nature portfolio

Peer Review File

Limited evidence that tropical inundation and precipitation powered the 2020-2022 methane surge

Corresponding Author: Professor Eric A. Kort

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

** Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors **

Dear Dr. Kort,

Your manuscript titled "Tropical Inundation and Precipitation Do Not Explain 2020-2022 Methane Surge" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
Link Redacted
** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Prabir Patra, PhD
Editorial Board Member
Communications Earth & Environment
orcid.org/0000-0001-5700-9389

Alice Drinkwater, PhD
Associate Editor
Communications Earth & Environment
Consulting Editor
Communications Sustainability

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

Editorial Policy: Policy requirements (Download the link to your computer as a PDF.)

For Manuscripts that fall into the following fields:
• Behavioural and social science
• Ecological, evolutionary & environmental sciences
• Life sciences
An updated and completed version of our Reporting Summary must be uploaded with the revised manuscript
You can download the form here:
https://www.nature.com/documents/nr-reporting-summary.zip

Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:
Communications Earth & Environment formatting checklist

and also in our style and formatting guide Communications Earth & Environment formatting guide .

*** DATA: Communications Earth & Environment endorses the principles of the Enabling FAIR data project (http://www.copdess.org/enabling-fair-data-project/). We ask authors to make the data that support their conclusions available in permanent, publically accessible data repositories. (Please contact the editor if you are unable to make your data available).

All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More information on this policy, is available at http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf.

In particular, the Data availability statement should include:
- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)
- Accession codes where appropriate
- If applicable, a statement regarding data available with restrictions
- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at http://www.nature.com/sdata/policies/repositories.

If a community resource is unavailable, data can be submitted to generalist repositories such as figshare or Dryad Digital Repository. Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The manuscript investigates the role of tropical wetlands in the recent acceleration of atmospheric methane concentrations. The authors use a CYGNSS based map of surface inundation and CARDAMON wetland methane models forced with different drivers of precipitation, temperature and moisture-proxies. They find that their model, and independent process-based models, do not show significant increases in wetland methane emissions for the tropics. They conclude, as stated in their title that Tropical Inundation and Precipitation Do Not Explain 2020-2022 1 Methane Surge
The work is well described and the methods are well documented. However, the title is very misleading and problematic. The results from their work are at odd with other independent lines of evidence from methane isotopes, atmospheric inversions, and several other studies. The authors are transparent about this contradiction and uncertainty in their approach, but their title does not reflect this and will likely confuse the community and non-experts.
One issue is that the year-to-year growth rates and their changes are different to the 'long' term trend of four 4 years. The prolonged 2023 and quite extreme El Nino has likely caused wetland methane emissions to decrease over Amazonia, but this is different to the 2019-2020 growth in atmospheric methane.
While the paper is novel in terms of the time period, the paper is not novel in terms of comparing GIEMS, SWAMPS, WAD2M and CYGNSS. Thus much of the results on areal extent, seasonal dynamics, and trends have been covered elsewhere in the literature, not requiring the publication of the results in a journal like Nature Communications.
The atmospheric growth rates do not match NOAA GML growth rates. Maybe these need to be updated?
Overall, the study is well carried out but the conclusion is too strong given uncertainties and other lines of evidence.

Reviewer #2 (Remarks to the Author):

This study shows that tropical wetland area keeps stable or slightly decreased over recent high atmospheric methane growth years (2020-2022), using high resolution satellite-based inundation maps and precipitation data during 2018-2023. The recent atmospheric methane surge is an interesting enigma to unveil. As tropical wetland emissions have large uncertainty between different products shown in this study, it is quite important to explore this new CYGNSS inundation maps and its relation with wetland methane emissions and methane growth rate.

The main point of this study relies on the Berkeley-RWAWC product. It is great to show the hotspots of tropical wetlands in Fig. 1 and Fig. S2. I am curious which regions or wetland types dominate the decreased trend of tropical wetland area. Wetland types can be overlap with GLWD wetland map. Can the detected decrease in regional/gridded wetland area be explained by precipitation or other related variables or independent evidence?

I appreciate that the authors used independent precipitation, GRACE-FO and Berkeley-RWAWC datasets to investigate the recent changes in wetland area. However, it seems contradictory that GRACE-FO shows increased tropical water storage (Fig. S8) while tropical precipitation (ERA5 and IMERG) show decreased trend (Fig. S4a). If we trust the GRACE-FO signals, it can be deduced that evapotranspiration (ET) and runoff decreased or tropical precipitation used in this study may have wrong trend. From historical data between precipitation and GRACE-FO, it is more likely that ERA5 and IMERG precipitation cannot capture the "real" world precipitation. It is worth to try more precipitation datasets which align with GRAVE-FO signals to persuade us the main point of this study – recent stable/slight decreased tropical wetland area.

Fig S6b shows that MERRA2 has more emissions in 2020 and 2021, more prominent in the upper bound (I guess from MERRA2 climate forcing also). Is the conclusion still robust when using MERRA2 precipitation?

Non inundation peatland (water table depth 0-20 cm) could emit methane also, Bekeley-RWAWC potential can distinguish inundated and non-inundated peatlands, with GLWD peatland map. The inundated peatland area decreased or non-peatland inundated area decreased, to explain the decrease in tropical wetland area by Bekeley-RWAWC?

Overall, I think this is an important study, so I would like to see more testing, as suggested, for the robustness of the conclusion.

For more information please visit http://www.springernature.com/orcid

If you experience problems in linking your ORCID, please contact the Platform Support Helpdesk.

Version 1:

Decision Letter:

** Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors **

Dear Professor Kort,

Your manuscript titled "Limited Evidence for Tropical Inundation and Precipitation as Drivers of the 2020-2022 Methane Surge" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

EDITORIAL REQUESTS:

Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table".

*****Please take care to match our formatting and policy requirements. We will check revised manuscript and return manuscripts that do not comply. Such requests will lead to delays. *****

Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files as a Related Manuscript file.

If you have any questions or concerns about any of our requests, please do not hesitate to contact me.

SUBMISSION INFORMATION:

In order to accept your paper, we require the files listed at the end of the Editorial Requests Table; the list of required files is also available at https://www.nature.com/documents/commsj-file-checklist.pdf .

