Discussion of "Pathways of CH_4 formation and emission in the subsaline reed wetland of Lake Neusiedl"

Baur et al.

In the following, the reviewer's comments are set in *italic* and the authors' responses are marked in blue.

Authors' response to Referee 2

We thank the reviewer for the time and the valuable comments for improving our manuscript.

The authors assessed four pathways of CH4 fluxes (vegetation-mediated, soil- and water-air diffusion, and ebullition), pathways of methanogenesis (acetoclastic, hydrogenotrophic, and methyltrophic), microbial communities, and sediment physical and chemical properties in a subsaline reed-dominated temperate wetland. CH4 fluxes were measured over 24-hour periods 4 times over one year covering all four seasons (spring, summer, fall, winter). Only vegetation-mediated CH4 flux was measured in all 4 seasons.

Yes, that is correct. Due to the intra-annual dynamics in this wetland with reed, the available land cover (water areas, open sediment areas, and reed stands) and thus the corresponding interfaces and emission pathways are not always available in every season (Buchsteiner et al., 2023). For example, in spring, the water level was high, so there was no sediment-air interface. In fall, however, the reed wetland was dry (no water level above the surface), so there was no water-air interface.

The abstract implies that the research results contribute to reducing uncertainty in estimates of CH4 emissions from wetlands and improving wetland greenhouse gas modeling. However, the link between the research results and their significance needs clarification in the main text. Specifically, how can the results improve models, and what important knowledge gaps do they fill?

In the revised manuscript we will more clearly describe the knowledge gaps in currently applied wetland CH_4 emission models and how our results can significantly contribute to reducing uncertainty in these models.

The CH_4 emissions in process-based vegetation models, e.g. like LPJ-GUESS in Kallingal et al. (2024) or CLM4Me model in Riley et al. (2011), only partially implement the plant-mediated transport by considering only the passive mechanism (concentration gradient) (Riley et al., 2011; Kallingal et al., 2024). They also do not consider the pressurized flow that occurs in plant species such as *Phragmites* or *Typha* sp. and others, although it is known that, for example, the CH_4 emissions by plant-mediated transport of *Phragmites australis* can be more than five times higher than by diffusion (Brix et al., 2001). According to Vroom et al. (2022), most other wetland greenhouse gas models do not implement plant-mediated CH_4 fluxes in wetlands and do not include them in the total flux due to high variability in their contribution and the lack of data about this variability.

- Therefore, our study can help to fill important knowledge gaps
  - by quantifying the temporal contribution (seasonal and diel) of plant-mediated transport of reed wetlands and highlighting the dominance of plant-mediated transport not only in summer (as previous studies did, e.g. van den Berg et al. (2020)).
  - by better understanding these emission pathways and their temporal (diel) pattern of the studied reed wetland for each season
  - by using the findings to improve the parametrization and implementation of emission pathways (especially the plant-mediated transport of wetland plants) in the models.
- Furthermore, the study contributes to alleviating the general lack of plant-mediated CH_4 flux data in wetlands, so that plant-mediated transport and especially the pressurized flow mechanism will hopefully be implemented in (more) wetland CH_4 emission models to reduce their uncertainties, but also to make them more realistic.
- In addition, our CH_4 flux data (for each available emission pathway) can be used to optimize wetland CH_4 emission models as validation data for modeled CH_4 emissions for plant-mediated transport, ebullition, and diffusion in process-based vegetation models.
- Moreover, the findings of this study contribute to a more comprehensive understanding of the characteristics of reed wetlands, including the temporal CH_4 emission dynamics, their sediment and water properties, and their microbial communities.

Discussion of the results of sediment physical and chemical property analysis is absent and should be added.

We will add a paragraph in the Discussion chapter, in which we will discuss the results of the physiochemical analysis of the sediments in the reed wetland, their seasonal changes and differences compared to other (reed) wetlands.

The authors should also define the term "subsaline" and clarify the significance of the wetland type studied. This is particularly important for convincing non-specialists of the research impact.

According to Hammer (1986), subsaline lakes are defined as lakes with a salinity between 0.5 and 3‰. We will include this salinity range in front of the cited reference in L56.

