

# Author Response to Review of Referee #3 for “Seasonal Variability of Stratospheric Methane: Implications for Constraining Tropospheric Methane Budgets Using Total Column Observations”

K. M. Saad<sup>1</sup>, D. Wunch<sup>1,2</sup>, N. M. Deutscher<sup>3,4</sup>, D. W. T. Griffith<sup>3</sup>, F. Hase<sup>5</sup>, M. De Mazière<sup>6</sup>, J. Notholt<sup>4</sup>, D. F. Pollard<sup>7</sup>, C. M. Roehl<sup>1</sup>, M. Schneider<sup>5</sup>, R. Sussmann<sup>8</sup>, T. Warneke<sup>4</sup>, and P. O. Wennberg<sup>1</sup>

<sup>1</sup>California Institute of Technology, Pasadena, California, USA

<sup>2</sup>University of Toronto, Toronto, Ontario, Canada

<sup>3</sup>University of Wollongong, Wollongong, NSW, Australia

<sup>4</sup>University of Bremen, Bremen, Germany

<sup>5</sup>Karlsruhe Institute of Technology, IMK-ASF, Karlsruhe, Germany

<sup>6</sup>Royal Belgian Institute for Space Aeronomy, Brussels, Belgium

<sup>7</sup>National Institute of Water and Atmospheric Research, Omakau, New Zealand

<sup>8</sup>Karlsruhe Institute of Technology, IMK-IFU, Garmisch-Partenkirchen, Germany

*Correspondence to:* K. M. Saad (katsaad@caltech.edu)

We thank Referee #3 for their additional comments.

In addition to the comments replied to below, two of the papers referenced have been changed: Ostler et al. (2015) has been updated to the published version, Ostler et al. (2016), and Toon and Wunch (2014) has been substituted for Wunch et al. (2015) as the more appropriate reference for the TCCON priors in Section 2.2.1.

5

**P 2, L29-33: I would rephrase the characterization of the Stephens et al. (2007) findings. Saying that the NH sink and tropical source were found to be overestimated "when constraining models with aircraft CO<sub>2</sub> profiles" really makes it sound as if the aircraft profiles were assimilated, which isn't the case.**

The wording has been changed to, “ [...] when comparing models to aircraft CO<sub>2</sub> profiles” to avoid mischaracterizing Stephens et al. (2007).

10

**P3, L13: These forward model dependencies of CH<sub>4</sub> concentrations \*on\* vertical transport**

The preposition in this sentence has been updated.

15 **P3, L23: emissions -> emission OR emissions fluxes -> emissions OR emissions fluxes -> fluxes**

This sentence has been changed to, “ [...] we compare the base case simulation to one in which emissions do not vary within each year [...]”

**P6, L7-11: Both reviewers commented on the oddness of this approach for deriving pseudo-aseasonal fluxes, which you**

**explained as being due to a technical limitation of the model setup. Please include this justification here as well, and not only in the Conclusions. Perhaps you could refer to Figure 13 in the appendix as well.**

The following sentences have been added to p.6 l.11: “The model infrastructure posed difficulties for setting the seasonally-varying fluxes constant throughout each year; thus we implement this scaling technique as an alternative to assess first-order impacts of emission seasonality. The resulting changes to the spatial distribution of CH<sub>4</sub> emissions are shown in Fig. 13.”

**P6, L12-15: Reads a bit awkwardly and as a result is a bit unclear. Perhaps break it into two sentences, or rewrite in some way.**

This sentence has been divided into two sentences to improve clarity:

10 “For comparisons with column measurements, model vertical profiles were smoothed with corresponding TCCON CH<sub>4</sub> averaging kernels, interpolated for the daily mean solar zenith angles, and prior profiles, scaled with daily median scaling factors, following the methodology in Rodgers and Connor (2003) and Wunch et al. (2010). Averaging kernels and prior profiles were interpolated to the model’s pressure grid, and all terms in the smoothing equation were interpolated to daily mean surface pressures measured at each site.”

