike Information Criteria (AIC) and residual diagnostics, with more emphasis on the latter. Temporal autocorrelation was modeled using an autoregressive structure of order 1 (AR1) in the daily, weekly, and monthly models. To meet the requirements of the `corAR1` argument in R, random effects in these models were nested to account for site-specific sampling times (e.g., daily model: *random = ~1 | Site/YearMonth, correlation = corAR1(form = ~ Day | Site/YearMonth)*). The nesting allowed for the inclusion of temporal autocorrelation within each temporal scale, for example “YearMonth”, at the site level, reducing residual temporal autocorrelation compared to models with un-nested random effects. However, incorporating AR1 in the half-hourly model did not improve model fit or reduce residual variance and was therefore excluded. In addition, despite improvements in AIC in the hourly model, inclusion of AR1 led to model non-convergence and it had to be excluded from the model, leading to higher

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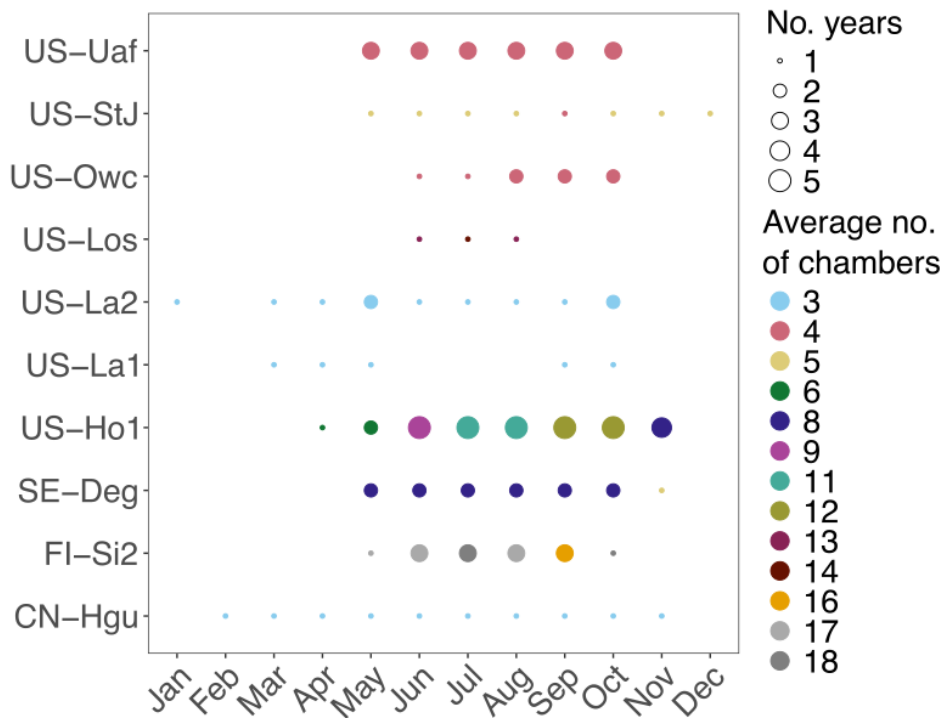
AIC but temporal autocorrelation and residual normality and variance heterogeneity were still acceptable when the random effect was nested (*Site/Date*).

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Heterogeneous residual variance caused by some of the predictors was modeled in some of the models using an exponential variance structure (*varExp*; half-hourly and hourly: VPD, u^* , PA; daily: PA and TS; weekly: PA; monthly: u_{WD} , u^*), as well as variance per stratum (*varIdent*; weekly: Year). We also tested other variance structures but, according to AIC and residual diagnostics, exponential variance structure led to best model fit and some of the other structures led to model non-convergence.

865 Despite our efforts to account for the residual variance heterogeneity, some heterogeneity remained in the models while AIC and general model residual heterogeneity improved.

Appendix B: Supplementary figures (Figures B1-B19)



870 **Figure B1.** Number of individual chambers and years per month per site. The size of the point describes the number of years and color the average number of individual chambers used within each month across years.

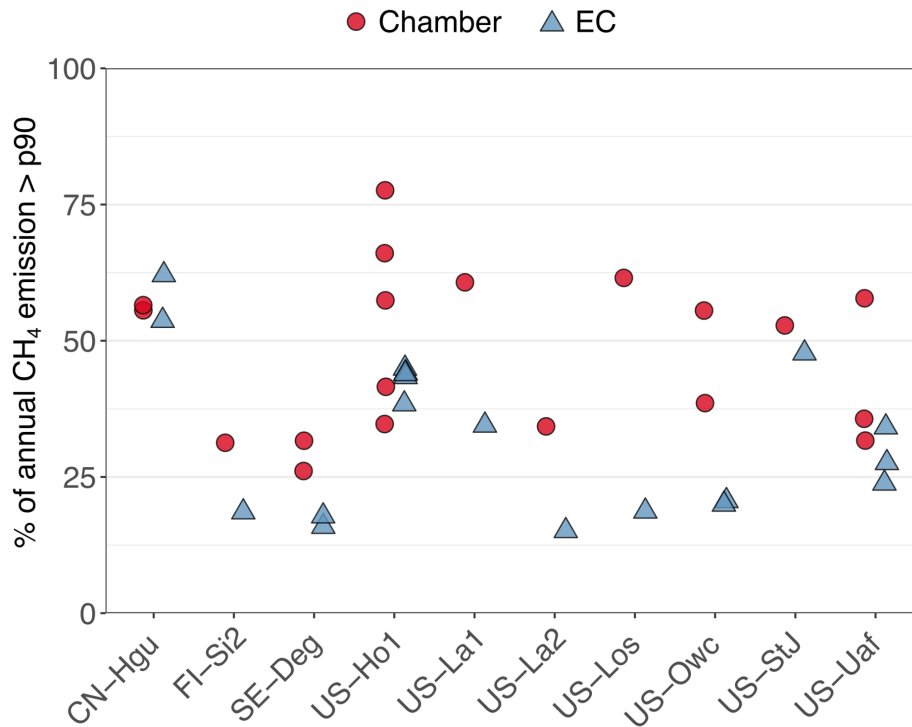


Figure B2. Contribution of high methane (CH₄) emissions to annual CH₄ emissions per site in the unaggregated data set. For each site and year, high CH₄ emissions were estimated as CH₄ flux (FCH₄) above the 90th percentile (p90) and their proportion (%) of the total annual CH₄ emission was calculated separately for chamber (red circle) and EC (blue triangle). In the unaggregated data set, all eddy covariance (EC) FCH₄ data is in the half-hourly scale, but the chamber data measurement frequency varies across sites (see Table S1).

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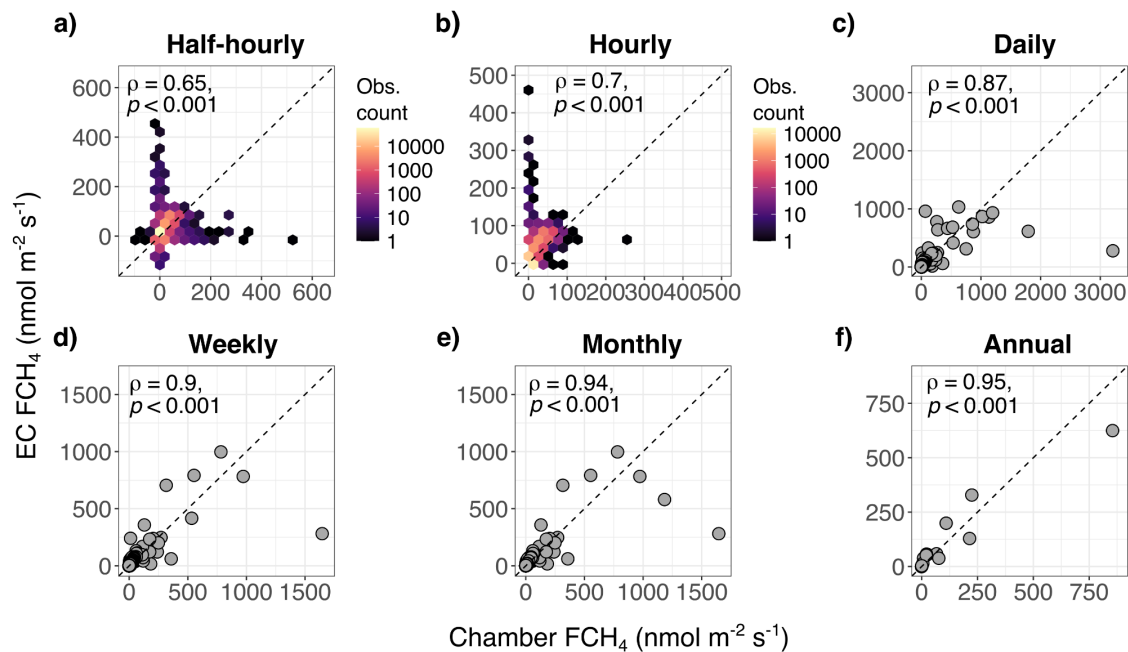


Figure B3. Relationship between eddy covariance (EC; ecosystem scale) methane (CH_4) flux (FCH_4) and chamber FCH_4 (plot
 885 scale) with untransformed plot axes. Higher Spearman correlation coefficients (ρ) indicate stronger agreement between EC
 FCH_4 and chamber FCH_4 . In a) and b) the points for half-hourly ($n=74482$) and hourly ($n=40072$) aggregations are shown in
 hexagonal density clouds with a log-transformed color range to highlight trends in high point density areas (colors represent
 number of observations per hexagon). For daily (c), weekly (d), monthly (e), and annual (f) aggregations, sample sizes were n
 = 1879, 349, 121, and 22, respectively. The dashed line represents 1:1 line.

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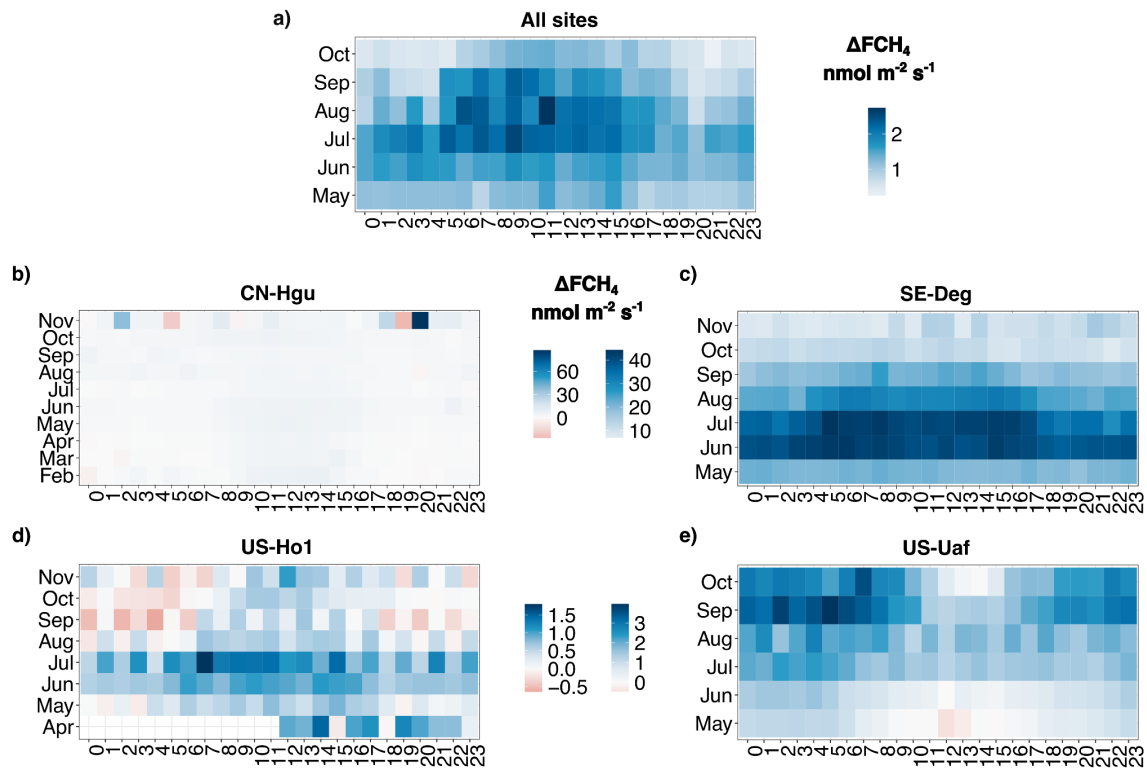


Figure B4. Heatmaps of hourly median methane (CH_4) flux (FCH_4) difference between ecosystem- and plot-scale FCH_4 (ΔFCH_4) across months in the half-hourly aggregation. Positive ΔFCH_4 (blue) represents higher eddy covariance (EC) FCH_4 than chamber FCH_4 , and negative (red) higher chamber FCH_4 than EC FCH_4 . X axis represents hours of day (24 h) and y axis months. a) Data set containing all sites ($n=4$ sites). Only months which were included in all sites are shown (May-October). b) CN-Hgu (all months), c) SE-Deg (all months), d) US-Ho1 (all months), e) US-Uaf (all months).