OPEN ACCESS:

Communications Earth & Environment is a fully open access journal. Articles are made freely accessible on publication. For further information about article processing charges, open access funding, and advice and support from Nature Research, please visit https://www.nature.com/commsenv/open-access

At acceptance, you will be provided with instructions for completing the open access licence agreement on behalf of all authors. This grants us the necessary permissions to publish your paper. Additionally, you will be asked to declare that all required third party permissions have been obtained, and to provide billing information in order to pay the article-processing charge (APC).

Please use the following link to submit the above items:
Link Redacted
** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Alice Drinkwater, PhD
Associate Editor
Communications Earth & Environment
Consulting Editor
Communications Sustainability

REVIEWERS' COMMENTS:

Reviewer #2 (Remarks to the Author):

The authors have done good job on the revision, and I do not have further comments.

Response to Reviewers Comments:

Reviewer #1 (Remarks to the Author):

The manuscript investigates the role of tropical wetlands in the recent acceleration of atmospheric methane concentrations. The authors use a CYGNSS based map of surface inundation and CARDAMON wetland methane models forced with different drivers of precipitation, temperature and moisture-proxies. They find that their model, and independent process-based models, do not show significant increases in wetland methane emissions for the tropics. They conclude, as stated in their title that Tropical Inundation and Precipitation Do Not Explain 2020-2022 Methane Surge

The work is well described and the methods are well documented. However, the title is very misleading and problematic. The results from their work are at odd with other independent lines of evidence from methane isotopes, atmospheric inversions, and several other studies. The authors are transparent about this contradiction and uncertainty in their approach, but their title does not reflect this and will likely confuse the community and non-experts.

Response: We sincerely appreciate your constructive feedback on our manuscript. We have revised the title to better reflect the findings of our study while maintaining transparency about the limitations and contradictions with other lines of evidence and reduce possible confusion amongst non-experts. The revised title is now:

"**Limited Evidence for Tropical Inundation and Precipitation as Drivers of the 2020-2022 Methane Surge**"

This new title more accurately states that our analysis does not support strong roles for these hydrological factors (i.e., inundation and precipitation), while acknowledging that other evidence (e.g., isotopic data, inversion studies) may point to different mechanisms. We believe that the revised title better aligns with the paper's findings and avoids potential misinterpretation.

One issue is that the year-to-year growth rates and their changes are different to the 'long' term trend of four 4 years. The prolonged 2023 and quite extreme El Nino has likely caused wetland methane emissions to decrease over Amazonia, but this is different to the 2019-2020 growth in atmospheric methane.

Response: Thanks for your insightful comment. We agree that the year-to-year variability in atmospheric methane growth rates differs from the 2020-2022 trend in our modeled wetland emissions, as evident in Fig. 3. This discrepancy supports our conclusion that tropical inundation and precipitation were unlikely to be the primary drivers of the 2020-2022 methane surge.

Regarding the 2023 extreme EI Niño’s impact on Amazonian wetlands, drought and elevated temperatures likely suppressed methane emissions, particularly in eastern Amazonia. This aligns with our correlation analysis between wetland methane emissions and ENSO index (ONI), which reveals a significant negative correlation is eastern Amazonia (Fig. 4f). This pattern indicates reduced methane emissions in eastern Amazonia during EI Niño phases and enhanced emissions during La Niña phases.

The 2019-2020 period began with an EI Niño phase, transitioned to neutral conditions, and ended with La Niña. This phase shift likely contributed to increased methane emissions from eastern Amazonia and the Sudd wetlands (Fig. 2d). Nevertheless, the magnitude of emission increases from these regions is much smaller than the observed atmospheric growth rate, suggesting that other anthropogenic sources are possibly the primary drivers.

While the paper is novel in terms of the time period, the paper is not novel in terms of comparing GIEMS, SWAMPS, WAD2M and CYGNSS. Thus much of the results on areal extent, seasonal dynamics, and trends have been covered elsewhere in the literature, not requiring the publication of the results in a journal like Nature Communications.

Response: We appreciate your feedback and agree that comparisons of existing inundation datasets (e.g., GIEMS-MC, SWAMPS, WAD2M) are not novel in isolation. However, our study advances the field in two ways:

1) A new CYGNSS-based inundation product for wetland methane modeling

While past studies have compared legacy inundation datasets and their spatiotemporal variations, our study novelly incorporated a new CYGNSS-based inundation product (Berkeley-RWAWC) into methane modeling to assess tropical wetland contributions to the 2020-2022 methane surge. As inundation dynamics present the largest uncertainty in wetland methane emissions (Saunois et al. 2024), particularly over the tropics, this new product provides a unique tool to reduce uncertainties in process-based models, considering its high spatial (0.01° × 0.01°) and temporal (August 2018 to the present) resolution.

2) Multi-framework analysis reveals limited evidence for inundation and precipitation driving the methane surge

We integrated inundation, precipitation, and GRACE terrestrial water storage anomaly and multiple wetland model frameworks (WetCHARTs, CARDAMOM, LPJ-EOSIM), none of which support tropical inundation and precipitation as primary drivers of the 2020-2022 atmospheric methane surge. This multi-framework analysis provides a crucial step forward in understanding tropical methane dynamics and providing a novel independent constraint to reconcile discrepancies between bottom-up and top-down approaches. Both the consideration of all these models and hydrological drivers, and the result from this analysis, which contradicts other inferences on methane emissions in this time frame, stand out as new and noteworthy.

We believe that these two advancements merit publication in **Communication Earth & Environment**, due to its dual contributions: (1) delivering a novel inundation product for wetland methane modeling, and (2) highlighting a key new finding in the debate about the role of wetlands in the recent methane surge through a uniquely multi-framework analysis.

We have added these two advancements in Line 406, Page 15, which reads as follows:

"In this study, we develop and apply a novel CYGNSS-based inundation product (Berkeley-RWAWC) that provides high spatiotemporal resolution for tropical wetland modeling, addressing a key uncertainty in methane emission estimates. Through a unique multi-framework analysis integrating inundation patterns, precipitation data, hydrological indicators, and process-based models, we demonstrate that tropical wetland dynamics were unlikely to be primary drivers of the 2020-2022 methane surge—a finding that challenges current paradigms and highlights the need to investigate alternative emission sources. These advances provide both a valuable tool for bottom-up models and critical constraints for reconciling global methane budget discrepancies."

The atmospheric growth rates do not match NOAA GML growth rates. Maybe these need to be updated?

