AGU ADVANCING EARTH AND SPACE SCIENCE

# AGU Advances

VIEWPOINT
10.1029/2021AV000533

This article is a companion to Ma et al. (2021), https://doi.org/10.1029/2021AV000408.

**Key Points:**

- Reducing methane emissions is key to limiting warming to 1.5 or 2.0°C in emission pathways to 2050
- The climate response of wetland methane emissions is an important uncertainty in how much anthropogenic emissions will need to be reduced
- Atmospheric observations and inverse modeling are crucial to monitoring emission reduction measures and changes in wetland emissions

**Correspondence to:**
R. L. Thompson,
rlt@nilu.no

**Citation:**
Thompson, R. L. (2021). Climate feedback from wetland emissions of methane may necessitate greater anthropogenic reductions. *AGU Advances*, *2*, e2021AV000533. https://doi.org/10.1029/2021AV000533

Received 30 JUL 2021
Accepted 9 AUG 2021



# Climate Feedback From Wetland Emissions of Methane May Necessitate Greater Anthropogenic Reductions

**Rona L. Thompson**[1]

[1]NILU—Norsk Institutt for Luftforskning, Kjeller, Norway

In 2020, global atmospheric methane ($CH_4$) levels continued an upward trend since 2007 and increased by 14.7 parts-per-billion (ppb)—the largest annual increase since atmospheric records began in 1983 (https://research.noaa.gov/article/ArtMID/587/ArticleID/2742/Despite-pandemic-shutdowns-carbon-dioxide-and-methane-surged-in-2020). This is concerning because $CH_4$ is the second most important long-lived greenhouse after $CO_2$ and has a global warming potential 28 times that of $CO_2$ per unit mass on a 100-year time scale (Myhre et al., 2013). Moreover, pathways to limit global warming to 1.5°C, or even 2.0°C, require reductions in non-$CO_2$ emissions and, in particular those of $CH_4$, by 35% with respect to 2010 levels by 2050 (Forster et al., 2018). An important consideration though in how much the anthropogenic emissions will need to be reduced, is how strong the climate feedback will be in natural emissions, especially those from wetlands, which are the most important natural source and the most uncertain component of the $CH_4$ budget (Saunois et al., 2020; Stocker et al., 2013; Zhang et al., 2017). Observational constraints are crucial to better understanding the climate sensitivity of wetland emissions. Ma et al. provide an innovative way to use atmospheric observations to explore how well land surface models capture wetland $CH_4$ emissions and their sensitivity to temperature, precipitation, and soil carbon availability globally.

Understanding of the global $CH_4$ budget has improved with the expansion of atmospheric observational networks. Atmospheric observations of $CH_4$ mole fractions provide an integrated picture of the net effect of the emissions from all sources and the atmospheric sink. Global measurements of atmospheric $CH_4$ mole fractions became available from satellites in the 2000s and have greatly improved in their accuracy and resolution since then. However, the use of atmospheric observations to constrain $CH_4$ emissions requires atmospheric chemistry transport models (ACTMs). ACTMs relate surface fluxes of $CH_4$ to atmospheric mole fractions by solving for transport and chemistry. However, to learn more about the $CH_4$ budget requires relating atmospheric mole fractions to fluxes—this is known as the "inverse problem" and can be solved by "inverse modelling" (a "top-down" method) (for more information see e.g., Rodgers, 2000). Since the problem is not well-constrained, statistical approaches are used to find the most probable fluxes given the observations, a prior estimate of the fluxes and their uncertainties. The prior flux estimate is usually based on process-based models and inventories (these are often described as "bottom-up" methods).

To learn more about wetland $CH_4$ emissions, it is useful to compare process-based model estimates (such as from land surface models) with those based on atmospheric observations, namely, from inverse modelling. Estimates from inverse modelling, however, are convolved with the prior information but fortunately this dependence can be quantified as:

$$x_a = Ax_{true} + (I - A)x_b \tag{1}$$

where $x_a$ is the "analyzed" or optimal flux, $x_{true}$ is the true flux, and A is the so-called Averaging Kernel, which depends on the ACTM and the prior uncertainties prescribed to the observations and prior information (see Rodgers, 2000). This equation is often used to compare independent observations or model simulations of mole fractions with satellite retrievals to make the two comparable by viewing these through the same "lens", that is, taking into account the dependence on the prior information as governed by the Averaging Kernel. Ma et al. (2021) have used this formula in a novel way to compare model-based estimates of wetland emissions to those derived from inverse modeling, and by doing so have eliminated differences between the two due to the dependence of the inversion on its prior information. In this case, the model-based estimate is given by $x_{true}$ and the outcome, $x_a$ can be compared to the inverse modeling estimate. This method has two caveats though: (a) it requires the Averaging Kernel, which cannot be, at least easily, obtained from inverse models using variational methods, and (b) the inverse modeling estimate can still be biased due to systematic errors, namely in the ACTM.

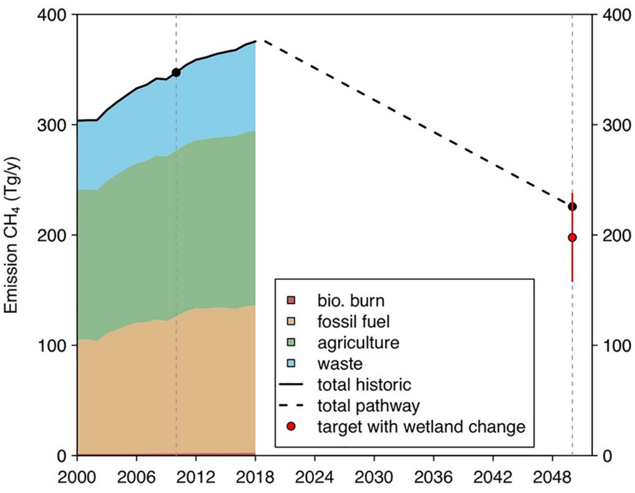


**Figure 1.** Anthropogenic emissions from 2000 to 2018 (based on EDGAR-v6.0) by major source category. The black dots show the 2010 reference and 2050 target anthropogenic emissions. The red dot shows the required 2050 target accounting for projected increases in wetland emissions under the RCP2.6 scenario according to Zhang et al. (2017) with the bar showing the range of the 95% confidence level.