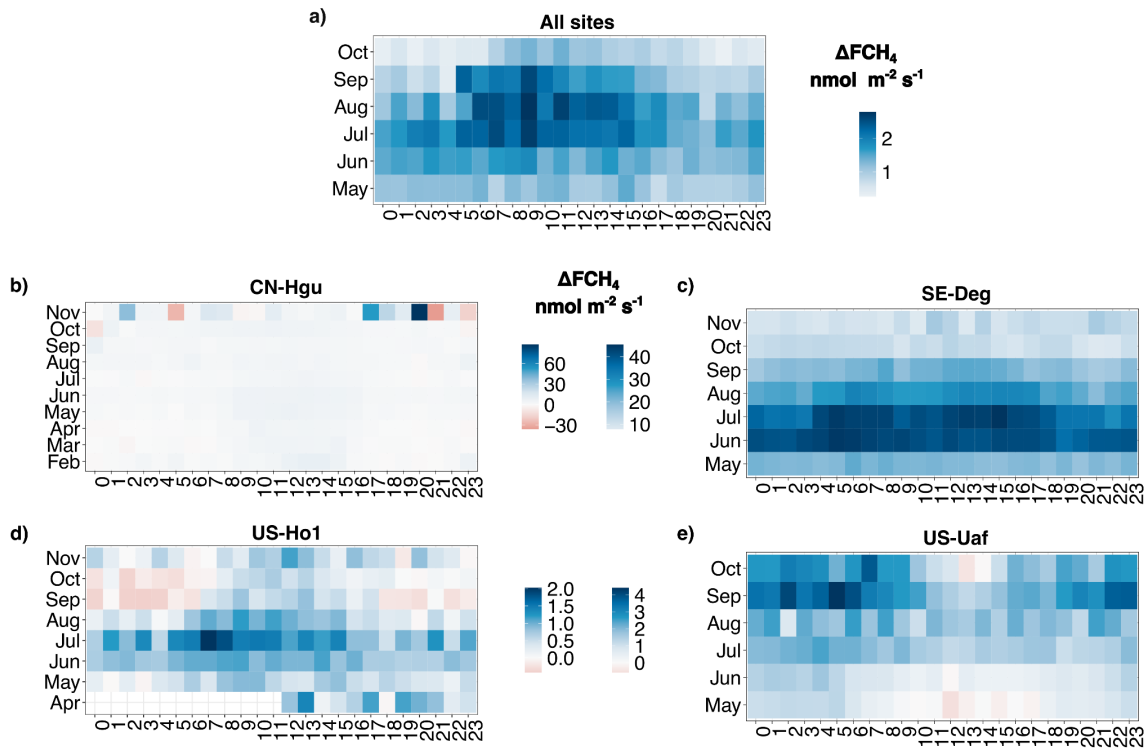


Figure B5. Heatmaps of hourly median methane (CH_4) flux (FCH_4) difference between ecosystem- and plot-scale FCH_4 (ΔFCH_4) across months in the hourly aggregation. Positive ΔFCH_4 (blue) represents higher ecosystem-scale (eddy covariance; EC) FCH_4 than plot-scale (chamber) FCH_4 , and negative (red) higher plot-scale FCH_4 than ecosystem-scale FCH_4 . X axis represents hours of day (24 h) and y axis months. a) Data set containing all sites ($n=4$ sites). Only months which were included in all sites are shown (May-October). b) CN-Hgu (all months), c) SE-Deg (all months), d) US-Ho1 (all months), e) US-Uaf (all months).

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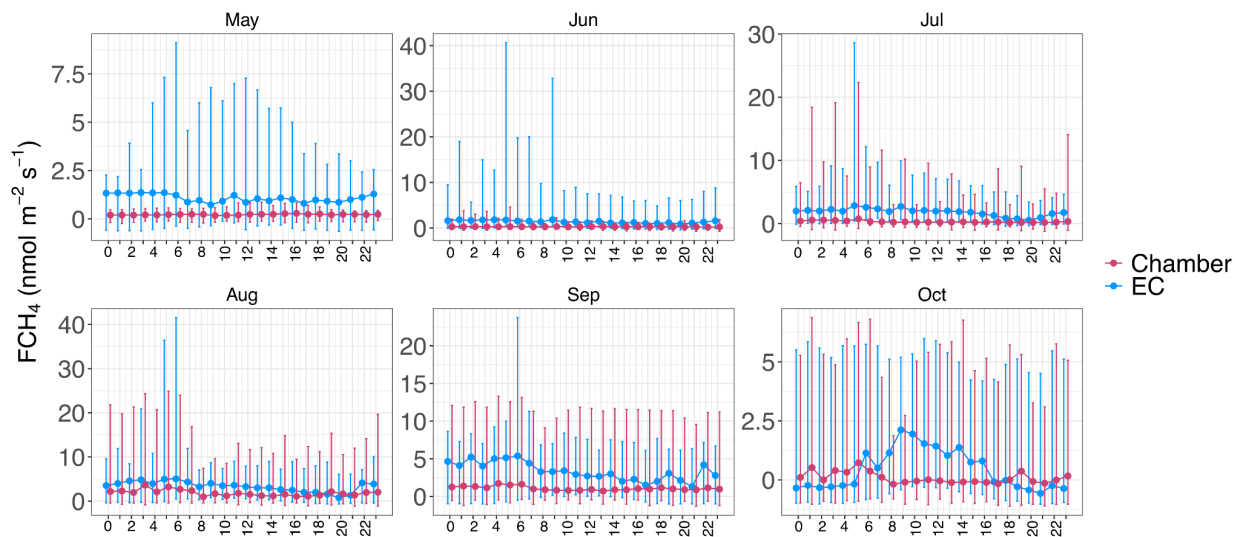


Figure B8. Hourly median chamber (red; plot scale) and eddy covariance (EC; ecosystem scale) methane (CH_4) flux (FCH_4 ; blue) per month in the half-hourly data set. Variation around the median is represented by the interquartile range (between 25% and 75%). Only months containing all sites ($n=4$) with automated chamber measurements are shown.

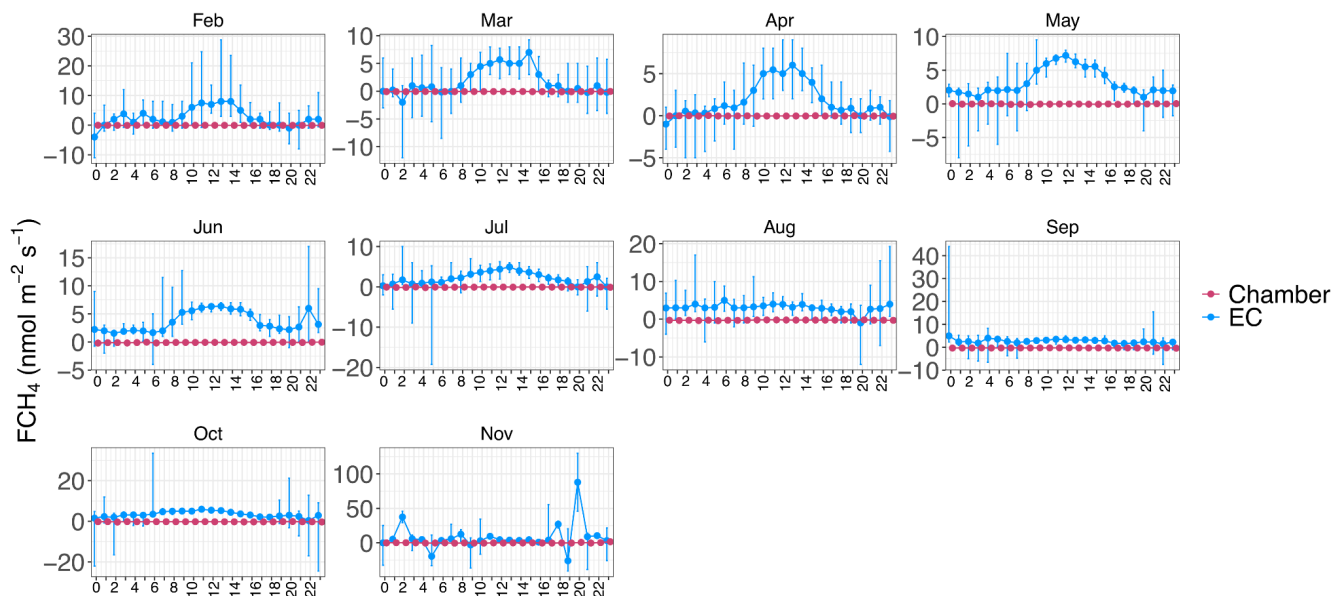


Figure B9. Hourly median chamber (red; plot scale) and eddy covariance (EC; ecosystem scale) methane (CH_4) flux (FCH_4 ;

930 blue) per month at CN-Hgu in the half-hourly dataset. Variation around the median is represented by the interquartile range (between 25% and 75%).

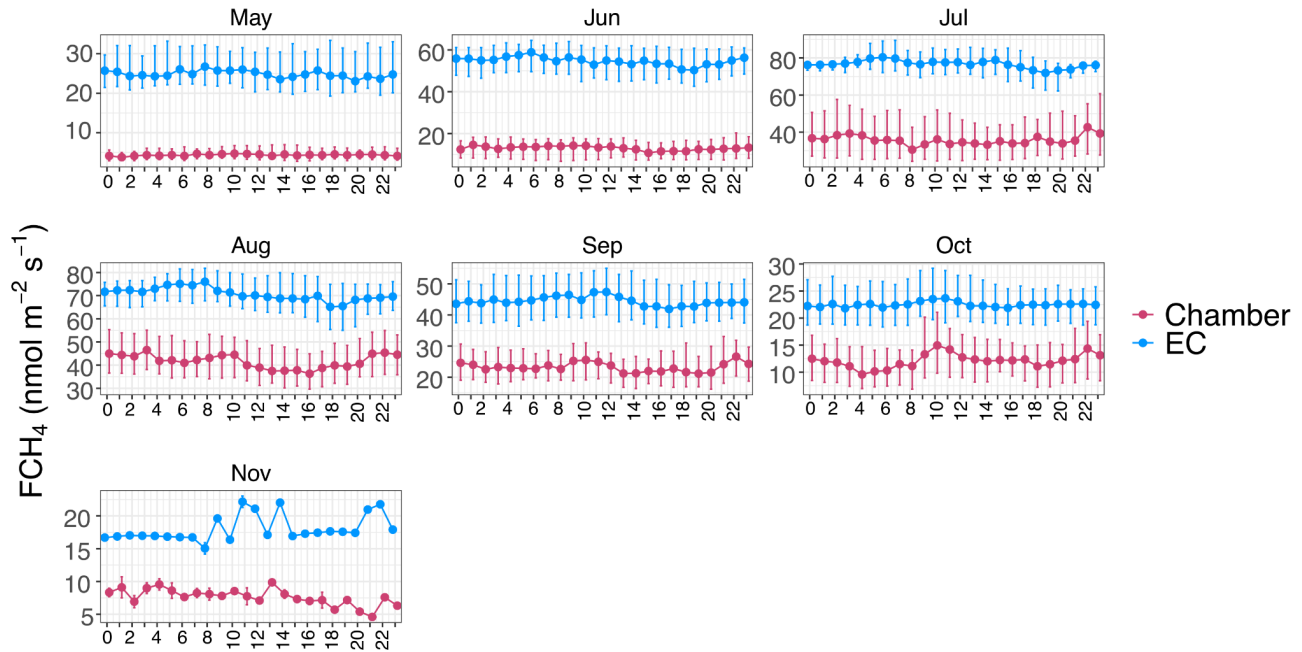


Figure B10. Hourly median chamber (red; plot scale) and eddy covariance (EC; ecosystem scale) methane (CH_4) flux (F_{CH_4} ;

935 (between 25% and 75%).

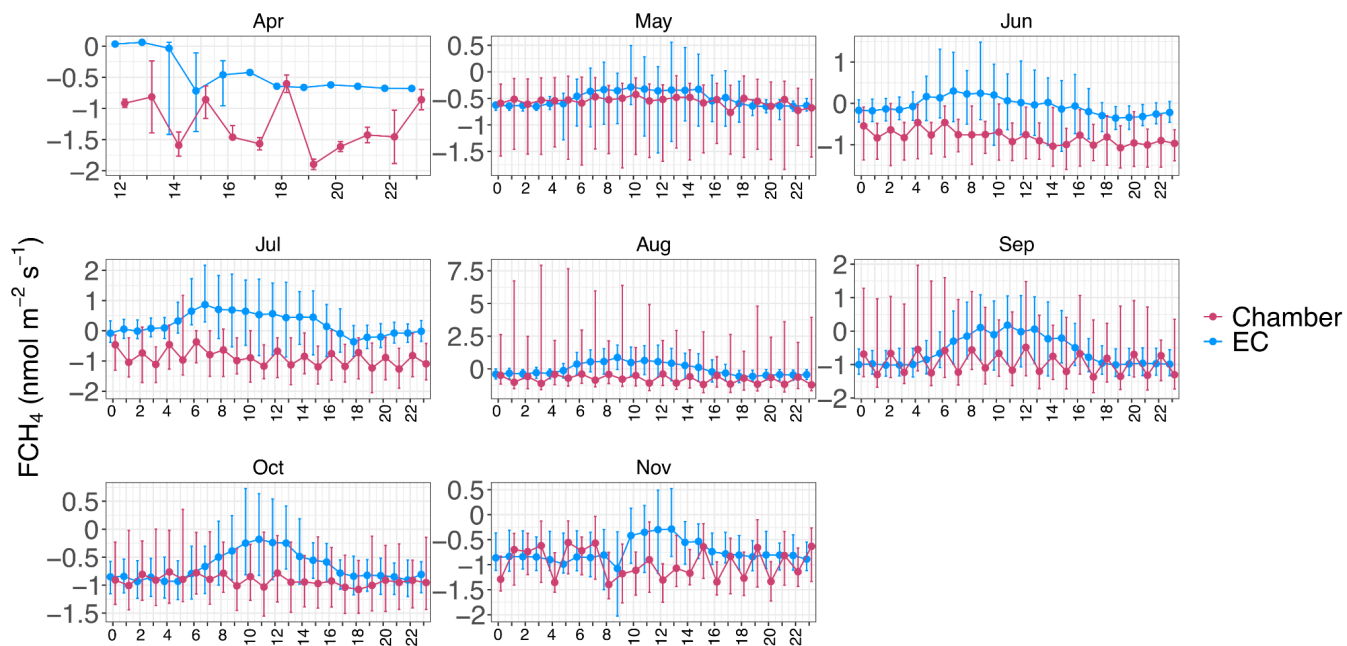


Figure B11. Hourly median chamber (red; plot scale) and eddy covariance (EC; ecosystem scale) methane (CH_4) flux (F_{CH_4} ; blue) per month at US-Ho1 in the half-hourly dataset. Variation around the median is represented by the interquartile range (between 25% and 75%).