Response: Thank you for your comment! We used an older version of methane growth rate from the NOAA GML website when submitting this manuscript. Because their preliminary estimate for the annual increase of a particular year is produced during April of the following year, which is likely to change and be updated as more samples are measured for CH_4 and included in the analysis (https://gml.noaa.gov/ccgg/trends_ch4/). We have updated growth rates throughout the main text as well as Figure 3 to reflect the most up-to-date numbers. It now reads as follows:

Line 211, Page 8: "According to NOAA's measurements, the global annual CH_4 growth rates have seen a substantial surge from 9.61 ± 0.60 ppb in 2019 to 17.66 ± 0.40 ppb in 2021, followed by a reduced growth to 13.18 ± 0.34 ppb in 2022. These rates suggest that the global methane source-sink imbalance has accelerated, increasing from 26.59 ± 1.66 Tg in 2019 to 48.87 ± 1.11 Tg in 2021, an 84 ± 7% surge from 2019 to 2021. The imbalance was higher by 14.39 ± 0.44 Tg, 22.27 ± 0.55 Tg, and 9.88 ± 0.72 Tg in 2020, 2021, and 2022, respectively, compared to the 2019 level (Fig. 3)."

Overall, the study is well carried out but the conclusion is too strong given uncertainties and other lines of evidence.

Response: We appreciate the reviewer for his/her thoughtful feedback. We agree that wetland methane modeling involves several uncertainties, which are reflected in our 36 ensemble estimates. We have made several revisions to better reflect these uncertainties while maintaining our key findings:

1) We have revised our title from "Tropical Inundation and Precipitation Do Not Explain 2020-2022 Methane Surge" to "Limited Evidence for Tropical Inundation and Precipitation as Drivers of the 2020-2022 Methane Surge" to more carefully frame our conclusions. The new title better reflects our key findings.

2) We have incorporated MERRA2 precipitation data alongside ERA5 and IMERG, to further demonstrate consistent precipitation patterns (i.e., higher in 2018-2020 and lower in 2021-2023) across multiple datasets. We further analyzed MERRA2-forced LPJ-EOSIM model estimates to reinforce the robustness of our main findings while acknowledging uncertainties in process-based models.

3) By overlaying the GLWD wetland map with our Berkeley-RWAWC inundation product, we confirmed that declining wetland areas were most pronounced in key methane-emitting regions. These reductions were primarily driven by losses in actively inundated peatland areas.

4) We emphasize the importance or added value of our study by positioning it in a broader context to demonstrate that our findings represent one important piece in the large methane puzzle.

The revised manuscript maintains our finding that hydrology indicators like inundation and precipitation were unlikely to be the primary drivers of the methane surge during 2020-2022, while more thoroughly acknowledging alternative explanations and limitations. We believe these modifications address the reviewer's concerns while strengthening the study's significant findings and contributions to understanding the recent methane surge.

Reviewer #2 (Remarks to the Author):

This study shows that tropical wetland area keeps stable or slightly decreased over recent high atmospheric methane growth years (2020-2022), using high resolution satellite-based inundation maps and precipitation data during 2018-2023. The recent atmospheric methane surge is an interesting enigma to unveil. As tropical wetland emissions have large uncertainty between different products shown in this study, it is quite important to explore this new CYGNSS inundation maps and its relation with wetland methane emissions and methane growth rate.

Response: We sincerely thank the reviewer for highlighting the complex relationship between tropical wetland dynamics and recent atmospheric methane growths. We fully acknowledge the inherent challenges in accurately representing wetland extent and emissions in bottom-up models. To address these uncertainties, we leverage the newly developed CYGNSS inundation map to improve wetland methane model parametrizations. Furthermore, we conduct systematic intercomparisons with alternative climate forcings (precipitation: ERA5, IMERG, and MERRA2; terrestrial water storage anomaly: GRACE-FO) and model frameworks (WetCHARTs, LPJ-EOSIM, and CARDAMOM) to evaluate emission estimates. This multi-dataset approach provides a more robust foundation for understanding wetland methane contributions to the recent methane growth.

The main point of this study relies on the Berkeley-RWAWC product. It is great to show the hotspots of tropical wetlands in Fig. 1 and Fig. S2. I am curious which regions or wetland types dominate the decreased trend of tropical wetland area. Wetland types can be overlap with GLWD wetland map. Can the detected decrease in regional/gridded wetland area be explained by precipitation or other related variables or independent evidence?

Response: Thanks for your insightful comment. We conducted additional spatial analyses to examine trends in tropical wetland extent from August 2018 to April 2023. As shown in Fig. R1, most tropical wetlands experienced a decline in inundated area during the study period, except for regions of eastern Amazonia, eastern Brazil, northern and southeastern Australia, and the Sudd wetland. Significant ($p < 0.05$, grey cross marker) declines were observed in western Amazonia, the Congo basin, the Pantanal wetland, Uruguay, and parts of Indonesia and Papua Islands, likely driving the pan-tropical decreasing trend.

To assess which wetland types contributed most to this decline, we overlaid the Berkeley-RWAWC inundation data with the widely used GLWD version 1 map (also employed in our wetland methane modeling). The lower panel of Fig. R1 shows the global distribution of wetland classes, such as freshwater marsh, swamp forest, coastal wetland, bog, fen, mire (peatland), wetland complex, etc. Our analysis revealed that freshwater marsh, floodplain—primarily located in northern Amazonia, southern Brazia, and the southeastern Indo-Gangetic Plain—exhibited the highest decline rate (-1.66%/decade), followed by reservoir (-0.86%/decade), river (-0.85%/decade), coastal wetland (-0.77%/decade) wetland complex (-0.67%/decade), 50-100% wet (-0.61%/decade), 25-50% wet (-0.59%/decade), swamp forest (-0.57%/decade), saline wetland (-0.45%/decade), and intermittent (-0.38%/decade). Inundated peatland categories, including swamp forest, 50-100% wet, and 25-50% wet, together exhibited a 1.77%/decade decrease. In contrast, non-inundated peatlands such as bogs (type 8 in GLWD), did not show significant trends.

