1 **High-resolution Carbon cycling data from 2019 to 2021 measured at six**
2 **Austrian Long-Term Ecosystem Research sites**

4 Thomas Dirnböck[1]*, Michael Bahn[2], Eugenio Diaz-Pines[3], Ika Djukic[1], Michael Englisch[4], Karl Gartner[4],
5 Günther Gollobich[4], Johannes Ingrisch[2], Barbara Kitzler[4], Karl Knaebel[1], Johannes Kobler[1], Andreas
6 Maier[5], Armin Malli[4], Ivo Offenthaler[1], Johannes Peterseil[1], Gisela Pröll[1], Sarah Venier[1], Christoph
7 Wohner[1], Sophie Zechmeister-Boltenstern[3], Anita Zolles[4], Stephan Glatzel[5]

9 [1] Environment Agency Austria, Spittelauer Lände 5, A-1090 Vienna, Austria

10 [2] Department of Ecology, Universität Innsbruck, Innsbruck, Austria; Innrain 52, 6020 Innsbruck

11 [3] Institute of Soil Research, Department of Forest- and Soil Sciences, BOKU University. Peter-Jordan-
12 Straße 82, 1190 Vienna, Austria

13 [4] Austrian Research Centre for Forests, Seckendorff-Gudent Weg 8, 1131 Vienna, Austria

14 [5] Department of Geography and Regional Research, Faculty of Earth Sciences, Geography and
15 Astronomy, University of Vienna, Josef-Holaubek-Platz 2, 1090 Vienna, Austria

16 *corresponding author: Thomas Dirnböck; thomas.dirnboeck@umweltbundesamt.at

18 Abstract

19 Seven long-term observation sites have been established in six regions across Austria, covering major
20 ecosystem types such as forests, grasslands and wetlands across a wide bioclimatic range. The
21 purpose of these observations is to measure key ecosystem parameters serving as baselines for
22 assessing the impacts of extreme climate events on the carbon cycle. The data sets collected include
23 meteorological variables, soil microclimate, CO_2 fluxes and tree stem growth, all recorded at high
24 temporal resolution (15 – 60 minutes) between 2019 and 2021 (including one year of average
25 climate conditions and two comparatively dry years). The DOIs of the dataset can be found in the
26 data availability chapter. The sites will be integrated into the European Research Infrastructure for
27 Integrated European Long-Term Ecosystem, Critical Zone, and Socio-Ecological Research (eLTER RI).
28 Subsequently, new data covering the variables presented here will be continuously available through
29 its data integration portal. This step will allow the data to reach its full potential for research on
30 drought-related ecosystem carbon cycling.

31

32 1. Introduction

33 Climate change has been affecting ecosystems globally with strong implications for the terrestrial
34 carbon (C) cycle, which in turn feeds back to the climate system (Heimann and Reichstein, 2008). As
35 an emerging feature of climate change, extreme climatic events (ECEs) are expected to occur with
36 increasing frequency and intensity in the coming decades (IPCC, 2021). ECEs are considered to exert
37 stronger impacts on ecosystems and the services they provide to mankind than gradual changes in
38 climate (Frank et al., 2015; Reichstein et al., 2013; Grünzweig et al., 2022; Anderegg et al., 2020).
39 Understanding, predicting and managing extreme climate events and their consequences for
40 ecosystems and societies will therefore be one of the big challenges in the coming decades. To detect

and attribute impacts of ECEs on ecosystem processes and services they need to be evaluated on the background of the typical interannual range of these processes (Ciais et al., 2005; Bernal et al., 2012; Fu et al., 2020; Schindlbacher et al., 2012) and analyses of ecosystem resilience to ECEs require a robust quantification of baselines of ecosystem functioning (Bahn and Ingrisch, 2018; Ingrisch and Bahn, 2018). For deriving such baselines as well as interannual variability of ecosystem carbon cycling, coordinated and representative observation networks need to be in place to enable data retrieval as well as rapid-response scientific campaigns to study after-effects and post-disturbance trajectories resulting from ECEs (Kulmala, 2018; Mahecha et al., 2017; Mirtl et al., 2018; Dirnböck et al., 2019; Müller and Bahn, 2022). Datasets obtained through such observation networks are also essential for benchmarking models (Futter et al., 2023; Baatz et al., 2021; Wu et al., 2018) and for comparison with ecosystem experiments (Kröel-Dulay et al., 2022).

Within a research infrastructure project focusing on ecosystem carbon, nitrogen, and water fluxes (Long-Term Ecosystem Research for Carbon, Water, and Nitrogen (LTER-CWN, https://www.lter-austria.at/cwn/), we equipped seven long-term observation sites in six regions, which are part of the existing Long-Term Ecological Research Network of Austria (LTER-Austria), with high temporal resolution (30-60 minutes) C cycle measurements. The sites cover three major ecosystem types occurring across Austria (forests, managed mountain grassland, wetlands) and most of them are part of socio-ecological research platforms for transdisciplinary studies (Figure 1). Here, we provide observational ecosystem response data capturing naturally-occurring ECEs from the first three years after the onset of the infrastructure, 2019 to 2021. These data sets include meteorological variables, soil microclimate, CO_2 flux measurements using automated chambers (soil CO_2 efflux) and eddy covariance techniques (net ecosystem exchange), respectively, and tree stem radial increments and shrinkage in forested plots.

2. Site descriptions

The sites are key research infrastructures for ecosystem-related greenhouse gas observations in Austria. They include forests (Klausen-Leopoldsdorf and Rosalia in Lower Austria, Zöbelboden in Upper Austria, and Stubai in Tyrol), mountain grassland (Stubai, Tyrol), and wetlands (Pürgschachen Moor, Styria and Lake Neusiedl reed belt, Burgenland). This network of sites covers typical forest, alpine and wetland ecosystems of Central Europe (Figure 1). Furthermore, the sites represent different geological characteristics, from crystalline rock in the central Alps to the limestone in the northern Alps to unconsolidated Holocene sediments in lowlands. All sites are part of the Austrian LTER network and, once officially launched, will be included in the European eLTER research infrastructure (https://elter-ri.eu/). For a detailed description of the sites, we refer to the Dynamic Ecological Information Management System - Site and dataset registry (DEIMS-SDR) (Table 1).

2.1. Rosalia Forest Demonstration Centre (Mixed beech forest)

The Rosalia Forest Demonstration Centre was settled in 1972, as a cooperation between the BOKU University, Vienna, Austria, and the Austrian Federal Forests, and has approximately 1000 ha in the western slopes of the Rosalia Mountains (Rosaliengebirge) in Lower Austria (Figure 1, Table 1). The forest hosts all major tree species occurring in Austria, i.e. European beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* (L.) H.Karst.), Scots pine (*Pinus sylvestris* L.), Larch (*Larix decidua* Mill.), and Fir (*Abies alba* Mill.). The altitude ranges from 320 to 725 m a.s.l., and mean annual temperature and mean annual precipitation are 6.5 °C and 796 mm, respectively. Substrate is mainly composed by crystalline rocks, and soils are predominantly cambisols (Working Group WRB 2015); sporadically in

85 combination with planosols (in plains and moderate slopes), with fluvisols (in valleys) or podzolic
86 cambisols (steep slopes) (Fürst et al., 2021).

87 The demonstration forest holds several experimental and observation sites distributed along its area,
88 including water, soil, vegetation and air observations (e.g. Gillespie et al., 2023). A watershed (220
89 ha) is subject to hydrological observations (Fürst et al., 2021), and the forest is regularly monitored
90 on permanent plots (Gollob et al., 2020). The meteorological data presented here originates from
91 three stations located at 385 (Mehlbeerleiten), 500 (Kuhwald) and 640 m a.s.l. (Heuberg). The C cycle
92 data was measured on a long-term experimental site launched in 2012. The site is located in a pure
93 mature beech stand at 600 m a.s.l. (47° 42' 26" N; 16° 17' 59" E). It faces north-west, with a slope of
94 approximately 20 %. This experiment focuses on investigating the effect of changing precipitation
95 patterns on soil nitrogen fluxes, soil microbial changes, greenhouse gas efflux, and soil water
96 processes (Leitner et al., 2017; Liu et al., 2019; Schwen et al., 2015; Gillespie et al., 2024). Monitoring
97 is performed on control and on manipulated plots. The data from both natural and manipulated plots
98 is published with this paper. Manipulation involves the use of rain-out-shelters (for simulating
99 drought periods of different length) and of an irrigation system (for recreating rainfall events of
100 different intensity). The monitoring infrastructure involves the measurements of greenhouse gases
101 (GHG) (N_2O, CH_4 and CO_2) fluxes, soil nutrients (suction cups) and microclimate parameters.

102   2.2. Klausen-Leopoldsdorf (Beech forest)

103 The site, Klausen-Leopoldsdorf, is located about 40 km south-west of Vienna on a NNE-facing slope
104 and was founded in the 1990s as one of Austria's site contributing to the International Co-operative
105 Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) (Neumann
106 and Starlinger, 2001). The site is divided into four different sub-areas within a small catchment: 1)
107 the ICP Forests site, 2) a weather station, located 2.7 km from the ICP Forests intensive plots at 398
108 m a.s.l., 3) a catchment runoff weir (475 m a.s.l.), and 4) the LTER-CWN measurement plot (520 m
109 a.s.l.), where the C-cycle data presented here was measured (Figure 1, Table 1). The forest within the
110 measurement plot is a pure beech (*Fagus sylvatica* L.) stand. The mean annual temperature is 8°C,
111 mean annual precipitation is 801 mm (2010-2022). The geological substrate is sandstone, the soil
112 type is mainly stagnic cambisol/dystric cambisol (Working Group WRB 2015). Instruments installed
113 on the LTER-CWN measurement area include a sap flow and dendrometer measurement system on
114 10 trees, 12 GHG automated measurement chambers for CO_2 respiration, soil moisture and soil
115 temperature sensors in different soil depths (5 – 30 cm).

116 In addition to the data presented here, many other data sets are available. Soil GHG fluxes (manual
117 sampling) were measured starting in the year 2001 (Kitzler et al., 2006). On the ICP Forests site,
118 instruments for long-term monitoring (since 1996) such as soil moisture, air temperature and relative
119 humidity, soil temperature, soil solution with suction cups, throughfall deposition, litterfall traps,
120 stemflow, and manual and automatic dendrometers are installed and the data is available under
121 https://bfw.ac.at/lims/level2.daten or via the ICP Forests Program Centre.

122   2.3. Lake Neusiedl (reed belt)

123 The measurement site is located in the eastern reed belt of the lake and as such inside the National
124 Park Lake Neusiedl - Seewinkel (Figure 1, Table 1). The region (average altitude: 120 m.a.s.l.) is
125 characterized by a (sub)-continental Pannonian climate with a mean annual precipitation of 576 mm
126 (2013-2022). The reed belt is a dynamic ecosystem consisting of a mosaic of reed stocks (*Phragmites
127 australis* (Cav.) Trin. ex Steud.), sediment and open water areas. Increasing dry periods and thus
128 successive drying of the reed belt since 2018 have led to an increase in reed stocks within the belt, as
129 well as an increase in sediment areas and a strong decline in open water areas, according to a 2021

130 study that investigated the spatial and temporal variations within the reed ecosystem at Lake
131 Neusiedl (Buchsteiner et al., 2023). Processes driving CH_4 emissions from the reed belt have recently
132 been investigated in detail (Baur et al., 2024).

133 The data presented here stems from devices permanently installed on site. They include an eddy
134 covariance tower for CO_2, CH_4 and water vapor fluxes and relevant accompanying meteorological
135 parameters as well as soil heat flux, soil moisture, and soil temperature sensors.

2.4. Pürgschachen Moor (peat bog)

137 The Pürgschachen Moor is located on the bottom of the Styrian Enns valley at an altitude of 632 m
138 a.s.l. (Figure 1, Table 1). It is a pine peat bog with an extent of about 62 ha. Thus, it is the largest (to a
139 large part) intact valley peat bog in Austria with a closed peat moss cover and a good example of the
140 formerly widely distributed peatlands of inner-alpine valleys of the European Alps. The mean average
141 temperature is 8.2 °C and mean annual precipitation is 1233 mm (2013-2022). The typical vegetation
142 of the peat bog is constituted of three associations of plants *Pino mugo-Sphagnetum magellanici*
143 (pine peat bog association), *Sphagnetum magellanici* (coloured bog moss association), and *Caricetum*
144 *limosae* (bog sedge association), depending on the prevailing hydrological site conditions. The
145 current mean water table depth is about 14 cm below soil surface at the central peat bog area. Peat
146 decomposition and related CO_2 and CH_4 fluxes were subject of a series of research studies (Drollinger
147 et al., 2019; Knierzinger et al., 2020; Müller et al., 2022; Glatzel et al., 2023).

