Dear Editor,

We herewith submit the revised version of our manuscript “High-resolution Carbon cycling data from 2019 to 2021 measured at six Austrian Long-Term Ecosystem Research sites”. In addition to the changes made in responses to two referees comments (see below), we made the following minor change.

We changed the names of two co-authors: Hofbauer to Malli since the colleague changed name meanwhile; Zechmeister to Zechmeister-Boltenstern since we missed the double name when submitting

We further want to make the following suggestion regarding Table 1. Both referees suggested more detailed information in this table: Metadata Table 1: since very detailed description of all sites is available via the cited link to DEIMS-SDR system, we do not want to overload the table and just added the most important information in order to more easily comprehend the data graphs in the manuscript.

We want to emphasize that the comments were very helpful to improve our work.

We hope that the revised version made the necessary adaptations to our initial submission so that it is now suitable for publication.

With best wishes

Thomas Dirnböck (on behalf of all authors)

Vienna, 2024-08-28

Response to Reviewer #1

Overview and general recommendation:

Extreme events are projected to happen more frequently in the future under the ongoing climate change. Understanding how ecosystem carbon fluxes and their components (e.g. soil respiration) respond to these extreme events, and identifying the critical regulators of these responses, is crucial. High-quality datasets are essential to address these questions. Despite a slightly short coverage of years, the carbon fluxes and relevant environmental factors at six Austrian sites, covering forests, grasslands, and wetlands, provided by Dirnböck et al., are valuable for quantifying the effects of extreme events on carbon dynamics. Overall, the manuscript clearly describes the site information, instrument setup, available data at each site, and relevant data processing procedures. I believe it can be a valuable dataset, but some issues need to be addressed before the manuscript is suitable for publication.

Author response: we are grateful for the positive evaluation and provide a point-by-point response to the major and minor comments below

Major Comments:

1. As one of the most important carbon cycling data, the ecosystem-level eddy covariance data have not been displayed in this manuscript. We suggested authors to display the EC data at least for one site in each vegetation type.

Author response: thank you for the suggestion. We will add this Fig. to the manuscript. Kindly note that our dataset includes EC data from two wetland sites (see table 3 of the manuscript); please see the figure for the site PUE as an example.

2. It is interesting and useful to have the continuous soil respiration observations in some of sites. However, there are lots of missing data especially in critical period in the growing season. I am wondering if this dataset can really achieve the goal to understand the effects of extreme events on carbon dynamics.

Author response: we agree that even three years of this kind of data can only to some extent be used to explore effects of climate extreme events. Therefore, we pointed out that "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." (Discussion L 350). As a baseline, the data covers a first set of three years, which will be prolonged in the Ecosystem Research Infrastructure (eLTER RI) and is supplemented with historical data published in previous manuscripts and data repositories (see Discussion in L379-L384). It is clear and unfortunate that the dataset has some data gaps (usually due to the malfunctioning of devices and complications during the installation and adjustment phases). In order to strengthen these limitations,

we added "While the three-year data with the usual measurement gaps can only to some extent capture aspects of drought related effects it represents a valuable baseline." (L373-L375).

3. A lot of abbreviations in the manuscript have not been clearly defined. To reach wider audiences and fully exploit the data, better definition of terms is needed.

Author response: we thank the reviewer for spotting this issue. We will add all the details for the abbreviations (see detailed response below)

Additionally, even though the manuscript is generally clearly described, text can be polished to make the description more concise and well linked.

Author response: we will rework the entire text.

Minor Comments:

1. Line 24: What "the high resolution" is? Half-hourly or daily? Could you specify them?

Author response: Here, we will specify the range "(15 – 60 minutes)", and will add the specific resolution to each measurement component

2. Line 55: "C" has not been defined before.

Author response: Right indeed, we will write C (carbon) in L34

3. Line 52: From the abbreviation of "LTER-CWN", the description before should be "carbon, water, and nitrogen"?

Author response: Thanks for pointing to this. We will add the long title.

4. Line 66-69: The names are not exactly consistent with the descriptions in Figure 1. Where is Kaserstattalm? In the site descriptions, authors also mentioned lowlands et al., it could be easier to understand if the authors could also add elevation in the map.

