Author Comments

Colour Key: Reviewer Comment Our Response New Manuscript Text

Reviewer 2

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

- The TOMCAT model is used to bridge between methane emissions and GOSAT observed column averaged mixing ratios. A model run without wetland emissions serves as a reference that is subtracted from the GOSAT data to derive an 'observational' dataset that is used to evaluate different configurations of the wetland model. It should be made clearer that this evaluation depends critically on the validity of the TOMCAT simulation without wetlands. The uncertainty of that simulation should receive more attention. The implicit assumption is that this uncertainty is small compared to uncertainties due to wetland emissions. However, no evidence is presented in its support. It would have been easy to include a figure comparing TOMCAT to background measurements and assess whether the model – data mismatch is consistent with wetlands as the most uncertain component. It is true that some important other sources do not show a strong seasonality, but due to seasonal variations in atmospheric transport their impact on total column methane will nevertheless vary seasonally.

Please see our response to Reviewer 1 who makes a similar point. We agree with the reviewer that including some additional analysis into the manuscript would strengthen the arguments that we are making in relation to the reliability of identifying an observed wetland methane signal.

- Even if the model performs well against background measurements, this is not a guarantee that GOSAT – model differences are due to wetland emissions. This needs to be acknowledged somewhere.

Please see our detailed response to Reviewer 1 who makes a similar point.

- An ensemble of wetland configurations is used to represent the uncertainty of wetlands, including an alternative representation of meteorology. However, it is unclear why the alternative meteorology is only used to drive the emission computation and not its transport in the atmosphere.

The purpose of this study was to evaluate the capability of the JULES land surface model to reproduce observed wetland methane emissions. Although in order to perform the evaluation using satellite data, these wetland fluxes need coupling with an atmospheric chemistry transport model, it is not within scope of this study to evaluate the performance of the model atmospheric transport itself. We will however make this clearer in the manuscript text as the reviewer is correct that it does introduce an additional uncertainty in the analysis which should be acknowledged.

- It would have been useful to include another representation of the global methane sink and methane sources other than wetlands in the ensemble.

We were very conscious in this study that the purpose is to evaluate JULES and it definitely was not to look into wider issues relating to global sources/sinks which are beyond the scope of this work. The Global Methane Budget team (e.g. Saunois et al., 2020) does an exceptional job at this and both JULES and GOSAT CH4 data are incorporated into that analysis.

- It is unclear how the TOMCAT model tracers are initialized. If the model starts at 2009, when also the comparison with GOSAT starts, the initialization needs to be very good to do without a spin-up to bring the global methane source and sink for each tracer in balance. An explanation is needed of how this was done.

We will add these additional details in to the manuscript text to clarify how the spin-up was performed:

The model was initialised using the same method as Parker et al. (2018) and Parker et al. (2020), which in turn were based on simulations from McNorton et al. (2016). The model tracers were initialised in 1977 and run up to 2004 at coarser resolution (2.8°) than the main simulation. At this point the tracers were scaled to match the overall observed surface concentration for CH4. The period 2004 - 2009 was then run at the 1° resolution, before the analysis begins in 2009.

- Figure 5: It is unclear why the correlation color legend starts at zero. How would negative correlations show up?

These are the correlation values per region:

Global	**0.85**
Northern Hemisphere	**0.81**
Southern Hemisphere	**0.29**
60 North to 60 South	**0.77**
Tropics	**0.43**
North Tropics	**0.73**
South Tropics	**0.00**
East US	**0.83**

Yucatan	**0.71**
West Amazon	**0.58**
East Amazon	**0.37**
Pantanal	**0.83**
Parana	**0.70**
Sudd	**0.23**
Congo	**0.31**
Southern Africa	**0.01**
Indo-Gangetic	**0.76**
China	**0.88**
S.E. Asia	**0.46**
Indonesia	**0.24**
Papua	**0.69**
N. Australia	**-0.16**
S.E. Australia	**0.01**

Table 1 - Correlation coefficients as described and presented in Figure 5 in the manuscript.