148 The data presented here stems from devices permanently installed roughly in the center of the peat
149 bog. They include an eddy covariance tower for CO_2, CH_4 and water vapor fluxes and relevant
150 accompanying meteorological parameters as well as soil heat flux, soil moisture, and soil
151 temperature sensors.

2.5. Stubai (subalpine hay meadow, Larch and Spruce forest)

153 The two observation plots used in this study are part of the LTER Site Stubai (Table 1), which is
154 located in the Stubai Alps in Tyrol, Austria (Figure 1). Research at the study site was established in
155 1993. The two observation plots are a mountain grassland and a subalpine forest at an alpine pasture
156 area called "Kaserstattalm". The underlying rock is siliceous and calcareous. The average air
157 temperature is about 3°C and the precipitation approx. 1100 mm. About 35% of the annual
158 precipitation occurs as snow during winter months.

159 The grassland site is located at an altitude of 1810 -1850 m a.s.l on a south-east facing slope with an
160 inclination of ca. 20°. The site is an extensively managed meadow that is harvested once a year in
161 early August and grazed lightly in late summer. The soil is a dystric cambisol (Working Group WRB
162 2015). The vegetation type is a *Trisetetum flavenscensis* and consists of perennials grasses and forbs
163 dominated by *Agrostis capillaris* L*., Festuca rubra* L*., Anthoxanthum odoratum* L*., Ranunculus*
164 *montanus* Willd*., Leontodon hispidus* L*., Trifolium repens* L. and *T. pretense* L. (Bahn et al., 2009;
165 Schmitt et al., 2010).

166 The forested observation plot is located close to the tree line at 1960 m a.s.l. on a slope with an
167 inclination of 20-35°. It is dominated by the two common tree species European larch (*Larix decidua*
168 Mill.) and Norway spruce (*Picea abies* (L.) H.Karst.). In former years, the plot was a pasture and it was
169 reforested in the 1980s (Oberleitner et al., 2022).

170 Both observation plots are equipped with micrometeorological stations, soil environment monitoring
171 (soil moisture, soil temperature), and soil CO_2 devices. At both observation plots, we measured soil
172 CO_2 fluxes with automated chambers during the summer. The forest plot is additionally equipped
173 with tree dendrometers and tree sapflow sensors. In the grassland, land use and drought related

174 carbon cycle research was carried out over the last two decades (Fuchslueger et al., 2014; Hasibeder
175 et al., 2015; Ingrisch et al., 2020; Ingrisch et al., 2018). Research using the forest plot started only
176 recently (Oberleitner et al., 2022).

177 ### 2.6. Zöbelboden (mixed Beech forest)

178 The site LTER Zöbelboden is located in the National Park Kalkalpen in the Northern Limestone Alps,
179 Austria (Figure 1). The measurements were established in 1992 as part of the International Cooperative
180 Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM) covering a 90 ha
181 catchment with an elevation range of 550 to 956 m a.s.l. (Table 1). The main underlying rock type is
182 Norian dolomite (*Hauptdolomit*), partly overlain by limestone (*Plattenkalk*). According to long-term
183 meteorological measurements (1993-2022), mean annual air temperature and precipitation are 8.2 °C
184 and 1645 mm, respectively. Maximum precipitation occurs in summer and snowfall usually between
185 December and April.

186 The data presented here was measured at the Intensive Plot II situated on a steep (36° on average)
187 north-westerly exposed slope at 880 m a.s.l. The soils of the plot are lithic and rendzic leptosols
188 (Working Group WRB 2015). The plot is dominated by beech (*Fagus sylvatica* L.) with intermixed
189 sycamore (*Acer pseudoplatanus* L.), European ash (*Fraxinus excelsior* L.) and spruce (*Picea abies* (L.)
190 H.Karst.). Since the year 1995, this plot is equipped with a number of field measurement devices for
191 long-term monitoring (throughfall deposition, litter fall traps, lysimeters, soil moisture and
192 temperature sensors, manual dendrometers) and supplemented by other monitoring activities (tree
193 inventory, needle and leave chemistry, soil chemistry, etc.; see e.g. Leitner et al., 2020; Kobler et al.,
194 2019; Dirnböck et al., 2016; Dirnböck et al., 2020). Drought-impacts on carbon allocation in the
195 forests of the catchment is currently one of the research foci for which long-term observation data
196 exists (see e.g. Hartl-Meier et al., 2014) as well as experimental plots with rainout shelters.

197 The instruments and data included here are soil respiration automated chambers, soil water
198 potential and temperature sensors as well as automated dendrometers. The meteorological data
199 stems from a station in close proximity at the plateau at 890 m a.s.l.. The site is also equipped with
200 an Eddy covariance tower, but this data will be published elsewhere.

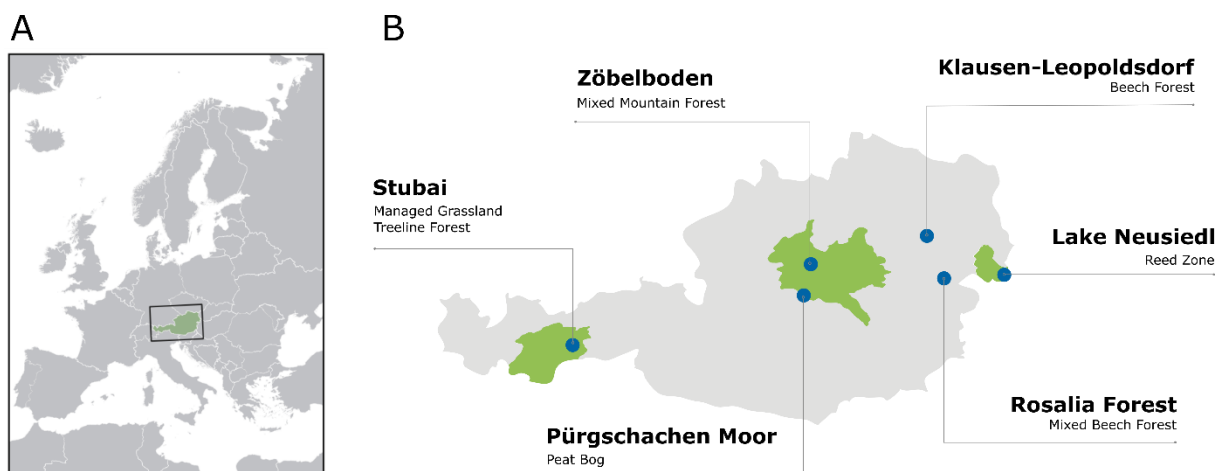
201

202
203 *Figure 1*. Location of sites in A) Europe and B) Austria. Blue dots indicate the sites; green areas are long-term socio-
204 ecological research platforms (LTSER) (from left to right: LTSER Tyrolian Alps, LTSER Eisenwurzen, and LTSER Lake Neusiedl)
205 within the LTER Austria network. For site information concerning altitude and climate see Table 1.

Table 1. Ecosystem type, altitude, climate and metadata links of the sites and observation plots. Geographic boundaries, linked data sets, etc. can be found in the site and dataset registry system DEIMS-SDR.

Site	Ecosystem type	Altitude (m a.s.l.)	Annual temperature (°C)	Annual precipitation (mm)	Site and observation plot	DEIMS.iD
Rosalia Forest Demonstration Centre (ROS)	Mixed beech forest	600	6.5	796	Site	https://deims.org/77c127c4-2ebe-453b-b5af-61858ff02e31
					Heuberg Meteorological Station	https://deims.org/locations/44854b32-64c3-4c9d-9aec-9b0b74f8ac70
					Kuhwald Meteorological Station	https://deims.org/locations/1225d57e-02da-47fd-9760-ab39d64999ef
					Mehlbeerleiten Meteorological Station	https://deims.org/locations/0becf0ce-98d7-4f64-a074-f89046083e5e
					Experimental Station	https://deims.org/locations/b7008603-fca2-452f-9b3d-aad30cdafc7a
Klausen-Leopoldsdorf (KLL)	Beech forest	520	8	801	Site	https://deims.org/bb472a51-f85f-4de0-8358-f21ecbe2a102
					Measuring station	https://deims.org/locations/d5cba3ce-7489-46d1-8d97-61641ffb5758
Lake Neusiedl (NSS)	reed zone	120	11.5	576	Same as site	https://deims.org/locations/4234987b-9031-4332-9bdd-f869d503ac51
Pürgschachen Moor (PUE)	peat bog	632	8.2	1233	Same as site	https://deims.org/locations/ab2d021b-f318-487a-a85b-ab34566e4c02
Stubai (KAS)	grassland	1830	3	1100	Site	https://deims.org/324f92a3-5940-4790-9738-5aa21992511c
					Kaserstattalm meadow	https://deims.org/locations/cf7843b7-32d6-44e9-ba82-9a8d915036a7
	Treeline forest	1960	3	1100	Kaserstattalm forest	https://deims.org/locations/af2afdad-d6fb-4580-b6e3-be7d07b56f8e
Zöbelboden (ZOE)	Mixed mountain forest	880	8.2	1645	Site	https://deims.org/8eda49e9-1f4e-4f3e-b58e-e0bb25dc32a6
					Intensive Plot II	https://deims.org/locations/bc96a499-1b20-4da8-be2d-17306d64b788

3. Dataset description, measuring methods, QA/QC

We followed routine quality assurance (QA) and quality control (QC) procedures to ensure functionality of the sensors and data quality comprising remote function control, on-site check of sensors and cables, regular sensor calibration, data checks through different quality assurance procedures (e.g. exceedance of thresholds, outlier detection, deviations from other measurements), and data quality flagging.

3.1. Meteorology, soil temperature and soil moisture

All meteorological stations are located within the boundaries of the respective sites except for Klausen-Leopoldsdorf, where the station is at a distance of 2.7 km from the site. Meteorological measurements in the wetland sites were implemented next to the Eddy Covariance tower. In addition to the routine data checks, we compared the measurements with nearby stations where appropriate. Meteorological measurements were detected in a one-minute-interval and averaged over half-hour periods while rain data was summed. The measurements include air temperature, precipitation, relative humidity, wind speed and direction, air pressure, and several radiation variables (at least global radiation, but also short- and longwave radiation, photosynthetic active radiation, etc.).

Table 2. Meteorological parameters measured at the six sites during 2019-2021. Availability is indicated using grey boxes. For parameter names we refer to the thesaurus at http://vocabs.lter-europe.net/EnvThes/

Meteorological parameters	KAS	KLL	NSS	PUE	ROS	ZOE
air relative humidity	■	■	■	■	■	■
air pressure	■				■	■
air temperature	■	■	■	■	■	■
precipitation amount	■	■	■	■	■	■
global radiation irradiance		■	■	■	■	■
net radiation irradiance			■	■		■
photosynthetically active radiation	■		■	■		■
sunshine duration						■
wind direction	■	■			■	■
wind speed	■	■			■	■

We used different types of soil temperature and soil moisture or soil water potential sensors, respectively (PT100 or thermoelements for soil temperature, TDR or FDR-sensors for soil moisture, and soil water potential sensors). Before we buried the soil temperature or soil moisture and soil water potential sensors into the soil, they had been calibrated or at least tested for consistency. Mostly, we used gravimetric samples to calibrate the TDR and FDR soil moisture sensors. At Zöbelboden, where stony, organic rich soils occur, we corrected the TDR values using water potential sensor data installed in the same soil profiles together with soil water retention functions derived from undisturbed soil cores. In addition to the regular QC procedures, we checked the data for consistency of the values across sensors (e.g. along the soil profiles) and compared them with other measurements (air temperature and precipitation). Half-hourly to hourly values are presented.

3.2. Carbon fluxes

3.2.1. Soil CO_2 efflux

We measured soil CO_2 efflux at five of the seven observation plots. The automated soil CO_2 respiration measurement systems are capable of operating autonomously during the snow-free periods The measurement chambers and measurement systems collected air from the chamber headspace continuously to determine the exchange of CO_2 between soil and atmosphere at the observation plots. In all sites, we used non-steady state, non through-flow chambers (Pumpanen et al., 2004). The chambers at each site measured consecutively every half-hour to hour. In addition to the automated systems, manual flux measurements were also performed which served to validate the automated measurement systems. Table 3 provides detailed information on the measurement systems used at the sites.