Author response: Thanks again. We will change the name to "Stubai", which is the site name and Kasterstattalm is a Subsite

5. Line 74: What is the "DEIMS-SDR" stands for, can you spell its full name?

Author response: Thanks, we again will spell out the abbreviation.

6. Line 76: Please specify the full name of "BOKU", this also applies for "FAO" and "WRB" in Line 83.

Author response: Since 2024 it is recommended to refer to BOKU as "BOKU University" in English; the alternative would be to use the official name Universität für Bodenkultur, which can be confusing for an international audience. We will added the correct reference for FAO/WRB at all placed it was cited.

7. Line 91: What is the meaning of "DRAIN" and where its location in the map?

Author response: Instead of adding the full name, we will skipp the abbreviation, as it is not considered crucial.

8. Line 94: What the selected soil biogeochemical and microbiological processes?

Author response: We suggest to keep this general description, since it is not considered important for the data we present here.

9. Line 104: Please specify the full name of "ICP" and explain what is the Level 2 site.

Author response: Again, we will spell out the abbreviation for ICP Forests, but will skipp "Level 2" because it is not important in the context of the manuscript.

10. Line 176: What "UNECE" stands for?

Author response: We will change the abbreviation to "International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM)".

11. Line 198: The vertical line of "Zöbelboden" is not visible.

Author response: Thanks for pointing this out. We will change the figure accordingly.

12. Line 199: Please properly define the LTSER.

Author response: We will do so by writing "Long-term socio-ecological research platforms (LTSER)".

13. Line 201-202: For Metadata Table 1, maybe the authors can add the information such as elevation, annual temperature and precipitation, dominant species, main equipped measurements, "data shared status" et al., to make the table more comprehensive so that the audience can have a general overview of the introduced Austrian LTER sites.

Author response: We will add the requested metadata after clarifying with the editor how comprehensive the overall table can be. In any case, we consider the DEIMS-SDR link - being rather long - crucial because this is where the site metadata is located.

14. Line 264-265: To confirm, the “Eddy covariance devices” were calibrated once a year or monthly?

Author response: In order to clarify this, we will write: “calibrated once a year in the lab, and monthly in the field.”

15. Line 274: What is the time resolution for the measurements of stem growth?

Author response: We added the time resolutions of all measurement components.

16. Line 294-295: “At KAS, the maximum temperatures in the year 2021 were lower (0.6 °C)”—compared to when?

Author response: Thanks for the question; this part was indeed misleading. We now write: “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 in the year 2021 with 2019 (≤< 0.5 6 °C).”

17. Line 297: It seems that Figure 3 is not about the soil temperature.

Author response: We apologize; the correct figure is Figure 4.

18. Line 299: In Figure 2, you may add the long-term monthly mean temperature and precipitation to better illustrate the 2019 and 2021 are drier years while 2020 is roughly close to average climate?

Author response: Indeed, we used the year 2020 as a reference for an average climate (see L297-L298). After discussing ways to show the long-term averages we suggest to use gridded long-term data from the Austrian meteorological service (https://data.hub.geosphere.at/dataset/winfore-v2-1d-1km). With this data, we are able to show - consistently for all sites - deviations of a drought index (SPEI - Standardized Precipitation Evapotranspiration Index) for 2019, 2020, and 2021 from a 30-year average (1980-2010). Using this new analysis, we will add to the chapter and adapt in the following way: “We used gridded SPEI (Standardized Precipitation Evapotranspiration Index) from the Austrian Meteorological Service (https://data.hub.geosphere.at/dataset/winfore-v2-1d-1km; Haslinger & Bartsch (2016)) to compare the long-term average water availability during the growing season (1980-2010; May to September) with those occurring in the measurement years (Table 3). The advantage of the SPEI is that it accounts for precipitation and temperature via evapotranspiration and integrates over a given temporal window (we used 30 days) (Vicente-Serrano et al. 2010) Accordingly, the 2021 was closest to the long-term average, the year 2020 was a particularly wet year, and the year 2019 was drier than the average. However, there were differences between the sites: Particularly the mountain station in the Tyrolian Alps (KAS) did not experience significant deviations in SPEI as compared to the long-term average apart from a wet growing season in 2021. The SPEI at the site in the Viennese Forest (KLL) does not indicate that in 2019, the growth period was

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 4)." (please see the SPEI results in the attachment; the table will be included in the manuscript)

19. Line 314: Rs should be defined

Author response: We will do so: "Soil respiration (Rs)".