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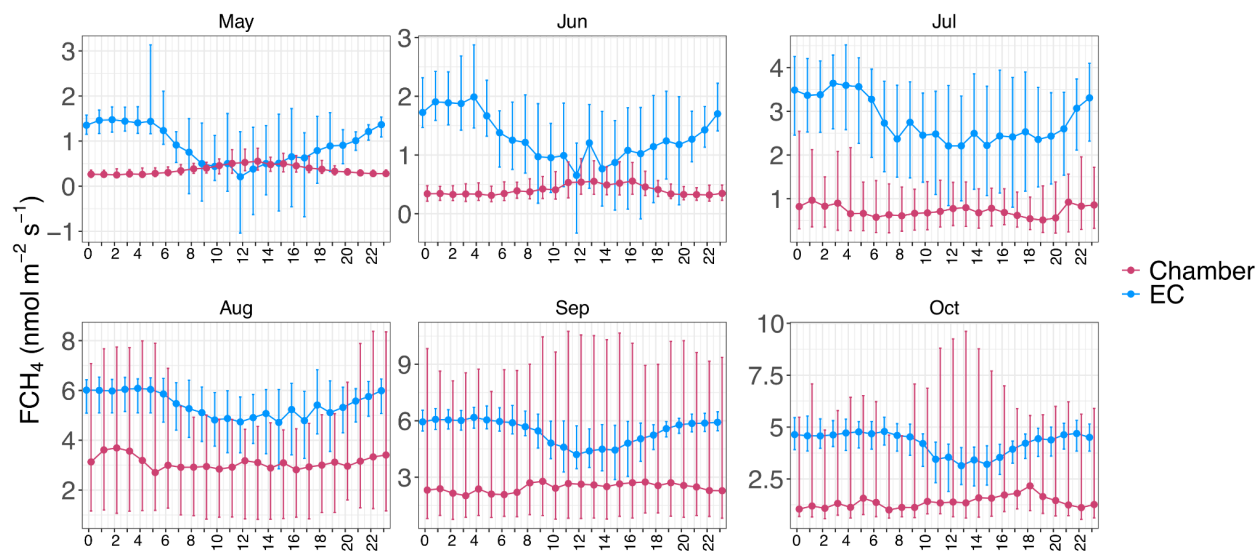


Figure B12. Hourly median chamber (red; plot scale) and eddy covariance (EC; ecosystem scale) methane (CH₄) flux (FCH₄; blue) per month at US-Uaf in the half-hourly dataset. Variation around the median is represented by the interquartile range (between 25% and 75%).

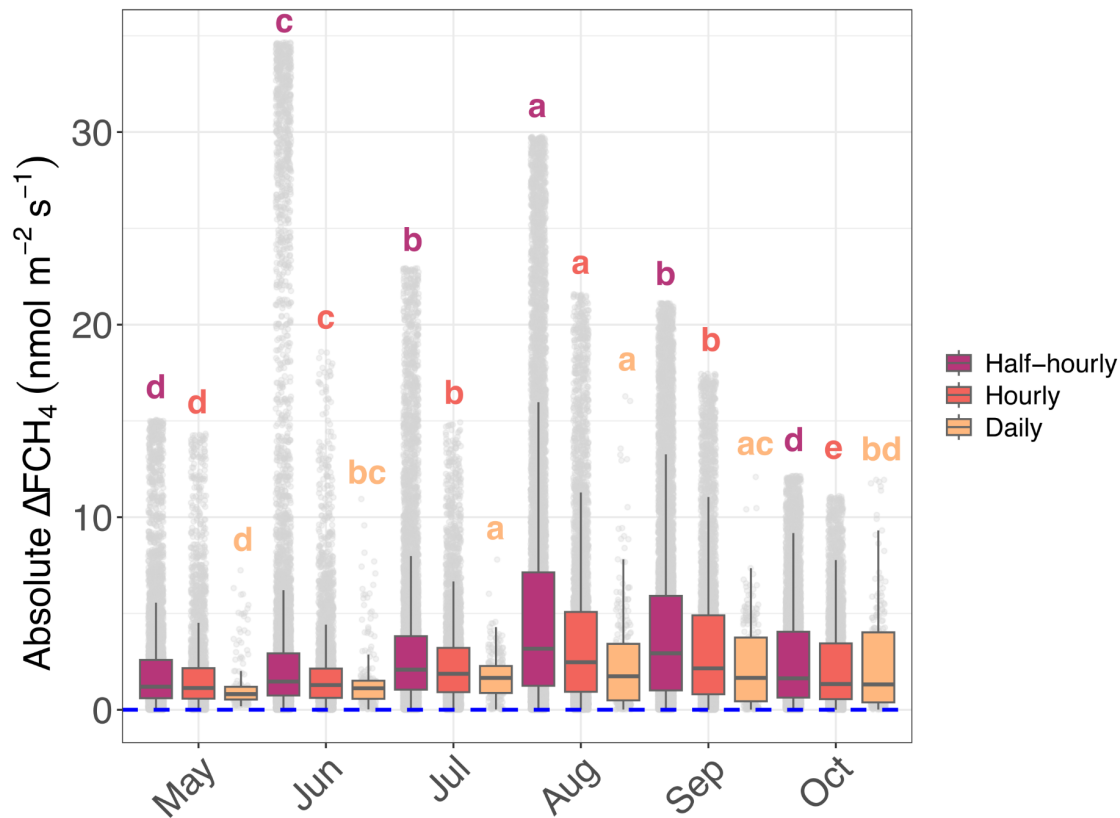


Figure B13. Absolute difference between ecosystem-scale (eddy covariance; EC) and plot-scale (chamber) methane (CH₄) flux (FCH₄) differences (ΔFCH₄) between months in half-hourly, hourly and daily aggregations. Different colors represent different temporal aggregations and gray points show the underlying data. For visualization, we filtered out data points 1.5 x IQR below the first quartile and 1.5 x IQR above the third quartile but statistics were based on the original data. The letters indicate whether ΔFCH₄ differs significantly between months: months that share at least one shared letter are not significantly different ($p > 0.05$) while months with different letters differ significantly ($p \leq 0.05$). Pairwise comparisons were conducted with the Conover-Iman post hoc test. While there was data in other months, the May-October period was chosen for this figure due to these months including either all ($n=4$; half-hourly and hourly aggregations) or almost all sites ($n=7$ or 8 sites; daily aggregation). Weekly and monthly aggregations did not have significant ΔFCH₄ differences between months (Kruskal-Wallis $p > 0.05$) and are not shown in this figure.

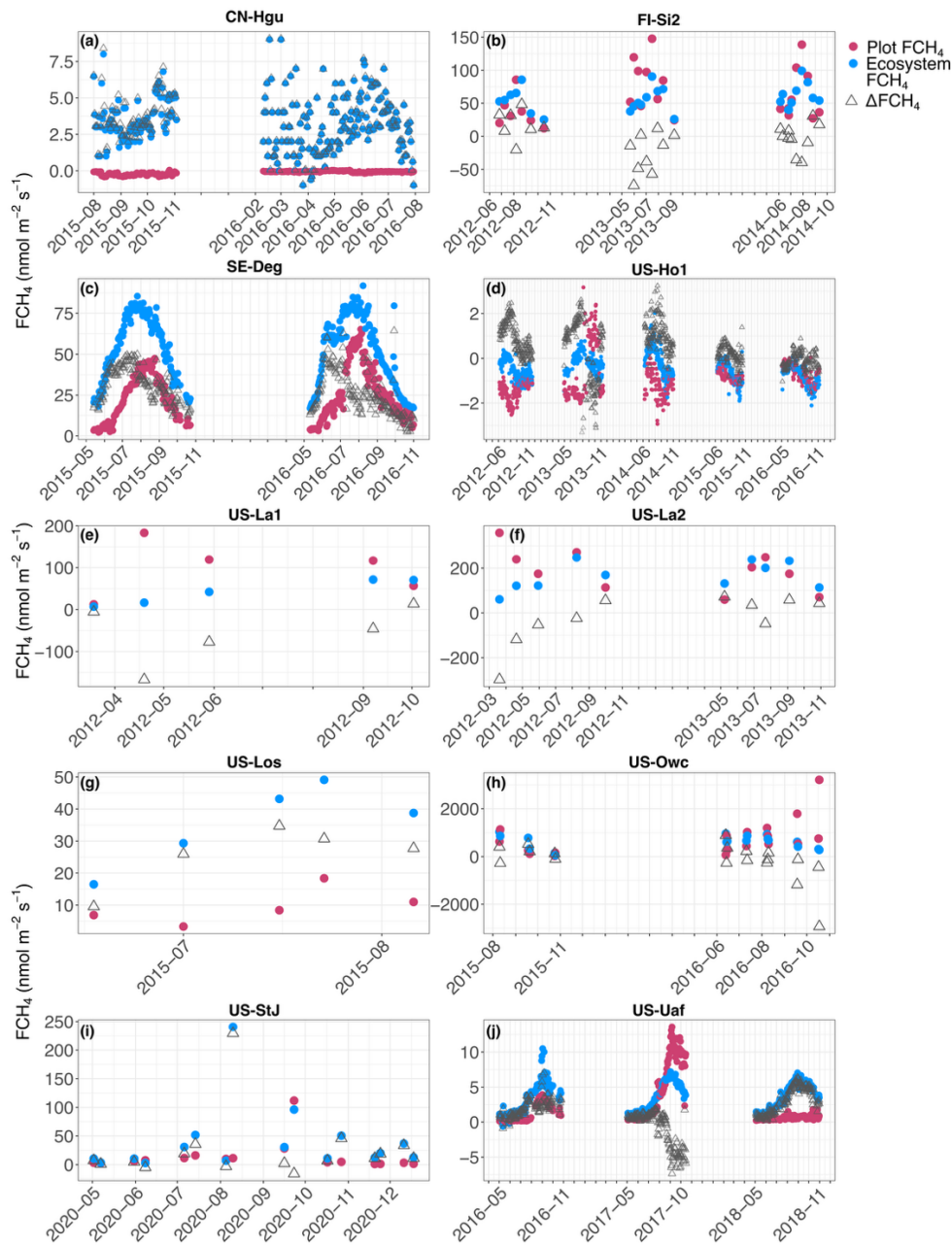


Figure B14. Site-specific trends in daily ecosystem- (eddy covariance; EC) and plot-scale (chamber) methane (CH_4) flux (FCH_4), and FCH_4 difference between ecosystem and plot scales (ΔFCH_4) (a to j). Red circles represent plot- and blue ecosystem-scale FCH_4 measurements. Hollow gray triangles are ΔFCH_4 . In d) 46 outlier points from 2013 were removed to

improve visualization. Negative ΔFCH_4 indicates higher plot-scale FCH_4 than ecosystem-scale FCH_4 , and positive higher ecosystem-scale FCH_4 than plot-scale FCH_4 .



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Figure B15. Daily-aggregated methane (CH_4) flux (FCH_4) at CN-Hgu between February and July highlighting the higher ecosystem- than plot-scale FCH_4 during the ice thawing period (February-end of April). Red circles represent plot- and blue ecosystem-scale FCH_4 measurements. Hollow gray triangles are the difference between ecosystem- and plot-scale FCH_4 (ΔFCH_4). Negative ΔFCH_4 indicates higher plot-scale FCH_4 than ecosystem-scale FCH_4 , and positive higher ecosystem-scale FCH_4 than plot-scale FCH_4 . The dashed vertical black line represents the mean end period of frozen-thawing period at a nearby peatland (between 2015 and 2016), calculated by Liu et al., (2021).

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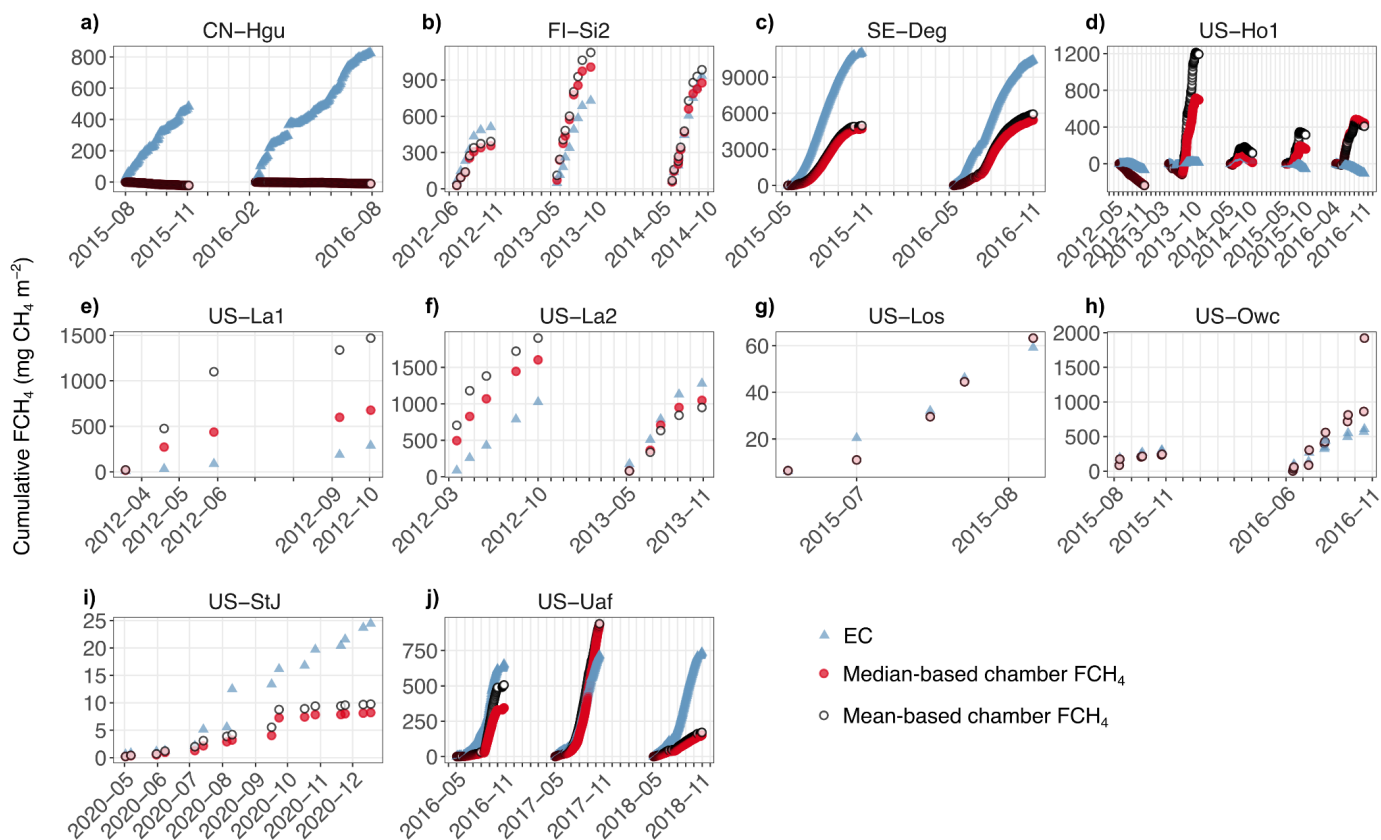


Figure B16. Cumulative sums of ecosystem-scale (eddy covariance; EC) and plot-scale (chamber) methane (CH₄) flux (FCH₄) at the daily scale across sites (a-j). Blue triangles represent EC, red points chamber FCH₄ calculated from the median-based aggregation, and white points chamber FCH₄ calculated from the mean-based aggregation. Note that since the chamber FCH₄ data at FI-Si2, US-La1, and US-La2 lacked hourly timestamps, we roughly estimated daily cumulative FCH₄ by using the daily chamber FCH₄ median or mean for all 24 hours of the measurement date (EC cumulative FCH₄ was calculated based on daily half-hourly FCH₄ from FLUXNET-CH₄), and these estimates should thus be interpreted with caution.

