

Author Comments

Colour Key: **Reviewer Comment** Our Response **New Manuscript Text**

Reviewer 1

We thank the reviewer for their comments and appreciate them taking the time to review our study.

From how I read the paper, there is a dependence upon accurate anthropogenic/other natural/fire CH₄ emissions for the attribution to wetlands from the GOSAT/TOMCAT retrievals. It appeared to me that those non-wetland sources were assumed to be perfect (along with the atmospheric inversions). I would have liked to see some attempt to understand how reasonable these other CH₄ source estimates were as all error terms were then pushed into the wetland methane emissions.

We agree with the comment (from both reviewers) that the non-wetland CH₄ emissions have the potential to cause issues with our analysis. We have attempted to mitigate these issues in the following ways:

Firstly, we deliberately maintained the same setup as used in Parker et al. (2020) so that we could directly compare the evaluation of JULES to that performed for WetCHARTs. This consistency allows us to draw wider conclusions about the utility of JULES compared against the state-of-the-art data-driven WetCHARTs dataset.

Secondly, the TOMCAT (non-wetland) model setup in this study (and Parker et al. 2020) uses a configuration of the TOMCAT model that has successfully been used in a range of studies. The model set-up, or a very similar one, has been used previously in McNorton et al. (2016), Wilson et al. (2016), Parker et al. (2018) and Parker et al. (2020). The emissions used in the current paper were also used as priors in CH₄ inversions documented in McNorton et al., (2018), Wilson et al. (2021) and Gloor et al. (2021).

Although the uncertainty in wetland methane emissions is typically larger than that from biomass burning, we acknowledge that in some regions the uncertainty on biomass burning may not be insignificant. We have performed (Wilson et al., 2021) a full global inversion of CH₄ flux using the same GOSAT data and model configuration as used in this study. Our findings from that study suggest that flux estimates in fire-affected regions (e.g. in South America and Africa) are generally consistent with the prior values. Despite wetland and burning regions often being spatially (and temporally) distinct, there is the possibility of some interference although any effect is expected to be small. In future work we plan to use newly-developed CO inversions to better represent the CH₄ flux from biomass burning.

The uncertainty introduced through model atmospheric transport and chemistry errors are likely larger than those from non-wetland emissions, and could be quantified in future analysis through use of multiple atmospheric transport models and/or representations of

transport and chemistry. However, the TOMCAT model has been shown in many studies to represent atmospheric transport of CH₄ very well (see references above).

In our revised manuscript we will follow the suggestion from Reviewer 1 and provide a more detailed discussion on the impact of these assumptions:

We do make the assumption that the uncertainties in the inter-annual variability of non-wetland CH₄ sources (such as biomass burning) are much smaller than the uncertainty in wetland methane emissions. This assumption has previously been tested (e.g. Parker et al., 2020, Wilson et al., 2021) and inversion results suggest that whilst it is possible for fire emissions to interfere with our analysis to a small degree, this is largely not the case with flux changes in fire-affected regions generally remaining consistent with the prior. In future work, CO inversions, currently under development, will allow us to better represent the CH₄ flux from biomass burning and separate any effect more explicitly.

In order to show the model performance in non-wetland regions, we will add this additional analysis (as suggested by Reviewer 2) into the appendix as a diagnosis of the non-wetland simulations.

We have performed analysis over three non-wetland areas (as highlighted in red in Figure 1), namely West US, Arabian Peninsula and Western Australia. These regions would not be expected to be dominated by wetland emissions and hence evaluation of the simulated CH₄ column against observations provides an assessment of how the non-wetland emissions in the model are performing. The detrended methane seasonal cycle for the model is compared against GOSAT observations in Figure 2 and we find a very good agreement (with correlation coefficients of 0.89, 0.96 and 0.90, respectively, for West US, Arabian Peninsula and Western Australia).

