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TundraFlux: A database of ecosystem respiration with biotic and abiotic metadata from Arctic and alpine tundra warming experiments

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Abstract

Empirical *in-situ* measurements of ecosystem carbon dioxide respiration (R_{eco}) in high-latitude ecosystems remain limited, yet they are essential for understanding how tundra carbon cycling responds to climate warming across different environmental contexts and for reducing uncertainties in upscaled carbon budgets and carbon–climate feedbacks. Here, we present the TundraFlux Database, which to date is the most comprehensive synthesis of tundra R_{eco} responses to experimental warming. The database compiles over 24,000 daily-aggregated *in-situ* R_{eco} measurements from control and plots warmed with open-top chambers at 64 Arctic and alpine tundra sites across 12 countries. By coupling R_{eco} measurements with extensive metadata on climate, vegetation, and soil characteristics, the TundraFlux Database enables the integration of field-scale ecological processes into large-scale models, offering new opportunities to refine global carbon budgets and test predictions of tundra ecosystem responses to warming. Open access to the TundraFlux Database empowers the research community to better quantify and predict how warming alters carbon cycling in Arctic and alpine tundra ecosystems.

Keywords: Arctic tundra, alpine tundra, ecosystem respiration, open-top chambers (OTCs), warming experiments, database, carbon dioxide flux, vegetation data, soil data, climate data

1 Introduction

Ecosystem carbon dioxide (CO_2) respiration, the sum of autotrophic respiration from plants and heterotrophic respiration from soil microbes, constitutes the largest natural carbon flux from terrestrial ecosystems to the atmosphere (Jones et al., 1999; Lu et al., 2013; Oberbauer et al., 1998; Schuur et al., 2008; Tarnocai et al., 2009). The Arctic and alpine tundra biome stores one-third of global soil organic carbon, which is nearly twice the atmospheric carbon pool (Schuur et al., 2015), much of it locked in permafrost, organic-rich mineral soils, and peat (Gorham, 1991; Hugelius et al., 2020; Park et al., 2025; Schuur et al., 2022; Tarnocai et al., 2009; Zimov et al., 2006). As ecosystem CO_2 respiration (R_{eco}) is a temperature-sensitive process (Davidson et al., 2006; Gudasz et al., 2021; Mahecha et al., 2010; Niu et al., 2024), understanding the consequences of the current rapid warming in Arctic and alpine tundra (Rantanen et al., 2022; Tingley and Huybers, 2013; Welker et al., 1999) is crucial for understanding climate-driven shifts in soil processes and carbon cycling globally. Rising air and soil temperatures are expected to thaw permafrost, release previously stored soil organic carbon, and accelerate microbial decomposition of soil organic matter, thereby increasing CO_2 emissions to the atmosphere (Dorrepaal et al., 2009; Friggens et al., 2025; Karhu et al., 2014; Maes et al., 2024; Rustad et al., 2001; Schimel et al., 2004, 2006), which could significantly amplify global climate change (Cox et al., 2000; Welker et al., 2004).

Its central role in the global carbon cycle, making it essential to predict how R_{eco} responds to climate change. However, accurately forecasting the magnitude, as well as the spatial and temporal variability of these responses, remains a major scientific challenge (Karhu et al., 2014; Maes et al., 2024; Rustad et al., 2001; Schuur et al., 2022; Sulman et al., 2018; Virkkala

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et al., 2021). Spatially, addressing these challenges requires moving beyond isolated case studies toward integrating empirical data across diverse tundra sites and microclimates. Temporally, interannual variability is high and data from the non-growing season are sparse, even though respiration during this period can contribute substantially to annual carbon budgets (Fahnestock et al., 1998, 1999; Natali et al., 2019; Welker et al., 2000). Here, we introduce the TundraFlux Database of R_{eco} measurements derived from open-top chamber (OTC) warming experiments, which provides a unique opportunity to disentangle patterns and drivers of CO_2 respiration under warming across bioclimatic gradients arising from differences in climate, vegetation, and soil characteristics (Maes et al., 2024). Experimental warming studies uniquely integrate multiple, interacting ecosystem responses, including vegetation dynamics, microbial activity, soil processes, and snow-mediated microclimate effects (Hollister et al., 2023; Leffler et al., 2016; Welker et al., 1997, 1999), all of which jointly regulate R_{eco} (Niu et al., 2024).

The TundraFlux Database currently includes 24,951 R_{eco} observations, aggregated to daily values (whenever multiple measurements were made within the same day) from warming experiments and associated control plots across 64 Arctic and alpine tundra sites (Fig. 1A) conducted between 2000 and 2024 (Fig. 1B). Here, we describe the data sources, the database structure and variables (Sect. 2), as well as potential applications (Sect. 3), data coverage and resolution (Sect. 4), future directions (Sect. 5), and availability (Sect. 6) of the TundraFlux Database.