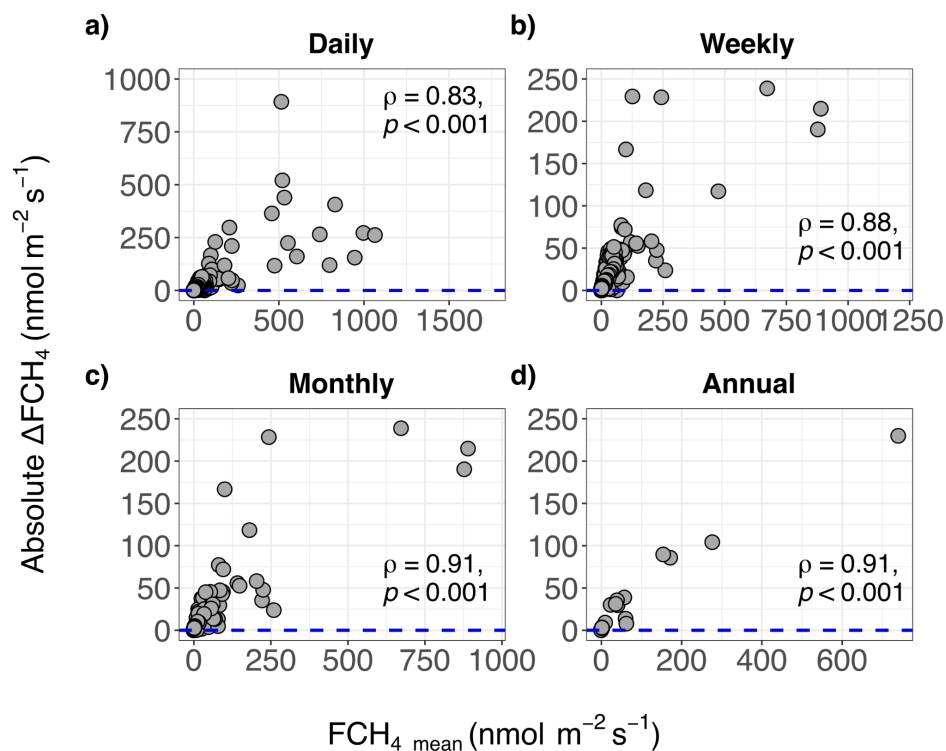


Figure B17. The relationship between methane (CH_4) flux (FCH_4) magnitude and absolute difference between ecosystem- and plot-scale FCH_4 (ΔFCH_4) with outliers in daily (a), weekly (b), monthly (c) and annual (d) scales. FCH_4_{mean} is the row-wise mean of eddy covariance (EC) FCH_4 and chamber FCH_4 , and EC-chamber FCH_4 difference (ΔFCH_4) was calculated by subtracting chamber FCH_4 from EC FCH_4 . Positive ΔFCH_4 indicates higher EC FCH_4 than chamber FCH_4 and negative values higher chamber FCH_4 than EC FCH_4 . The blue dashed line represents the line of equality where EC FCH_4 and chamber FCH_4 are equal. ρ represents Spearman correlation coefficient, followed by its statistical significance ($\alpha = 0.05$). Higher ρ represents stronger deviation from the line of equality, i.e. $\Delta FCH_4 = 0$ while perfect agreement between chamber and EC FCH_4 would result in $\rho = 0$.

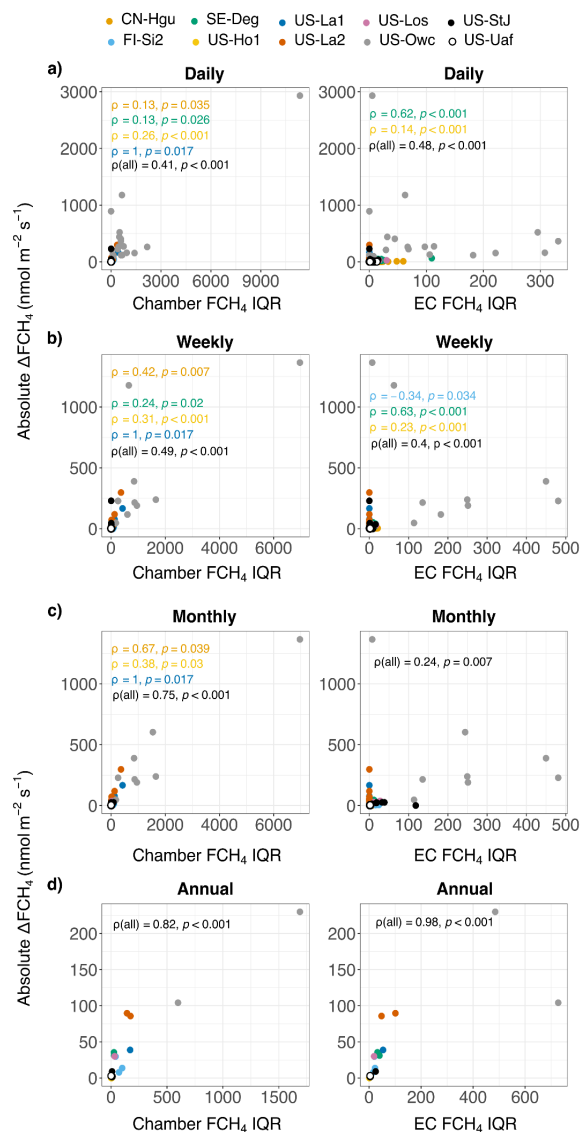
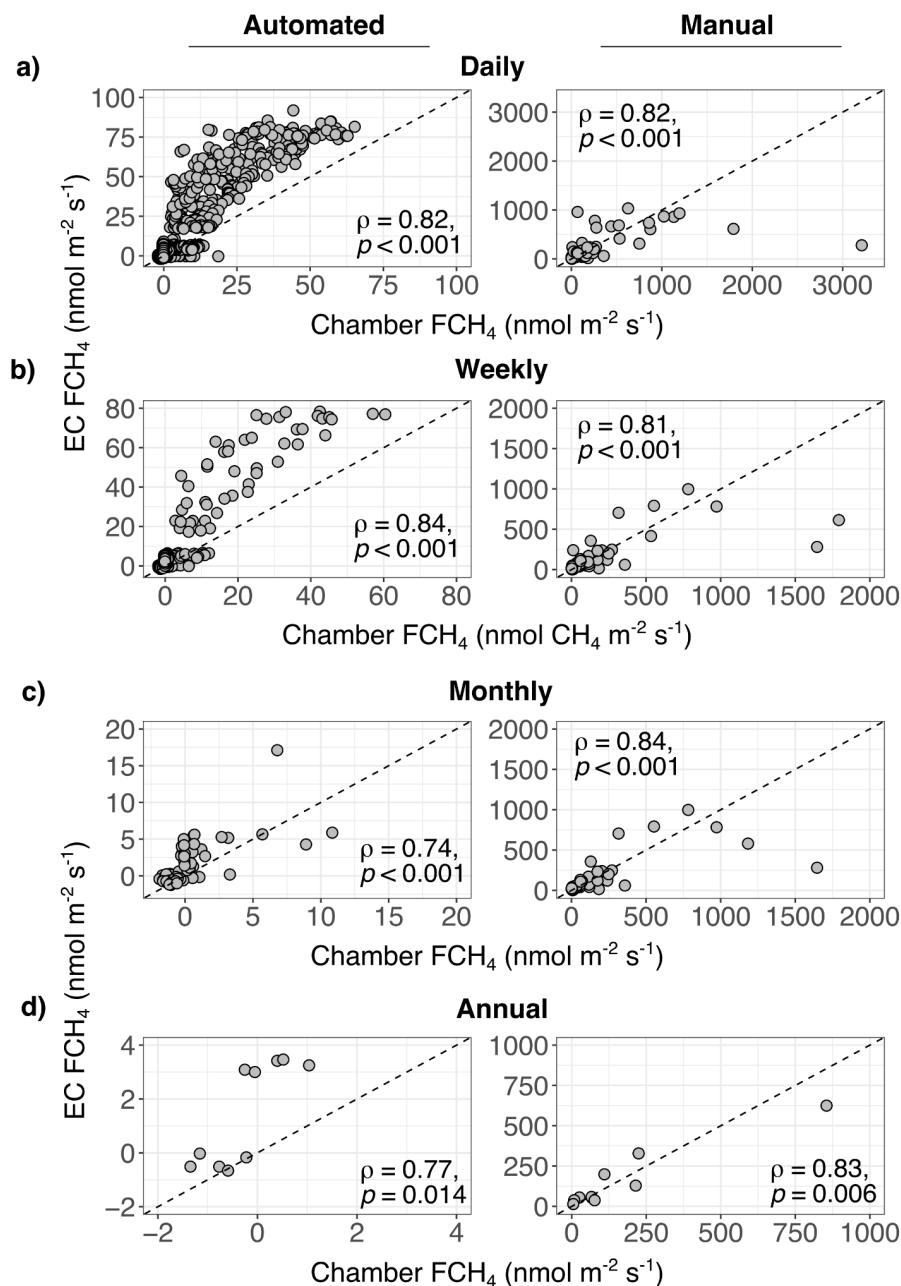


Figure B18. Untransformed absolute difference between ecosystem (eddy covariance; EC)- and plot-scale (chamber) methane (CH₄) flux (FCH₄) (ΔFCH_4), chamber and EC FCH₄ IQR in daily (a), weekly (b), monthly (c), and annual (d) aggregations. Different colors represent individual sites. Plots in the left panel show the relationship between daily variation in FCH₄ between individual chambers within each site and site-level absolute ΔFCH_4 . The right side panel shows the same but with daily variation in EC FCH₄. The strength and general direction of the relationship was measured with Spearman correlation coefficient (ρ). “ $\rho(\text{all})$ ” refers to the Spearman correlation for the whole dataset.

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1025 **Figure B19.** Automated (left panel) and manual (right panel) chamber methane (CH₄) flux (FCH₄) had strong positive relationships with EC FCH₄ across sites and temporal scales (a to d). The dashed line represents the 1:1 line, and ρ Spearman correlation coefficient of the relationship. Automated chambers were included in four sites (CN-Hgu, SE-Deg, US-Ho1, and US-Uaf) and manual chambers in six sites (FI-Si2, US-La1, US-La2, US-Los, US-Owc, and US-StJ). Half-hourly and hourly plots are in Fig. 3. Note different x and y axis scales.

1030 **Appendix C: Supplementary tables (Tables C1-C14)**

Table C1. Methodological and data details of the site chamber (CH) and eddy covariance (EC) measurement systems. “CH method” refers to whether the chambers are manual or automated, and whether chambers were dark or transparent to sunlight. CH meas. frequency = chamber measurement frequency. CH-EC overlap is the total duration of overlap between chamber and EC measurements in days (note: the measurements are spread out over different seasons and years; see Fig. B1 and Table 1).

1035 Gap-filled EC is the percentage of ANN-gap-filled EC methane (CH₄) flux (FCH₄) values of all EC FCH₄ values per site (in the unaggregated data set). Further details of the CH and EC measurement systems can be found in the corresponding references. Abbreviations in “CH analyzer”: LI-COR = LI-COR Biosciences, Nebraska, USA; Picarro = Picarro Inc., Santa Clara, CA, USA; Los Gatos = Los Gatos Research Inc., San Jose, CA, USA; Aerodyne = TILDAS CS, Aerodyne Research Inc., Billerica, MA, USA; Varian = Varian, Inc., Palo Alto, CA, USA; Shimadzu = Shimadzu Scientific Instruments, Kyoto, Japan.

FLUX NET-CH ₄ ID	Location (lat, lon)	CH method	CH analyzer	EC analyzer	EC tower height (m)	No. of CH	CH meas. frequency	EC-CH start, end year	EC-CH overlap days	Gap-filled EC (%)	CH data ref.	EC data ref.
CN-Hgu	32.845278, 102.59	automated, dark	near infrared laser gas analyzer (model 915-0011, Los Gatos)	open-path infrared gas analyzer (LI-7700; LI-COR)	3	3	56 min	2015, 2016	363	44	Wang et al. (2021)	Niu and Chen (2020)
FI-Si2	61.8372, 24.1967	manual, dark	gas chromatograph (Agilent Technologies 7890A) and liquid handler (Gilson GX-271)	open-path gas analyzer (LI-7700, LI-COR)	2.4	18	1-3 x month	2012, 2014	26	5	Korrensalo et al. (2018)	Alekseychik et al. (2021), Vesala et al. (2020)
SE-Deg	64.182029, 19.556539	automated, dark and transparent	cavity ring-down spectrometer (model GGA-24EP, Los Gatos)	Closed-path gas analyzer (Model 911-0011-0004, Los Gatos)	3	4	1 hour	2015, 2016	338	31	Bond-Lamberty et al. (2020), Järveoja et al. (2018)	Nilsson and Peichl (2020)
US-Ho1	45.2041, -68.7402	automated, dark	cavity ring-down spectrometer (model	Closed-path gas analyzer (model	31	20	ca. 1 hour (varied between years and	2012, 2016	759	52	Richardson et al. (2019)	Richardson and Hollinger (2020)

			G2121-i; Picarro) & Aerodyne Quantum Cascade Laser (Aerodyne)	G2311-f, Picarro cavity ring- down spectrom eter)			chambers)						
US-La1	29.501 3, - 90.444 9	manual, dark	gas chromatogra ph (model CP-3800, Varian)	open- path gas analyzer (LI-7700, LI-COR)	3.4	3	1 x month	2012, 2012	5	0	Krauss et al. (2016)	Holm et al. (2020a)	
US-La2	29.858 7, - 90.286 9	manual, dark	gas chromatogra ph (model CP-3800, Varian)	open - path gas analyzer (LI-7700, LI-COR)	3.6	3	1 x month	2012, 2013	10	10	Krauss et al. (2016)	Holm et al. (2020b)	
US-Los	46.082 7, - 89.979 2	manual, dark	near- infrared laser gas analyzer (Los Gatos UGGA)	open- path gas analyzer (LI-7700, LI-COR)	10.2	14	1-3 x month	2015, 2015	5	31	Desai (2025b)	Desai (2025a), Desai and Thom (2020)	
US-Owc	41.379 51667, - 82.512 4667	manual, dark	gas chromatogra ph (GC- 2014, Shimadzu)	open- path gas analyzer (LI-7700, LI-COR)	2.7	4	1 x month	2015, 2016	18	50	Bohrer et al. (2019)	Bohrer et al. (2020)	
US-StJ	39.088 21106, - 75.437 22534	manual, dark	near- infrared laser gas analyzer (Los Gatos)	open- path gas analyzer (LI-7700, LI-COR)	3.5	5	1-2 x month	2020	16	0	Hill and Vargas (2022)	Vargas (2018)	
US-Uaf	64.866 27, - 147.85 553	automated, dark	near- infrared laser gas analyzer (Los Gatos)	closed- path gas analyzer (RMT20 0 Fast Methane Analyzer or Greenhou se Gas Analyzer, Los Gatos)	6	5	30 min	2016, 2018	458	59	Ueyama et al. (2022)	Iwata et al. (2020)	

Table C2. Details of chamber methane (CH₄) flux (FCH₄) data quality control and chamber placement rationale in the study sites. Data quality control was done by data providers prior to sharing chamber FCH₄ data, and a summary of the methods are listed here. For more details, please see the site-specific references. EC = eddy covariance.