We limited the colour scale to start from 0 as only Northern Australia showed a negative correlation and as can be seen by Figure 5 in the manuscript, the wetland signal in Northern Australia is very small (<5 ppb) and hence a correlation is not particularly meaningful. We will however clarify this in the text manuscript.

The lower-limit of the colour scale in Figure 5 is capped at 0, although it should be noted that one region (N. Australia) has a negative correlation of -0.16. However, the seasonal cycle over this region is very small (<5 ppb) and hence the correlation is not particularly meaningful.

- How are regional averages in Figure 5 taken? I suppose that model has been sampled to the coordinates of the GOSAT soundings? But then the global and other region averages are weighted by the uneven coverage of the GOSAT data. In addition, the impact of regional emissions on the total column is not limited to the region where the emission takes place. It could be that emissions from another region contribute more to the reported variability of methane over a region that the sources that are located there. How is this issue dealt with?

Yes, the model is sampled at the time/location of the GOSAT measurement with the scene-specific averaging kernels applied. The time series is then produced by averaging this data over the region and the statistics for the wetland seasonal cycle are produced as outlined in Section 4.

While it is true that some of the total column signal observed by GOSAT will be influenced by emissions from outside of the region considered, this is much less of an issue for GOSAT than it would be for other instruments. GOSAT measurements measure in the shortwave infrared and a consequence of this is that the observations are particularly sensitive to the surface (and hence to emissions). This is in contrast to a thermal infrared instrument (such as IASI) which is most sensitive to the mid-troposphere.

- Related to the previous point: what could be the influence of the seasonally varying coverage of the GOSAT measurements on the derived seasonality for a particular region? How do you avoid that spatial differences between GOSAT and TOMCAT "alias" into apparent seasonal differences?

As we were focusing over tropical wetlands, the seasonal coverage is not as extreme as it would be at high latitude. The reviewer is correct, were we examining boreal wetlands this would be a much larger issue. Furthermore, as our GOSAT retrieval uses the “proxy” method, we are far less susceptible to cloud cover interfering with the retrieval or introducing seasonal sampling biases. GOSAT measures in a gridded pattern, returning to the same location each time and hence the spatial coverage remains consistent.

The figure below (Figure 3) shows an example of this spatial coverage in the form of the sampling density for the African continent, highlighting the very regular measurement locations that are routinely returned to. As discussed in the conclusions to the manuscript text, the Congo area remains challenging to evaluate fully due to the difficulty in obtaining observations and although the observations that are obtained are consistently sampled over space and time, they are much fewer of them than in the other areas we examine.

