Climate feedback from wetland emissions of methane may necessitate larger anthropogenic reductions to stay within 1.5°C or 2.0°C warming

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Abstract

In 2020, global atmospheric methane (CH4) levels 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) continuing an upward trend since 2007. This is concerning since CH4 is the second most important long-lived greenhouse after CO2 and has global warming potential 28 times that of CO2 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 non-CO2 emissions and, in particular, CH4 emissions, to be reduced by 35% with respect to 2010 levels by 2050 (Forster et al. 2018).

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Climate feedback from wetland emissions of methane may necessitate larger anthropogenic reductions to stay within 1.5°C or 2.0°C warming

Viewpoint Commentary on: Satellite constraints on the latitudinal distribution and temperature sensitivity of wetland methane emissions by Ma et al.

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Main Text

In 2020, global atmospheric methane (CH4) levels 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) continuing an upward trend since 2007. This is concerning since CH4 is the second most important long-lived greenhouse after CO2 and has global warming potential 28 times that of CO2 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 non-CO2 emissions and, in particular, CH4 emissions, to be reduced by 35% with respect to 2010 levels by 2050 (Forster et al. 2018).

Causes for the increase in CH4 over the decade since 2007 likely include emissions from fossil fuel production and use, as well as from agriculture and waste, and a small increase from natural wetlands, with the anthropogenic sources accounting for 80% of the increase (Jackson et al. 2020). The cause of the surge in CH4 in 2020, however, is not yet known. Although the role of wetlands is thought to be relatively small in the last decade, it remains the most uncertain source in the global CH4 budget and one of the most variable (Saunois et al. 2019). In addition, wetland emission of CH4 could represent an important climate feedback mechanism (Zhang et al. 2017; Stocker et al. 2013), hence, if emissions increase from this natural source, even greater reductions in anthropogenic emissions would be required to attain the 1.5°C or 2.0°C targets.

Understanding of the global CH4 budget has improved with the expansion of atmospheric observational networks. Atmospheric observations of CH4 mole fractions provide an integrated picture of the net effect of the emissions from all sources and the atmospheric sink. Global measurements of atmospheric CH4 mole fractions became available from satellites in the 2000s and have greatly improved in their accuracy and resolution since then with new instruments, such as TROPOMI onboard the satellite Sentinel 5P. However, the use of atmospheric observations to constrain CH4 emissions requires atmospheric chemistry transport models (ACTMs). ACTMs relate surface fluxes of CH4 to atmospheric mole fractions, but to learn more about the CH4 budget requires relating atmospheric mole fractions to fluxes – this is known as the “inverse problem”. Since the problem is not well-constrained, statistical approaches are used to find the most probable fluxes given the observations. Using Bayes’ Theorem and assuming Gaussian probability distributions, this can be formulated as finding the fluxes that minimize the cost function:

$$J(x) = (x - x_b)^T B^{-1} (x - x_b) + (H(x) - y)^T R^{-1} (H(x) - y) \quad (1)$$

Where x and x_b are vectors of the optimal and prior values of the flux, H(x) is the ACTM applied to the fluxes, y is the vector of atmospheric observations, B is the error covariance matrix for the prior flux estimate and R is the observation error covariance matrix (for details see (Rodgers, 2000). The optimal flux estimate, x, depends on the prior estimate, x_b, where the dependence is governed by the number and quality of the observations as well as on how they relate to the fluxes as determined by the ACTM.

To learn more about wetland CH4 emissions, it is useful to compare process-based model estimates 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:

$$x_a = Ax_{\text{true}} + (I - A)x_b \quad (2)$$

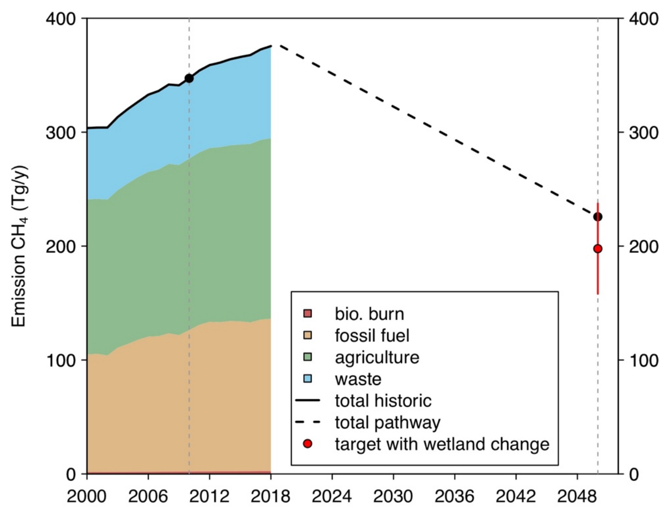
Where x_a is the "analysed" or optimal flux, x_{true} is the true flux, and A is the so-called Averaging Kernel, which depends on the ACTM and the error covariance matrices, B and R (see Rodgers, 2000). This equation is often used to compare independent observations or model simulations of mole fractions with satellite retrievals to make the two comparable by viewing these through the same "lens", i.e., 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 an atmospheric inversion, 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 modelling estimate. This method has two caveats though: i) it requires the Averaging Kernel, which cannot be, at least easily, obtained from inverse models using variational methods, and ii) the inverse modelling estimate can still be biased due to systematic errors, namely in the ACTM.

Using this method of comparison, Ma et al. (2021) compared 42 model-based estimates of global wetland emissions with an inversion estimate derived from GOSAT satellite retrievals of CH4, 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% and 19 ± 24% (mean and 2-sigma standard deviation) globally by 2050 with respect to 2010 levels for climate scenarios where warming is likely not to exceed 2°C, i.e., RCP2.6 and RCP4.5, respectively. The projected increases were mostly in the tropics owing to changes in precipitation patterns and wetland extent, consistent with Ma et al. (2021), but not unexpected since their ecosystem model (LPJ-wsl) was ranked as one of the high performing models by Ma et al. based on the agreement with the inversion estimates. 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 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). 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 under the RCP2.6 scenario, the required reductions would increase to 150 Tg/y, and for 95% confidence to 189 Tg/y or equivalently by 54% with respect to 2010 levels (Figure 1).

This highlights the importance of understanding the sensitivity wetland emissions to climate changes, as this will determine how effective mitigation pathways for CH4 will be, and how much additional emission reduction may be necessary to limit warming to 1.5°C or 2.0°C. Moreover, if temperature increases exceed 2°C before 2050, then greater changes in wetland CH4 emissions are expected, requiring even greater reductions in anthropogenic emissions.



The reduction of CH4 emissions is an essential feature of the emission pathways to 2050, thus it is necessary to carefully monitor CH4 emissions using atmospheric observations and inversions to guide emission reduction measures and to monitor their effectiveness. In addition, it is essential to monitor and improve understanding of natural, especially wetland, emissions, the future evolution of which is an important component of uncertainty in the remaining C budget to achieve 1.5°C or 2.0°C warming limits.

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.

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Data availability

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