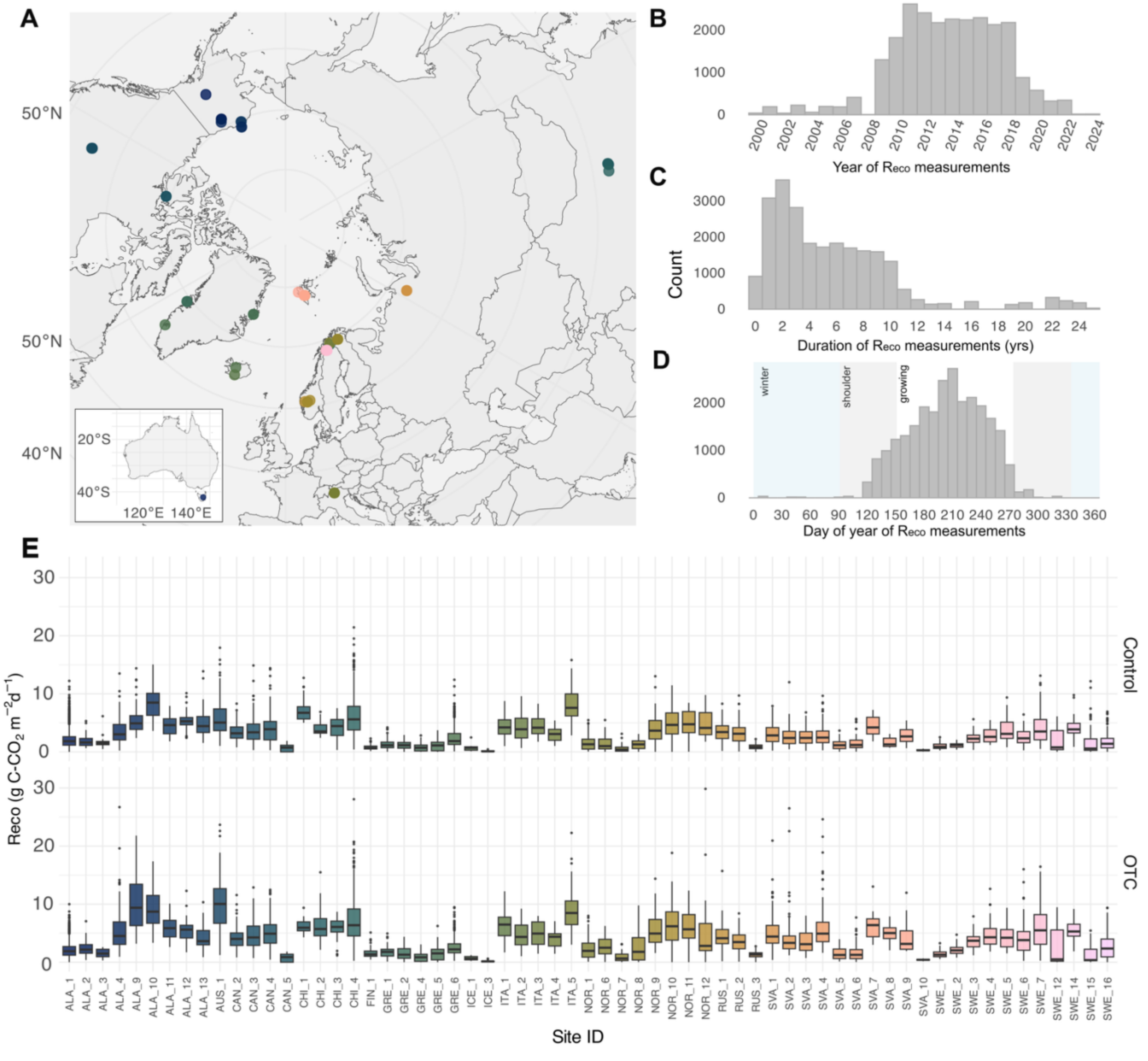

Figure 1 A. Map showing the locations of the of the 64 open-top chamber experiments from which the ecosystem CO₂ respiration (R_{eco}) measurements in the TundraFlux Database were derived. Temporal spread of the data showing **B.** the distribution of the year of R_{eco} measurements, **C.** the duration of R_{eco} measurements (start of flux measurements - start of the experiment), and **D.** the distribution of day-of-year for R_{eco} measurements, with shaded regions highlighting winter (Dec–Mar, light blue), shoulder (Oct–Nov, Apr-May, grey), and growing (Jun-Sep, white) seasons. **E.** Boxplots showing the daily average Reco (g C–CO₂ m⁻² d⁻¹) for each site, for both the unmanipulated control (i.e., ambient conditions, **top**) and the warmed treatment with open-top chambers (OTC, **bottom**). Boxes show the median and interquartile range (IQR, 25th–75th percentiles); whiskers extend to 1.5 × IQR, and values beyond the whiskers are plotted as outliers. Colours for site_id are the same for all panels. The database includes occasional negative and exact-zero R_{eco} values. Negative values can result from instrument noise or brief net CO₂ uptake, while exact zeros may reflect contributor preprocessing (e.g., rounding or thresholding small fluxes).