Two different automated chamber systems were used: a LI-COR System and custom-made chambers in combination with LI-COR trace gas analysers (Table 3). The custom-made soil chambers are equipped with a fan and a thermometer. The controlling unit and the gas analyzer (either a CH_4/CO_2 LI-COR 7810, a LI-COR 840, or a LI-COR 8100A, LI-COR Biosciences, USA) are located in already existing measurement containers. Remote access to the devices allows for checking plausibility of the data and chamber leakage in real time. We visited the instruments at weekly to monthly intervals, with maintenance and supervision works including a check of the tightness of the gas lines, connections and chamber lids, the correct closing and opening of the chambers and the functioning of ventilation fans inside the chambers, ingrowth of plants, and the gas analyser. The gas analysers were calibrated once a year in the laboratory with calibration gases. We de-installed and serviced the chambers during winter but frames stayed permanently on site to avoid disturbance of the soil.

At Klausen-Leopoldsdorf, the gas fluxes of readings were determined using the R package "gasfluxes" (Fuss, 2020). At Rosalia, a custom-made Python script was used. Zöbelboden and Kaserstattalm process the data with SoilFlux Pro Software (LI-COR Biosciences, 2019). We used the R^2 of the fitted empirical models to select valid data. We refer to Table 3 and the metadata published with the data for the detailed specifications.

Table 3. Specifications of the different soil CO_2 flux systems following the standard of (Bond-Lamberty et al., 2021).

Field Name	Description	Unit	Klausen-Leopoldsdorf	Stubai grassland	Rosalia	Zöbelboden
System			**auto**	**Auto**	**auto**	**auto**
GHG chambers			Custom-made (n=12)	LI-8100-104 (n=4)	Custom-made (n=12)	LI-8100-104 (n=6)
INSTRUMENT	Measurement instrument model		LI-COR LI-7810	LI-8100A	LI-840	LI-8100A
MSMT_VAR	Type of flux measured		Soil respiration (Rs)			
AREA	Soil surface measurement area	cm^2	2500	317.8	2500	317.8
VOLUME	Volume of measurement chamber	cm^3	37500	4076.1	37500	4076.1
V/A	Volume/Area ratio	cm	15	12.83	15	12.83

COLLAR_DEPTH	Depth of collar insertion	cm	5	2	10	2
OPAQUE	Opaque chamber		no	Yes	no	yes
chamber system	static chamber - closed or open		non-steady state, non through-flow chambers			
closing time	closing time of chamber (=time used for flux calculation)	sec	175	depending on year	1620	210
PLANTS_REMOVED	Plants removed from inside the collar		no, but hardly any	Yes	no, but hardly any	no plants
flow_rate	sample flow rate through tubing	l min^{-1}	1	1 to 2	0.25	1.7
FAN	Mixing fan in chamber?		yes	No	yes	no
CRVFIT_CO2	Flux computation method ("Lin" or "Exp" for linear and exponential, others)		linear	automated[1]	Lin/HMR[2]	Automated[1]
R2_CO2	R^2 of flux computation	fraction	0.90	0.95	0.95	0.99
Calculation of flux			R Package gasfluxes	LI-COR Soilflux Pro	custom-made python script	LI-COR Soilflux Pro

[1] "Exp" in the data indicates that the exponential fit was better than the linear fit (Exp_SSN<Lin_SSN). "Lin" indicates that the linear fit was better after the maximum number of iterations; the non-linear coefficients have therefore been derived from the linear fit.
[2] Hutchinson and Mosier (1981)

267   3.2.2. Eddy Covariance measurements at wetland sites

268 In both wetland sites, the Pürgschachen Moor and Lake Neusiedl, fully equipped Eddy-Covariance
269 systems are in place. Wind speed and direction were measured using a three-axis ultrasonic
270 anemometer (WindMaster Pro, Gill Instruments, Lymington, UK). CO_2 and H_2O mixing ratios were
271 measured using the closed-path infrared gas analyser LI-7200 while CH_4 was detected with the open
272 path gas analyser LI-7700 (both LI-COR Inc, Lincoln, USA). The measurements were performed with a
273 sampling rate of 10 Hz. We installed the devices at a vegetation dependent height, 3.05 m above
274 ground in the Pürgschachen Moor and in the reed belt of Lake Neusiedl 8.6 m, respectively. The Eddy
275 Covariance devices were checked daily via remote access, calibrated once a year in the lab, and
276 monthly in the field.

277 The EC data contains half-hour eddy covariance flux measurements for CO_2, CH_4 and water vapor. We
278 calculated the fluxes with the EddyPro® Software package in the Express mode with default settings
279 (double rotation, block averaging, covariance maximization, etc.) as part of the SmartFlux® 2 System,
280 providing fully corrected and valid fluxes with quality flags ranging from 0-2. The final flags are based
281 on a combination of partial flags accounting for steady state and turbulent conditions. Only fluxes

282 flagged with 0 (best quality fluxes) or 1 (fluxes suitable for general analysis such as annual budgets)
283 are shown in the data. Gaps in the data-set result from missing micro-meteorological conditions,
284 from data cleaning due to the quality flags or from power breakdowns.

285 ### 3.3. Radial tree stem growth at forest sites

286 Zöbelboden, Klausen-Leopoldsdorf, Rosalia used the DR26 sensor (EMS, Brno, Czech Republic), Stubai
287 used Ecomatic DC2 (Germany) for registering the radial stem increment in a 15 minutes to 30 minutes
288 interval. Maintenance involved avoiding any shift of the sensor during the operation. Concerning data
289 quality and control methods the Mini32 software (EMS, Brno, Czech Republic), includes graphical
290 features to process the measured stem increment data. Data processing comprises outlier detection
291 by visual assessment based on expert knowledge. Ecomatic raw data was treated with custom-made
292 R scripts. In both cases, unrealistic values beyond the slowly increasing linear growth rates were
293 visually assessed and deleted.

294 ## 4. Data file structure

295 We used the eLTER Data specification, which is available on Zenodo
296 (www.doi.org/10.5281/zenodo.6373409). Apart from the data files, the measurement locations
297 (Station files) and the sensors (methods) are included.

298

299 ## 5. Data validation

300 *Table 4. Comparison between long-term (1980-2010) meteorological drought (SPEI - Standardized Precipitation*
301 *Evapotranspiration Index) and the measurement years during the growing season (May-September). Significant differences*
302 *between these years and the long-term averages are shown: *** p<0.001; ** p<0.005; * p<0.01 according to a Mann-*
303 *Whitney U Test. SPEI was calculated using a 30 days window in a daily resolution using gridded data:*
304 *https://data.hub.geosphere.at/dataset/winfore-v2-1d-1km (Haslinger & Bartsch, 2016). Negative values indicate dry years.*

Site Code	1980-2010	2019	2020	2021
ZOE	-0.05±0.94	-0.49±1.22***	0.42±0.69***	-0.02±1.39
KLL	-0.01±0.99	-0.23±1.22	0.39±0.86***	-0.02±1.24
KAS	-0.05±0.97	-0.1±1.17	-0.12±0.78	0.23±1.07**
PUE	-0.02±0.94	-0.54±1.26***	0.17±0.59**	-0.12±1.2
NSS	-0.01±1	-0.22±1.13*	0.2±0.87**	-0.2±1.34
ROS	-0.03±0.98	-0.34±1.01***	0.17±0.83	-0.28±1.08

305

306 We used gridded SPEI (Standardized Precipitation Evapotranspiration Index) from the Austrian
307 Meteorological Service (https://data.hub.geosphere.at/dataset/winfore-v2-1d-1km; Haslinger &
308 Bartsch (2016)) to compare the long-term average water availability during the growing season
309 (1980-2010; May to September) with those occurring in the measurement years (Table 4). The
310 advantage of the SPEI is that it accounts for precipitation and temperature via evapotranspiration
311 and integrates over a given temporal window (we used 30 days) (Vicente-Serrano et al. 2010). Note,
312 that gridded SPEI data set is based on meteorological data for the period 1960 to 2021. Accordingly,
313 the 2021 was closest to the long-term average, the year 2020 was a particularly wet year, and the
314 year 2019 was drier than the average. However, there were differences between the sites:
315 particularly the mountain station in the Tyrolian Alps (KAS) did not experience significant deviations
316 in SPEI as compared to the long-term average apart from a wet growing season in 2021. The SPEI at
317 the site in the Viennese Forest (KLL) does not indicate that in 2019, the growth period was
318 particularly dry.

The monthly precipitation and temperature patterns are shown in Figure 2, and soil water content and soil temperatures in Figure 3 and Figure 5. Differences in the seasonal precipitation patterns between the measurement years vary a lot between sites. In sum, lower precipitation occurred in 2019 and 2021 than in 2020 in all sites. The mean annual temperature maxima (90 percentile) were between 0.3 °C (KAS) and 2.3 °C (ZOE) higher in the year 2019 than in 2020. These differences were lower when comparing the year 2021 with 2019 (≤ 0.6 °C). In accordance with SPEI, precipitation and temperature, soil water content showed the lowest values during the years 2019 followed by the year 2021, and soil temperature were higher during these years (Figure 3Figure 4).

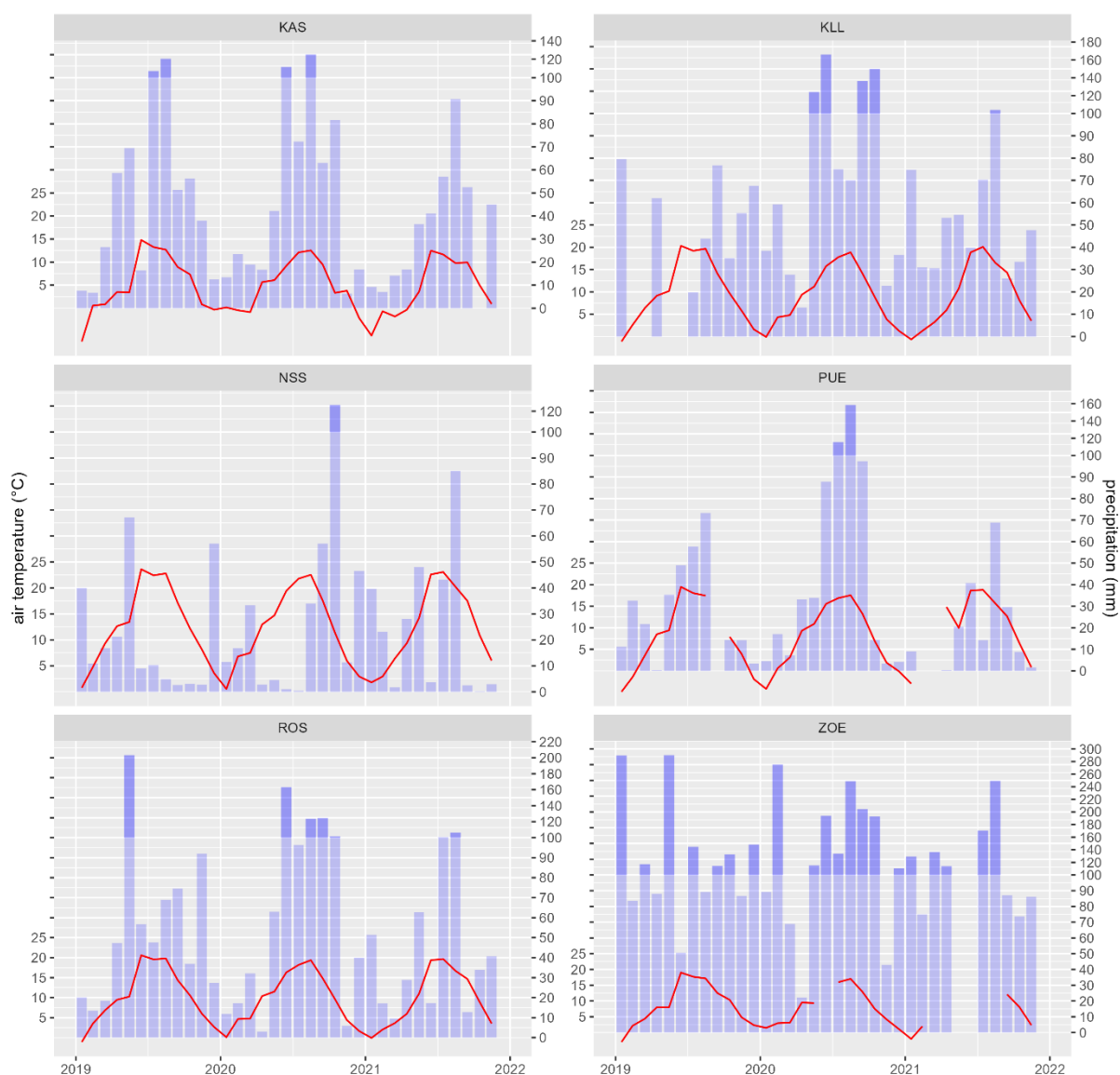
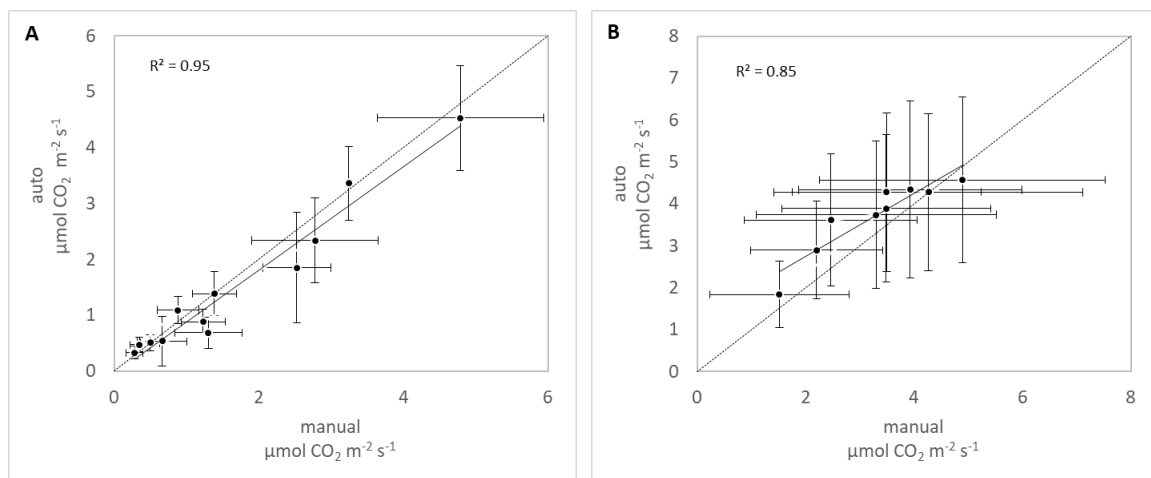