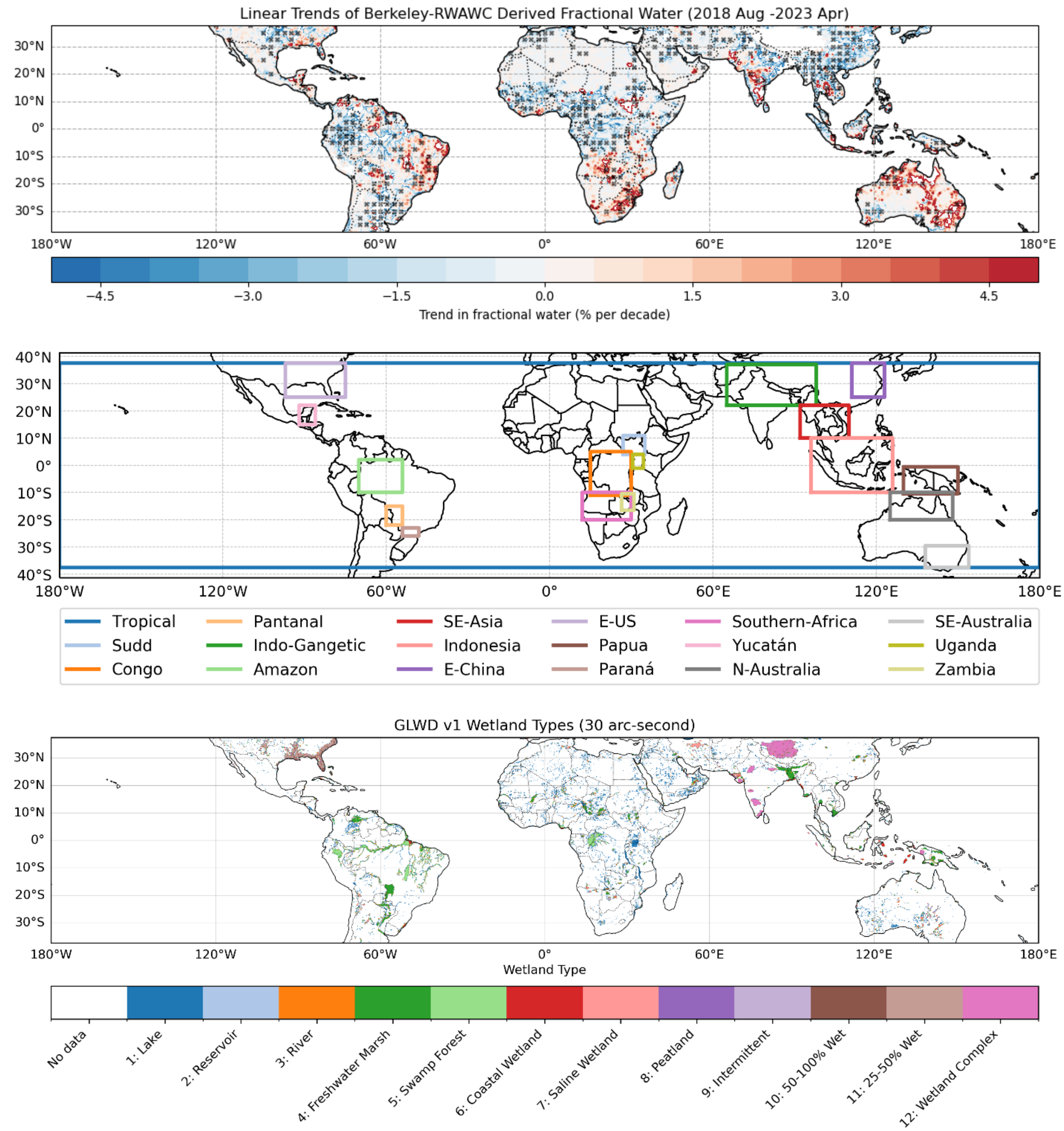

Figure R1. Top panel: Linear trends in Berkeley-RWAWC-derived fractional water across the tropics (August 2018—April 2023). Grey crosses (x) mark significant trends ($p < 0.05$). Middle panel: Locations of 17 wetland basins studied. Lower panel: Wetland types from GLWD Level 3, Version 1 (Lehner and Döll 2004).

In summary, the most pronounced wetland losses occurred in western Amazonia, the Congo basin, the Pantanal wetland, Uruguay, and parts of Indonesia and Papua Islands, with inundated peatlands (-1.77%/decade), and freshwater marsh, floodplain (-1.66%/decade) declining fastest among different wetland classes. We have replaced Fig. S3 (in SI) with Fig. R1 and added this discussion to Line 123, Page 4. It now reads as follows:

"To identify the regions and wetland types contributing most to declining tropical wetland extent, we conducted a spatial analysis combining the Berkeley-RWAWC inundation data with the Global Lakes and Wetlands Database (GLWD) version 1 (Lehner and Döll 2004). Figure S3 shows both the spatial trends in inundated areas and wetland type distributions across the tropics. Our analysis revealed that freshwater marshes and floodplains - particularly those in northern Amazonia, southern Brazil, and the southeastern Indo-Gangetic Plain - experienced the most rapid declines (-1.66%/decade), followed by reservoirs (-0.86%/decade), rivers (-0.85%/decade), and coastal wetlands (-0.77%/decade). Notably, key methane-emitting peatland including swamp forests (-0.57%/decade) and water-saturated areas (50-100% wet: -0.61%/decade; 25-50% wet: -0.59%/decade) collectively decreased by 1.77%/decade, while non-inundated peatlands like bogs (type 8 in GLWD) showed no significant trends."

We also acknowledge the upcoming release of GLWD version 2 (under reviewed in *Earth System Science Data Discussion* (Lehner et al. 2024)), which offers higher resolution (~500 m) and 33 wetland classes (*vs.* 12 in v1). Future work could integrate this improved dataset into wetland methane models. Lastly, we evaluated our inundation product against independent precipitation and hydrological datasets, as detailed in our response to your next question.

I appreciate that the authors used independent precipitation, GRACE-FO and Berkeley-RWAWC datasets to investigate the recent changes in wetland area. However, it seems contradictory that GRACE-FO shows increased tropical water storage (Fig. S8) while tropical precipitation (ERA5 and IMERG) show decreased trend (Fig. S4a). If we trust the GRACE-FO signals, it can be deduced that evapotranspiration (ET) and runoff decreased or tropical precipitation used in this study may have wrong trend. From historical data between precipitation and GRACE-FO, it is more likely that ERA5 and IMERG precipitation cannot capture the “real” world precipitation. It is worth to try more precipitation datasets which align with GRAVE-FO signals to persuade us the main point of this study – recent stable/slight decreased tropical wetland area.