2 Description and structure

2.1 Scope and purpose

Warming alters tundra ecosystems through a suite of interacting biotic and abiotic pathways, including changes in vegetation composition (Bjorkman et al., 2020; Collins et al., 2021; García Criado et al., 2025; Wilson and Nilsson, 2009), plant productivity (Hollesen et al., 2015; Myers-Smith et al., 2019), microbial activity (Frossard et al., 2021), decomposition rates (Sarneel et al., 2020; Schwieger et al., 2025), nutrient cycling (Weedon et al., 2012), growing season length (Barichivich et al., 2013; Collins et al., 2021; Myers-Smith et al., 2019; Oberbauer et al., 1998), and snow-mediated microclimate conditions (Morgner et al., 2010; Pattison and Welker, 2014; Rixen et al., 2022). These processes jointly regulate R_{eco}, making it an integrative indicator of tundra ecosystem responses to climate warming.

As these responses occur at multiple spatial and temporal scales and are significantly influenced by the local environmental context, a robust evaluation of the effects of warming on R_{eco} requires long-term, spatially diverse datasets that link flux measurements with detailed site and plot-level metadata The TundraFlux Database was developed to address this issue, systematically compiling R_{eco} measurements from experimental warming studies in Arctic and alpine tundra ecosystems.

In addition to standardized R_{eco} flux data, the database includes extensive metadata on vegetation (e.g., plant community composition, functional traits, biomass), soils (e.g., pH, organic carbon and nitrogen content, soil organic matter), and microclimate (e.g., air and soil temperature, soil moisture). This structure enables users to categorise analyses according to ecosystem properties, environmental factors or experimental design. This supports hypothesis testing, model evaluation and the large-scale synthesis of tundra carbon–climate feedback.

2.2 Data sources and data collection

The TundraFlux Database compiles *in-situ* measurements of daily-aggregated terrestrial ecosystem-level CO_2 fluxes (g C-CO_2 m^{-2} day^{-1}) from Arctic and alpine tundra ecosystems to assess warming effects on ecosystem CO_2 respiration (R_{eco}). We compiled data from experiments across the Arctic and alpine tundra biome using open-top chambers (OTCs), small greenhouses that passively increase air temperatures during the snow-free season while allowing relatively free entry of precipitation (Hollister et al., 2023; Marion et al., 1997; Welker et al., 1997). They are commonly used to simulate climate warming at a plot-scale in low-stature Arctic and alpine tundra systems, e.g., in the International Tundra Experiment network (ITEX; https://www.gvsu.edu/itex/; Henry and Molau, 1997; Hollister et al., 2023).

We contacted potential data contributors through established research networks like ITEX, WaRM, INTERACT and the Permafrost Carbon Network, and identified relevant contact information from authors of previously published meta-analyses on R_{eco} responses in warming experiments (Table S1).

We included data from experiments situated within the Arctic and alpine tundra biome (i.e., treeless regions beyond the climatic limit for tree growth) that reported *in-situ* measurements of ecosystem respiration (R_{eco}) in both warmed open-top chamber

(OTC) and unmanipulated control plots. Based on these criteria, we compiled 40,160 individual R_{eco} measurements, encompassing repeated observations across multiple plots, years, days, and, in some cases, multiple measurement times within a day at each site.

To maximize data usability and harmonize temporal resolution across studies, we provide two interlinked versions of the R_{eco} dataset. The raw dataset retains all individual measurements at their original temporal resolution, including multiple measurements per day and associated quality-control information, allowing users full flexibility in data filtering and aggregation. In addition, we provide a daily-aggregated dataset in which R_{eco} values were averaged within each site (site_id), treatment (OTC or control), plot (plot_id), year (flux_year), and day of year (flux_doy) when multiple measurements occurred per day. This aggregation reduces short-term variability and preprocessing effort for synthesis applications, resulting in a total of 24,951 daily mean observations (OTC, n = 11,046; control, n = 13,905; Fig. 1E).

We define a *dataset* as all R_{eco} measurements from a given site and year (site_id × flux_year), including both OTC and control treatments, all replicate plots, and one or more measurement dates (Table S2). Plot-level data were retained by design to preserve within-site replication and enable flexible, user-defined aggregation and statistical modeling approaches, including treatment-wise averaging or hierarchical analyses.

Alongside R_{eco}, we compiled *in-situ* metadata on microclimate conditions, geolocation, vegetation cover, plant traits, and soil characteristics. These ancillary variables were measured at both plot and site levels, with some recorded concurrently with flux measurements (and provided within the Carbon flux data, Fig. 2), and others representing broader site-level environmental context that can be linked to the relevant flux measurements (Fig. 2, Fig. 3, Table S3).

Part of the database compiled through this effort was previously presented in (Maes et al., 2024), which focused exclusively on growing season measurements (i.e., June to August) and included data up to the year 2020. This current published version of the TundraFlux Database extends the earlier synthesis by incorporating updated measurements through 2024 (Fig. 1B) and by including shoulder season fluxes from April to May and September to November (Fig. 1D).

2.3 Data structure and variables

The TundraFlux Database comprises 74 variables describing R_{eco} from 64 tundra sites spanning 2000–2024 (Fig. 1A, B). A comprehensive data dictionary with a description of the variables of the site, vegetation, soil and method metadata, including data-type and unit is provided in the Supplementals (Table S3).