Using this method of comparison, Ma et al. (2021) compared 42 model-based (bottom-up) estimates of global wetland emissions with a (top-down) inversion estimate derived from GOSAT satellite retrievals of $CH_4$, and for which the Averaging Kernel is available. They assessed not only the emissions but also the choice of key parameters and driving data in the models affecting the emissions. They found a temperature sensitivity of tropical wetland emissions that was less than expected, and that tropical emissions are more strongly determined by rainfall, and related to this, wetland area extent. On the other hand, extra-tropical wetlands were mostly sensitive to soil carbon availability and temperature. An independent study, by Zhang et al. (2017) based on land ecosystem models, predicted that wetland emissions will increase by 14 ± 20% (mean and 2-sigma standard deviation) globally by 2050 with respect to 2010 levels for the RCP2.6 climate scenario in which warming is likely not to exceed 2°C. The projected increases were mostly in the tropics owing to changes in precipitation patterns and wetland extent, consistent with Ma et al. (2021). In contrast though, Zhang et al. found little change in northern wetland emissions, even though this is where temperature increases are expected to be the highest over the coming decades (Hoegh-Guldberg et al., 2018) and where Ma et al. find a strong temperature sensitivity.

To achieve 1.5°C or even 2.0°C requires anthropogenic $CH_4$ emissions to be reduced by 122 Tg/y by 2050 (i.e., 35% reduction with respect to 2010 using emission estimates from the Emission Database for Global Atmospheric Research, EDGAR-v6.0, Crippa et al., 2021, Figure 1). The pathways, however, assume no changes in natural emissions, which is a recognized source of uncertainty (Forster et al., 2018). Based on the Zhang et al. (2017) wetland emission changes the required reductions would increase to 150 Tg/y, and for 95% confidence to 189 Tg/y with respect to 2010 levels. This highlights the importance of understanding the sensitivity wetland emissions to climate changes. The kind of observation-based analyses that Ma et al. have used are valuable to unravelling the dependencies of wetland emissions on environmental drivers under current global conditions.

Currently we are not on track to reduce $CH_4$ emissions with fossil fuel use, agriculture and waste having driven much of the recent growth in the atmosphere (Jackson et al., 2020). As temperature increases and patterns of rainfall change, we may see increases in wetland emissions, and this would mean even greater reductions in anthropogenic emissions are needed to achieve climate mitigation targets.

## Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

## Data Availability Statement

Anthropogenic emissions for EDGAR-v6.0 are available from https://edgar.jrc.ec.europa.eu/dataset_ghg60. The wetland CH4 emission projections are available from https://www.pnas.org/content/114/36/9647.

## References

Crippa, M., Guizzardi, D., Schaaf, E., Solazzo, E., Muntean, M., Monforti-Ferrario, F., et al. (2021). *Fossil CO2 and GHG emissions of all world countries*. JRC Report. in prep.

Forster, P., Huppman, E., Kriegler, E., Mundaca, L., Smith, C., Rogelj, J., & Séférian, R. (2018). Mitigation pathways compatible with 1.5°C in the context of sustainable development supplementary material. In *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Retrieved from https://ww.ipcc.ch/sr15/

Hoegh-Guldberg, O., Jacob, D., & Taylor, M. (2018). Impacts of 1.5°C of global warming on natural and human systems. In *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas* *emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Retrieved from https://www.ipcc.ch/sr15/

Jackson, R. B., Saunois, M., Bousquet, P., Canadell, J. G., Poulter, B., Stavert, A. R., et al. (2020). Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources. *Environmental Research Letters*, *15*, 1–8. https://doi.org/10.1088/1748-9326/ab9ed2

Ma, S., Worden, J. R., Bloom, A. A., Zhang, Y., Poulter, B., Cusworth, D. H., et al. (2021). *Satellite constraints on the latitudinal distribution and temperature sensitivity of wetland methane emissions*. AGU Advances. accepted.

Myhre, G., Shindell, D., Bréon, F. M., Collins, W., Fuglestvedt, J., Huang, J., et al. (2013). Chapter 8: Anthropogenic and natural radiative forcing. In *Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*.

Rodgers, C. D. (2000). *Inverse methods for atmospheric sounding: Theory and practice*. World Scientific. https://doi.org/10.1142/3171

Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., et al. (2020). The global methane budget 2000-2017. *Earth System Science Data*, 1–138. https://doi.org/10.5194/essd-2019-128

Stocker, B. D., Roth, R., Joos, F., Spahni, R., Steinacher, M., Zaehle, S., et al. (2013). Multiple greenhouse-gas feedbacks from the land biosphere under future climate change scenarios. *Nature Climate Change*, *3*(7), 666–672. https://doi.org/10.1038/nclimate1864

Zhang, Z., Zimmermann, N. E., Stenke, A., Li, X., Hodson, E. L., Zhu, G., et al. (2017). Emerging role of wetland methane emissions in driving 21st century climate change. *Proceedings of the National Academy of Sciences*, *114*(36), 9647–9652. https://doi.org/10.1073/pnas.1618765114