Figure 2. Monthly mean air temperature (red line) and monthly precipitation sums (blue bars; different scale > 100 mm) at the six regions.

We measured soil CO_2 respiration at four sites (Figure 4). The complexity of automated chamber measurements resulted in some data gaps: at KAS and ROS during the years 2019 and 2021 respectively; at KLL and ZOE, the respiration data covers most of the snow-free period (see Table 2).

334   At Klausen-Leopoldsdorf (KLL) and Zöbelboden (ZOE), we compared the automatically measured soil
335   CO_2 flux rates with manual measurements. For both sites, we used a portable infrared gas analyzer
336   (EGM-4) connected to a manual soil respiration chamber (SRC) (PP Systems International Inc.,
337   Amesbury, MA, USA). The two measurement sites were equipped with permanently installed collars
338   (KLL: randomly distributed within the site in immediate vicinity of the automated chambers (n = 12);
339   area = 284 cm² and 2 cm insertion depth; Zöbelboden: regular grid covering the entire plot (n = 30),
340   area = 78 cm² and 1.5 cm insertion depth). The chamber closure time was 60 and 100 seconds in KLL
341   and ZOE, respectively. Manual measurements took place in monthly intervals from Oct. 2019-Jun.
342   2020 at Klausen-Leopoldsdorf and from Jun. 2019 until Oct. 2019 (monthly interval) and in July 2020
343   (diurnal variation) at ZOE. Soil respiration (Rs) was calculated automatically by fitting a linear (KLL) or
344   quadratic function (ZOE; quadratic fit for flow rates > 0.2 ppm s^{-1}, otherwise a linear fit was used) to
345   the increasing CO_2 headspace concentration.

346   The mean CO_2 fluxes of the automated chambers correlated well with the manually measured fluxes
347   during the measurement campaigns (Figure 3). At KLL, the R^2 was 0.95 (p-value < 0.05, t-test), at ZOE
348   it was 0.85 (p-value < 0.05, t-test). In both sites, neither the intercept nor the slope was significantly
349   different from 0 (p-value > 0.2, t-test) and 1 (p-value > 0.49, t-test), respectively. At ZOE, the spatial
350   flux variation was much higher than at KLL (Figure 3A and 3B). This reflects the heterogeneity of the
351   soil conditions (shallow rendzic leptosols with interspersed fine-scale patches of deeper soils), the
352   canopy gaps (with lower root density), and the uneven distribution of litter due to the steep slope at
353   the plot (Kobler et al. 2019). This heterogeneity is more effectively captured in the manual
354   measurement (n=30) than by the automated chambers (n=6). In summary, we conclude that the
355   spatial variation in CO_2 fluxes was higher at both sites than the difference in fluxes caused by the
356   measurement devices (Figure 3).

358   *Figure 3.* Comparison of automated and manual soil CO_2 fluxes at A) Klausen-Leopoldsdorf and B) Zöbelboden. See *Table 3*
359   for the specification of automated chamber data. Error bars indicate spatial variation (standard deviations).

360

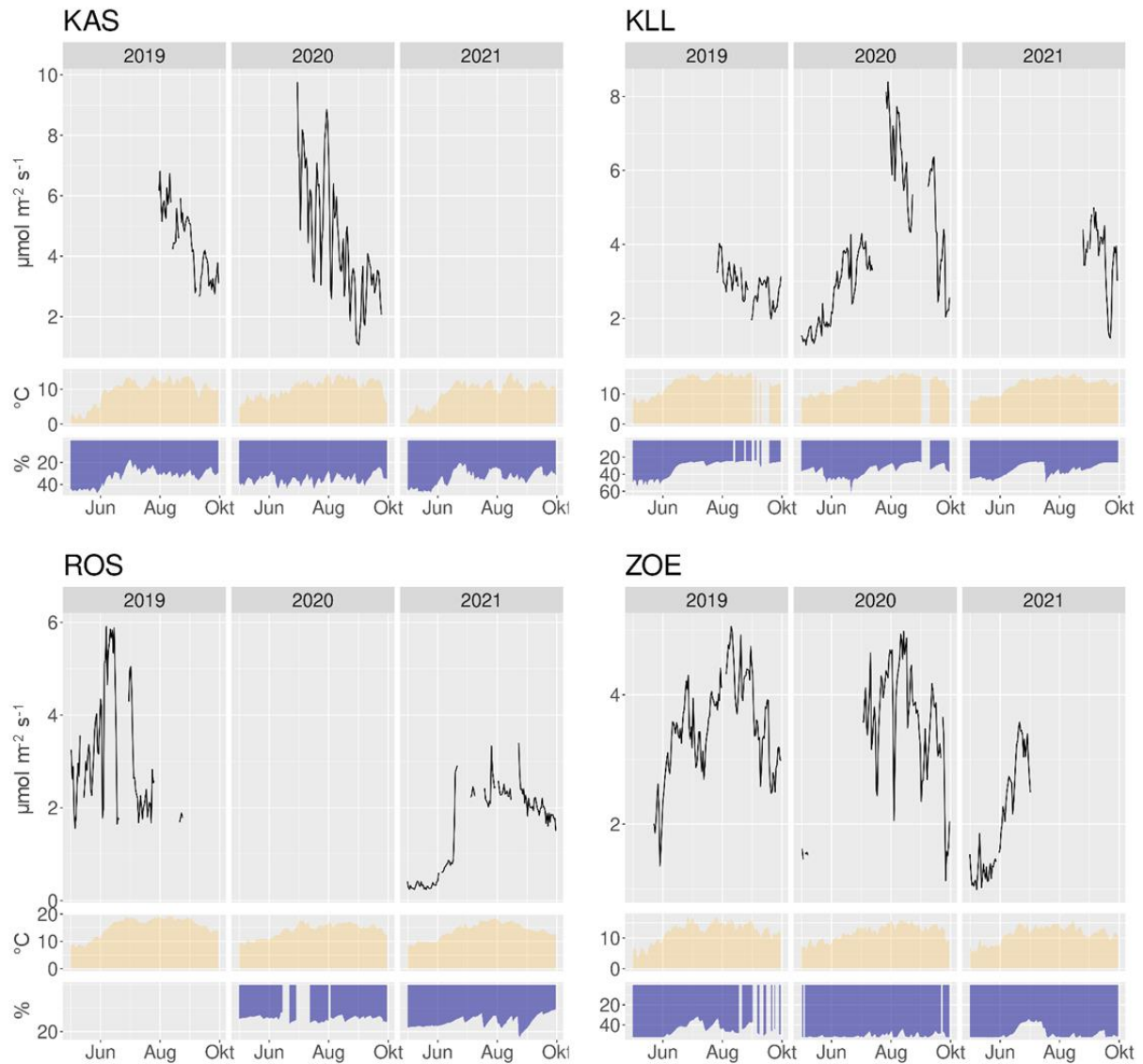
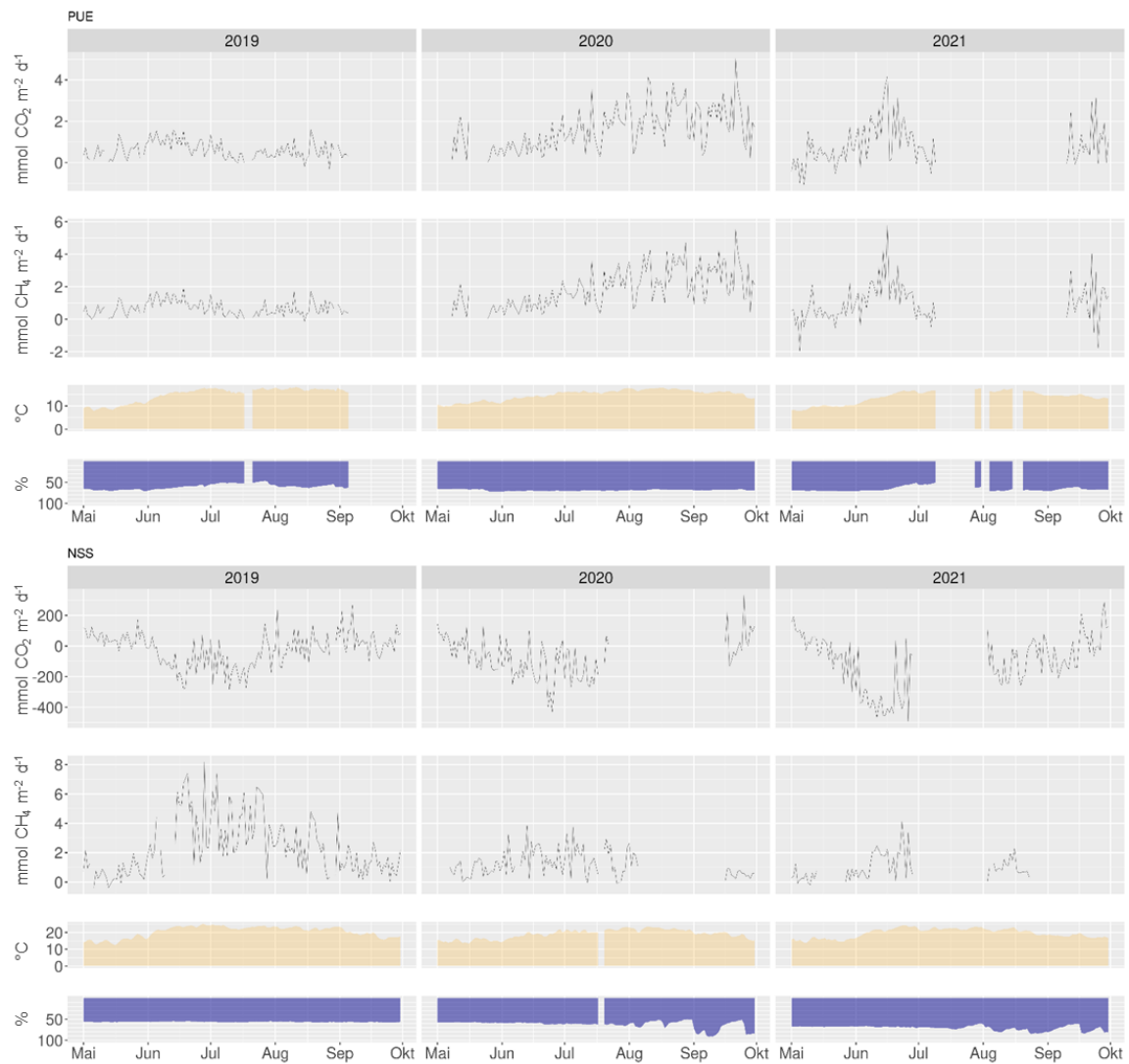



Figure 4. Soil CO$_2$ respiration (mean of all chambers), soil temperature (mean of sensors in 5-15 cm depth) and soil water content (mean of sensors in 5-15 cm depth) in the forested sites Kaserstattalm forest (KAS), Klausen-Leopoldsdorf (KLL), Rosalia (ROS), and Zöbelboden (ZOE).