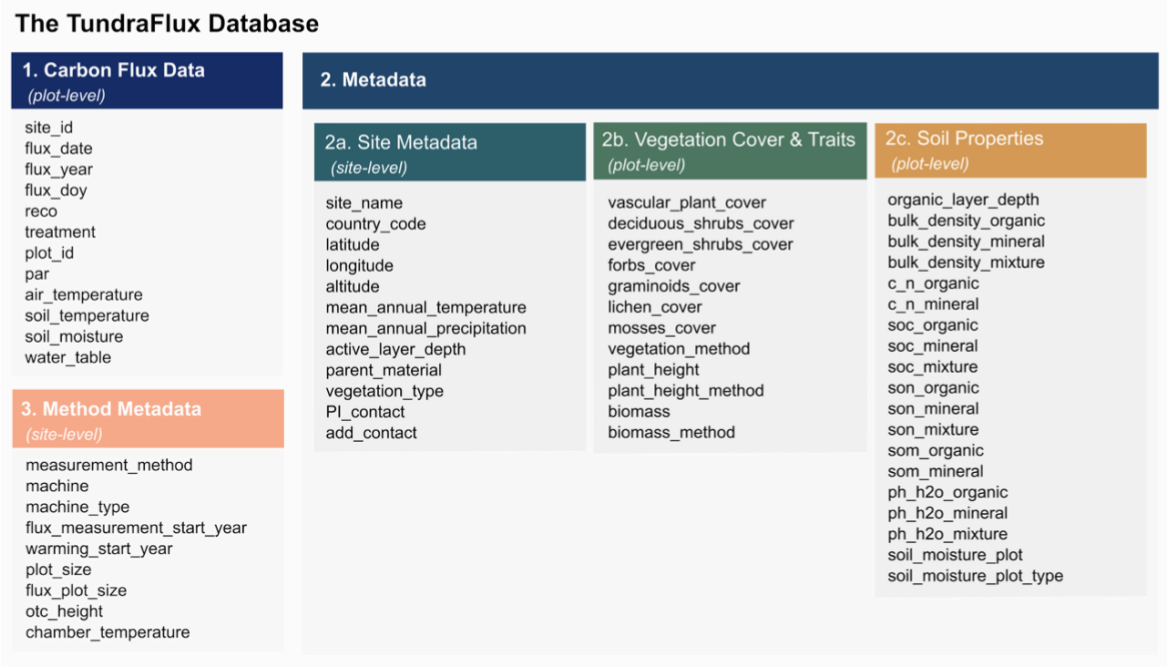

Figure 2. Data structure of the TundraFlux Database. Boxes represent the main data types: (1) Carbon flux data, including plot-level daily averages of ecosystem CO_2 respiration (R_{eco}) in g C-CO_2 m^{-2} d^{-1} and data measured along with flux measurements; (2) Metadata, including information on (a) site, (b) vegetation cover and plant traits at plot-level, and (c) soil properties at plot level; (3) Method data including documentation of experimental setups; and (4) Contact details. Variables listed inside the boxes correspond to column names in the database (identical to Table S3).

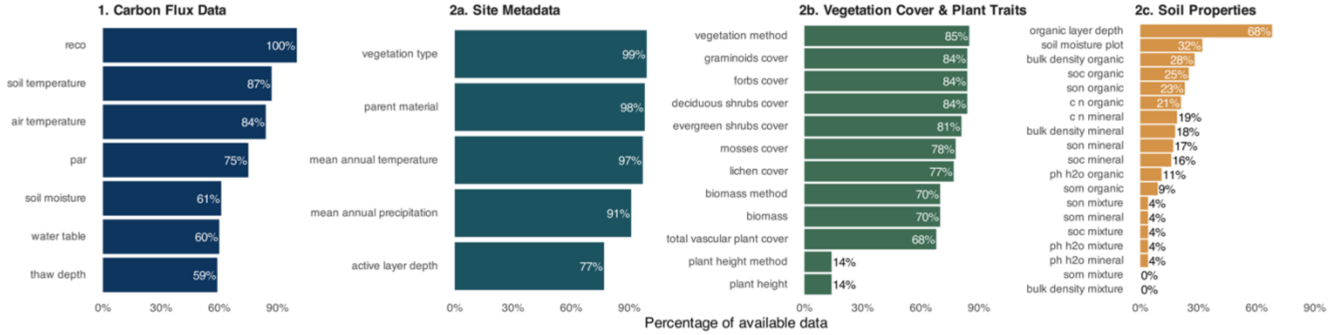

Figure 3. Percentage of available observations for metadata variables presented in Figure 2 relevant for CO_2 modeling. Soil organic carbon (SOC), soil organic nitrogen (SON), carbon-to-nitrogen ratio (c_n), soil organic matter (SOM).