20. Line 335-337: How do you conclude this, do you have some analysis to demonstrate this statement?

Author response: Thank you for your question. We agree that it is not possible to draw such a conclusion from the way we present the data in this paper. While we don't think that such a specific analysis would be needed for a data paper, we could provide if the editor considers this to be helpful or needed. Our suggestion is to included some references, which back up the statement for the sites.

21. Line 345: It seems that there are quite large variations in stem growth between 2019 and 2021, how was the stem growth in normal year 2020?

Author response: We suggest adding the data from the year 2020 in a then three-panel figure. In 2020, higher soil moisture particularly during spring and early summer (the main growth period) leads to a continuously increasing stem diameter without the pumps occurring during dry periods in 2019 and 2021 (we add this figure as an attachment).

22. Line 387: ICOS should be defined as "Integrated Carbon Observation System".

Author response: We will changed the text accordingly.

Response to Reviewer #2

Summary

This study provided observational data from seven sites, including meteorological and soil variables, CO2 fluxes, and tree stem growth during 2019-2021. These observations are essential for understanding and modeling of ecosystem carbon responses to climate variations or extreme climate events. The authors provided detailed site descriptions and how they measured the data and conducted the QA/QC. They also visualized the data and briefly analyzed the data. The manuscript is generally well organized. However, to further improve the quality of this paper and increase the data's impacts, please address my comments probably below.

Author response: thank you for the positive feedback and evaluation. Please find a point-by-point response to your comments below

1) Title: 'LTER', please give its full name since many readers might not know what does such an acronym mean.

Author response: we agree and will provide the full name for the abbreviation.

2) Abstract, line 19: seven 'long-term' observation sites. I understand that the seven sites belong to the LTER and will continue providing new data when available in the future. However, ESSD is a data journal, and this paper only provided data during 2019-2021, which are not long-term observations. So it's a bit tricky to refer to these sites as long-term sites now. If so, I would say lots of sites are long-term sites since they will also provide measures in the future, however, this may mislead data-users.

Author response: we understand your point when only considering the carbon-related flux variables. However, the sites are indeed long-term observation sites because they already exist for many years providing long-term data for numerous ecosystem variables, including some of those compiled in this manuscript for the years 2019-2021 (e.g. meteorology, soil temperature and moisture). We would therefore like to keep the term "long-term".

3) Line 45: add comma behind 'ecosystem carbon cycling'

Author response: we will do so

4) Line 55: for the high temporal resolution, what's the temporal resolution for each site?

Author response: this detail was also asked for by reviewer #1. We will specify the specific resolution to each measurement component for each site in chapter 3.

5) Table 1 is important for readers to quickly learn about the sites. However, this table only provided very limited information. Although there are some descriptions for each site in the main text, it would be great to explicitly list the key information for each site in Table 1, such as the annual mean meteorological conditions, latitude and longitude, major land/vegetation covers, CO2 flux measurement period (which year and month is measured vs. what period is not covered), what environmental variables are measured for each site.

Author response: reviewer #1 asked for such information as well. Therefore, we will add the requested metadata after clarifying with the editor how comprehensive the overall table can be. In any case, we consider the DEIMS-SDR link - being rather long - crucial because this is where the detailed site metadata is located.

6) Line 217: relative or specific humidity?

Author response: it is relative humidity; we will add this specification

7) Line 217-218: 'several radiation variables', please clearly list what variables are measured for each site so that the readers can easily understand the data availability for each site.

Author response: we agree and will add an additional table specifying the meteorological data

8) This study mentions multiple times of CH4 fluxes measured. Do the authors also intend to make the CH4 fluxes publicly available in this study?

Author response: yes, CO4 eddy covariance data is provided by the two wetland sites (Pürschachen Moor bog and the reed belt of lake Neusiedler See). Please see chapter 3.2.2. In response to a suggestion of reviewer #2, we will add an additional Figure visualizing this data (see uploaded Figure "eddy_flux_pue.png").