Site	FCH ₄ corrections	Low-quality FCH ₄ data filtering	Ebullition removal	Chamber placement rationale	Reference
CN-Hgu	Air temperature and H ₂ O dilution	R ² <0.9	No (ebullition assumed negligible)	To investigate the effect of experimental warming on CH ₄ uptake. Both the warming treatment and the control each included three chambers. The chambers were located approx. 500 m from the EC tower and covered spatial variation in environmental conditions	Wang et al. (2021)
FI-Si2	Air temperature	Nonlinear changes in CH ₄ concentrations removed (altogether 10.4% of measurements removed)	Yes	To cover spatial variation in vegetation and environmental conditions (three chambers per plant community/bog microtopography type: high hummock, hummock, high lawn, lawn, hollow, and bare peat). Chamber placement was based on a systematic survey of surface cover within a 200 m radius the EC tower	Korrensalo et al. (2018)
SE-Deg	Air temperature and H ₂ O dilution	R ² <0.95 and RMSE>0.02	Yes	To understand how different microtopographic forms (water table level and	Bond-Lamberty et al. (2020),

vegetation composition) Järveoja et al.
 explain EC flux patterns. (2018)
 In addition, cross-
 checking the information
 from EC at the diel scale,
 especially during
 calm night-time
 conditions

US-Ho1	Air temperature, air pressure and H ₂ O dilution	R ² <0.9	No	To sample representative land cover classes covered by the EC footprint for measuring CO ₂ , CH ₄ and N ₂ O (3-5 chambers per upland control, upland trenched, transitional and wetland class)	Richardson et al. (2019)
US-La1	Air temperature	None (few data points discarded based on very low R ² and standard deviation >3 from the mean)	No	To sample representative areas (chambers installed around vegetation clusters to avoid cutting roots. Open water not included) within the EC footprint.	Krauss et al. (2016)
US-La2	Air temperature	None (few data points discarded based on very low R ² and standard deviation >3 from the mean)	No	To sample representative areas within the EC footprint (chambers installed around boardwalks)	Krauss et al. (2016)
US-Los	Air temperature, air pressure and H ₂ O dilution	None (but most mean R ² >0.9 across replicates; ca. 15% R ² <0.66)	No	To sample representative landscapes (hummocks, hollows, shrubs, open water) within the EC	Desai (2025b)

footprint to evaluate drivers, spatial variation, and hotspots/moments of FCH₄ and ways to scale fluxes from chambers to EC to landscape

US-Owc	Air temperature and air pressure	R ² ≤0.85 (whole chamber measurement discarded if in n>3 observations within measurement)	Yes	To sample random locations with equal sample size per patch type (open water, <i>Typha</i> sp., floating vegetation). Chambers were placed floating on the water, excluding plants	Bohrer et al. (2019)
US-StJ	Air temperature, air pressure and H ₂ O dilution	R ² <0.9 (based on CO ₂ flux measured simultaneously)	Yes	To sample representative (based on marsh vegetation) areas within the EC footprint that were safely accessible. The main goal was to investigate when to measure CH ₄ fluxes with manual chambers in a spatiotemporally heterogeneous wetland and using this information, to see how and when to combine both EC and manual chamber measurements for analyses.	Hill and Vargas (2022a, 2022b)

US-Uaf	Air temperature, air pressure and H ₂ O dilution	RMSE>0.3 ppb or R ² <0.1	No (ebullition assumed negligible)	To cover spatial variation in forest floor microtopography and vegetation in 2016-2018 (one chamber per wet <i>Sphagnum</i> , wet <i>Carex</i> spp., dry lichen, and dry <i>Carex</i> spp.)	Ueyama et al. (2022)
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Table C3. Details of the used environmental data. FLUXNET-CH₄ soil temperature data was from the topmost soil depths (2-10 cm below soil surface). Abbreviations: NEE = net ecosystem exchange, u* = friction velocity, WD = wind direction, WS = wind speed, VPD = vapor pressure deficit, PA = air pressure, WTL = water table level, TS = soil temperature, ANN = artificial neural network, MDS = marginal distribution sampling.

Site	Environmental variable	Data	Data reference	
CN-Hgu	NEE	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	Delwiche et al. (2021); Knox et al. (2019)	
	u*	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled		
	WD	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled		
	WS	Half-hourly FLUXNET-CH ₄ : gap-filled		
	VPD	Half-hourly FLUXNET-CH ₄ : gap-filled		
	PA	Half-hourly FLUXNET-CH ₄ : gap-filled		
	WTL	-		-
	TS	Half-hourly FLUXNET-CH ₄		
FI-Si2	NEE	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	Delwiche et al. (2021); Knox et al. (2019)	
	u*	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled		
	WD	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled		
	WS	Half-hourly FLUXNET-CH ₄ : gap-filled		
	VPD	Half-hourly FLUXNET-CH ₄ : gap-filled		

	PA	Half-hourly FLUXNET-CH ₄ : gap-filled	
	WTL	Mean of daily gap-filled FLUXNET-CH ₄ WTL and chamber-associated WTL	Delwiche et al. (2021); Knox et al. (2019), Korrensalo et al. (2018)
	TS	Chamber-associated TS	Korrensalo et al. (2018)
	NEE	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	u*	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	WD	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	Delwiche et al. (2021); Knox et al. (2019)
	WS	Half-hourly FLUXNET-CH ₄ : gap-filled	
SE-Deg	VPD	Half-hourly FLUXNET-CH ₄ : gap-filled	
	PA	Half-hourly FLUXNET-CH ₄ : gap-filled	
	WTL	Mean of half-hourly gap-filled FLUXNET-CH ₄ WTL and chamber-associated WTL	Delwiche et al. (2021); Knox et al. (2019); Järveoja et al. (2018); Bond-Lamberty et al. (2020)
	TS	Mean of half-hourly FLUXNET-CH ₄ TS and chamber-associated TS	
	NEE	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	u*	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
US-Ho1	WD	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	Delwiche et al. (2021); Knox et al. (2019)
	WS	Half-hourly FLUXNET-CH ₄ : gap-filled	
	VPD	Half-hourly FLUXNET-CH ₄ : gap-	

		filled	
	PA	Half-hourly FLUXNET-CH ₄ : gap-filled	
	WTL	Half-hourly FLUXNET-CH ₄ : gap-filled	
	TS	Chamber-associated TS	Richardson et al. (2019)
	NEE	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	u*	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	WD	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	Delwiche et al. (2021);
	WS	Half-hourly FLUXNET-CH ₄ : gap-filled	Knox et al. (2019)
US-La1 & US-La2	VPD	Half-hourly FLUXNET-CH ₄ : gap-filled	
	PA	Half-hourly FLUXNET-CH ₄ : gap-filled	
	WTL	Mean of daily FLUXNET-CH ₄ WTL and chamber-associated WTL	Delwiche et al. (2021);
	TS	Mean of daily gap-filled FLUXNET-CH ₄ TS and chamber-associated TS	Knox et al. (2019); Krauss et al. (2016)
	NEE	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	u*	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
US-Los	WD	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	Delwiche et al. (2021);
	WS	Half-hourly FLUXNET-CH ₄ : gap-filled	Knox et al. (2019)
	VPD	Half-hourly FLUXNET-CH ₄ : gap-	

		filled	
	PA	Half-hourly FLUXNET-CH ₄ : gap-filled	
	WTL	Mean of half-hourly gap-filled FLUXNET-CH ₄ WTL and chamber-associated WTL	Delwiche et al. (2021);
	TS	Mean of half-hourly FLUXNET-CH ₄ TS and chamber-associated TS	Knox et al. (2019); Pugh et al. (2018)
US-Owc	NEE	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	u*	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	WD	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	Delwiche et al. (2021);
	WS	Half-hourly FLUXNET-CH ₄ : gap-filled	Knox et al. (2019)
	VPD	Half-hourly FLUXNET-CH ₄ : gap-filled	
	PA	Half-hourly FLUXNET-CH ₄ : gap-filled	
	WTL	Mean of half-hourly gap-filled FLUXNET-CH ₄ WTL and chamber-associated WTL	Delwiche et al. (2021); Knox et al. (2019); Bohrer et al. (2019)
	TS	Half-hourly FLUXNET-CH ₄ TS	Delwiche et al. (2021); Knox et al. (2019)
US-StJ	NEE	Half-hourly: MDS-gap-filled	
	u*	Half-hourly: not gap-filled	Hill and Vargas (2022); Vargas (2018)
	WD	Half-hourly: not gap-filled	

	WS	Half-hourly: not gap-filled	
	VPD	Half-hourly: not gap-filled	
	PA	Half-hourly: not gap-filled	
	WTL	Half-hourly: gap-filled with a linear relationship with NOAA water table level	
	TS	Half-hourly: gap-filled with a linear relationship with water temperature	
US-Uaf	NEE	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	u*	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	
	WD	Half-hourly FLUXNET-CH ₄ : ANN-gap-filled	Delwiche et al. (2021);
	WS	Half-hourly FLUXNET-CH ₄ : gap-filled	Knox et al. (2019)
	VPD	Half-hourly FLUXNET-CH ₄ : gap-filled	
	PA	Half-hourly FLUXNET-CH ₄ : gap-filled	
	WTL	Mean of half-hourly gap-filled FLUXNET-CH ₄ WTL and chamber-associated WTL	Delwiche et al. (2021);
	TS	Mean of half-hourly FLUXNET-CH ₄ TS and chamber-associated TS	Knox et al. (2019); Ueyama et al. (2023)

1070 **Table C4.** Descriptive statistics and Wilcoxon-Mann-Whitney test results based on temporal aggregations from chamber and eddy covariance (EC) methane (CH₄) flux (FCH₄) means instead of medians. Proportions of annual chamber and EC CH₄ emission (i.e., FCH₄≤0 excluded) above the 90th percentile (p90) are reported to highlight the contribution of high CH₄ emission values to FCH₄. Abbreviations: IQR = interquartile range, SD = standard deviation, CV = coefficient of variation (%), EC = eddy covariance.

Data set	ΔFCH₄ median (IQR), nmol m⁻² s⁻¹	ΔFCH₄ mean (SD), nmol m⁻² s⁻¹	ΔFCH₄ CV (%)	Wilcoxon- Mann- Whitney test	Chamber FCH₄ p90 (% of total FCH₄)	EC FCH₄ p90 (% of total FCH₄)
Half-hourly	1.23 (5.74)	4.84 (18.56)	206	<i>p</i> <0.001 (n _{EC} =74482, n _{CH} =74482)	36.42 (46)	64.31 (44)
Hourly	1.19 (5.42)	4.76 (16.28)	198	<i>p</i> <0.001 (n _{EC} =40072, n _{CH} =40072)	36.62 (46)	75.81 (24)
Daily	1.11 (4.77)	-1.16 (170.67)	1106	<i>p</i> <0.001 (n _{EC} =1879, n _{CH} =1879)	43.47 (78)	66.67 (60)
Weekly	1.03 (6.73)	-19.55 (284.31)	770	<i>p</i> =0.015 (n _{EC} =349, n _{CH} =349)	98.12 (82)	77.82 (64)
Monthly	1.05 (13.15)	-58.55 (472.15)	566	<i>p</i> =0.511 (n _{EC} =121, n _{CH} =121)	315.38 (78)	218.47 (63)
Annual	0.28 (16.93)	-70.94 (311.86)	333	<i>p</i> =0.972 (n _{EC} =22, n _{CH} =22)	307.19 (72)	251.67 (60)

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Table C5. Descriptive statistics and Wilcoxon-Mann-Whitney test results for the difference between ecosystem- and plot-scale methane (CH₄) flux (FCH₄) (Δ FCH₄) based on cumulative eddy covariance (EC) and chamber FCH₄ (mg CH₄ m⁻²) at daily to annual aggregations (note: cumulative FCH₄ were calculated only for exact EC-chamber FCH₄ timestamps and do not represent cumulative sums for ecosystem CH₄ budget calculations). Due to a lack of hourly timestamps in the chamber FCH₄ data at FI-Si2, US-La1 and US-La2, these three sites were excluded from this table, resulting in n=7 sites. Results are given separately for data sets based on median (left) and mean (right) aggregations of chamber and EC FCH₄ at each temporal scale. The EC and chamber data sample sizes in Wilcoxon-Mann-Whitney tests are reported as n_{EC} and n_{CH}, respectively. Abbreviations: IQR = interquartile range, SD = standard deviation, CV = coefficient of variation (%).

	Median-based aggregation				Mean-based aggregation			
Data set	Δ FCH ₄ median (IQR), mg CH ₄ m ⁻²	Δ FCH ₄ mean (SD), mg CH ₄ m ⁻²	Δ FCH ₄ CV (%)	Wilcoxon-Mann-Whitney test	Δ FCH ₄ median (IQR), mg CH ₄ m ⁻²	Δ FCH ₄ mean (SD), mg CH ₄ m ⁻²	Δ FCH ₄ CV (%)	Wilcoxon-Mann-Whitney test
Daily	1.29 (5.5)	5.88 (29.22)	303	<i>p</i> <0.001 (n _{EC} =1838, n _{CH} =1838)	1.15 (5.47)	4.99 (29.1)	305	<i>p</i> <0.001 (n _{EC} =1838, n _{CH} =1838)
Weekly	6.39 (32.68)	34.65 (117.8)	212	<i>p</i> =0.006 (n _{EC} =312, n _{CH} =312)	5.53 (32.52)	29.37 (116.05)	211	<i>p</i> =0.028 (n _{EC} =312, n _{CH} =312)
Monthly	13.4 (93.83)	117.5 (385.22)	213	<i>p</i> =0.314 (n _{EC} =92, n _{CH} =92)	8.85 (88.37)	99.62 (385.22)	209	<i>p</i> =0.485 (n _{EC} =92, n _{CH} =92)
Annual	37.1 (742.78)	675.63 (2024.37)	193	<i>p</i> =0.897 (n _{EC} =16, n _{CH} =16)	35.23 (781.38)	572.81 (1945.22)	188	<i>p</i> =0.897 (n _{EC} =16, n _{CH} =16)

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1090 **Table C6.** Linear mixed effects model results for assessing the slopes between ecosystem-scale (eddy covariance; EC)
methane (CH₄) flux (FCH₄) and plot-scale (chamber) FCH₄. To meet residual normality assumptions of linear mixed models,
EC FCH₄ was transformed with inverse hyperbolic sine (IHS) and the fixed effect estimates, *p*-values and standard errors (SE)
are in transformed scale. Average marginal effects (AME) and their 95% confidence intervals (CI) are reported in the back-
1095 across all chamber FCH₄ observations. AME CIs were obtained with parametric simulation from the fixed effect estimate and
covariance. Half-hourly and hourly models are not included due to non-convergence and residual non-normality.