2.4 Data standardization and quality control

Data were processed in R version 4.5.1 (R Core Team 2025). We mainly used the R package TIDYVERSE (v. 2.0.0) for data handling. For each dataset (defined by a unique combination of site_id and flux_year) we calculated treatment- and plot-specific daily mean R_{eco} values, whenever multiple measurements were made within the same day. We provide an R script on

Zenodo (DOI: 10.5281/zenodo.17976235) that documents the full aggregation procedure, and the un-aggregated dataset (see the 'Data Availability' section). All individual flux measurements were standardized to a common unit (g C–CO_2 m^{-2} d^{-1}) to ensure comparability across studies. We screened the data for poor-quality records and inconsistencies in unit or sign conventions, contacting data contributors in cases of uncertainty. Spatial coordinates were validated by visualizing all sites on a map, and any imprecise or conflicting locations were corrected in consultation with site researchers.

All experiments measured daytime R_{eco} using dark or opaque chambers, except for the CiPEHR site in Alaska (ALA_1), where automated chambers continuously measured CO_2 respiration using clear chambers. To obtain comparable respiration estimates for this site, we extracted only night-time fluxes, defined by photosynthetically active radiation (PAR) values below 5 µmol m^{-2} s^{-1}, as these best approximated dark chamber conditions. These night-time measurements were therefore used as the site's R_{eco} values.

The same quality-control procedures were applied to associated metadata to ensure consistency in spatial reference and measurement units across sites. Soil moisture data, reported at the plot level, were provided either as volumetric or gravimetric values and were subsequently converted to percentages. Bulk density was standardized to g dwt cm^{-3}. Soil organic carbon (SOC) and soil organic nitrogen (SON) were standardized to g C kg^{-1} soil and g N kg^{-1} soil, respectively, while soil organic matter (SOM) was standardized to percentages.

The TundraFlux Database includes occasionally negative and exact-zero R_{eco} value (Table S2). These originate from the heterogeneity of measurement techniques and pre-processing procedures used in the studies that contribute to the database. Negative fluxes can occur in chamber-based measurements due to short-term CO_2 concentration fluctuations, instrument noise, pressure-induced artefacts or brief periods of apparent net CO_2 uptake when R_{eco} is close to the detection limit. We retained such values exactly as reported in the original datasets in order to preserve data fidelity. Exact-zero values appear when the net change in chamber CO_2 concentration falls within instrument noise, or when contributors apply local preprocessing (e.g. rounding small negative fluxes to zero or applying minimum detection thresholds) prior to submission. As preprocessing conventions differed between studies, both negative and zero values are present in the compiled dataset. Users may apply additional filtering or thresholding, in line with their research objectives, for instance by removing negative fluxes, setting minimum detection limits or utilizing the quality control flags provided in the non-aggregated dataset.

2.4.1 Outlier detection and handling

We chose not to filter outliers from the database before calculating daily averages to preserve the original data structure. However, recognizing the substantial variability in carbon fluxes across sites (Fig. 1E) and years (Table S2), we developed a tailored outlier detection and flagging procedure for R_{eco} data. This method applies the Median Absolute Deviation (MAD, Leys et al., 2013) to the non-aggregated R_{eco} values. This resulted in 285 flagged outliers (0.71% of the original 40,160 data points) and the user should consider whether or not to remove them or use other criteria for outlier detection. We added a column to the non-aggregated dataset that indicates the flagged outliers. A full description of this method is provided in the

Supplement. The R scripts used for data processing are archived on Zenodo (DOI: 10.5281/zenodo.17976235, Schwieger et al., 2026) and are developed and maintained in a public GitHub repository.

3 Applications of the TundraFlux database

3.1 Identifying magnitude and drivers of ecosystem respiration response to warming through meta-analysis

The TundraFlux Database builds on an initial in a global synthesis of how ecosystem respiration in Arctic and alpine tundra responds to experimental warming (Maes et al., 2024). Using 136 datasets from 56 OTC experiments at 28 tundra sites worldwide (60% of the data presented here), the study quantified that a mean rise of 1.4 °C [confidence interval (CI) 0.9–2.0 °C] in air and 0.4 °C [CI 0.2–0.7 °C] in soil temperatures causes a 30% [CI 22–38%] increase in growing season R_{eco}. It further showed that this stimulation persisted for up to 25 years of warming treatment, with evidence pointing to enhanced plant and microbial activity as the underlying drivers. By linking respiration responses to changes in local soil conditions (i.e., nitrogen concentration and carbon-to-nitrogen ratio), Maes et al. (2024) demonstrated that tundra sites with stronger nitrogen limitations and sites in which warming had stimulated plant and microbial nutrient turnover seemed particularly sensitive in their R_{eco} response to warming. This example highlights the power of standardized, long-term experimental data to uncover generalizable patterns in climate responses. It also showcases how the TundraFlux Database enables large-scale syntheses that identify not only the direction but also the mechanism of possible climate change feedbacks on tundra ecosystems, which are essential to improve carbon–climate feedback projections in Earth System Models.