Response: We sincerely appreciate your thoughtful comments. To further address the apparent discrepancy between GRACE-FO-derived liquid water equivalent (LWE) trends and inundation data (Berkeley-RWAWC), we incorporated MERRA2 (The Modern-Era Retrospective analysis for Research and Applications, version 2) as an additional independent dataset. As illustrated in Fig. R2, all three precipitation products (ERA5, MERRA2, and IMERG) consistently show higher tropical rainfall during 2018-2020 and lower precipitation in 2021-2023. This interannual variability aligns with the CYGNSS-derived inundation trends but contrasts with GRACE-FO LWE signals.

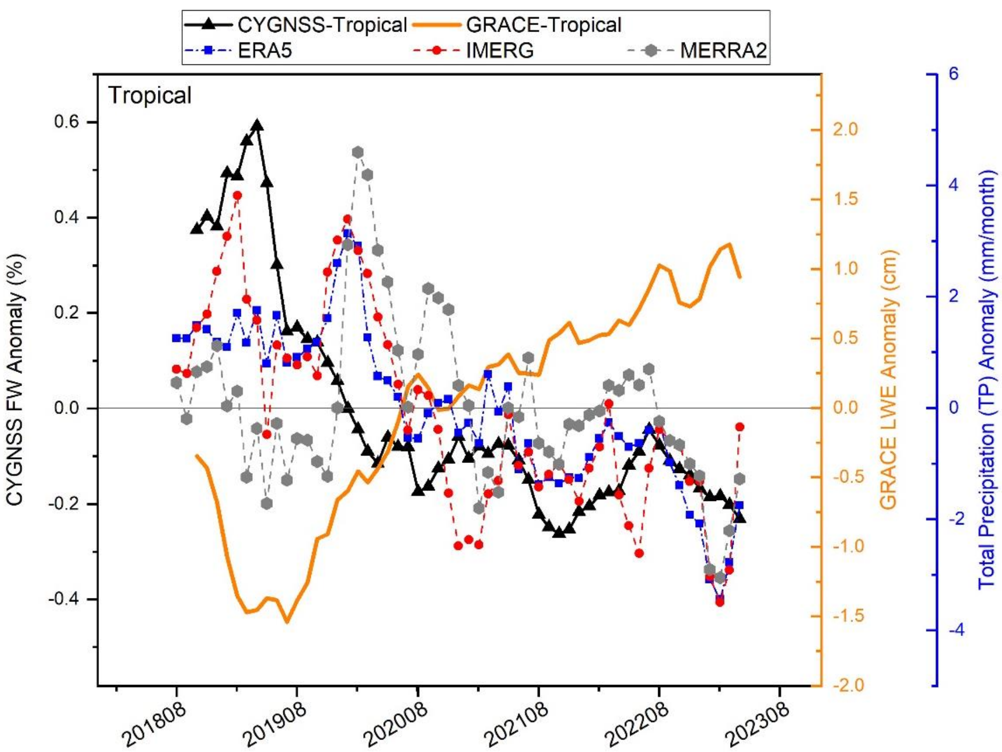

Fig. R2. A comparison of 3-month rolling anomalies of total precipitation in the tropics from the MERRA2 (grey dashed line), ERA5 (blue dashed line) reanalysis products and IMERG observations (red dashed line) and fractional water (FW) from Berkeley-RWAWC (CYGNSS, in black solid line) as well as LWE from the GRACE-FO between August 2018 and June 2023.

We emphasize that GRACE-FO measures integrated terrestrial water storage, which reflects not only precipitation but also complex climatic and anthropogenic influences, including monsoon variability and ENSO dynamics, groundwater extraction and dam construction, deforestation-driven changes in evapotranspiration and runoff, and sea-level-induced groundwater fluctuations (Ahmed et al. 2014; Rodell et al. 2024). For example, Ahmed et al. (2014) analyzed decadal GRACE data across Africa and found that 9 of 15 basins exhibited significant GRACE LWE trends despite near-steady precipitation (validated against TRMM, CMAP, CMORPH, and NOAA GHCN stations, see Table R1). This demonstrates that GRACE and precipitation are often decoupled due to non-precipitation factors.

Table R1. GRACE LWE trends (mm/yr, 01/2023-09/2012) along with their confidence level (CI, %) for the examined basins, subbasins, and aquifer systems in Africa. (Ahmed et al. 2014)

Location	GRACE trend		Rainfall trend
	Value (mm/yr)	CI (%)	
Niger Basin	6.31 ± 0.36	99	Increasing
Lake Chad Basin	1.43 ± 0.27	97	Increasing
Okavango Basin	**15.35 ± 0.79**	**99**	**Near-steady**
Zambezi Basin	**16.68 ± 1.09**	**99**	**Near-steady**
Limpopo Basin	-2.58 ± 0.46	99	Decreasing
Mozambique Northeast Coast Basin	-4.34 ± 0.52	99	Decreasing
East-Central Coast Basin	-1.18 ± 0.70	<65	Decreasing
Volta Basin	**14.41 ± 1.02**	**99**	**Near-steady**
Blue Nile and Atbara Subbasins	**3.14 ± 0.27**	**99**	**Near-steady**
Kasai Subbasin	-3.59 ± 1.18	88	Decreasing
Ubangi Subbasin	**-8.32 ± 0.80**	**99**	**Near-steady**
Sangha Subbasin	**-2.81 ± 1.38**	**95**	**Near-steady**
Congo Subbasin	**-4.95 ± 1.00**	**99**	**Near-steady**
Nubian Sandstone Aquifer in Egypt	**-3.72 ± 0.27**	**99**	**Near-steady**
North-Western Sahara Aquifer System	**-0.81 ± 0.16**	**99**	**Near-steady**

It is likely that the recent inundation trend from Berkeley-RWAWC product agrees with multiple precipitation datasets (ERA5, IMERG, MERRA-2), despite opposite to GRACE signals, largely because GRACE is not a direct proxy for wetland extent, as it integrates broader hydrological processes like groundwater and anthropogenic impacts. The divergence between GRACE and precipitation certainly can happen, given terrestrial water storage's sensitivity to non-precipitation drivers.