Soil CO$_2$ fluxes are temperature dependent, thus follow the seasonal changes in soil temperature (Figure 4). Their additional limitation through soil water availability for plant metabolism and microbial activity is usually much less pronounced in these temperate zone ecosystems (Bahn et al. 2008; Chen et al. 2014). For detailed interpretation of the CO$_2$ respiration fluxes and their limiting factors, we refer to the citations listed in the site description chapter. Drollinger et al. (2019) provides interpretations of the patterns of CO$_2$ and CH$_4$ fluxes, measured using Eddy covariance techniques at the bog site Pürgschachen Moor (PUE), and likewise, Baur et al. (2024), for the reed belt of Neusiedler See (NSS). Stem growth limitations can, on the other hand, be closely related to soil water content, particularly at sites with relatively low precipitation such as Klausen-Leopoldsdorf (KLL) (Figure 6). For an in-depth study of drought related effects on tree growth at the treeline forest at Kasterstattalm (KAS), we refer to Oberleitner et al. (2022).

376

377 *Figure 5. CO$_2$ and CH$_4$ fluxes in the sites Pürgschachen Moor peat bog (PUE) and Lake Neusiedl reed zone (NLL) as well as*
378 *temperature and soil water content*

379

380

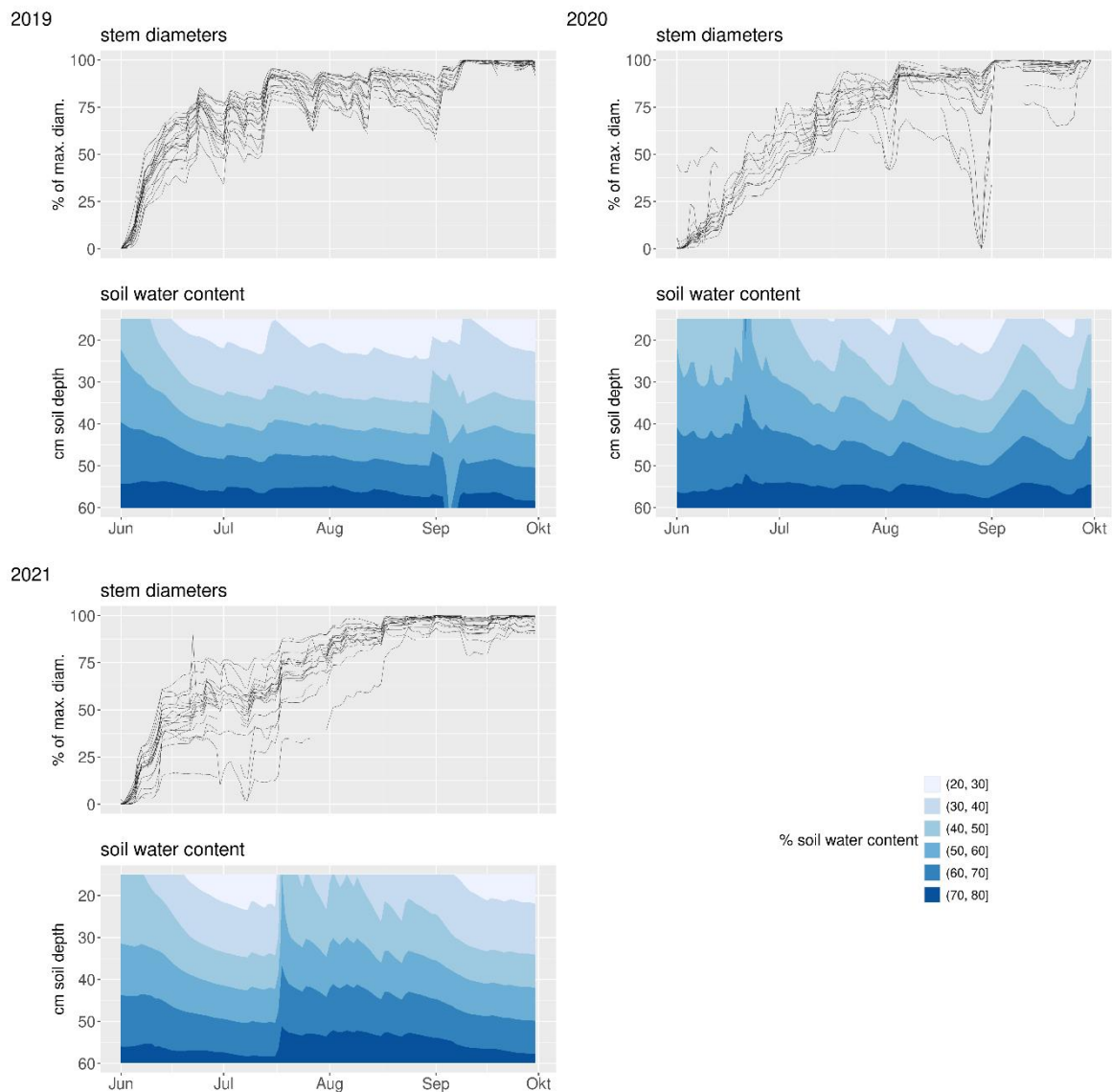



Figure 6. Relative stem diameters and soil moisture at the site Klausen-Leopoldsdorf (KLL) during the years 2019 - 2021.
Stem diameter values were scaled to an annual amplitude of 100.

383

6. Discussion

We provide baseline ecosystem data related to the carbon cycle and capture naturally occurring ECEs
across various ecosystem types typical for Austria and other regions of Central Europe. Such data sets
are scarce because the measurements are demanding in terms of maintenance and funding.
Automated soil respiration data in high temporal resolution, as we report it here, is rare too owing to
a lack of dedicated monitoring or research infrastructures (Bond-Lamberty et al., 2021). However,
soil CO_2 respiration constitutes the second-largest flux in the global carbon cycle, hence is key in
estimating ecosystem response to ECEs (Bond-Lamberty and Thomson, 2010). In addition, we
provide soil temperature and moisture measurements in the same resolution, being key variables
determining soil respiration (Pumpanen et al., 2015). High-resolution measurements of tree stem
circumference have been developed as complementary data to relate drought stress with changes in
carbon allocation in trees (Zweifel, 2016; Zweifel et al., 2021). The microclimatic, soil, and tree

396 physiological data is complemented by CO_2 and CH_4 fluxes between the vegetation and the
397 atmosphere measured with Eddy covariance techniques of the two wetland sites.

398 Our data is particularly useful for drought-related research. Triggered by the pan-European drought
399 of 2003 (Ciais et al., 2005), a key scientific question has been how droughts affect greenhouse gas
400 sinks and sources in ecosystems (Rödenbeck et al., 2020; Reichstein et al., 2013; Anderegg et al.,
401 2020). Droughts usually reduce soil respiration due to the decrease in autotrophic respiration but
402 also because soil microbial activity drops due to water limitation (Grünzweig et al., 2022).
403 Furthermore, rewetting can result in pulses of high soil respiration (Borken and Matzner, 2009).
404 Drought effects on the ecosystem C cycle can persist for years (Kannenberg et al., 2020; Müller and
405 Bahn, 2022) and novel approaches are being developed for assimilating high-resolution data for
406 understanding and quantifying such legacies (Yu et al., 2022; Fu et al., 2020). In this context, the
407 availability of long-term, high-resolution measurements of key ecosystem parameters is key for
408 understanding and quantifying the effects of recurrent droughts (Oberleitner et al., 2022). While the
409 three-year data with the usual measurement gaps occurring in field campaigns in rather difficult
410 terrain can only to some extent capture aspects of drought related effects, it represents a valuable
411 baseline.

412

413 The sites presented here are currently being upgraded towards their implementation in the
414 European Research Infrastructure for Integrated European Long-Term Ecosystem, critical zone and
415 socio-ecological Research (eLTER RI), together with another ~200 sites in Europe (Mirtl et al., 2018).
416 Climate change impacts on ecosystem processes including the carbon cycle are among the targeted
417 research areas the eLTER RI will focus on. The measurements resulting in the data presented here
418 will continue in future under the umbrella of eLTER RI. Compiling longer-term data series depends
419 upon the availability of already validated data sets - as it is presented here - before the RI is being
420 operational. Furthermore, long-term ecosystem observations already exist in these sites with regard
421 to water and nitrogen cycle allowing for a contextual interpretation of the trends seen in C related
422 parameters.

423 Combining several research and monitoring activities at already heavily instrumented sites not only
424 saves money but widens the data analyses portfolio (Futter et al. 2023; Kulmala 2018). Even though
425 we provide Eddy covariance data for two of our sites, Austria is not part of the Integrated Carbon
426 Observation System (ICOS). A combination of data capturing long-term boundary layer exchange of C
427 together with soil C fluxes, microclimate, and, in forests, tree physiological data obviously holds great
428 potential (Zweifel et al., 2023; Ramonet et al., 2020). Hence, using the sites simultaneously for other
429 research infrastructures, such as ICOS, providing high-quality Eddy covariance measurements would
430 obviously be ideal. The more so because European Research Infrastructures follow the FAIR data
431 principles to make data Findable, Accessible, Interoperable and Reusable (Wilkinson et al., 2016).

432 While the eLTER RI data infrastructure is still under development, we comply with the standards
433 already implemented. We used DEIMS-SDR (https://deims.org/) as the catalogue documenting the
434 sites (Wohner et al., 2019; Wohner et al., 2022). It issues persistent identifiers for sites (see Table 1)
435 that allow to uniquely identify sites across research projects and networks. Tools are being
436 developed to query available information about sites programmatically (Oggioni et al., 2023;
437 Wohner, 2023) providing contextual ecosystem information.

438

439 7.   Data availability

 7.1 Data access

441 The data and metadata is accessible at B2SHARE (https://b2share.eudat.eu/), a service provided by
442 the EUDAT Collaborative Data Infrastructure. DOIs of the datasets are listed in Table 5. The site
443 metadata in DEIMS-SDR (Table 1) is part of the data metadata so that site information can easily be
444 accessed. In chapter8, we provide a jupyter notebook to download and merge the single datasets,
445 and to visualize parameters.