The expanded TundraFlux Database, which now includes spring and autumn (‘shoulder-season’) measurements and updated observations through 2024, enables new high-impact research questions that could not be addressed in Maes et al. (2024). For example, users can quantify how experimental warming affects R_{eco} beyond the peak growing season and evaluate whether the environmental controls of R_{eco} differ between early-season, peak-season, and late-season periods. These additions substantially improve the capacity to analyze seasonal dynamics and long-term trajectories of tundra carbon cycling, thereby supporting more robust evaluations of climate–carbon feedbacks.

3.2 Carbon model parameterization and validation

Accurately predicting carbon release from permafrost soils under warming scenarios remains a major challenge in climate science (Knoblauch et al., 2021; Schuur et al., 2015) due to the high variability in ecosystem responses and the limited availability of long-term data (Swindles et al., 2015). The Warming Permafrost Model Intercomparison Project (WrPMIP) led by Woodwell Climate Research Center is using the TundraFlux Database to bridge the gap between experimental warming studies and large-scale carbon modeling (warmingpermafrost.nau.edu). In this project, multi-model simulations are being run at both regional and site scales to align with the spatial and temporal dimensions of experimental data (Wells et al., 2023). By aligning field-based warming measurements from the TundraFlux Database with model simulations, the project will enhance our ability to project the magnitude and timing of carbon release from permafrost regions under climate change.

4 Data coverage and resolution

As with any large database, not all biotic and abiotic variables, seasons, plant functional types, habitats, regions, or bioclimatic settings within the Arctic and alpine biomes are equally represented in the TundraFlux Database. Here, we identify some limitations related to gaps in the spatial and temporal resolution the database, which highlight clear priorities for future data collection efforts.

4.1 Spatial coverage and bias

While the TundraFlux Database inherently reflects a sampling imbalance, particularly the underrepresentation of key Arctic regions such as the Canadian High Arctic archipelago and Siberia (López-Blanco et al., 2024; Fig. 1A, Table S4), it still represents the most comprehensive effort currently available of data from warming treatments. In particular, high-latitude North America and northern Europe are generally the best-represented regions (Table 1). This geographical concentration reflects a well-documented spatial bias in Arctic field sampling toward long-established research hubs with good accessibility and infrastructure (Metcalfe et al., 2018).

There is substantial variability in the number of measurements across sites (median = 120, IQR = 133.5; total measurements = 24,951). In particular, the CiPEHR site (ALA_1) near Eight Mile Lake, Alaska, USA, with 13,572 daily-aggregated observations, contributed 52.5% of the R_{eco} data in the TundraFlux Database (Table S4). A large proportion of observations from a single, well-studied site increases temporal and treatment-level detail but may disproportionately influence cross-site or pan-Arctic analyses if not accounted for. How to address this imbalance ultimately depends on the user's research question and analytical framework, but several approaches can help prevent disproportionate influence of high-density sites. These include applying hierarchical or mixed-effects models that treat site as a random effect, using equal or inverse-effort site weighting, aggregating fluxes to common temporal resolutions, conducting sensitivity analyses (e.g., subsampling or excluding dominant sites), or using site-level bootstrapping or partial-pooling approaches (Choi and Kang, 2025). At the same time, these long-term, high-density datasets provide valuable opportunities for method development, uncertainty quantification, and benchmarking models at sites with robust metadata.

By systematically compiling data from OTC experiments across Alaska, Greenland, Svalbard, Iceland, Fennoscandia, Canada, and Russia, the TundraFlux Database is the most comprehensive resource currently available for evaluating warming effects on tundra carbon cycling. Importantly, tundra ecosystems exhibit substantial spatial variability in both abiotic and biotic conditions (Aalto et al., 2022; Magnússon et al., 2023), meaning that each site, regardless of data quantity, contributes distinct information about ecosystem responses under different environmental and vegetation contexts.

Table 1. Number and percentages of daily R_{eco} observations by region. See Table S4 for classification of sites into regions and distribution of individual sites across the regions.

Region	Daily_obs	%	Nb of sites
High-latitude North American	15,906	61.6	13
Oceanic	3,083	11.9	8
High-latitude European	4,682	18.1	30
Alpine European	479	1.9	5
High-latitude Asian	542	2.1	3
Alpine Asian	1,136	4.4	4

4.2 Longer-term data on R_{eco} response to experimental warming

In the TundraFlux Database, 93% of the averaged daily data points (n = 22,534) come from experiments that lasted 11 years or less, and over half (51%, (n = 12,239) lasted fewer than 4 years. Out of the 64 sites in total, 7 sites (11.1%) represent long-term experiments with continuous measurements (≥5 years), while 56 sites (88.9%) represent short-term experiments (<5 years) with often only single measurements (Table S4). Consequently, longer-term measurements (>11-24 years) are rare (n = 1,573), and data from measurements exceeding 24 years are absent (Fig. 1C). This clearly highlights the importance of maintaining long-term experiments, particularly given that changes in soil processes or vegetation composition driven by warming may unfold over decades in Arctic and alpine tundra (Hollister et al., 2005; Jónsdóttir et al., 2023; Wei et al., 2025). At the same time, both OTCs and manual chamber measurements may introduce experimental disturbance effects (e.g., trampling, vegetation damage, soil compaction) that can accumulate over time (Hollister et al., 2023). Such disturbance may increasingly influence ecosystem functioning the longer an experiment runs. Thus, while longer-term data would help capture slow ecological changes, extended experiment duration may simultaneously amplify disturbance-related artefacts, complicating the interpretation of long-term trends.