We have added Fig. R2 to the SI as Fig. S8 and include this discussion in Line 325, Page 13, which now reads as follows:

"GRACE-FO observations indicate an increase in water storage across the tropics since April 2019, which contrasts with the inundation observations from Berkeley-RWAWC and GIEMS-MC, as well as reduced precipitation in ERA5, MERRA2, and IMERG datasets (Fig. S8). The divergence between GRACE-FO's increasing terrestrial water storage trends and declining precipitation/inundation patterns (Fig. S8) may simply reflect fundamental differences in what these systems measure. While precipitation datasets (ERA5, IMERG, MERRA2) and CYGNSS-derived inundation (Berkeley-RWAWC) track atmospheric and surface water dynamics, GRACE-FO integrates all subsurface and anthropogenic water storage components—including groundwater recharge, dam operations, and deforestation-altered runoff (Ahmed et al. 2014; Rodell et al. 2024). This integration explains GRACE-FO's trends can diverge from precipitation trends. For instance, Ahmed et al. (2014) found that GRACE detected significant water storage changes in 9 of 15 African basins despite near-steady rainfall, highlighting how groundwater extraction or other climate variability can dominate integrated signals. In regions with deep aquifers and complex hydrology, surface inundation may show negligible change even when GRACE-FO indicates water storage increase. Even considering the difference in observed GRACE-FO trend, CARDAMOM model simulations constrained by GRACE-FO still do not explain the 2020-2021 surge (Fig. 3)."

Fig S6b shows that MERRA2 has more emissions in 2020 and 2021, more prominent in the upper bound (I guess from MERRA2 climate forcing also). Is the conclusion still robust when using MERRA2 precipitation?

Response: Thanks for raising this important point. We acknowledge that the MERRA2-driven upper-bound emission estimates in LPJ-EOSIM model (Fig. S6b) show higher wetland methane emissions in 2020 and 2021 than in 2019. To rigorously assess whether this affects our conclusions, we compared these estimates with observed atmospheric methane growth.

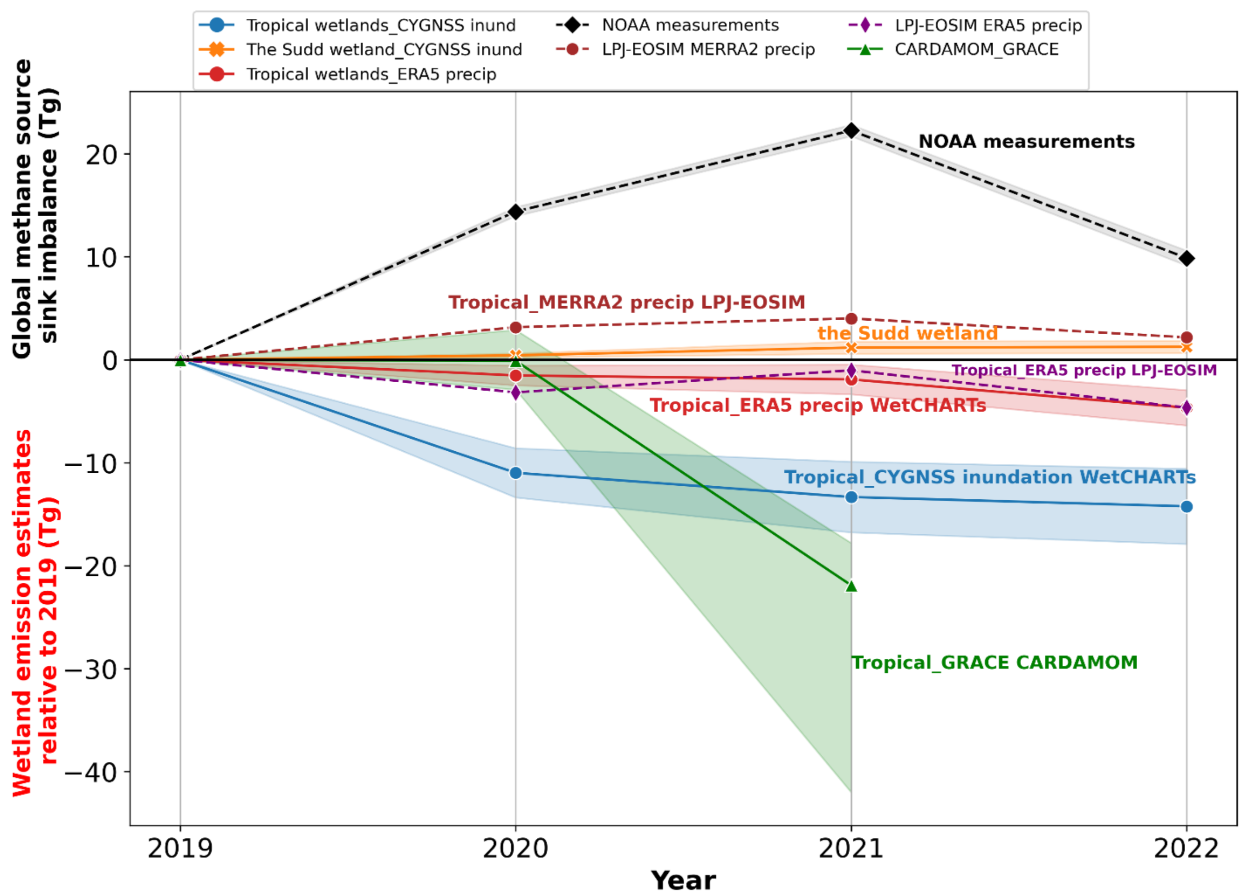

Fig. 3. Growth in atmospheric methane (NOAA) surges in 2020-2022, with tropical wetland emissions derived from multiple models and hydrological drivers unable to capture this large growth. Models driven by Berkeley-RWAWC inundation, ERA5 precipitation, and GRACE water storage anomalies all show methane emissions decline, with one model driven by MERRA2 precipitation predicting very small growth in 2020-2021, much smaller than the atmospheric growth as observed by NOAA. The reference year is 2019 and the shaded area represents the standard deviation.

As shown in Fig. 3, while MERRA2-forced LPJ-ESOIM simulations show a slight emission increase (3.2, 4.0, and 2.2 Tg higher in 2020–2022 *vs.* 2019; brown dashed line), these changes are relatively small compared to the global methane source-sink imbalance (14.4, 22.3, and 9.9 Tg higher for the same years). Additionally, MERRA2 precipitation itself shows a significant increasing trend during 2019-2020 (Fig. R2), followed by a decrease from 2021 to 2023. The highest emission increase in 2021 (4.0 Tg) suggests that LPJ-EOSIM model's sensitivity to MERRA2 may involve non-precipitation variables such as temperature and evapotranspiration.