446 *Table 5. Dataset DOIs*

Site	Dataset	DOI	Reference
Klausen-Leopoldsdorf	Meteorology	https://doi.org/10.23728/b2share.8f872a37513c4768b16ce755eca4bb57	(Gartner et al., 2024a)
	Soil climate	https://doi.org/10.23728/b2share.8d49c0b557f1455a9e66689e035b8cce	(Gartner et al., 2024b)
	Soil CO_2 respiration	https://doi.org/10.23728/b2share.5286bd1bc6aa491f874b9bb12d1c5673	(Kitzler and Hofbauer, 2024)
	Stem increment	https://doi.org/10.23728/b2share.68d84a913f0c4875be5c680ad4d6959e	(Gartner and Gollobich, 2024)
Rosalia Forest Demonstration Centre	Meteorology	https://doi.org/10.23728/b2share.96c52c247eb846deb2a3ec5e2c27b4f1	(Diaz-Pines, 2024a)
	Soil climate	https://doi.org/10.23728/b2share.c68143fc11224c44ae5529bd6a35a76d	(Diaz-Pines, 2024c)
	Soil CO_2 respiration	https://doi.org/10.23728/b2share.d167e727abe947abbc8efc04057557f6	(Diaz-Pines, 2024b)
	Stem increment	https://doi.org/10.23728/b2share.d0d185f1eb184ae48f6d06ea9aa8dbdf	(Diaz-Pines, 2024d)
Zöbelboden	Meteorology	https://doi.org/10.23728/b2share.762e665273234b129d09ef017416bcfb	(Kobler et al., 2024a)
	Soil climate	https://doi.org/10.23728/b2share.46e19191ce9c427d90f48ce38f56a0e1	(Kobler et al., 2024c)
	Soil CO_2 respiration	https://doi.org/10.23728/b2share.4f44006b932142e68981106a016f1f56	(Kobler et al., 2024b)
	Stem increment	https://doi.org/10.23728/b2share.2de5b37a0cad4f82a19f477531d6af24	(Pröll et al., 2024)
Stubai - Kaserstattalm	Meteorology	https://doi.org/10.23728/b2share.77462914dc0b43cb8c24a967e6851665	(Ingrisch and Bahn, 2024c)
	Soil climate	https://doi.org/10.23728/b2share.026d76094e8f4512b09b35b7a0d2a9d7	(Ingrisch and Bahn, 2024d)
	Soil CO_2 respiration	https://doi.org/10.23728/b2share.cfe8c7ad1965433484650ea9026512ca	(Ingrisch and Bahn, 2024a)
	Stem increment	https://doi.org/10.23728/b2share.0e3eed54ff30418f8720806b5f05cca9	(Ingrisch and Bahn, 2024b)
Pürgschachen Moor	Meteorology	https://doi.org/10.23728/b2share.5442510ad03e4968afb4e2108e85a64d	(Maier and Glatzel, 2024e)
	Soil climate	https://doi.org/10.23728/b2share.9380364098d14978b876a87517652d62	(Maier and Glatzel, 2024f)
	Eddy Covariance	https://doi.org/10.23728/b2share.4f783e3ff2884abca5c59960db0b7955	(Maier and Glatzel, 2024d)
Lake Neusiedl	Meteorology	https://doi.org/10.23728/b2share.f7176c9ee982464f947d2fe9fb8f389d	(Maier and Glatzel, 2024b)
	Soil climate	https://doi.org/10.23728/b2share.4e6474cd55f9487d97e3d31e83baa530	(Maier and Glatzel, 2024c)

| Eddy Covariance | https://doi.org/10.23728/b2share.b83caca 3efe44868a1ed49129b4a576a | (Maier and Glatzel, 2024a) |

447

7.2 Data visualization, workflow integration

The software stack used to store, import and quality control the provided data is built on PostgreSQL database with a Post-GIS extension. The database structure is derived from the Time Series Management (TSM) system developed by the Research Center Jülich (Wohner, C., Dirnböck, T., Peterseil, J., Pröll, G., Geiger, S., 2021) and originally deployed during the LTER CWN project but was repurposed to better fit the needs of the data management and working group. Now, for the import and quality control of data, a number of Python scripts deployed in a Jupyter environment are used. This is also includes scripts to visualise the data on the fly in Jupyter.

8. Code availability

A Jupyter notebook to access, merge, and visualize the data from all sites is available at https://gist.github.com/1O/9bbe44a03f12801c6c742202b005db57.

9. Author contribution

DT, BM, DPM, DI, EM, GK, GG, MA, IJ, KB, KJ, MA, PG, VS, ZBS, ZA, and GS designed the measurements and carried them out. WC, PJ designed and constructed the database. KK, VS, and PG customized and filled the database. OI developed the Jupyter notebook. DT prepared the manuscript with contributions from all co-authors.

10. Competing interests

The authors declare that they have no conflict of interest.

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482

13. References

Anderegg, W. R. L., Trugman, A. T., Badgley, G., Anderson, C. M., Bartuska, A., Ciais, P., Cullenward, D., Field, C. B., Freeman, J., Goetz, S. J., Hicke, J. A., Huntzinger, D., Jackson, R. B., Nickerson, J., Pacala, S., and Randerson, J. T.: Climate-driven risks to the climate mitigation potential of forests, Science, 368, eaaz7005, https://doi.org/10.1126/science.aaz7005, 2020.

Baatz, R., Hendricks Franssen, H. J., Euskirchen, E., Sihi, D., Dietze, M., Ciavatta, S., Fennel, K., Beck, H., Lannoy, G. de, Pauwels, V. R. N., Raiho, A., Montzka, C., Williams, M., Mishra, U., Poppe, C., Zacharias, S., Lausch, A., Samaniego, L., van Looy, K., Bogena, H., Adamescu, M., Mirtl, M., Fox, A., Goergen, K., Naz, B. S., Zeng, Y., and Vereecken, H.: Reanalysis in Earth System Science: Toward Terrestrial Ecosystem Reanalysis, Reviews of Geophysics, 59, https://doi.org/10.1029/2020RG000715, 2021.

Bahn, M. and Ingrisch, J.: Accounting for Complexity in Resilience Comparisons: A Reply to Yeung and Richardson, and Further Considerations, Trends in Ecology & Evolution, 33, 649–651, https://doi.org/10.1016/j.tree.2018.06.006, 2018.

Bahn, M., Rodeghiero, M., Anderson-Dunn, M., Dore, S., Gimeno, C., Drösler, M., Williams, M., Ammann, C., Berninger, F., Flechard, C., Jones, S., Balzarolo, M., Kumar, S., Newesely, C., Priwitzer, T., Raschi, A., Siegwolf, R., Susiluoto, S., Tenhunen, J., Wohlfahrt, G., and Cernusca, A.: Soil Respiration in European Grasslands in Relation to Climate and Assimilate Supply, Ecosystems, 11, 1352–1367, https://doi.org/10.1007/s10021-008-9198-0, 2008.

Bahn, M., Schmitt, M., Siegwolf, R., Richter, A., and Brüggemann, N.: Does photosynthesis affect grassland soil-respired CO_2 and its carbon isotope composition on a diurnal timescale?, New Phytologist, 182, 451–460, https://doi.org/10.1111/j.1469-8137.2008.02755.x, 2009.

Baur, P. A., Henry Pinilla, D., and Glatzel, S.: Is ebullition or diffusion more important as methane emission pathway in a shallow subsaline lake?, Science of The Total Environment, 912, 169112, https://doi.org/10.1016/j.scitotenv.2023.169112, 2024.

Bernal, S., Hedin, L. O., Likens, G. E., Gerber, S., and Buso, D. C.: Complex response of the forest nitrogen cycle to climate change, Proceedings of the National Academy of Sciences, 109, 3406–3411, https://doi.org/10.1073/pnas.1121448109, 2012.

Bond-Lamberty, B. and Thomson, A.: Temperature-associated increases in the global soil respiration record, Nature, 464, 579–582, 2010.

Bond-Lamberty, B., Christianson, D. S., Crystal-Ornelas, R., Mathes, K., and Pennington, S. C.: A reporting format for field measurements of soil respiration, Ecological Informatics, 62, 101280, https://doi.org/10.1016/j.ecoinf.2021.101280, 2021.

Borken, W. and Matzner, E.: Reappraisal of drying and wetting effects on C and N mineralization and fluxes in soil, Global Change Biology, 15, 808–824, 2009.

Buchsteiner, C., Baur, P. A., and Glatzel, S.: Spatial Analysis of Intra-Annual Reed Ecosystem Dynamics at Lake Neusiedl Using RGB Drone Imagery and Deep Learning, Remote Sensing, 15, 3961, https://doi.org/10.3390/rs15163961, 2023.

Chen, S., Zou, J., Hu, Z., Chen, H., and Lu, Y.: Global annual soil respiration in relation to climate, soil properties and vegetation characteristics: Summary of available data, Agricultural and Forest Meteorology, 198-199, 335–346, https://doi.org/10.1016/j.agrformet.2014.08.020, 2014.

Ciais, P., Reichstein, M., Viovy, N., Granier, A., Ogée, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, C., Carrara, A., Chevallier, F., Noblet, N. de, Friend, A. D., Friedlingstein, P., Grünwald, T., Heinesch, B., Keronen, P., A. Knohl, A., Krinner, G., Loustau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J. M., Papale, D., Pilegaard, K., Rambal, S., Seufert, G., Soussana, J. F., M. J. Sanz, Schulze, E.-D., Vesala, T., and Valentini, R.: Europe-wide reduction in primary productivity caused by the heat and drought in 2003, Nature, 437, 529–533, 2005.

530 Diaz-Pines, E.: Rosalia forest (Austria) - meteorological data (2020-2021),
531   https://doi.org/10.23728/B2SHARE.96C52C247EB846DEB2A3EC5E2C27B4F1, 2024a.
532 Diaz-Pines, E.: Rosalia forest (Austria) - soil CO2 respiration (2019-2021),
533   https://doi.org/10.23728/B2SHARE.D167E727ABE947ABBC8EFC04057557F6, 2024b.
534 Diaz-Pines, E.: Rosalia forest (Austria) - soil temperature and soil moisture (2019-2021),
535   https://doi.org/10.23728/B2SHARE.C68143FC11224C44AE5529BD6A35A76D, 2024c.
536 Diaz-Pines, E.: Rosalia forest (Austria) - tree increments (2019-2021),
537   https://doi.org/10.23728/B2SHARE.D0D185F1EB184AE48F6D06EA9AA8DBDF, 2024d.
538 Dirnböck, T., Brielmann, H., Djukic, I., Geiger, S., Hartmann, A., Humer, F., Kobler, J., Kralik, M., Liu, Y.,
539   Mirtl, M., and Pröll, G.: Long- and Short-Term Inorganic Nitrogen Runoff from a Karst Catchment
540   in Austria, Forests, 11, 1112, https://doi.org/10.3390/f11101112, 2020.
541 Dirnböck, T., Haase, P., Mirtl, M., Pauw, J., and Templer, P. H.: Contemporary International Long-
542   Term Ecological Research (ILTER)—from biogeosciences to socio-ecology and biodiversity
543   research, Reg Environ Change, 19, 309–311, https://doi.org/10.1007/s10113-018-1445-0, 2019.
544 Dirnböck, T., Kobler, J., Kraus, D., Grote, R., and Kiese, R.: Impacts of management and climate
545   change on nitrate leaching in a forested karst area, Journal of Environmental Management, 165,
546   243–252, https://doi.org/10.1016/j.jenvman.2015.09.039, 2016.
547 Drollinger, S., Maier, A., and Glatzel, S.: Interannual and seasonal variability in carbon dioxide and
548   methane fluxes of a pine peat bog in the Eastern Alps, Austria, Agricultural and Forest
549   Meteorology, 275, 69–78, https://doi.org/10.1016/j.agrformet.2019.05.015, 2019.
550 Frank, D., Reichstein, M., Bahn, M., Thonicke, K., Frank, D., Mahecha, M. D., Smith, P., van der Velde,
551   M., Vicca, S., Babst, F., Beer, C., Buchmann, N., Canadell, J. G., Ciais, P., Cramer, W., Ibrom, A.,
552   Miglietta, F., Poulter, B., Rammig, A., Seneviratne, S. I., Walz, A., Wattenbach, M., Zavala, M. A.,
553   and Zscheischler, J.: Effects of climate extremes on the terrestrial carbon cycle: concepts,
554   processes and potential future impacts, Global Change Biology, 21, 2861–2880,
555   https://doi.org/10.1111/gcb.12916, 2015.
556 Fu, Z., Ciais, P., Bastos, A., Stoy, P. C., Yang, H., Green, J. K., Wang, B., Yu, K., Huang, Y., Knohl, A.,
557   Šigut, L., Gharun, M., Cuntz, M., Arriga, N., Roland, M., Peichl, M., Migliavacca, M., Cremonese, E.,
558   Varlagin, A., Brümmer, C., La Gourlez de Motte, L., Fares, S., Buchmann, N., El-Madany, T. S.,
559   Pitacco, A., Vendrame, N., Li, Z., Vincke, C., Magliulo, E., and Koebsch, F.: Sensitivity of gross
560   primary productivity to climatic drivers during the summer drought of 2018 in Europe,
561   Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 375,
562   20190747, https://doi.org/10.1098/rstb.2019.0747, 2020.
563 Fuchslueger, L., Bahn, M., Fritz, K., Hasibeder, R., and Richter, A.: Experimental drought reduces the
564   transfer of recently fixed plant carbon to soil microbes and alters the bacterial community
565   composition in a mountain meadow, New Phytologist, 201, 916–927,
566   https://doi.org/10.1111/nph.12569, 2014.
567 Fürst, J., Nachtnebel, H. P., Gasch, J., Nolz, R., Stockinger, M. P., Stumpp, C., and Schulz, K.: Rosalia:
568   an experimental research site to study hydrological processes in a forest catchment, Earth Syst.
569   Sci. Data, 13, 4019–4034, https://doi.org/10.5194/essd-13-4019-2021, 2021.
570 Fuss, R.: gasfluxes: greenhouse gas flux calculation from chamber measurements, 2020.
571 Futter, M. N., Dirnböck, T., Forsius, M., Bäck, J. K., Cools, N., Diaz-Pines, E., Dick, J., Gaube, V.,
572   Gillespie, L. M., Högbom, L., Laudon, H., Mirtl, M., Nikolaidis, N., Poppe Terán, C., Skiba, U.,
573   Vereecken, H., Villwock, H., Weldon, J., Wohner, C., and Alam, S. A.: Leveraging research
574   infrastructure co-location to evaluate constraints on terrestrial carbon cycling in northern
575   European forests, Ambio, 52, 1819–1831, https://doi.org/10.1007/s13280-023-01930-4, 2023.
576 Gartner, K. and Gollobich, G.: Klausen-Leopoldsdorf (Austria) - tree increments (2019-2021),
577   https://doi.org/10.23728/B2SHARE.68D84A913F0C4875BE5C680AD4D6959E, 2024.