4.3 Shoulder and winter season respiration

Our database contains 21,830 daily-aggregated R_{eco} observations from the growing season (defined here as June-September in the Northern Hemisphere, and December-March in the Southern Hemisphere), and 3,297 observations from outside the growing season, highlighting a gap in our understanding of carbon fluxes in the shoulder (i.e., April, May, October, and November, n = 3,330) and winter seasons (i.e., December-March in the Northern Hemisphere, n=0, Australia excluded) (Fig. 1D, Fig. 4).

As Arctic soils are usually covered in snow during the winter months, the spring and autumn shoulder seasons are particularly vulnerable to the effects of global warming (Hassol, 2004; Shukla et al., 2019). Despite its length and significance, winter remains the most understudied season in Arctic ecosystems, yet it can play a crucial role in the annual carbon budget of the region (Natali et al., 2019; Zona et al., 2016). Arctic winters have been strongly affected by climate warming, with potentially large effects on terrestrial ecosystems (Cooper, 2014; Rixen et al., 2022). Additionally, alpine ecosystems are experiencing dramatic changes in snow regimes and glacial melt due to warming (Ernakovich et al., 2014). Warming effects and mechanisms identified during the growing season (Maes et al., 2024) may not apply to the winter season, when factors such as snow depth and duration exert great control over carbon fluxes (Björkman et al., 2010; Grogan, 2012; Morgner et al., 2010; Rixen et al., 2022; Semenchuk et al., 2016; Slatyer et al., 2022).

More research focusing on the effects of warming on carbon fluxes during the underrepresented winter and shoulder seasons and developing a mechanistic understanding of winter carbon dynamics is therefore essential to improve predictions of future CO_2 emissions from Arctic soils. Overlooking this season risks underestimating both the magnitude and variability of carbon release from rapidly warming Arctic soils.

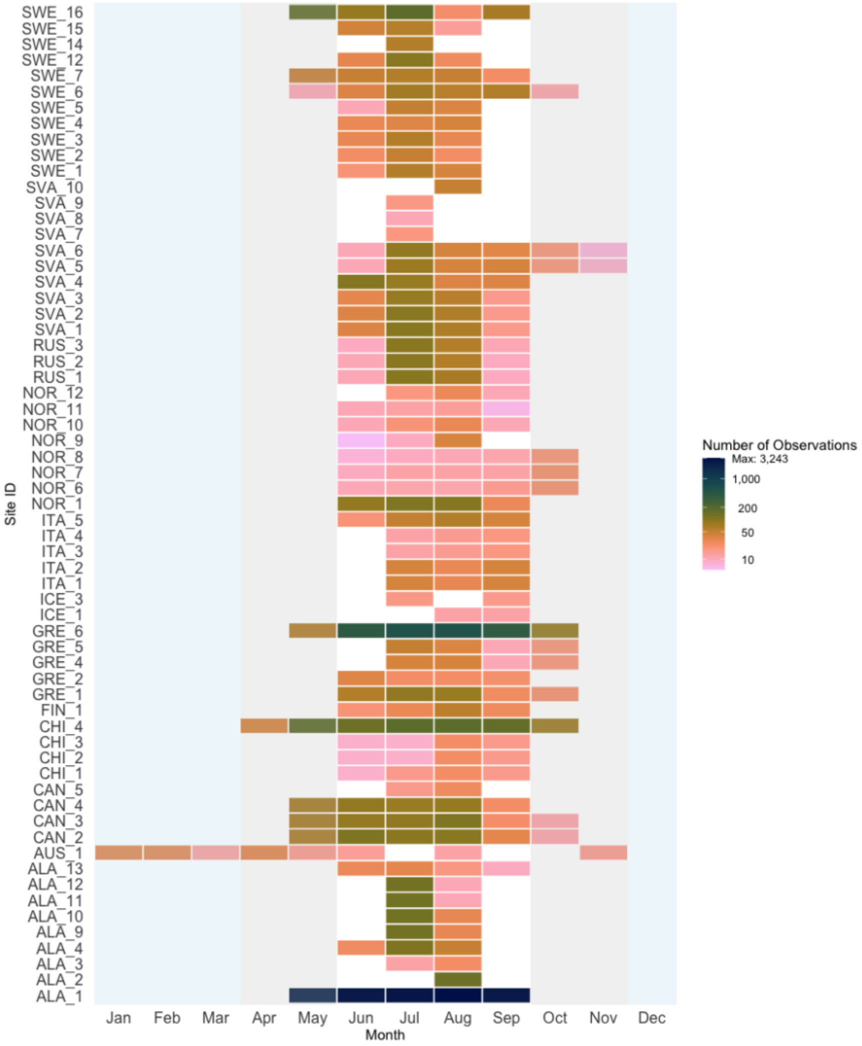

Figure 4. Monthly R_{eco} availability aggregated across all years. White/ light grey/ light blue cells = 0 observations. Color intensity based on Log10(Number of Observations + 1) due to strong bias of ALA_1. Growing season = June–September in the Northern Hemisphere, December – March in the Southern Hemisphere. Except for AUS_1, shaded areas indicate winter months (light blue) and shoulder months (light grey).