9) Line 263-265: what do you mean 'monthly in the field'? checked or calibrated?

Author response: we will specify this by writing "The Eddy Covariance devices were checked daily via remote access, calibrated once a year in the lab, and monthly in the field"

10) Line 272, why data-set without micro-meteorological conditions was regarded as gaps?

Author response: Thank you for making us aware. Here, we indeed described it the wrong way because the quality flags (0-2) obviously result from the use of the micrometeorological Eddy Covariance data, too. Therefore we will change the sentence to: "In addition, gaps resulted from power breakdowns".

11) Line 288-297, this paragraph is quite confusing. Please revise it carefully. For example, line 288-289: what do you mean 'long-term averages' here? How did you draw the conclusion that 2020 is closer to average while 2019/2021 drier/warmer? It's unclear from Fig. 2.

Author response: we agree, this is a weak part of the manuscript. Reviewer #1 spotted it too (see comment 18). The assessment of the meteorological conditions of the three years were now done in a different way and the entire paragraph will be rewritten in the following way: "We used gridded SPEI (Standardized Precipitation Evapotranspiration Index) from the Austrian Meteorological Service (https://data.hub.geosphere.at/dataset/winfore-v2-1d-1km; Haslinger & Bartsch (2016)) to compare the long-term average water availability during the growing season (1980-2010; May to September) with those occurring in the measurement years (Table 3). The advantage of the SPEI is that it accounts for precipitation and temperature via evapotranspiration and integrates over a given temporal window (we used 30 days) (Vicente-Serrano et al. 2010) Accordingly, the 2021 was closest to the long-term average, the year 2020 was a particularly wet year, and the year 2019 was drier than the average. However, there were differences between the sites: Particularly the mountain station in the Tyrolian Alps (KAS) did not experience significant deviations in SPEI as compared to the long-term average apart from a wet growing season in 2021. The SPEI at the site in the Viennese Forest (KLL) does not indicate that in 2019, the growth period was 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 4)." The new Table 3 was uploaded.

12) Line 291-292, 'In sum, the dry periods resulted in lower precipitation in 2019 and 2021 in all sites.' It's really hard to directly retrieve this information from Fig.2. Please use some statistical number to support this.

Author response: please see the response to comment 11 above

13) Line 292-295: the same issue. Hard to understand.

Author response: please see the response to comment 11 above

14) Line 295-297: you mean Fig.4? Honestly, it's hard to draw such a conclusion directly from Fig.4. You mean annual mean soil water content/temperature here?

Author response: please see the response to comment 11 above

15) Line 304: what's the snow-free period? Please also see my comment#5.

Author response: we agree that this is important information and will add it to Table 1 (see our response to comment 5 above)

16) Line 318-320: what kinds of statistics test did you use?

Author response: we used a t-test statistic. We will add this to the p-values

17) Line 325-326: could you please clearly show the magnitude of the spatial variation in CO2 fluxes and the magnitude difference caused by measurement devices, and then get such a conclusion. The current statement always makes me feel less rigorous.

Author response: We are not entirely sure whether we understand the comment. Figure 3 visualizes spatial variation (error bars) and uncertainty in measurements (at least a proxy

since we can only compare automated and manual chambers). The latter is shown in the deviation of the two regression lines in each plot. The conclusion we derive is taken from Figure 3. We will add an additional reference to Figure 3 after the conclusion in order to make this clear.

18) Line 335-337: again, it's hard to see such conclusion directly from Fig. 4.

Author response: Reviewer #1 made us aware of this issue, too. We agree that it is not possible to draw such a conclusion from the way we present the data in this paper. While we don't think that such a specific analysis would be needed for a data paper, we could provide if the editor considers this to be helpful or needed. Our suggestion is to included some references, which back up the statement for the sites.

19) Fig. 4, what's the temporal resolution for each variable? From Fig. 4, it seems that the temperature and water content are continually measured. Why not aggregate to the same temporal resolution to soil respiration and then show the data?

Author response: We have again discussed how to visualize the data and see no particular advantage in aggregating the CO2 data. One drawback among others is that we would lose temporal coverage in our visualization. We suggest to keep Figure 4 as it is.

20) Why not include CH4 flux in the results?

Author response: we refer to our response to comment 8.