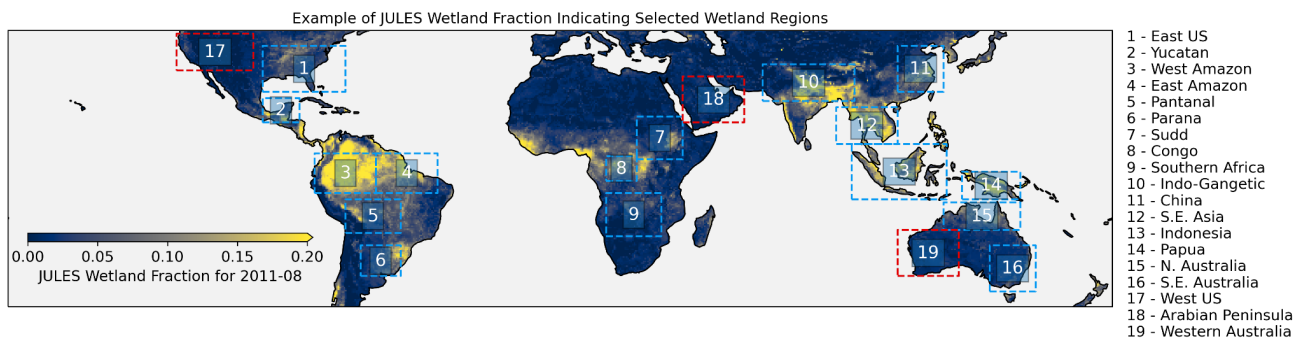


Figure 1 - As Figure 3 in main text but including 3 non-wetland background regions highlighted in red.