4.4 Partitioning data

R_{eco} responses to climate change depend on the dynamics of its two main components: autotrophic (plant-derived) and heterotrophic (microbial) respiration (Bond-Lamberty et al., 2004; Hicks Pries et al., 2013). Because these two components can respond differently to changes in climate (Borken et al., 2006; Muhr & Borken, 2009; Gomez-Casanovas et al., 2012), understanding their individual contributions would be beneficial for accurately predicting ecosystem carbon dynamics and modeling carbon–climate feedback processes. However, partitioning R_{eco} into these source fluxes remains methodologically challenging. As respiration partitioning measurements are usually destructive, altering ecosystem dynamics and making long-term measurements difficult, such data are still relatively scarce. For example, in the above-mentioned meta-analysis by Maes et al. (2024) on the drivers of R_{eco} in Arctic and alpine tundra, only nine out of 136 R_{eco} datasets included information on the partitioning between autotrophic and heterotrophic respiration.

5 Future directions

In the coming years, our aim is to expand the scope of the TundraFlux Database beyond R_{eco} by incorporating methane fluxes, net ecosystem exchange (NEE), and gross primary productivity (GPP). We also plan to expand the scope of warming manipulations represented in the database by including additional climate change treatments, such as the use of snow fences to manipulate snow depth. This will enable us to distinguish between the effect of summer warming (OTC) and winter warming (snow fences) on R_{eco}, as well as their combination (Hermesdorf et al., 2024). Finally, we plan to link the TundraFlux Database with other major available databases, such as the Tundra Trait Team database (Bjorkman et al., 2018), the Manipulation Experiments Synthesis Initiative (MESI; Van Sundert et al., 2023), and the ABCflux database (Leffler et al., 2025; Virkkala et al., 2022). Importantly, integration remains challenging due to differences in data formats, identifiers, and metadata standards. Establishing common protocols will therefore be crucial for advancing synthesis across databases.

To follow updates on ongoing and future projects, please visit our website https://arcticflux.org/. To contribute new datasets to our TundraFlux Database, please contact us via our mail tundrafluxdatabase@lists.umu.se.

6 Conclusions

The TundraFlux Database provides the most comprehensive synthesis of tundra R_{eco} responses to experimental warming, integrating over 40,000 individual *in-situ* R_{eco} observations into 24,951 daily-aggregated R_{eco} measurements from open-top chamber and control plots across 64 Arctic and alpine sites. By combining these data with extensive environmental metadata, the database enables cross-scale analyses that link ecological processes to global carbon modeling. Although long-term (>24 years) data and measurements from outside the growing season remain limited, the TundraFlux Database establishes a foundation for coordinated synthesis and future expansion to include methane fluxes, NEE, and GPP. When linked with other ecological datasets, it will contribute to forming an unprecedented platform for cross-network analyses of Arctic and alpine carbon dynamics.

Data availability

The TundraFlux Database is organized as a set of interlinked R data files (.rds) that can be merged using shared identifiers such as site_id, flux_year, and, for plot-level data, plot_id. For users who prefer a modular workflow, separate metadata files are available, including site (site_metadata_v1.rds), vegetation (plant_metadata_v1.rds), soil properties (soil_metadata_plot_v1.rds), and methodological details (method_metadata_site_v1.rds). These metadata files can be linked to R_{eco}-specific datasets, such as Reco_microclimate_daily_v1.rds, using the shared identifiers mentioned above.
For users who want a ready-to-use dataset, two fully integrated data files are provided: TundraFlux_daily_v1.rds, which contains daily aggregated Reco measurements along with site, vegetation, soil, and methodological metadata (Table S3), and TundraFlux_raw_v1.rds, which contains non-aggregated individual R_{eco} measurements with quality-control flags.
Missing values are consistently represented as NA across all files.
All data can be provided upon request from the corresponding author and will be made publicly available on Zenodo (DOI: 10.5281/zenodo.17976235, Schwieger et al., 2026) after acceptance of the paper.

Code availability

The code associated with this publication will be made publicly available on Zenodo (DOI: 10.5281/zenodo.17976235, Schwieger et al., 2026). The R scripts used for data processing are archived alongside the data and are also maintained in a public GitHub repository and can the provided upon request from the corresponding author.

Supplement link

Author contribution

The TundraFlux database was conceptualized by JD, JS, ED, MB, and SLM. JD and SLM compiled the data in 2020. JD and SS updated the data in 2023 and 2025. Data screening and curation by JD, SLM and SS. SS drafted and coordinated the manuscript in close collaboration with SLM, JD, JS, BL, JW and MB. SS prepared the code and data files for the repository, revised by BL and JD. All authors contributed to the realization of the TundraFlux Database and participated in reviewing and editing of the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

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