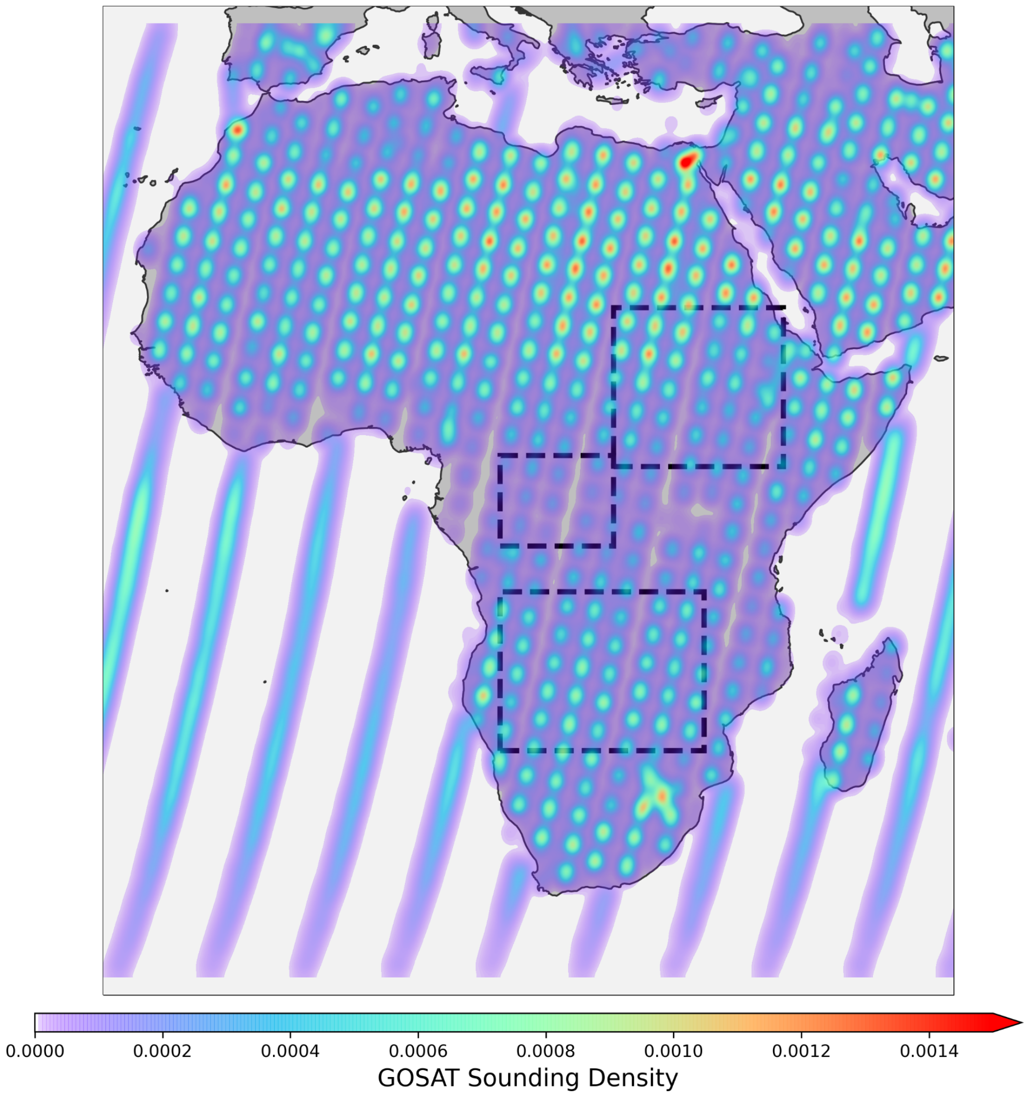

Figure 3: Figure showing the GOSAT measurement density over Africa. The three African wetland regions that we study (Sudd, Congo, Southern Africa) are highlighted by the black boxes.

- Figure 6: Why are changes in correlation coefficient and standard deviation only in positive direction? What happens if the correlation coefficient or standard deviation of the subset is less? If these plots represent the absolute value of changes than the explanation in the caption about improvement or worsening makes no sense. An extended explanation is needed here.

We have attempted to explain this in the manuscript but we will modify this to present a clearer clarification. The values we report are the **change above the minimum value** for each pair/triplet. By construction this is a positive (or zero) value.

For clarity, the values that we report are the change above the minimum value for each pair/triplet and hence, by construction, this is a positive (or zero) value.

- Given its importance, it would be useful – without much work – to differentiate the impact of meteorology further. Is precipitation the dominant factor?

By choosing two different sets of meteorological data (ERA-Interim vs WFDEI) we have attempted to show this effect already. An analysis of the specific differences between these datasets is beyond the scope of this work and is already covered elsewhere (Weedon et al., 2014) but we do highlight some key differences in the manuscript and we will adjust the text to make these more explicit.

In this context, an important factor is that WFDEI precipitation is bias corrected using the observed monthly mean (Weedon et al., 2014). This is likely the cause of the significant improvement in wetland extent obtained by using WFDEI over ERA-Interim.

- Figure 8: The two ensemble member need more distinct colors to be able to see which is which.

We will adjust the colours (currently red and green) to make them more distinct.

- Figure 10, 12 and 13: the references to subfigures in the captions is wrong. What is the color legend of the MODIS imagery, is this RGB?

Fixed captions. The MODIS imagery is RGB and we will clarify this in the captions.

MODIS Imagery (RGB of surface reflectance)

References

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