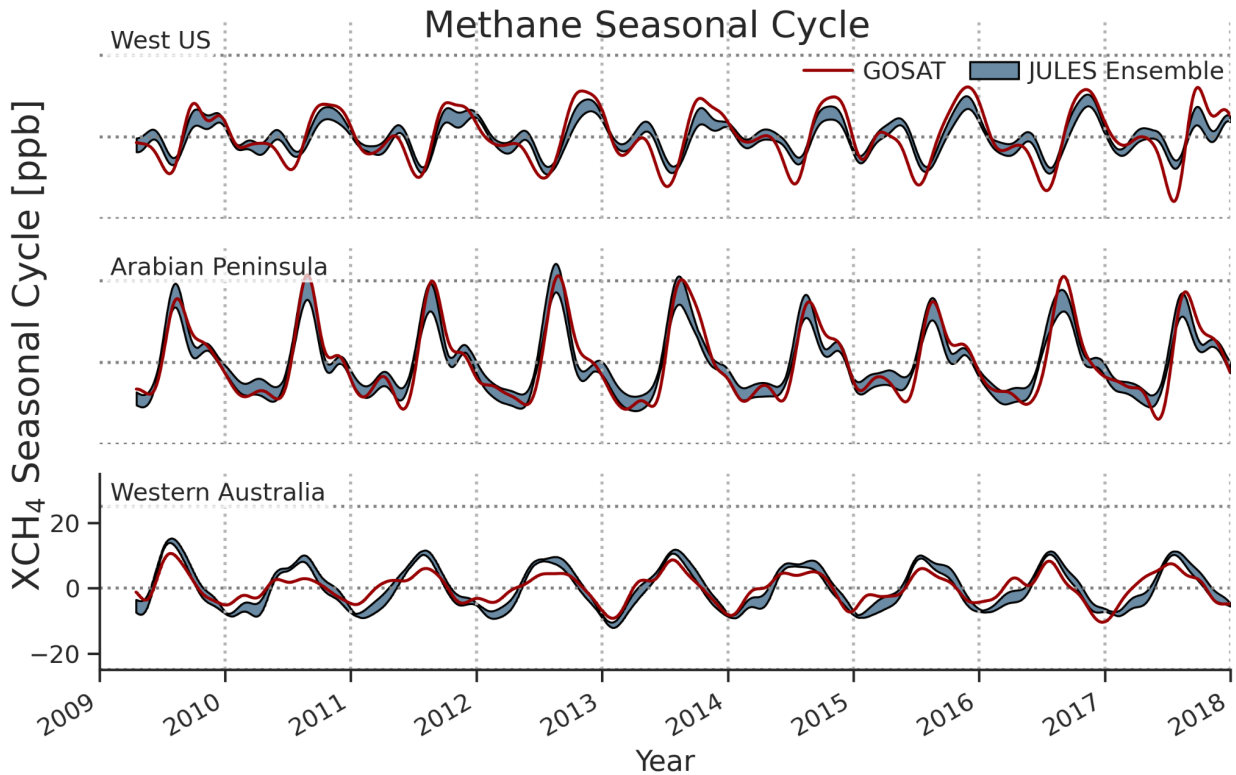


Figure 2: Comparison of the modelled methane seasonal cycle to GOSAT observations over the three background regions.

Minor comments:

- Line 78: 'A deep layer of restrictive water flow' - does that just mean that you provide a no flow condition at 3 m?

Yes, that's correct. JULES appends a 'bedrock layer' below the simulated soil layers and water cannot move into the bedrock (and with the standard configuration the soil layers stop at 3 m).

- L109: Why is the time series scaled to 180 in particular? Why is this step necessary or desired?

The emissions from JULES are scaled so that the global total wetland methane annual emissions for 2000 has a value of 180 Tg/yr to ensure consistency with the best estimate of this value from Saunois et al. (2016). This is the same approach as used for JULES simulations in Comyn-Platt et al. (2018). If this step were not performed, the geographical masking of the JULES emissions by the SWAMPS wetland mask would result in low wetland emissions as rather than re-apportioning the fluxes to the wetland area, they would simply be discarded. This global re-scaling is a common approach and also utilised in the WetCHARTs model (Bloom et al., 2017).

We have clarified the reason for this in the manuscript.

In a post-processing step, the time series of annual wetland emissions of each ensemble member is separately scaled to give annual emissions of 180 Tg CH₄ yr⁻¹ for the year 2000 (Saunois et al., 2016), as described in Comyn-Platt et al. (2018). This step is necessary as the geographic masking of the JULES wetland area with the SWAMPS data would otherwise result in unrealistically low methane emissions due to the more limited geographic area.

- Fig 2: Do all of those in the grid actually give 180 Tg/yr in 2000? Ones like the bottom left seem to hardly be able to (although I realize the time shown is Aug 2011)

Yes, the global total for 2000 is scaled to 180 Tg yr⁻¹ so as to be consistent with Saunois et al. (2016).

- L 137: When a single C pool is used does that mean both the litter and soil (humified) C are tracked in only one pool?

For soil_bgc_model = 1 the single carbon pool is prescribed and not updated in time. We will update the manuscript to clarify this.

..single (fixed) soil carbon....

- L 150: Why use the SWAMPS dataset by itself, with its known inability to detect saturated, but not inundated, wetlands, and not make use of something like WAD2M? I see you use WAD2M later so are definitely aware of it.

Part of this was a practical reason. At the time when we ran our simulations the WAD2M data were not available. These data became available whilst we were performing our final analysis and hence for completeness we incorporated it into the study as part of the interpretation of the results. Reproducing the JULES data with the WAD2M data would be a significant undertaking and hence more suited to a future study, especially given the promising results from CaMa-Flood which we would also incorporate in future work.

Further, we do not expect our use of SWAMPS data instead of WAD2M data to affect the main arguments reported in the study, as ultimately we are evaluating the performance of the JULES land surface model. In either case, the application of an external wetland mask of the simulations is non-ideal and instead the focus is on identifying the processes required in future versions of JULES (such as fluvial inundation) that would allow accurate wetland simulation and negate the requirement for such masking. The use of WAD2M (along with WetCHARTs, GEOS-Chem flux inversions, JULES-CaMa-Flood and MODIS Imagery) in the analysis allowed a strong narrative to be constructed towards these goals.

- line 179 - fix ref.

Fixed

- Fig 4 - what are the units?

The units are in ppb as indicated in the y-axis title. We will make this clear in the figure caption.

- L 320 - WAD2M uses more than microwave remote sensing. Perhaps give a bit more detail here otherwise it sounds like it is just SWAMPS (which does form the seasonality but there are other important differences)

We have updated Section 5.1.2 to provide additional details on WAD2M to address this.