Model	Fixed effect	Estimate β (IHS scale)	<i>p</i>-value	SE	AME (95% CI)
Daily	Intercept	3.647	<0.001	0.657	0.007 (0.0006-
	Chamber FCH ₄	0.0004	0.031	0.0002	0.032)
Weekly	Intercept	3.612	<0.001	0.645	0.011 (-0.0007-
	Chamber FCH ₄	0.0006	0.066	0.0003	0.049)
Monthly	Intercept	3.591	<0.001	0.646	0.009 (-0.005-
	Chamber FCH ₄	0.0005	0.183	0.0004	0.049)
Annual	Intercept	3.653	<0.001	0.636	0.02 (0.002-0.088)
	Chamber FCH ₄	0.001	0.044	0.0004	

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1105 **Table C7.** Wilcoxon-Mann-Whitney test results for half-hourly aggregation. The eddy covariance (EC) and chamber data
sample sizes in Wilcoxon Mann-Whitney tests are reported as n_{EC} and n_{CH} , respectively. Proportions of annual chamber and
EC methane (CH_4) emission (i.e., CH_4 flux (FCH_4) ≤ 0 excluded) above the 90th percentile (p90) are reported as the mean of
year-specific 90th percentiles (not in parentheses) and percentages (in parentheses). This data set contains chamber
measurements only from automated chambers (n=4 sites). Abbreviations: IQR = interquartile range, CV = coefficient of
1110 variation (%).

Site	Mean EC FCH ₄ (SD), <i>nmol m⁻²s⁻¹</i>	Mean chamber FCH ₄ (SD), <i>nmol m⁻²s⁻¹</i>	Median EC FCH ₄ (IQR, CV), <i>nmol m⁻²s⁻¹</i>	Median chamber FCH ₄ (IQR, CV), <i>nmol m⁻²s⁻¹</i>	Median ΔFCH_4 (IQR, CV), <i>nmol m⁻²s⁻¹</i>	Chamber FCH ₄ p90 (% of total FCH ₄)	EC FCH ₄ p90 (% of total FCH ₄)	Wilcoxon-Mann- Whitney test
CN-Hgu	4.73 (25.36)	-0.12 (0.35)	3.0 (6.0, 241)	-0.1 (0.24, 165)	3.12 (6.04, 239)	0.63 (55)	20 (58)	$p < 0.001$ ($n_{EC} = 9571$, $n_{CH} = 9571$)
SE-Deg	53.18 (22.31)	25.19 (18.24)	54.1 (36.28, 42)	21.61 (24.24, 72)	26.94 (23.98, 62)	50.5 (25)	79.85 (17)	$p < 0.001$ ($n_{EC} = 13987$, $n_{CH} = 13987$)
US-Ho1	-0.21 (1.84)	1.21 (10.47)	-0.4 (1.32, 158)	-0.89 (1.44, 334)	0.38 (2.36, 311)	18.06 (49)	3.24 (43)	$p < 0.001$ ($n_{EC} = 30716$, $n_{CH} = 30716$)
US-Uaf	3.61 (4.35)	2.45 (3.58)	3.39 (4.17, 107)	0.78 (2.32, 146)	1.22 (3.76, 146)	5.73 (36)	6.99 (29)	$p < 0.001$ ($n_{EC} = 20208$, $n_{CH} = 20208$)

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Table C8. Wilcoxon-Mann-Whitney test results for hourly aggregation. The eddy covariance (EC) and chamber data sample sizes in Wilcoxon Mann-Whitney tests are reported as n_{EC} and n_{CH} , respectively. Proportions of annual chamber and EC methane (CH_4) emission (i.e., CH_4 flux (FCH_4) ≤ 0 excluded) above the 90th percentile (p90) are reported as the mean of year-specific 90th percentiles (not in parentheses) and percentages (in parentheses). This data set contains chamber measurements only from automated chambers ($n=4$ sites). Abbreviations: IQR = interquartile range, CV = coefficient of variation (%).

Site	Mean EC FCH ₄ (SD), <i>nmol CH₄ m⁻²s⁻¹</i>	Mean chamber FCH ₄ (SD), <i>nmol CH₄ m⁻²s⁻¹</i>	Median EC FCH ₄ (IQR, CV), <i>nmol CH₄ m⁻²s⁻¹</i>	Median chamber FCH ₄ (IQR, CV), <i>nmol CH₄ m⁻²s⁻¹</i>	Median ΔFCH_4 (IQR, CV), <i>nmol CH₄ m⁻²s⁻¹</i>	Chamber FCH ₄ p90 (% of total FCH ₄)	EC FCH ₄ p90 (% of total FCH ₄)	Wilcoxon-Mann- Whitney test
CN-Hgu	4.56 (22.87)	-0.11 (0.26)	3.0 (6.11, 229)	-0.09 (0.2, 145)	3.08 (5.99, 227)	0.6 (54)	19.75 (56)	$p < 0.001$ ($n_{EC} = 5305$, $n_{CH} = 5305$)
SE-Deg	53.17 (22.05)	25.11 (17.42)	54.41 (36.28, 41)	21.6 (25.34, 69)	26.9 (23.04, 51)	49.59 (23)	79.67 (17)	$p < 0.001$ ($n_{EC} = 7243$, $n_{CH} = 7243$)
US-Ho1	-0.21 (1.53)	-0.37 (3.05)	-0.36 (1.23, 149)	-0.95 (1.27, 192)	0.47 (1.95, 188)	7.43 (53)	2.82 (41)	$p < 0.001$ ($n_{EC} = 17215$, $n_{CH} = 17215$)
US-Uaf	3.61 (3.71)	2.37 (3.53)	3.32 (4.04, 96)	0.73 (2.17, 149)	1.28 (3.55, 137)	5.47 (35)	7.02 (27)	$p < 0.001$ ($n_{EC} = 10309$, $n_{CH} = 10309$)

Table C9. Wilcoxon-Mann-Whitney test results for daily aggregation. The eddy covariance (EC) and chamber data sample sizes in Wilcoxon-Mann-Whitney tests are reported as n_{EC} and n_{CH} , respectively. Proportions of annual chamber and EC CH_4 emission (i.e., CH_4 flux (FCH_4) ≤ 0 excluded) above the 90th percentile (p90) are reported as the mean of year-specific 90th percentiles (not in parentheses) and percentages (in parentheses). This dataset contains all sites ($n=10$). Note: due to small sample sizes ($n=5$) in US-La1 and US-Los, the Wilcoxon-Mann-Whitney test results should be interpreted with caution. Abbreviations: IQR = interquartile range, CV = coefficient of variation (%).

Site	Mean EC FCH ₄ (SD), nmol CH ₄ m ⁻² s ⁻¹	Mean chamber FCH ₄ (SD), nmol CH ₄ m ⁻² s ⁻¹	Median EC FCH ₄ (IQR, CV), nmol CH ₄ m ⁻² s ⁻¹	Median chamber FCH ₄ (IQR, CV), nmol CH ₄ m ⁻² s ⁻¹	Median ΔFCH_4 (IQR, CV), nmol CH ₄ m ⁻² s ⁻¹	Chamber FCH ₄ p90 (% of total FCH ₄)	EC FCH ₄ p90 (% of total FCH ₄)	Wilcoxon-Mann- Whitney test
CN-Hgu	3.22 (1.79)	-0.12 (0.11)	3.0 (2.14, 55)	-0.07 (0.12, 93)	3.2 (2.21, 54)	0.04 (17)	5.69 (20)	$p < 0.001$ ($n_{EC} = 265$, $n_{CH} = 265$)
FI-Si2	57.13 (18.74)	62.14 (37.85)	54.37 (21.48, 33)	49.46 (57.04, 61)	0.81 (30.53, 132)	98.37 (25)	77.5 (19)	$p = 0.737$ ($n_{EC} = 26$, $n_{CH} = 26$)
SE-Deg	52.44 (20.75)	24.24 (15.76)	55.88 (39.7, 40)	21.39 (24.96, 65)	0.81 (30.53, 132)	48.56 (21)	78.16 (15)	$p < 0.001$ ($n_{EC} = 317$, $n_{CH} = 317$)
US-Ho1	-0.43 (0.54)	-0.68 (1.67)	-0.45 (0.73, 96)	-1.01 (0.9, 130)	0.39 (1.22, 165)	2.04 (52)	0.4 (39)	$p < 0.001$ ($n_{EC} = 759$, $n_{CH} = 759$)
US-La1	41.49 (29.79)	97.72 (65.37)	42.12 (53.85, 72)	116.91 (62.59, 67)	-45.43 (71.64, 115)	157.64 (37)	71.03 (34)	$p = 0.222$ ($n_{EC} = 5$, $n_{CH} = 5$)
US-La2	163.74 (63.81)	191.35 (93.46)	150.22 (103.39, 39)	189.16 (117.65, 49)	5.75 (103.92, 141)	276.98 (32)	226.3 (30)	$p = 0.436$ ($n_{EC} = 10$, $n_{CH} = 10$)
US-Los	35.37 (12.78)	9.61 (5.62)	38.75 (13.82, 36)	8.43 (4.09, 58)	27.75 (4.74, 37)	15.42 (38)	46.72 (28)	$p = 0.016$ ($n_{EC} = 5$, $n_{CH} = 5$)

US-Owc	607.26 (289.11)	770.24 (766.66)	652.8 (490.18, 48)	579.95 (721.2, 100)	-108.22 (485.14, 169)	1306.07 (46)	936.62 (28)	$p=0.988$ ($n_{EC} = 18,$ $n_{CH} = 18)$
US-StJ	39.2 (58.96)	13.98 (27.01)	16.4 (29.69, 150)	5.26 (8.31, 193)	9.15 (20.85, 202)	22.15 (63)	73.94 (54)	$p=0.007$ ($n_{EC} = 16,$ $n_{CH} = 16)$
US-Uaf	3.5 (2.09)	2.15 (3.12)	3.49 (3.96, 60)	0.66 (2.0, 145)	1.27 (2.29, 111)	4.97 (25)	6.09 (20)	$p<0.001$ ($n_{EC} = 458,$ $n_{CH} = 458)$

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Table C10. Wilcoxon-Mann-Whitney test results for weekly aggregation. The eddy covariance (EC) and chamber data sample sizes in Wilcoxon-Mann-Whitney tests are reported as n_{EC} and n_{CH} , respectively. Proportions of annual chamber and EC methane (CH_4) emission (i.e., CH_4 flux (FCH_4) ≤ 0 excluded) above the 90th percentile (p90) are reported as the mean of year-specific 90th percentiles (not in parentheses) and percentages (in parentheses). This dataset contains all sites ($n=10$). Note: due to small sample sizes ($n=5$) in US-La1 and US-Los, the Wilcoxon-Mann-Whitney test results should be interpreted with caution. Abbreviations: IQR = interquartile range, CV = coefficient of variation (%).

Site	Mean EC FCH ₄ (SD), <i>nmol CH₄ m⁻²s⁻¹</i>	Mean chamber FCH ₄ (SD), <i>nmol CH₄ m⁻²s⁻¹</i>	Median EC FCH ₄ (IQR, CV), <i>nmol CH₄ m⁻²s⁻¹</i>	Median chamber FCH ₄ (IQR, CV), <i>nmol CH₄ m⁻²s⁻¹</i>	Median ΔFCH_4 (IQR, CV), <i>nmol CH₄ m⁻²s⁻¹</i>	Chamber FCH ₄ p90 (% of total FCH ₄)	EC FCH ₄ p90 (% of total FCH ₄)	Wilcoxon-Mann- Whitney test
CN-Hgu	3.02 (1.18)	-0.12 (0.11)	3.0 (1.98, 39)	-0.07 (0.13, 90)	3.08 (1.98, 39)	0.02 (59)	4.26 (20)	$p < 0.001$ ($n_{EC} = 40$, $n_{CH} = 40$)
FI-Si2	55.43 (17.61)	59.55 (35.23)	53.36 (18.93, 32)	49.46 (48.82, 59)	1.45 (24.92, 139)	88.39 (27)	73.87 (22)	$p = 0.789$ ($n_{EC} = 22$, $n_{CH} = 22$)
SE-Deg	50.17 (21.18)	22.73 (15.64)	50.94 (38.12, 42)	18.74 (22.04, 69)	24.83 (19.9, 43)	46.5 (27)	76.31 (19)	$p < 0.001$ ($n_{EC} = 50$, $n_{CH} = 50$)
US-Ho1	-0.42 (0.48)	-0.69 (1.34)	-0.42 (0.72, 90)	-0.99 (0.91, 112)	0.32 (1.28, 146)	6.02 (43)	0.41 (27)	$p < 0.001$ ($n_{EC} = 119$, $n_{CH} = 119$)
US-La1	41.49 (29.79)	97.72 (65.37)	42.12 (53.85, 72)	116.91 (62.59, 67)	-45.43 (71.64, 115)	157.64 (37)	71.03 (34)	$p = 0.222$ ($n_{EC} = 5$, $n_{CH} = 5$)
US-La2	163.74 (63.81)	191.35 (93.46)	150.22 (103.39, 39)	189.16 (117.65, 49)	5.75 (103.92, 141)	276.98 (32)	226.3 (30)	$p = 0.436$ ($n_{EC} = 10$, $n_{CH} = 10$)
US-Los	35.37 (12.78)	9.61 (5.62)	38.75 (13.82, 36)	8.43 (4.09, 58)	27.75 (4.74, 37)	15.42 (38)	46.72 (28)	$p = 0.016$ ($n_{EC} = 5$, $n_{CH} = 5$)

US-Owc	561.44 (287.63)	753.88 (619.97)	642.45 (446.31, 51)	552.85 (657.0, 82)	47.22 (728.26, 145)	1185.44 (56)	828.1 (45)	$p=0.796$ ($n_{EC} = 9,$ $n_{CH} = 9$)
US-StJ	39.2 (58.96)	13.98 (27.01)	16.4 (29.69, 150)	5.26 (8.31, 193)	9.15 (20.85, 202)	22.12 (63)	73.94 (54)	$p=0.007$ ($n_{EC} = 16,$ $n_{CH} = 16$)
US-Uaf	3.4 (1.97)	2.01 (3.04)	3.46 (3.82, 58)	0.64 (1.87, 151)	1.18 (2.13, 107)	4.76 (29)	5.85 (23)	$p<0.001$ ($n_{EC} = 73,$ $n_{CH} = 73$)

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Table C11. Wilcoxon-Mann-Whitney test results for monthly aggregation. The eddy covariance (EC) and chamber data sample sizes in Wilcoxon-Mann-Whitney tests are reported as n_{EC} and n_{CH} , respectively. Proportions of annual chamber and EC methane (CH_4) emission (i.e., CH_4 flux (FCH_4) ≤ 0 excluded) above the 90th percentile (p_{90}) are reported as the mean of year-specific 90th percentiles (not in parentheses) and percentages (in parentheses). This dataset contains all sites ($n=10$). Note: 1175 due to small sample sizes ($n=5$) in US-La1 and US-Los, the Wilcoxon-Mann-Whitney test results should be interpreted with caution. Abbreviations: IQR = interquartile range, CV = coefficient of variation (%). * CN-Hgu had only negative chamber FCH_4 values and chamber p_{90} was not calculated for this site.