15

**P8, L5: in the both the base and -> in both the base and**

The extraneous “the” has been removed.

**P12, Figure 7 caption: Reunion is not in the Northern Hemisphere, which is implied here.**

20 The inclusion of Réunion Island in the figure caption was an oversight, as Saga and Réunion Island were the only sites with less than a year of measurements a seasonal cycle. The caption now reads, “[...] averaged across Northern Hemisphere sites, excluding Saga, which has less than one year of measurements prior to 2012.”

25 **P14, L11-12: "The model’s stratospheric response to emissions perturbations differ from that of the troposphere and are subject to different transport and loss errors." -> "The model’s stratospheric response to emission perturbations differs from that of the troposphere and is subject to different transport and loss errors."**

The grammatical numbering in this sentence has been changed from plural to singular.

**P15: in text on Figure 9, change "Emissions Seasonality" to either "Emissions’ Seasonality" or "Emission Seasonality"**

30 The legend on Figure 9 now reads “Tropospheric Dependence on Emission Seasonality.”

**P15, L2: emissions errors -> emission errors OR emissions’ errors**

The wording has been changed to “emission errors” on this line, as well as on p. 10 l.6.

**P15, L5-6: "These posterior emissions are scaled for each sector according to their a priori fraction of total emissions in each grid box." Well, it depends a bit on the inversion set-up. Not every system does it quite like this, it depends also on the a priori uncertainties assigned to each sector/process. I don't disagree with the general conclusions, but if you're**  
5 **going to describe a specific inversion approach, please reference it as such. It is possible to not specify the seasonal cycle in the prior, but have it driven by the data alone.**

This phrasing was intended to provide a simplified description of how underlying assumptions about the spatial distribution of a priori emissions for a given sector relative to those of other sectors will impact posterior emissions. In optimizing total CH<sub>4</sub> emissions, we agree that the spatial distribution and seasonality is driven primarily by assimilated data (assuming correct  
10 transport and OH fields). However, even if seasonal cycles for various emissions sectors are not specified a priori, the inversion must include some assumptions about how different sectors are scaled relative to each other for a given data-driven adjustment. In addition, the uncertainties for CH<sub>4</sub> emissions are sufficiently large and unknown that many inversions assign a fixed percentage error for each sector that does not add information about the sectors' relative contributions.

We acknowledge that the phrasing of this sentence could be misunderstood for a delineation of inversion methodology, with-  
15 out consideration of more sophisticated inversion techniques, and have changed it to, "Attribution of these posterior emissions to different sectors depends on a priori information and assumptions about how they vary in time and location relative to one another."

**P 15: "derived by calculating the total emissions resulting from an increase of 1 ppb of CH<sub>4</sub> in each tropospheric**  
20 **column and scaling". I better understood what you did after reading the response to my comment. Please integrate this information into the manuscript so that other readers may also benefit from this clarification (explaining, for instance, that transport is not considered, which is a critical limitation of the approach). And please, reword this sentence to say "the total emissions required to produce an increase of 1 ppb..."**

The additional clarification has been inserted into the text, and the suggestion for the parenthetical on l.9 has also been  
25 incorporated:

"For example, Fig. 10b illustrates the sensitivity of posterior wetland emissions to a three-month lag in the Northern Hemisphere. The change in posterior emissions is derived by calculating the total emissions required to produce an increase of 1 ppb of CH<sub>4</sub> in each tropospheric column and scaling those emissions according to the a priori contribution of wetlands, estimated as the fractional contribution of wetlands to the total monthly mean emissions.  
30 The difference between this change in wetland emissions and the value in the same location three months prior produces the sensitivity of wetland emissions to the tropospheric phase lag. This approach provides an alternative to the computationally expensive calculation of the gain matrix over the entire time series but does not include information about model transport."

**P17, L35: scaled -> scales**

This wording has been updated.

5 **P21, L6: wrong style of reference to Wunch et al. (2015)**

The citation has been corrected to be in-text instead of parenthetical.