Gartner, K., Gollobich, G., and Zolles, A.: Klausen-Leopoldsdorf (Austria) - meteorological data (2019-2021), https://doi.org/10.23728/B2SHARE.8F872A37513C4768B16CE755ECA4BB57, 2024a.

Gartner, K., Gollobich, G., and Zolles, A.: Klausen-Leopoldsdorf (Austria) - soil temperature and soil moisture (2019-2021), https://doi.org/10.23728/B2SHARE.8D49C0B557F1455A9E66689E035B8CCE, 2024b.

Gillespie, L. M., Kolari, P., Kulmala, L, Leitner, S. M., Pihlatie, M., Zechmeister-Boltenstern, S., and Díaz-Pinés, E.: Drought effects on soil greenhouse gas fluxes in a boreal and a temperate forest, Biogeochemistry, 167, 155–175, https://doi.org/10.1007/s10533-024-01126-2, 2024.

Gillespie, L. M., Triches, N. Y., Abalos, D., Finke, P., Zechmeister-Boltenstern, S., Glatzel, S., and Díaz-Pinés, E.: Land inclination controls CO2 and N2O fluxes, but not CH4 uptake, in a temperate upland forest soil, SOIL, 9, 517–531, https://doi.org/10.5194/soil-9-517-2023, 2023.

Glatzel, S., Worrall, F., Boothroyd, I. M., and Heckman, K.: Comparison of the transformation of organic matter flux through a raised bog and a blanket bog, Biogeochemistry, https://doi.org/10.1007/s10533-023-01093-0, 2023.

Gollob, C., Ritter, T., and Nothdurft, A.: Comparison of 3D Point Clouds Obtained by Terrestrial Laser Scanning and Personal Laser Scanning on Forest Inventory Sample Plots, Data, 5, 103, https://doi.org/10.3390/data5040103, 2020.

Grünzweig, J. M., Boeck, H. J. de, Rey, A., Santos, M. J., Adam, O., Bahn, M., Belnap, J., Deckmyn, G., Dekker, S. C., Flores, O., Gliksman, D., Helman, D., Hultine, K. R., Liu, L., Meron, E., Michael, Y., Sheffer, E., Throop, H. L., Tzuk, O., and Yakir, D.: Dryland mechanisms could widely control ecosystem functioning in a drier and warmer world, Nat Ecol Evol, 6, 1064–1076, https://doi.org/10.1038/s41559-022-01779-y, 2022.

Hartl-Meier, C., Zang, C., Büntgen, U., Esper, J., Rothe, A., Göttlein, A., Dirnböck, T., and Treydte, K.: Uniform climate sensitivity in tree-ring stable isotopes across species and sites in a mid-latitude temperate forest, Tree Physiology, https://doi.org/10.1093/treephys/tpu096, 2014.

Hasibeder, R., Fuchslueger, L., Richter, A., and Bahn, M.: Summer drought alters carbon allocation to roots and root respiration in mountain grassland, New Phytologist, 205, 1117–1127, https://doi.org/10.1111/nph.13146, 2015.

Haslinger, K., Bartsch, A.: Creating long-term gridded fields of reference evapotranspiration in Alpine terrain based on a recalibrated Hargreaves method. Hydrology and Earth System Sciences, 20, 1211–1223, https://hess.copernicus.org/articles/20/1211/2016/, 2016.

Heimann, M. and Reichstein, M.: Terrestrial ecosystem carbon dynamics and climate feedbacks, Nature, 451, 289–292, 2008.

Hutchinson, G. L. and Mosier, A. R.: Improved Soil Cover Method for Field Measurement of Nitrous Oxide Fluxes, Soil Sci. Soc. Am. j., 45, 311–316, https://doi.org/10.2136/sssaj1981.03615995004500020017x, 1981.

Ingrisch, J. and Bahn, M.: Kaserstattalm (Austria) - forest soil CO2 respiration (2019-2020), https://doi.org/10.23728/B2SHARE.CFE8C7AD1965433484650EA9026512CA, 2024a.

Ingrisch, J. and Bahn, M.: Kaserstattalm (Austria) - forest tree increments (2019-2021), https://doi.org/10.23728/B2SHARE.0E3EED54FF30418F8720806B5F05CCA9, 2024b.

Ingrisch, J. and Bahn, M.: Kaserstattalm (Austria) - meteorological data (2019-2021), https://doi.org/10.23728/B2SHARE.77462914DC0B43CB8C24A967E6851665, 2024c.

Ingrisch, J. and Bahn, M.: Kaserstattalm (Austria) - soil temperature and soil moisture (2019-2021), https://doi.org/10.23728/B2SHARE.026D76094E8F4512B09B35B7A0D2A9D7, 2024d.

Ingrisch, J. and Bahn, M.: Towards a Comparable Quantification of Resilience, Trends in Ecology & Evolution, 33, 251–259, https://doi.org/10.1016/j.tree.2018.01.013, 2018.

624 Ingrisch, J., Karlowsky, S., Hasibeder, R., Gleixner, G., and Bahn, M.: Drought and recovery effects on
625   belowground respiration dynamics and the partitioning of recent carbon in managed and
626   abandoned grassland, Glob Chang Biol, 26, 4366–4378, https://doi.org/10.1111/gcb.15131, 2020.
627 Ingrisch, J., Karlowsky, S., Anadon-Rosell, A., Hasibeder, R., König, A., Augusti, A., Gleixner, G., and
628   Bahn, M.: Land Use Alters the Drought Responses of Productivity and CO2 Fluxes in Mountain
629   Grassland, Ecosystems, 21, 689–703, https://doi.org/10.1007/s10021-017-0178-0, 2018.
630 IPCC: Climate Change 2021: The Physical Science Basis: Contribution of Working Group I to the Sixth
631   Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University
632   Press, Cambridge, United Kingdom and New York, NY, USA, 2021.
633 Kannenberg, S. A., Schwalm, C. R., and Anderegg, W. R. L.: Ghosts of the past: how drought legacy
634   effects shape forest functioning and carbon cycling, Ecology Letters, 23, 891–901,
635   https://doi.org/10.1111/ele.13485, 2020.
636 Kitzler, B., Zechmeister-Boltenstern, S., Holtermann, C., Skiba, U., and Butterbach-Bahl, K.: Controls
637   over N2O, NOx and CO2 fluxes in a calcareous mountain forest soil, Biogeosciences, 3, 383–395,
638   2006.
639 Kitzler, B. and Hofbauer, A.: Klausen-Leopoldsdorf (Austria) - soil CO2 respiration for the years (2019-
640   2020), https://doi.org/10.23728/B2SHARE.5286BD1BC6AA491F874B9BB12D1C5673, 2024.
641 Knierzinger, W., Drescher-Schneider, R., Knorr, K.-H., Drollinger, S., Limbeck, A., Brunnbauer, L.,
642   Horak, F., Festi, D., and Wagreich, M.: Anthropogenic and climate signals in late-Holocene peat
643   layers of an ombrotrophic bog in the Styrian Enns valley (Austrian Alps), E&G Quaternary Sci. J.,
644   69, 121–137, https://doi.org/10.5194/egqsj-69-121-2020, 2020.
645 Kobler, J., Dirnböck, T., and Pröll, G.: Zöbelboden (Austria) - meteorological data (2019-2021),
646   https://doi.org/10.23728/B2SHARE.762E665273234B129D09EF017416BCFB, 2024a.
647 Kobler, J., Dirnböck, T., and Pröll, G.: Zöbelboden (Austria) - soil CO2 respiration for the years (2019-
648   2021), https://doi.org/10.23728/B2SHARE.4F44006B932142E68981106A016F1F56, 2024b.
649 Kobler, J., Dirnböck, T., and Pröll, G.: Zöbelboden (Austria) - soil temperature and soil moisture (2019-
650   2021), https://doi.org/10.23728/B2SHARE.46E19191CE9C427D90F48CE38F56A0E1, 2024c.
651 Kobler, J., Zehetgruber, B., Dirnböck, T., Jandl, R., Mirtl, M., and Schindlbacher, A.: Effects of aspect
652   and altitude on carbon cycling processes in a temperate mountain forest catchment, Landscape
653   Ecol, https://doi.org/10.1007/s10980-019-00769-z, 2019.
654 Kröel-Dulay, G., Mojzes, A., Szitár, K., Bahn, M., Batáry, P., Beier, C., Bilton, M., Boeck, H. J. de, Dukes,
655   J. S., Estiarte, M., Holub, P., Jentsch, A., Schmidt, I. K., Kreyling, J., Reinsch, S., Larsen, K. S.,
656   Sternberg, M., Tielbörger, K., Tietema, A., Vicca, S., and PeÑUelas, J.: Field experiments
657   underestimate aboveground biomass response to drought, Nature ecology & evolution, 6, 540–
658   545, https://doi.org/10.1038/s41559-022-01685-3, 2022.
659 Kulmala, M.: Build a global Earth observatory, Nature, 553, 21–23, https://doi.org/10.1038/d41586-
660   017-08967-y, 2018.
661 Leitner, S., Dirnböck, T., Kobler, J., and Zechmeister-Boltenstern, S.: Legacy effects of drought on
662   nitrate leaching in a temperate mixed forest on karst, Journal of Environmental Management,
663   262, https://doi.org/10.1016/j.jenvman.2020.110338, 2020.
664 Leitner, S., Minixhofer, P., Inselsbacher, E., Keiblinger, K. M., Zimmermann, M., and Zechmeister-
665   Boltenstern, S.: Short-term soil mineral and organic nitrogen fluxes during moderate and severe
666   drying–rewetting events, Applied Soil Ecology, 114, 28–33,
667   https://doi.org/10.1016/j.apsoil.2017.02.014, available at:
668   https://www.sciencedirect.com/science/article/pii/S0929139316303018, 2017.
669 LI-COR Biosciences: SoilFluxPro Software: Instruction manual, 2019.
670 Liu, D., Keiblinger, K. M., Leitner, S., Wegner, U., Zimmermann, M., Fuchs, S., Lassek, C., Riedel, K.,
671   and Zechmeister-Boltenstern, S.: Response of Microbial Communities and Their Metabolic

672   Functions to Drying ̄Rewetting Stress in a Temperate Forest Soil, Microorganisms, 7,
673   https://doi.org/10.3390/microorganisms7050129, 2019.

674 Mahecha, M. D., Gans, F., Sippel, S., Donges, J. F., Kaminski, T., Metzger, S., Migliavacca, M., Papale,
675   D., Rammig, A., and Zscheischler, J.: Detecting impacts of extreme events with ecological in situ
676   monitoring networks, Biogeosciences, 14, 4255–4277, https://doi.org/10.5194/bg-14-4255-2017,
677   2017.

678 Maier, A. and Glatzel, S.: Lake Neusiedl (Austria) - eddy flux data (2019-2021),
679   https://doi.org/10.23728/B2SHARE.B83CACA3EFE44868A1ED49129B4A576A, 2024a.

680 Maier, A. and Glatzel, S.: Lake Neusiedl (Austria) - meteorological data (2019-2021),
681   https://doi.org/10.23728/B2SHARE.F7176C9EE982464F947D2FE9FB8F389D, 2024b.

682 Maier, A. and Glatzel, S.: Lake Neusiedl (Austria) - soil temperature and soil moisture (2019-2021),
683   https://doi.org/10.23728/B2SHARE.4E6474CD55F9487D97E3D31E83BAA530, 2024c.

684 Maier, A. and Glatzel, S.: Puergschachen Bog (Austria) - eddy covariance data (2019-2021),
685   https://doi.org/10.23728/B2SHARE.4F783E3FF2884ABCA5C59960DB0B7955, 2024d.