We use the Wetland Area and Dynamics for Methane Modeling (WAD2M) wetland extent dataset (Zhang et al., 2021) which provides global $0.25^\circ \times 0.25^\circ$ estimates of wetland fraction for inundated and non-inundated vegetated wetlands. WAD2M is derived using a combination of surface inundation based on microwave remote sensing data along with static datasets that identify inland waters, agricultural areas, shorelines, and non-inundated wetlands. Areas containing permanent water bodies (such as lakes, rivers, etc), rice paddies and coast wetlands are excluded. The resulting dataset therefore represents the spatiotemporal patterns of inundated and non-inundated vegetated wetlands and is expected to improve estimates of wetland CH₄ fluxes. In this study we use the updated version which spans 2000-2018.

- Fig 12 - missing reference at end? (Fig: boxplot)?

Fixed

- Line 492 - chimney venting? Is this aerenchymal transport that is meant?

Yes. We have clarified this in the text.

Finally, ongoing developments within JULES, such as the “chimney venting” of CH₄ by vegetation (i.e. aerenchymal transport)...

- Code availability - user account required limits reviewers ability to check over code (should they wish to remain anonymous).

We absolutely agree with this and it is part of a wider issue with access to code such as JULES. There is an ongoing initiative to relax the license and make the JULES code openly available. Unfortunately that is not yet available and as such, as a compromise, access is available via a user account.

- L 532- doesn't quite make sense. Needs rewording.

We have reworded this sentence so it is clearer.

References

Bloom, A. A., et al., A global wetland methane emissions and uncertainty dataset for atmospheric chemical transport models (WetCHARTs version 1.0), Geosci. Model Dev., 10, 2141–2156, <https://doi.org/10.5194/gmd-10-2141-2017>, 2017

Comyn-Platt, E. et al, Carbon Budgets for 1.5 and 2 °C Targets Lowered by Natural Wetland and Permafrost Feedbacks, *Nature Geoscience*, 11, 568–573, <https://doi.org/10.1038/s41561-018-0174-9>, 2018

Gloor M, et al., Large Methane Emissions From the Pantanal During Rising Water-Levels Revealed by Regularly Measured Lower Troposphere CH₄ Profiles. *Global Biogeochemical Cycles*. **35**(10) <https://doi.org/10.1029/2021GB006964>, 2021.

McNorton J., et al., Role of regional wetland emissions in atmospheric methane variability. *Geophysical Research Letters*. **43**(21), pp. 11433-11444, <https://doi.org/10.1002/2016GL070649>, 2016.

McNorton, J., et al., Attribution of recent increases in atmospheric methane through 3-D inverse modelling, *Atmos. Chem. Phys.*, 18, 18149–18168, <https://doi.org/10.5194/acp-18-18149-2018>, 2018.

Parker, R. J. et al., Evaluating year-to-year anomalies in tropical wetland methane emissions using satellite CH₄ observations, *Remote Sensing of Environment*, <https://doi.org/10.1016/j.rse.2018.02.011>, 2018

Parker, R. J. et al., Exploring constraints on a wetland methane emission ensemble (WetCHARTs) using GOSAT observations, *Biogeosciences*, 17, 5669–5691, <https://doi.org/10.5194/bg-17-5669-2020>, 2020.

Saunois, M. et al., The global methane budget 2000–2012, *Earth Syst. Sci. Data*, 8, 697–751, <https://doi.org/10.5194/essd-8-697-2016>, 2016.

Wilson C., et al., Contribution of regional sources to atmospheric methane over the Amazon Basin in 2010 and 2011. *Global Biogeochemical Cycles*. **30**(3), pp. 400-420, <https://doi.org/10.1002/2015GB005300>, 2016.

Wilson, C., et al., Large and increasing methane emissions from eastern Amazonia derived from satellite data, 2010–2018, *Atmos. Chem. Phys.*, 21, 10643–10669, <https://doi.org/10.5194/acp-21-10643-2021>, 2021.