Site	Mean EC FCH_4 (SD), $nmol CH_4 m^{-2} s^{-1}$	Mean chamber FCH_4 (SD), $nmol CH_4 m^{-2} s^{-1}$	Median EC FCH_4 (IQR, CV), $nmol CH_4 m^{-2} s^{-1}$	Median chamber FCH_4 (IQR, CV), $nmol CH_4 m^{-2} s^{-1}$	Median ΔFCH_4 (IQR, CV), $nmol CH_4 m^{-2} s^{-1}$	Chamber FCH_4 p_{90} (% of total FCH_4)	EC FCH_4 p_{90} (% of total FCH_4)	Wilcoxon- Mann- Whitney test
CN-Hgu	3.1 (1.06)	-0.12 (0.1)	3.0 (1.08, 34)	-0.07 (0.14, 84)	3.05 (1.2, 34)	-*	4.14 (30)	$p < 0.001$ ($n_{EC} = 10$, $n_{CH} = 10$)
FI-Si2	52.49 (16.25)	51.0 (26.4)	53.36 (23.22, 31)	47.79 (44.33, 52)	2.68 (26.17, 120)	73.18 (32)	68.51 (29)	$p = 0.635$ ($n_{EC} = 14$, $n_{CH} = 14$)
SE-Deg	46.58 (22.45)	20.66 (15.23)	46.85 (44.64, 48)	15.7 (22.22, 74)	25.1 (11.52, 46)	40.22 (33)	73.06 (25)	$p = 0.002$ ($n_{EC} = 13$, $n_{CH} = 13$)
US-Ho1	-0.44 (0.45)	-0.8 (0.97)	-0.46 (0.6, 86)	-1.05 (0.8, 88)	0.35 (1.12, 124)	2.86 (67)	0.28 (41)	$p < 0.001$ ($n_{EC} = 32$, $n_{CH} = 32$)
US-La1	41.49 (29.79)	97.72 (65.37)	42.12 (53.85, 72)	116.91 (62.59, 67)	-45.43 (71.64, 115)	157.64 (37)	71.03 (34)	$p = 0.222$ ($n_{EC} = 5$, $n_{CH} = 5$)
US-La2	163.74 (63.81)	191.35 (93.46)	150.22 (103.39, 39)	189.16 (117.65, 49)	5.75 (103.92, 141)	276.98 (32)	226.3 (30)	$p = 0.436$ ($n_{EC} = 10$, $n_{CH} = 10$)
US-Los	32.8 (14.3)	7.78 (2.88)	38.75 (13.34, 44)	6.91 (2.78, 37)	27.75 (14.07, 57)	10.18 (47)	42.28 (44)	$p = 0.1$ ($n_{EC} = 3$, $n_{CH} = 3$)
US-Owc	575.34 (301.58)	705.33 (549.45)	642.45 (446.31, 52)	667.58 (756.29, 78)	131.03 (524.49, 144)	1056.3 (58)	828.57 (47)	$p = 0.798$ ($n_{EC} = 8$, $n_{CH} = 8$)
US-StJ	24.14 (19.65)	9.92 (11.72)	21.19 (22.71, 81)	6.0 (7.45, 118)	18.45 (22.01, 82)	20.73 (47)	44.15 (33)	$p = 0.105$ ($n_{EC} = 8$, $n_{CH} = 8$)
US-Uaf	3.39 (1.87)	2.17 (3.15)	3.42 (3.87, 55)	0.65 (1.97, 145)	1.24 (1.84, 114)	4.5 (34)	5.52 (28)	$p = 0.006$ ($n_{EC} = 18$, $n_{CH} = 18$)

1180 **Table C12.** Wilcoxon-Mann-Whitney test results for annual aggregation. The eddy covariance (EC) and chamber data sample sizes in Wilcoxon-Mann-Whitney tests are reported as n_{EC} and n_{CH} , respectively. Annual chamber and EC methane (CH_4) flux (FCH_4) 90th percentiles were not calculated for this aggregation. This dataset contains all sites ($n=10$). Note: due to small sample sizes ($n=5$) in US-La1 and US-Los, the Wilcoxon-Mann-Whitney test results should be interpreted with caution. Abbreviations: IQR = interquartile range, CV = coefficient of variation (%).

Site	Mean EC FCH_4 (SD), $nmol CH_4 m^{-2}s^{-1}$	Mean chamber FCH_4 (SD), $nmol CH_4 m^{-2}s^{-1}$	Median EC FCH_4 (IQR, CV), $nmol CH_4 m^{-2}s^{-1}$	Median chamber FCH_4 (IQR, CV), $nmol CH_4 m^{-2}s^{-1}$	Median ΔFCH_4 (IQR, CV), $nmol CH_4 m^{-2}s^{-1}$	Wilcoxon- Mann- Whitney test
CN-Hgu	3.04 (0.06)	-0.15 (0.14)	3.04 (0.04, 2)	-0.15 (0.1, 94)	3.2 (0.14, 6)	-
FI-Si2	55.7 (2.45)	53.01 (23.84)	55.19 (2.41, 4)	66.22 (20.91, 45)	-7.85 (21.73, 138)	$p=0.7$ ($n_{EC} = 3$, $n_{CH} = 3$)
SE-Deg	54.08 (3.69)	20.78 (0.59)	54.08 (2.61, 7)	20.78 (0.42, 3)	33.3 (2.19, 9)	-
US-Ho1	-0.38 (0.27)	-0.82 (0.45)	-0.51 (0.34, 70)	-0.77 (0.57, 55)	0.25 (0.78, 111)	$p=0.095$ ($n_{EC} = 5$, $n_{CH} = 5$)
US-La1	37.77 (-)	76.56 (-)	37.77 (-, -)	76.56 (-, -)	-38.79 (-, -)	-
US-La2	163.81 (49.76)	161.89 (74.25)	163.81 (35.19, 30)	161.89 (52.5, 46)	1.93 (87.69, 141)	-
US-Los	38.18 (-)	8.12 (-)	38.18 (-, -)	8.12 (-, -)	30.05 (-, -)	-
US-Owc	476.61 (209.52)	539.49 (445.72)	476.61 (148.15, 44)	539.49 (315.17, 83)	-62.88 (167.02, 141)	-
US-StJ	14.06 (-)	4.97 (-)	14.06 (-, -)	4.97 (-, -)	9.09 (-, -)	-
US-Uaf	3.38 (0.11)	0.65 (0.34)	3.42 (0.11, 3)	0.52 (0.32, 52)	2.95 (0.41, 16)	$p=0.1$ ($n_{EC} = 3$, $n_{CH} = 3$)

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Table C13. Final linear mixed effects model results of significant predictors of the difference between ecosystem- and plot-scale methane (CH₄) flux (FCH₄) (Δ FCH₄) for the half-hourly model (site n=3) with soil temperature (TS) instead of Month as one of the predictors. Absolute Δ FCH₄ was Yeo-Johnson-transformed, centered and scaled, while all continuous predictors were only centered and scaled. The predictors are listed in decreasing order based on β -coefficients. The reference level in Hour was 0 and May in Month. Abbreviations: SE = standard error, Df = degrees of freedom of denominator, LOOCV = leave-one-out cross validation, MAE = mean absolute error, RMSE = root mean square error, PA = air pressure (kPa), u* = friction velocity (m s⁻¹), WTL = water table level (cm), TS = soil temperature (°C), NEE = net ecosystem exchange (μ mol CO₂ m⁻² s⁻¹), VPD = vapor pressure deficit (hPa), vWD = v wind component (m s⁻¹), uWD = u wind component (m s⁻¹).

Predictors	β -coefficient	SE	<i>p</i> -value (<i>t</i> -test)	Marginal R ²	Conditional R ²	Df	Random effect variation explained, %	LOOCV		
								R ²	MAE	RMSE
Intercept	0.0581	0.5465	0.9153	0.0109	0.805	43522	-0.94	1.36	1.5	
Fixed effects										
Hour										
- 5 AM	0.0838	0.0166	0			43522				
u*	0.0836	0.004	0			43522				
Hour	-0.0565	0.01	0			43522				
- 6 AM	0.0727	0.0163	0			43522				
PA	-0.0684	0.0105	0			43522				
Hour										
- 4 AM	0.0567	0.0163	0.0005			43522				
- 7 AM	0.0489	0.0165	0.003			43522				
- 10 AM	-0.0406	0.0169	0.0161			43522				
- 8 AM	0.0392	0.0166	0.0181			43522				
- 3 AM	0.0375	0.0166	0.0238			43522				
- 10 PM	-0.0311	0.0163	0.0559			43522				
- 5 PM	-0.0294	0.0166	0.0776			43522				
NEE	-0.0289	0.004	0			43522				
TS	-0.027	0.0068	0.0001			43522				
VPD	-0.0268	0.0054	0			43522				
Hour										
- 3 PM	-0.0248	0.0172	0.1498			43522				
- 9 PM	-0.0246	0.0168	0.1412			43522				
- 6 PM	-0.0221	0.0163	0.1741			43522				
- 8 PM	-0.0201	0.0165	0.2224			43522				
- 7 PM	-0.018	0.0165	0.2745			43522				
vWD	-0.018	0.0036	0			43522				

Hour				
- 2 AM	0.0175	0.0163	0.2827	43522
- 1 PM	-0.0148	0.0173	0.394	43522
- 12 PM	-0.0094	0.0172	0.5833	43522
- 1 AM	0.0072	0.0166	0.6597	43522
- 11 PM	-0.0054	0.0165	0.7413	43522
- 2 PM	-0.0042	0.0171	0.8068	43522
- 11 AM	-0.0028	0.0172	0.8698	43522
- 9 AM	-0.0024	0.0171	0.8847	43522
- 4 PM	-0.0013	0.0167	0.9376	43522

Random effects

Site	72.29
Date	8

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Table C14. Half-hourly and hourly linear mixed effects model results after backward variable selection. In the models, absolute the difference between ecosystem- and plot-scale methane (CH₄) flux (FCH₄) (Δ FCH₄) was Yeo-Johnson-transformed, centered and scaled, while all continuous predictors were only centered and scaled. Note that in both models temporal variables were included in nested random effects (see Supplementary Methods A2). In both models, the reference level in dominant vegetation type was *Sphagnum* moss, 0 in Hour and May in Month. Note that we excluded TS from the half-hourly model due to high multicollinearity with Month (VIF>3; see models with TS instead of Month in S17). The predictors are listed in a decreasing order according to their β -coefficients. SE = standard error, Df = degrees of freedom of denominator, LOOCV = leave-one-out cross validation, MAE = mean absolute error, RMSE = root mean square error, PA = air pressure (kPa), u* = friction velocity (m s⁻¹), WTL = water table level (cm), TS = soil temperature (°C), NEE = net ecosystem exchange (μ mol CO₂ m⁻²s⁻¹), VPD = vapor pressure deficit (hPa), vWD = v wind component (m s⁻¹), uWD = u wind component (m s⁻¹).