686 Maier, A. and Glatzel, S.: Puergschachen Bog (Austria) - meteorological data (2019-2021),
687   https://doi.org/10.23728/B2SHARE.5442510AD03E4968AFB4E2108E85A64D, 2024e.

688 Maier, A. and Glatzel, S.: Puergschachen Bog (Austria) - soil temperature and soil moisture (2019-
689   2021), https://doi.org/10.23728/B2SHARE.9380364098D14978B876A87517652D62, 2024f.

690 Mirtl, M., T. Borer, E., Djukic, I., Forsius, M., Haubold, H., Hugo, W., Jourdan, J., Lindenmayer, D.,
691   McDowell, W. H., Muraoka, H., Orenstein, D. E., Pauw, J. C., Peterseil, J., Shibata, H., Wohner, C.,
692   Yu, X., and Haase, P.: Genesis, goals and achievements of Long-Term Ecological Research at the
693   global scale: A critical review of ILTER and future directions, Science of The Total Environment,
694   626, 1439–1462, https://doi.org/10.1016/j.scitotenv.2017.12.001, 2018.

695 Müller, L. M. and Bahn, M.: Drought legacies and ecosystem responses to subsequent drought, Glob
696   Chang Biol, 28, 5086–5103, https://doi.org/10.1111/gcb.16270, 2022.

697 Müller, R., Maier, A., Inselsbacher, E., Peticzka, R., Wang, G., and Glatzel, S.: 13C-Labeled Artificial
698   Root Exudates Are Immediately Respired in a Peat Mesocosm Study, Diversity, 14, 735,
699   https://doi.org/10.3390/d14090735, 2022.

700 Neumann, M. and Starlinger, F.: The significance of different indices for stand structure and diversity
701   in forests, Forest Ecology and Management, 145, 91–106, 2001.

702 Oberleitner, F., Hartmann, H., Hasibeder, R., Huang, J., Losso, A., Mayr, S., Oberhuber, W., Wieser, G.,
703   and Bahn, M.: Amplifying effects of recurrent drought on the dynamics of tree growth and water
704   use in a subalpine forest, Plant, Cell & Environment, 45, 2617–2635,
705   https://doi.org/10.1111/pce.14369, 2022.

706 Oggioni, A., Silver, M., Ranghetti, L., and Tagliolato, P.: ReLTER: An Interface for the eLTER
707   Community, https://github.com/ropensci/ReLTER, 2023.

708 Pröll, G., Venier, S., and Dirnböck, T.: Zöbelboden (Austria) - tree increments (2019-2021),
709   https://doi.org/10.23728/B2SHARE.2DE5B37A0CAD4F82A19F477531D6AF24, 2024.

710 Pumpanen, J., Kulmala, L., Lindén, A., Kolari, P., Nikinmaa, E., and Hari, P.: Seasonal dynamics of
711   autotrophic respiration in boreal forest soil estimated by continuous chamber measurements,
712   2015.

713 Pumpanen, J., Kolari, P., Ilvesniemi, H., Minkkinen, K., Vesala, T., Niinistö, S., Lohila, A., Larmola, T.,
714   Morero, M., Pihlatie, M., Janssens, I., Yuste, J. C., Grünzweig, J. M., Reth, S., Subke, J.-A., Savage,
715   K., Kutsch, W., Østreng, G., Ziegler, W., Anthoni, P., Lindroth, A., and Hari, P.: Comparison of
716   different chamber techniques for measuring soil CO2 efflux, Agricultural and Forest Meteorology,
717   123, 159–176, https://doi.org/10.1016/j.agrformet.2003.12.001, 2004.

718 Ramonet, M., Ciais, P., Apadula, F., Bartyzel, J., Bastos, A., Bergamaschi, P., Blanc, P. E., Brunner, D.,
719   Di Caracciolo Torchiarolo, L., Calzolari, F., Chen, H., Chmura, L., Colomb, A., Conil, S., Cristofanelli,

P., Cuevas, E., Curcoll, R., Delmotte, M., Di Sarra, A., Emmenegger, L., Forster, G., Frumau, A., Gerbig, C., Gheusi, F., Hammer, S., Haszpra, L., Hatakka, J., Hazan, L., Heliasz, M., Henne, S., Hensen, A., Hermansen, O., Keronen, P., Kivi, R., Komínková, K., Kubistin, D., Laurent, O., Laurila, T., Lavric, J. V., Lehner, I., Lehtinen, K. E. J., Leskinen, A., Leuenberger, M., Levin, I., Lindauer, M., Lopez, M., Myhre, C. L., Mammarella, I., Manca, G., Manning, A., Marek, M. V., Marklund, P., Martin, D., Meinhardt, F., Mihalopoulos, N., Mölder, M., Morgui, J. A., Necki, J., O'Doherty, S., O'Dowd, C., Ottosson, M., Philippon, C., Piacentino, S., Pichon, J. M., Plass-Duelmer, C., Resovsky, A., Rivier, L., Rodó, X., Sha, M. K., Scheeren, H. A., Sferlazzo, D., Spain, T. G., Stanley, K. M., Steinbacher, M., Trisolino, P., Vermeulen, A., Vítková, G., Weyrauch, D., Xueref-Remy, I., Yala, K., and Yver Kwok, C.: The fingerprint of the summer 2018 drought in Europe on ground-based atmospheric CO2 measurements, Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 375, 20190513, https://doi.org/10.1098/rstb.2019.0513, 2020.

Reichstein, M., Bahn, M., Ciais, P., Frank, D., Mahecha, M. D., Seneviratne, S. I., Zscheischler, J., Beer, C., Buchmann, N., Frank, D. C., Papale, D., Rammig, A., Smith, P., Thonicke, K., van der Velde, M., Vicca, S., Walz, A., and Wattenbach, M.: Climate extremes and the carbon cycle, Nature, 500, 287–295, https://doi.org/10.1038/nature12350, 2013.

Rödenbeck, C., Zaehle, S., Keeling, R., and Heimann, M.: The European carbon cycle response to heat and drought as seen from atmospheric CO2 data for 1999-2018, Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 375, 20190506, https://doi.org/10.1098/rstb.2019.0506, 2020.

Schindlbacher, A., Wunderlich, S., Borken, W., Kitzler, B., Zechmeister-Boltenstern, S., and Jandl, R.: Soil respiration under climate change: prolonged summer drought offsets soil warming effects, Global Change Biology, 18, 2270–2279, https://doi.org/10.1111/j.1365-2486.2012.02696.x, 2012.

Schmitt, M., Bahn, M., Wohlfahrt, G., Tappeiner, U., and Cernusca, A.: Land use affects the net ecosystem CO(2) exchange and its components in mountain grasslands, Biogeosciences, 7, 2297–2309, https://doi.org/10.5194/bg-7-2297-2010, 2010.

Schwen, A., Zimmermann, M., Leitner, S., and Woche, S. K.: Soil Water Repellency and its Impact on Hydraulic Characteristics in a Beech Forest under Simulated Climate Change, Vadose Zone Journal, 14, 1–11, https://doi.org/10.2136/vzj2015.06.0089, 2015.

Vicente-Serrano, S. M., Beguería S, and López-Moreno, J. I.: A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index, Journal of Climate, 23, 1696-1718, https://doi.org/10.1175/2009JCLI2909.1, 2010.

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., Gonzalez-Beltran, A., Gray, A. J. G., Groth, P., Goble, C., Grethe, J. S., Heringa, J., Hoen, P. A. C., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S. J., Martone, M. E., Mons, A., Packer, A. L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M. A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., and Mons, B.: The FAIR Guiding Principles for scientific data management and stewardship, Scientific data, 3, 160018, https://doi.org/10.1038/sdata.2016.18, 2016.

Wohner, C.: deimsPy, https://pypi.org/project/deims/, 2023.

Wohner, C., Peterseil, J., and Klug, H.: Designing and implementing a data model for describing environmental monitoring and research sites, Ecological Informatics, 70, 101708, https://doi.org/10.1016/j.ecoinf.2022.101708, available at: https://www.sciencedirect.com/science/article/pii/S1574954122001583, 2022.

767 Wohner, C., Peterseil, J., Poursanidis, D., Kliment, T., Wilson, M., Mirtl, M., and Chrysoulakis, N.:
768   DEIMS-SDR – A web portal to document research sites and their associated data, Ecological
769   Informatics, 51, 15–24, https://doi.org/10.1016/j.ecoinf.2019.01.005, 2019.
770 Wohner, C., Dirnböck, T., Peterseil, J., Pröll, G., Geiger, S.: Providing high resolution data for the long-
771   term ecosystem research infrastructure on the national and European scale, in:
772   Umweltinformationssysteme – Wie verändert die Digitalisierung unsere Gesellschaft?, edited by:
773   Freitag, U., Fuchs-Kittowski, F., Abecker, A., Hosenfeld, F., Springer Vieweg, Wiesbaden, 2021.
774 Working Group WRB: World Reference Base for Soil Resources 2014, update 2015 International soil
775   classification system for naming soils and creating legends for soil maps, World Soil Resources
776   Reports No. 106. FAO, Rome, 2015.
777 Wu, D., Ciais, P., Viovy, N., Knapp, A. K., Wilcox, K., Bahn, M., Smith, M. D., Vicca, S., Fatichi, S.,
778   Zscheischler, J., He, Y., Li, X., Ito, A., ARNETH, A., Harper, A., Ukkola, A., Paschalis, A., Poulter, B.,
779   Peng, C., Ricciuto, D., Reinthaler, D., Chen, G., Tian, H., Genet, H., Mao, J., Ingrisch, J., Nabel, J. E.
780   S. M., Pongratz, J., Boysen, L. R., Kautz, M., Schmitt, M., Meir, P., Zhu, Q., Hasibeder, R., Sippel, S.,
781   Dangal, S. R. S., Sitch, S., Shi, X., Wang, Y., Luo, Y., Liu, Y., and Piao, S.: Asymmetric responses of
782   primary productivity to altered precipitation simulated by ecosystem models across three long-
783   term grassland sites, Biogeosciences, 15, 3421–3437, https://doi.org/10.5194/bg-15-3421-2018,
784   2018.
785 Yu, X., Orth, R., Reichstein, M., Bahn, M., Klosterhalfen, A., Knohl, A., Koebsch, F., Migliavacca, M.,
786   Mund, M., Nelson, J. A., Stocker, B. D., Walther, S., and Bastos, A.: Contrasting drought legacy
787   effects on gross primary productivity in a mixed versus pure beech forest, Biogeosciences, 19,
788   4315–4329, https://doi.org/10.5194/bg-19-4315-2022, 2022.
789 Zweifel, R.: Radial stem variations - a source of tree physiological information not fully exploited yet,
790   Plant Cell and Environment, 39, 231–232, https://doi.org/10.1111/pce.12613, 2016.
791 Zweifel, R., Pappas, C., Peters, R. L., Babst, F., Balanzategui, D., Basler, D., Bastos, A., Beloiu, M.,
792   Buchmann, N., Bose, A. K., Braun, S., Damm, A., D'Odorico, P., Eitel, J. U., Etzold, S., Fonti, P.,
793   Rouholahnejad Freund, E., Gessler, A., Haeni, M., Hoch, G., Kahmen, A., Körner, C., Krejza, J.,
794   Krumm, F., Leuchner, M., Leuschner, C., Lukovic, M., Martínez-Vilalta, J., Matula, R., Meesenburg,
795   H., Meir, P., Plichta, R., Poyatos, R., Rohner, B., Ruehr, N., Salomón, R. L., Scharnweber, T.,
796   Schaub, M., Steger, D. N., Steppe, K., Still, C., Stojanović, M., Trotsiuk, V., Vitasse, Y., Arx, G. von,
797   Wilmking, M., Zahnd, C., and Sterck, F.: Networking the forest infrastructure towards near real-
798   time monitoring – A white paper, Science of The Total Environment, 872, 162167,
799   https://doi.org/10.1016/j.scitotenv.2023.162167, 2023.
800 Zweifel, R., Etzold, S., Basler, D., Bischoff, R., Braun, S., Buchmann, N., Conedera, M., Fonti, P.,
801   Gessler, A., Haeni, M., Hoch, G., Kahmen, A., Köchli, R., Maeder, M., Nievergelt, D., Peter, M.,
802   Peters, R. L., Schaub, M., Trotsiuk, V., Walthert, L., Wilhelm, M., and Eugster, W.: TreeNet–The
803   Biological Drought and Growth Indicator Network, Front. For. Glob. Change, 4,
804   https://doi.org/10.3389/ffgc.2021.776905, 2021.
805