We highlight that the ERA5-forced LPJ-EOSIM simulations yield decreasing emissions (−3.2, −1.0, −4.6 Tg for 2020–2022; purple dashed line), which is consistent with our WetCHARTs results, further underscoring model sensitivity to climate forcing choice.

We are currently investigating why MERRA2 and ERA5 forcings produce opposite emission trends—a topic for future work. However, this uncertainty does not undermine our core findings, as both scenarios agree that tropical wetlands were not primary contributors to the recent global methane surge, reinforcing other sources (e.g., agriculture, fossil fuels) likely dominated.

We have updated Fig. 3 and added this discussion to Line 306, Page 12, which reads as follows:

"While the MERRA2-driven LPJ-EOSIM model estimates (Fig. S6b) show slightly higher wetland methane emissions in 2020-2022 compared to 2019 (3.2, 4.0, and 2.2 Tg higher annually, Fig. 3), these increases remain relatively small when compared to the global methane source-sink imbalance (14.4, 22.3, and 9.9 Tg higher for the same years). We note that MERRA2 precipitation itself shows interannual variability, with an increase during 2019-2020, followed by a decrease through 2023 (Fig. S8). The peak emission increase in 2021 (4.0 Tg) suggests that LPJ-EOSIM's sensitivity to MERRA2 forcing may involve non-precipitation variables like temperature and evapotranspiration. The discrepancy between MERRA2 and ERA5 forcing results requires further investigation, though both scenarios agree that tropical wetlands were not primary drivers of the recent global methane surge."

Non inundation peatland (water table depth 0-20 cm) could emit methane also, Bekeley-RWAWC potential can distinguish inundated and non-inundated peatlands, with GLWD peatland map. The inundated peatland area decreased or non-peatland inundated area decreased, to explain the decrease in tropical wetland area by Bekeley-RWAWC?

Response: Thank you for your insightful comment. We agree that peatlands with water table depths within 0-20cm can still emit methane even when not fully inundated. Our analysis using Berkeley-RWAWC data (August 2018-April2023) reveals significant declines ($p < 0.05$) in inundated areas across major tropical wetland regions (Fig. R1, top panel), including western Amazonia, the Congo basin, the Pantanal wetland, Uruguay, and parts of Indonesia and Papua Islands—areas known to contain extensive peatlands (Fig. R1, lower panel). By combining this with the GLWD wetland map, we found these declines were particularly evident in specific peatland-associated categories: swamp forest decreased by -0.57%/decade, 50-100% wet and 25-50% wet areas declined by -0.61%/decade and -0.59%/decade, respectively. In contrast, non-inundated peatlands like bogs showed relatively stable trends during 2018-2023.

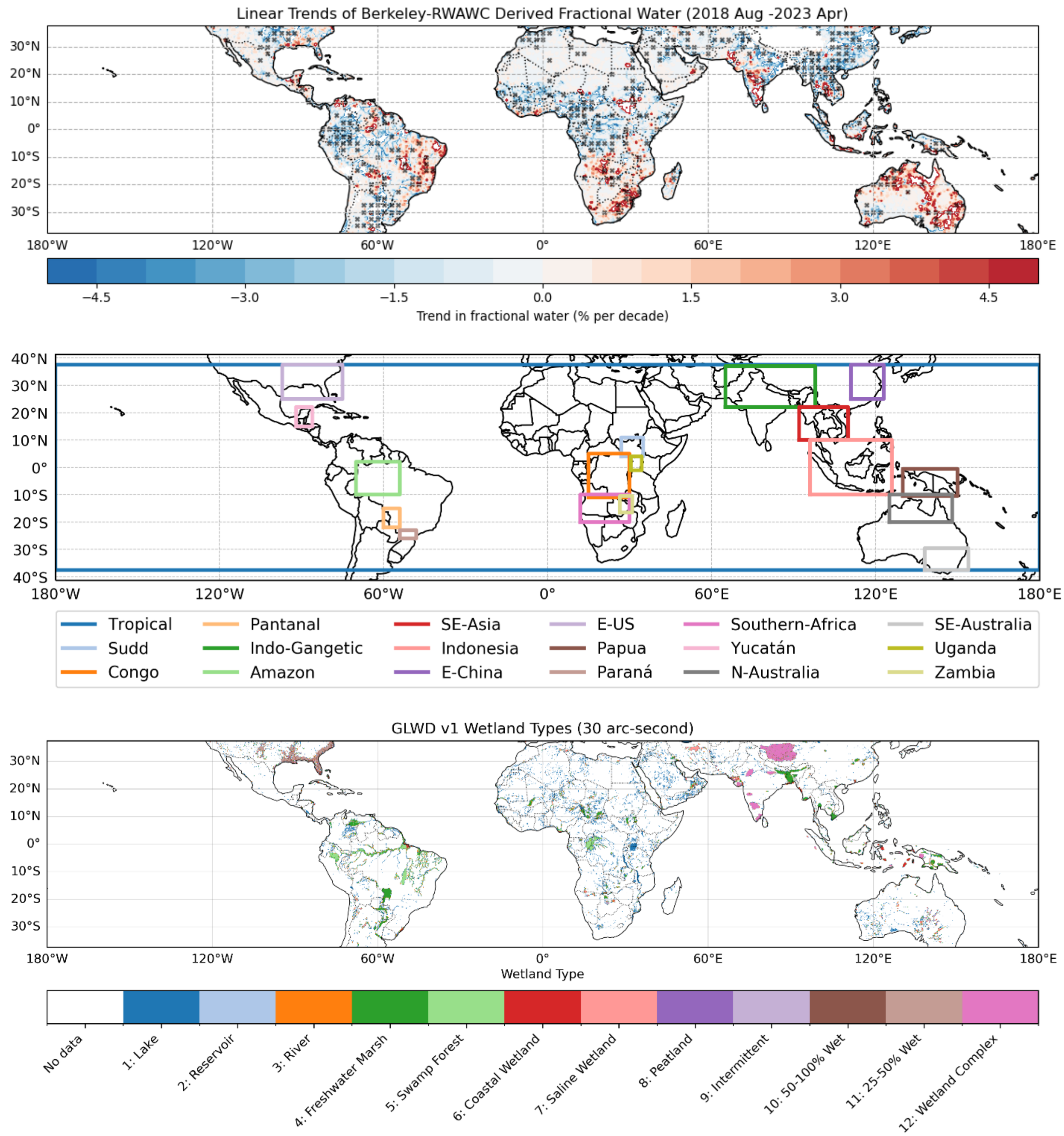

Figure R1. Top panel: Linear trends in Berkeley-RWAWC-derived fractional water across the tropics (August 2018—April 2023). Grey crosses (x) mark significant trends ($p < 0.05$). Middle panel: Locations of 17 wetland basins studied. Lower panel: Wetland types from GLWD Level 3, Version 1 (Lehner and Döll 2004).