The significance of the wetland type studied can be demonstrated for several reasons, which we will clarify in the revised manuscript:

The studied wetland type is one of the largest connected reed wetlands in Europe and has a special water characteristic for inland waters, e.g. subsalinity. Subsaline wetland ecosystems, and especially subsaline reed ecosystems, are rarely ever studied and therefore need to be (further) investigated. Because of the salinity, these ecosystems are to some degree more comparable to brackish coastal ecosystems than to freshwater ecosystems. However, the salt composition of the reed wetland in this study differs from that of coastal salt marshes because the main salt is sodium bicarbonate, not sodium chloride. It also differs greatly from other inland ecosystems such as reed fens (see e.g. van den Berg et al. (2020)) due to different soil properties. In addition, the studied lake, in which more than half is covered by the reed wetland, has been severely affected by droughts since mid-2015, which have influenced the carbon cycle, its processes and fluxes (Baur et al., 2024a). The international importance of this wetland is also shown by its cross-border protected areas as a Ramsar site, a UNESCO World Heritage site, and a National Park. All these made it very interesting to study this wetland type for a better understanding of carbon-related processes in different wetland types and conditions.

I also have some concerns regarding the research design using punctual 24-hour assessments of fluxes over four seasons, which may not adequately capture within-season temporal variation in fluxes, particularly ebullition. Further justification of 24-hour monitoring periods and comparison of flux pathways across seasons is needed. Is there potential for bias in the seasonal measurements given the short duration of monitoring periods?

If the authors are willing to address these issues, I'm happy to review a revised version of the manuscript in further detail.

We will address your questions in the revised manuscript:

We have taken great care to come up with meaningful results by studying the seasonal differences in the diel variation of the CH_4 fluxes for each available emission pathway of a reed wetland. We used the research design of one intensive 24 h campaign per season because it was feasible but also sufficient for our study objectives, as we did not want to use it for budgeting, but to study the pattern and variability. However, we would like to point out that these intensive 24 h campaigns required a great deal of logistical and human effort, as all available emission pathways were measured using manual and, in some cases, large chambers (including spatial replicates), and water, reed and sediment samples were collected and analyzed. Of course, more measurement days would always be great if resources and time allowed. However, in Table 1, we have summarized the characteristics of each individual 24 h campaign to present and allow comparison with other days/nights in the same season. Furthermore, there were exactly three months between the campaigns to avoid subjective selection of the measurement days/nights. Unfortunately, the winter campaign had to be postponed due to channel sediment excavation work (including local sediment deposits) in the study area, which would have affected the measurements too much.

We believe that our median CH_4 emissions of the ebullition pathway measured with bubble traps during the spring and summer campaigns capture the temporal variations in fluxes during a season quite well, as they are comparable to the median of the weekly collected and continuously measured CH_4 ebullition rates within the reed belt, separated by seasons, in Baur et al. (2024b): In the spring season in Baur et al. (2024b), the median ± standard deviation of the measured ebullition rates from March to May is 0.04 ± 0.86 mg CH_4 m^{-2} h^{-1}, while the median flux of the ebullition pathway in the spring campaign is 0.00 ± 1.00 mg CH_4 m^{-2} h^{-1} (see Table 2). In the summer season, when the water level was above the surface (from June to mid-July), the median ebullition rate is 1.19 ± 1.35 mg CH_4 m^{-2} h^{-1}, while the median flux of the ebullition pathway in the summer campaign is 1.35 ± 3.69 mg CH_4 m^{-2} h^{-1} (see Table 2).

Furthermore, the authors were unable to measure all four fluxes in all four seasons, with the exception of vegetation-mediated CH4 emissions. How does the research address the need to "incorporate all emission pathways across all seasons" (Line 39) and investigate "diel patterns of each available emission pathway during all season" (Lines 53 – 54)? Please address these questions in the main text of the manuscript.

Thank you for pointing out that we obviously did not clearly describe this issue. Due to the intra-annual dynamics of reed wetlands, the different land covers and their interfaces and emission pathways were not always available in each season (Buchsteiner et al., 2023). Of course, we can only measure each emission pathway per season that is available. For example, in spring the water level was high, so there was no sediment-air interface. In fall, for example, the reed wetland was dry (no water level above the surface), so there was no water-air interface. However, the water level was too low to set up bubble traps before and during the winter campaign, because the reed belt was completely dry in fall and we would have destroyed the sediment surface when installing the funnels, see L153ff. Nevertheless, ebullition rates during winter are expected to be very low due to the temperature dependence (e.g. Aben et al. (2017)).

So we studied all pathways assessable during all seasons which is a methodological advancement compared to previous studies of reed wetlands (van den Berg et al., 2020; Brix et al., 2001; Jeffrey et al., 2019). Considering the dynamic nature of wetlands, we were able to measure all accessible pathways in any given season. In the revised manuscript, we will clarify this issue to rule out any misunderstanding.

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