**P23, L3: as reference -> for reference**

This wording has been updated.

## References

- Ostler, A., Sussmann, R., Patra, P. K., Wennberg, P. O., Deutscher, N. M., Griffith, D. W. T., Blumenstock, T., Hase, F., Kivi, R., Warneke, T., Wang, Z., De Mazière, M., Robinson, J., and Ohyama, H.: The imprint of stratospheric transport on column-averaged methane, doi:10.5194/acpd-15-20395-2015, <http://www.atmos-chem-phys-discuss.net/15/20395/2015/>, 2015.
- 5 Ostler, A., Sussmann, R., Patra, P. K., Houweling, S., De Bruine, M., Stiller, G. P., Haenel, F. J., Plieninger, J., Bousquet, P., Yin, Y., Saunio, M., Walker, K. A., Deutscher, N. M., Griffith, D. W. T., Blumenstock, T., Hase, F., Warneke, T., Wang, Z., Kivi, R., and Robinson, J.: Evaluation of column-averaged methane in models and TCCON with a focus on the stratosphere, *Atmospheric Measurement Techniques*, 9, 4843–4859, doi:10.5194/amt-9-4843-2016, <http://www.atmos-meas-tech.net/9/4843/2016/>, 2016.
- Rodgers, C. D. and Connor, B. J.: Intercomparison of remote sounding instruments, *Journal of Geophysical Research*, 108, 4116, doi:10.1029/2002JD002299, 2003.
- 10 Stephens, B. B., Gurney, K. R., Tans, P. P., Sweeney, C., Peters, W., Bruhwiler, L., Ciais, P., Ramonet, M., Bousquet, P., Nakazawa, T., Aoki, S., Machida, T., Inoue, G., Vinnichenko, N., Lloyd, J., Jordan, A., Heimann, M., Shibistova, O., Langenfelds, R. L., Steele, L. P., Francey, R. J., and Denning, A. S.: Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO<sub>2</sub>, *Science*, 316, 1732–1735, doi:10.1126/science.1137004, <http://science.sciencemag.org/content/316/5832/1732>, 2007.
- 15 Toon, G. C. and Wunch, D.: A stand-alone a priori profile generation tool for GGG2014, <http://dx.doi.org/10.14291/tcon.ggg2014.priors.R0/1221661>, doi:10.14291/tcon.ggg2014.priors.R0/1221661, 2014.
- Wunch, D., Toon, G. C., Wennberg, P. O., Wofsy, S. C., Stephens, B. B., Fischer, M. L., Uchino, O., Abshire, J. B., Bernath, P., Biraud, S. C., Blavier, J.-F. L., Boone, C., Bowman, K. P., Browell, E. V., Campos, T., Connor, B. J., Daube, B. C., Deutscher, N. M., Diao, M., Elkins, J. W., Gerbig, C., Gottlieb, E., Griffith, D. W. T., Hurst, D. F., Jiménez, R., Keppel-Aleks, G., Kort, E. a., Macatangay, R., Machida, T., 20 Matsueda, H., Moore, F., Morino, I., Park, S., Robinson, J., Roehl, C. M., Sawa, Y., Sherlock, V., Sweeney, C., Tanaka, T., and Zondlo, M. a.: Calibration of the Total Carbon Column Observing Network using aircraft profile data, *Atmospheric Measurement Techniques*, 3, 1351–1362, doi:10.5194/amt-3-1351-2010, <http://www.atmos-meas-tech.net/3/1351/2010/>, 2010.
- Wunch, D., Toon, G. C., Sherlock, V., Deutscher, N. M., Liu, C., Feist, D. G., and Wennberg, P. O.: The Total Carbon Column Observing Network's GGG2014 Data Version, Tech. rep., Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A. doi: 10.14291/tcon.ggg2014.documentation.R0/1221662, doi:10.14291/tcon.ggg2014.documentation.R0/1221662, 25 <http://dx.doi.org/10.14291/tcon.ggg2014.documentation.R0/1221662>, 2015.