Data set	Predictors	β - coefficient	SE	<i>p</i> -value (<i>t</i> -test)	Marginal R ²	Conditional R ²	Df	Random effect		
								variation explained, %	R ²	MAE
Half- hourly (n=3 sites)	Intercept	-0.236	0.5259	0.6537	0.0329	0.7933	43522	-0.62	1.37	1.22
	Fixed effects									
	Month									
	- Aug	0.4626	0.0291	0			1408			
	- Jul	0.4169	0.029	0			1408			
	- Sep	0.3972	0.0294	0			1408			
	- Jun	0.2157	0.0293	0			1408			
	- Apr	0.1615	0.0164	0.6751			1408			
	- Oct	0.1105	0.0316	0.0005			1408			
	u*	0.0876	0.0039	0			43522			
	Hour									
	- 5 AM	0.0873	0.0166	0			43522			
	- 6 AM	0.0742	0.0163	0			43522			
	WTL	0.0617	0.0121	0			43522			
	Hour									
- 4 AM	0.0593	0.0163	0.0003			43522				

PA	-0.056	0.0097	0	43522
Hour				
- 7 AM	0.0486	0.0165	0.0032	43522
- 10 AM	-0.0449	0.0168	0.0075	43522
- 3 AM	0.0409	0.0166	0.0137	43522
VPD	-0.0394	0.0049	0	43522
Hour				
- 8 AM	0.0376	0.0166	0.0235	43522
Month				
- Nov	0.0372	0.0535	0.4865	1408
Hour				
- 10 PM	-0.0323	0.0163	0.0476	43522
- 5 PM	-0.0323	0.0166	0.0515	43522
- 3 PM	-0.0297	0.0171	0.0825	43522
NEE	-0.0295	0.0039	0	43522
Hour				
- 9 PM	-0.0259	0.0168	0.1221	43522
- 6 PM	-0.0245	0.0163	0.1319	43522
- 8 PM	-0.0207	0.0164	0.2072	43522
- 1 PM	-0.0206	0.0172	0.2309	43522
- 7 PM	-0.0198	0.0165	0.2293	43522
- 2 AM	0.0194	0.0163	0.2336	43522
vWD	-0.0179	0.0035	0	43522
Hour				
- 12 PM	-0.0155	0.0171	0.363	43522
- 2 PM	-0.0095	0.017	0.5736	43522

	- 1 AM	0.0089	0.0166	0.5925				43522				
	- 11 AM	-0.008	0.0171	0.6385				43522				
	- 11 PM	-0.0052	0.0165	0.7522				43522				
	- 4 PM	-0.0049	0.0166	0.7696				43522				
	- 9 AM	-0.0045	0.0171	0.7928				43522				
<u>Random effects</u>												
	Site								72.44			
	Date								6.22			
Hourly (n=3 sites)	Intercept	-0.2978	0.5368	0.5791	0.0439	0.816	25231			-0.46	1.22	1.37
<u>Fixed effects</u>												
	Month											
	- Aug	0.6418	0.0359	0				1405				
	- Jul	0.5815	0.0365	0				1405				
	- Sep	0.5118	0.035	0				1405				
	- Apr	-0.3979	0.4686	0.3959				1405				
	- Jun	0.27	0.0354	0				1405				
	- Oct	0.1829	0.0373	0				1405				
	Hour											
	- 5 AM	0.1371	0.0208	0				25231				
	WTL	0.0936	0.0142	0				25231				
	Hour											
	- 7 AM	0.0926	0.0207	0				25231				
	- 3 AM	0.0841	0.0206	0				25231				
	TS	-0.0838	0.0092	0				25231				
	Hour											
	- 6 AM	0.0831	0.0204	0				25231				
	u*	0.0687	0.0051	0				25231				
	Hour											
	- 9 AM	0.0657	0.0216	0.0024				25231				
	- 8 AM	0.0656	0.0207	0.0016				25231				
	- 1 AM	0.0594	0.0206	0.0039				25231				
	- 11 PM	0.0578	0.0204	0.0046				25231				
	- 1 PM	0.0488	0.0222	0.028				25231				
	- 7 PM	0.0479	0.0206	0.0197				25231				

- 11 AM	0.0476	0.022	0.0302	25231
PA	-0.0458	0.0117	0.0001	25231
Hour				
- 4 AM	0.0417	0.0201	0.0383	25231
- 3 PM	0.0417	0.0218	0.056	25231
- 2 AM	0.0377	0.0201	0.0612	25231
- 12 PM	0.0336	0.0219	0.1259	25231
- 2 PM	0.0272	0.0218	0.2113	25231
- 5 PM	0.0267	0.021	0.2039	25231
NEE	-0.0243	0.0052	0	25231
Hour				
- 10 AM	-0.0183	0.0215	0.3942	25231
VPD	-0.0181	0.0066	0.0063	25231
Month				
- Nov	0.0176	0.0628	0.7792	1405
Hour				
- 6 PM	-0.0167	0.0204	0.4144	25231
- 9 PM	0.0149	0.0207	0.4738	25231
- 4 PM	0.0148	0.0212	0.4851	25231
- 8 PM	-0.0129	0.0202	0.523	25231
- 10 PM	-0.0121	0.0202	0.5514	25231
vWD	-0.0081	0.0045	0.0705	25231

Random effects

Site	72.46
Date	8.29

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Table C15. Full linear mixed effects model results. In the models, absolute the difference between ecosystem- and plot-scale methane (CH₄) flux (FCH₄) (Δ FCH₄) was Yeo-Johnson-transformed, centered and scaled, while all continuous predictors were only centered and scaled. This table presents the full models with both nonsignificant and significant predictors before backward variable selection. The final daily and monthly models were the full models which are shown in Table 3 of the main text. Note that in all models temporal variables were included in nested random effects (see methods and Supplementary Methods A2). In all models, the reference level in site dominant vegetation (VEG) was *Sphagnum* moss, 0 in Hour and May in Month. Annual models were not included due to an inadequate number of observations. Due to lack of complete case observations, US-Owc was not included in the weekly and monthly models (n=7 sites). We excluded TS from the half-hourly model due to high multicollinearity with Month (VIF>3). Due to multicollinearity in the weekly model, we built one model without NEE and one without VPD. Fixed effects are listed in decreasing order based on their β -coefficients. SE = standard error, Df = degrees of freedom of denominator, LOOCV = leave-one-out cross validation, MAE = mean absolute error, RMSE = root mean square error, PA = air pressure (kPa), u* = friction velocity (m s⁻¹), WTL = water table level (cm), TS = soil temperature (°C), NEE = net ecosystem exchange (μ mol CO₂ m⁻² s⁻¹), VPD = vapor pressure deficit (hPa), vWD = v wind component (m s⁻¹), uWD = u wind component (m s⁻¹).

Data set	Predictors	β - coefficient	SE	<i>p</i> -value (<i>t</i> -test)	Marginal R ²	Conditional R ²	Df	Random effect variation explained, %	LOOCV			
									R ²	MAE	RMSE	
Half- hourly (n=3 sites)	Intercept	0.0962	0.7069	0.8917	0.2041	0.8518	43521		-2.27	1.46	1.55	
	<u>Fixed effects</u>											
	VEG											
	- Tree	-0.9969	1.2237	0.5648				1				
	Month											
	- Aug	0.4629	0.029	0				1408				
	- Jul	0.4172	0.029	0				1408				
	- Sep	0.3974	0.0294	0				1408				
	- Jun	0.2161	0.0294	0				1408				
	- Apr	0.1613	0.3852	0.6753				1408				
	- Oct	0.1109	0.0316	0.0005				1408				
u*	0.088	0.004	0				43521					
Hour												

- 5 AM	0.0873	0.0166	0	43521
- 6 AM	0.0741	0.0163	0	43521
WTL	0.0615	0.0121	0	43521
Hour				
- 4 AM	0.0592	0.0163	0.0003	43521
PA	-0.056	0.0097	0	43521
Hour				
- 7 AM	0.0484	0.0165	0.0033	43521
- 10 AM	-0.0451	0.0168	0.0073	43521
- 3 AM	0.0409	0.0166	0.0138	43521
VPD	-0.0393	0.0049	0	43521
Month				
- Nov	0.0376	0.0535	0.4822	1408
Hour				
- 8 AM	0.0373	0.0166	0.0244	43521
- 5 PM	-0.0325	0.0166	0.0502	43521
- 10 PM	-0.0323	0.0163	0.0476	43521
- 3 PM	-0.0299	0.0171	0.0808	43521
NEE	-0.0294	0.0039	0	43521
Hour				
- 9 PM	-0.0259	0.0168	0.1219	43521
- 6 PM	-0.0247	0.0163	0.1296	43521
- 8 PM	-0.0208	0.0164	0.2056	43521
- 1 PM	-0.0207	0.0172	0.2282	43521
- 7 PM	-0.0199	0.0165	0.2267	43521
- 2 AM	0.0194	0.0163	0.234	43521
vWD	-0.0182	0.0036	0	43521

	Hour										
	- 12 PM	-0.0156	0.0171	0.3593			43521				
	- 2 PM	-0.0097	0.017	0.5678			43521				
	- 1 AM	0.0089	0.0166	0.5925			43521				
	- 11 AM	-0.0082	0.0171	0.6317			43521				
	- 11 PM	-0.0052	0.0165	0.7538			43521				
	- 4 PM	-0.0051	0.0166	0.7589			43521				
	- 9 AM	-0.0047	0.0171	0.7818			43521				
	uWD	-0.0015	0.0035	0.6716			43521				
<u>Random effects</u>											
	Site								75.96		
	Date								5.43		
Hourly (n=3 sites)	Intercept	0.0199	0.7487	0.9788	0.2116	0.8752	25230		-2.45	1.53	1.62
<u>Fixed effects</u>											
	VEG										
	- Tree	-0.9517	1.2957	0.5967			1				
	Month										
	- Aug	0.6413	0.036	0			1405				
	- Jul	0.5811	0.0366	0			1405				
	- Sep	0.5114	0.035	0			1405				
	- Apr	-0.3974	0.4686	0.3966			1405				
	- Jun	0.2697	0.0355	0			1405				
	- Oct	0.1826	0.0373	0			1405				
	Hour										
	- 5 AM	0.1371	0.0208	0			25230				
	WTL	0.0933	0.0142	0			25230				
	Hour										

- 7 AM	0.0927	0.0207	0	25230
- 3 AM	0.0841	0.0206	0	25230
TS	-0.0837	0.0093	0	25230
Hour				
- 6 AM	0.0831	0.0204	0	25230
u*	0.0685	0.0052	0	25230
Hour				
- 9 AM	0.0658	0.0217	0.0024	25230
- 8 AM	0.0656	0.0207	0.0015	25230
- 1 AM	0.0594	0.0206	0.0039	25230
- 11 PM	0.0578	0.0204	0.0046	25230
- 1 PM	0.0488	0.0222	0.028	25230
- 7 PM	0.048	0.0206	0.0196	25230
- 11 AM	0.0476	0.022	0.0302	25230
PA	-0.0455	0.0117	0.0001	25230
Hour				
- 3 PM	0.0417	0.0218	0.0558	25230
- 4 AM	0.0417	0.0201	0.0384	25230
- 2 AM	0.0377	0.0201	0.0611	25230
- 12 PM	0.0336	0.0219	0.126	25230
- 2 PM	0.0272	0.0218	0.2111	25230
- 5 PM	0.0268	0.021	0.2028	25230
NEE	-0.0244	0.0052	0	25230
Hour				
- 10 AM	-0.0183	0.0215	0.3958	25230
VPD	-0.0182	0.0066	0.0061	25230
Month				
- Nov	0.0177	0.0628	0.7786	1405

<hr/>											
	Hour										
	- 6 PM	-0.0166	0.0204	0.4159						25230	
	- 4 PM	0.0149	0.0212	0.4826						25230	
	- 9 PM	0.0149	0.0207	0.4738						25230	
	- 8 PM	-0.0129	0.0202	0.5236						25230	
	- 10 PM	-0.0121	0.0202	0.5505						25230	
	vWD	-0.0079	0.0045	0.0833						25230	
	uWD	0.0009	0.0044	0.8346						25230	
<u>Random effects</u>											
	Site									77.37	
	Date									6.81	
Weekly	Intercept	0.3046	0.3665	0.407	0.5468	0.8357	180		-1.15	1.34	1.58
(no NEE, n=9 sites)	<u>Fixed effects</u>										
	VEG										
	- Tree	-1.4712	0.702	0.0903							5
	- Aerenchymatous	0.9949	0.5112	0.1092							5
	- Ericaceous shrub	0.5253	0.7163	0.4962							5
	Month										
	- Apr	0.3907	0.416	0.3502							86
	- Nov	0.3193	0.2602	0.2232							86
	- Dec	0.316	0.6993	0.6524							86
	- Jul	0.3104	0.142	0.0315							86
	- Aug	0.3012	0.1442	0.0396							86
	- Sep	0.2964	0.14	0.0371							86
	- Jun	0.2082	0.1388	0.1373							86
	- Oct	0.169	0.1457	0.2492							86
	WTL	-0.0727	0.0551	0.1887							180

PA	-0.0604	0.0407	0.14				180				
VPD	-0.0352	0.0318	0.2701				180				
u*	0.0317	0.0272	0.244				180				
Month											
- Mar	-0.0234	0.5319	0.9649				86				
vWD	-0.0167	0.0175	0.3418				180				
TS	-0.0104	0.06	0.862				180				
uWD	-0.0081	0.0198	0.6819				180				
<u>Random effects</u>											
Site									63.74		
Year-month									6.38e ⁻⁰⁷		
Weekly (no VPD, n=9 sites)	Intercept	0.3008	0.3724	0.4202	0.5423	0.8365	180		-1.03	1.3	1.54
<u>Fixed effects</u>											
VEG											
- Tree	-1.4642	0.713	0.0952				5				
-Aerenchymatous	0.9763	0.5228	0.1208				5				
-Ericaceous shrub	0.4435	0.7268	0.5684				5				
Month											
- Apr	0.3611	0.4145	0.386				86				
- Dec	0.3525	0.7059	0.6188				86				
- Nov	0.3375	0.263	0.2029				86				
- Aug	0.317	0.1484	0.0355				86				
- Jul	0.3144	0.1438	0.0315				86				
- Sep	0.3086	0.1408	0.0311				86				
- Jun	0.2001	0.141	0.1596				86				
- Oct	0.1847	0.1473	0.2134				86				
- Mar	-0.0786	0.5287	0.8822				86				
PA	-0.0737	0.039	0.0603				180				

WTL	-0.07	0.0546	0.2046	180
u*	0.032	0.0276	0.2464	180
TS	-0.019	0.0637	0.7663	180
vWD	-0.0184	0.0175	0.2962	180
uWD	-0.0137	0.0201	0.4953	180
NEE	0.01	0.0266	0.7117	180

Random effects

Site	64.27
Year-month	4.91e ⁻⁰⁷

1240 **Code and data availability**

The timestamp-aligned data sets containing ecosystem and plot-scale CH₄ flux and environmental data at half-hourly, hourly, daily, weekly, monthly, and annual scales can be accessed via Zenodo (Määttä et al., 2025; doi: 10.5281/zenodo.17312404). The R code used for processing the EC and chamber CH₄ flux data, statistical analyses and producing the figures can be accessed at <https://github.com/tiia-maa/Cross-site-comparison-of-ecosystem-and-plot-scale-methane-fluxes-across-multiple-sites.git>.

Author contribution

TM, AM, SB, KD, AD, SF, EFC, RJ, SK, GM, LM, ZO, OS, MU, RV, EW, ZZ, AT, and MH conceptualized the study. Data was provided by AD, GB, JJ, AK, KK, LM, MN, SN, MP, KS, ET, MU, RV, JW, EW, and ZZ, and data curation was conducted by TM, AM, AD, GB, KD, EFC, JJ, SK, AK, KK, GM, MN, SN, MP, KS, ET, MU, RV, JW, EW, and ZZ. Formal analysis (data processing and statistical analyses) and visualization were done by TM. Investigation was conducted by TM and AM. AM supervised the study. Project administration was done by TM, AM and RJ. Funding acquisition for the study was done by AM and RJ. TM and AM prepared the original manuscript draft and TM, AM, AD, GB, SB, KD, SF, EFC, RJ, JJ, SK, LM, MN, ZO, MP, OS, ET, MU, RV, JW, EW, ZZ, AT, and MH contributed to the review and editing.

Competing interests

1255 The authors declare that they have no conflict of interest.

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