This analysis demonstrates that while non-inundated peatlands do contribute to methane emissions, the observed reduction in tropical wetland area was primarily driven by losses in actively inundated peatland areas. The most pronounced decreases occurred in regions with significant peatland coverage, suggesting that declining inundation in these peat-rich ecosystems is a key factor behind the overall tropical wetland reduction observed in Berkeley-RWAWC.

We have added a paragraph to Line 123, Page 4, which reads as follows:

"To identify the regions and wetland types contributing most to declining tropical wetland extent, we conducted a spatial analysis combining the Berkeley-RWAWC inundation data with the Global Lakes and Wetlands Database (GLWD) version 1. Figure S3 shows both the spatial trends in inundated areas and wetland type distributions across the tropics. Our analysis revealed that freshwater marshes and floodplains - particularly those in northern Amazonia, southern Brazil, and the southeastern Indo-Gangetic Plain - experienced the most rapid declines (-1.66%/decade), followed by reservoirs (-0.86%/decade), rivers (-0.85%/decade), and coastal wetlands (-0.77%/decade). Notably, key methane-emitting peatlands including swamp forests (-0.57%/decade) and water-saturated areas (50-100% wet: -0.61%/decade; 25-50% wet: -0.59%/decade) collectively decreased by 1.77%/decade, while non-inundated peatlands like bogs (type 8 in GLWD) showed no significant trends."

Overall, I think this is an important study, so I would like to see more testing, as suggested, for the robustness of the conclusion.

Response: We sincerely appreciate the reviewer's constructive feedback and the opportunity to further strengthen our conclusions! We conducted multiple complementary analyses, including:

(1) Incorporated MERRA2 precipitation data alongside ERA5 and IMERG, revealing consistent interannual patterns (i.e., higher in 2018-2020, lower in 2021-2023) that align with Berkeley-RWAWC inundation data but contrast with GRACE-FO signals.

(2) Analyzed MERRA2-forced LPJ-EOSIM model estimates to recent atmospheric methane growth, showing only minor emission increases ($\leq$ 4 Tg/yr) versus observed atmospheric methane surge (10-22 Tg/yr, relative to 2019).

(3) Overlaid GLWD map with CYGNSS inundation product, confirming that declining wetland areas were most pronounced in key methane-emitting regions, such as Amazon, Congo, Pantanal, and Indonesia. Peatland-associated categories (swamp forests, 50-100% wet, 25-50% wet: -1.77%/decade) and freshwater mashes, floodplain (-1.66%/decade) exhibited the most significant decreases.

These additional tests collectively strengthen our conclusion that tropical wetland emissions were insufficient to drive the 2020-2022 methane surge. We've added these analyses and discussions to both main text and supplementary material.

References:

Ahmed, M., Sultan, M., Wahr, J., & Yan, E. (2014). The use of GRACE data to monitor natural and anthropogenic induced variations in water availability across Africa. *Earth-Science Reviews*, *136*, 289-300

Lehner, B., Anand, M., Fluet-Chouinard, E., Tan, F., Aires, F., Allen, G.H., Bousquet, P., Canadell, J.G., Davidson, N., Finlayson, C.M., Gumbricht, T., Hilarides, L., Hugelius, G., Jackson, R.B., Korver, M.C., McIntyre, P.B., Nagy, S., Olefeldt, D., Pavelsky, T.M., Pekel, J.F., Poulter, B., Prigent, C., Wang, J., Worthington, T.A., Yamazaki, D., & Thieme, M. (2024). Mapping the world's inland surface waters: an update to the Global Lakes and Wetlands Database (GLWD v2). *Earth Syst. Sci. Data Discuss., 2024*, 1-49

Lehner, B., & Döll, P. (2004). Development and validation of a global database of lakes, reservoirs and wetlands. *Journal of Hydrology*, *296*, 1-22

Rodell, M., Barnoud, A., Robertson, F.R., Allan, R.P., Bellas-Manley, A., Bosilovich, M.G., Chambers, D., Landerer, F., Loomis, B., Nerem, R.S., O'Neill, M.M., Wiese, D., & Seneviratne, S.I. (2024). An Abrupt Decline in Global Terrestrial Water Storage and Its Relationship with Sea Level Change. *Surveys in Geophysics, 45*, 1875-1902

Saunois, M., Martinez, A., Poulter, B., Zhang, Z., Raymond, P., Regnier, P., Canadell, J.G., Jackson, R.B., Patra, P.K., Bousquet, P., Ciais, P., Dlugokencky, E.J., Lan, X., Allen, G.H., Bastviken, D., Beerling, D.J., Belikov, D.A., Blake, D.R., Castaldi, S., Crippa, M., Deemer, B.R., Dennison, F., Etiope, G., Gedney, N., Höglund-Isaksson, L., Holgerson, M.A., Hopcroft, P.O., Hugelius, G., Ito, A., Jain, A.K., Janardanan, R., Johnson, M.S., Kleinen, T., Krummel, P., Lauerwald, R., Li, T., Liu, X., McDonald, K.C., Melton, J.R., Mühle, J., Müller, J., Murguia-Flores, F., Niwa, Y., Noce, S., Pan, S., Parker, R.J., Peng, C., Ramonet, M., Riley, W.J., Rocher-Ros, G., Rosentreter, J.A., Sasakawa, M., Segers, A., Smith, S.J., Stanley, E.H., Thanwerdas, J., Tian, H., Tsuruta, A., Tubiello, F.N., Weber, T.S., van der Werf, G., Worthy, D.E., Xi, Y., Yoshida, Y., Zhang, W., Zheng, B., Zhu, Q., Zhu, Q., & Zhuang, Q. (2024). Global Methane Budget 2000-2020. *Earth Syst. Sci. Data Discuss., 2024*, 1-147