Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2019-131-AC2, 2019

Interactive comment on "Is Shale Gas a Major Driver of Recent Increase in Global Atmospheric Methane?" *by* Robert W. Howarth et al.

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Received and published: 3 June 2019

Author response to anonymous review #2 (3 June 2019):

I greatly appreciate the kind words of the reviewer in finding my study novel and valuable. The reviewer has one major question, one major suggestion, and several more minor additional comments. I respond to each of these below.

GENERAL COMMENT #1: "I have tried at some length, but I cannot understand equation 1. Figure 3A shows the weighting used by Worden et al, whereas Figure 3B has the new weighting used here. My understanding is that equation 1 converts the results of Worden et al shown in Fig 3A into the new division of Fig 3B. It makes sense to neglect biomass burning here as that's assumed to be the same in both. I don't understand, however, why the Worden et al estimate for biogenic (left side of equation 1) would be equal to the redistributed sum including the total CG term. For example, if there were no shale gas production (SG=0), this equation should maintain the Worden et al results, but it seems to me it doesn't as the CG*DA-CG term would still be there. Should not the 'CG' in that equation actually represent the change in CG in the reweighted values compared with the Worden et al value rather than the entire CG emissions? Then the equation would represent the revised biomass term, the shift due to the additional SG term, and the decreased allocation to CG, which should sum to the total of the original biomass plus CG from Figure 3A."

The reviewer is correct. In the revised manuscript, I have completely rewritten the approach, deriving new equations, and better explaining the logic. The new language follows:

"To explore the contribution of methane emissions from shale gas, we build on the analysis of Worden et al. (2017). Figure 3-A shows the δ13C values used by them as well as their mean estimates for changes in emissions since 2008 (as they estimated using the δ13C data of Schwietzke et al. 2016). Figure 3-A represents a weighting for the change in emissions (y-axis) and the δ13C values of those emissions (x-axis) by individual sources. Our addition is to separately consider shale gas emissions, recognizing that methane emissions from shale gas are more depleted in 13C than for conventional natural gas or all other fossil fuels as considered by Worden et al. (2017). For this analysis, we accept that net total emissions increased by 24.7 Tg per year ($\pm$ 14. Tg per year) since 2007, driven by an increase of $\sim$28.4 Tg per year for the sum of biogenic emissions and emissions from fossil fuels and a decrease of $\sim$3.7 Tg per year for emissions from biomass burning (Worden et al. 2017).

"We start with the Eq. (1) which explicitly considers methane emissions from shale gas:

(BN - BW) + (FFN - FFW) + SG = 0 (1) where BN is the estimate from Worden et al. (2017) for the increase in biogenic emissions of methane globally after 2007, BW is our new estimate for the increase in these biogenic fluxes, FFN is the estimate from Worden et al. (2017) for the increase in emissions of methane globally from fossil fuels after 2007, FFW is our new estimate for the increase in fossil fuel emissions after 2007 other than from shale gas, and SG is our estimate for emissions from shale gas after 2007. That is, the inclusion of an estimate for shale gas is matched by changes in the estimated fluxes from biogenic sources and other fossil fuels.

"Eq. (2) then reweights the information in Figure 3-A for the difference between most fossil fuels and shale gas, multiplying global mass fluxes for each source by the difference between the δ13C ratio of each source and the flux-weighted mean for all sources:

(BN - BW) * DB-A = [(FFN - FFW) * DA-FF)] + (SG * DA-SG) (2)

where DB-A , DFF-A, and DSG-A are the differences in the δ13C ratio of biogenic emissions, fossil fuels, and shale gas compared to the flux-weighted mean δ13C ratio for all sources (A). The x-axis of Figure 3-B shows the δ13C for each source; note that the y-axis is the estimate of the change in emissions for each of these sources that we derive below. Next, if we multiply both sides of equation 1 by DB-A and rearrange,

(BN - BW) * (DB-A) = - [(FFN - FFW) * (DB-A)] - (SG * DB-A) (3)

"Subtracting equation 3 from equation 2,

0 = [(FFN - FFW) * (DA-FF + DB-A)] + [SG * (DA-SG + DB-A) (4)

"Rearranging equation 4,

SG = - (FFN - FFW) * (DA-FF + DB-A) / (DA-SG + DB-A) (5)

"Note that from Worden et al. (2017), FFN is 16.4 Tg per year."

From here, the text closely follows that in the "discussion" manuscript, except using updated values in response to comments from reviewers #1 and #3.

MAJOR SUGGESTION: “2) In addition to using isotopic data to identify the source of the recent increase in observed methane concentrations, the other information that previous studies have used is the geographic location of observed trends. This can help determine if the source is likely tropical (and hence probably biogenic) or from Northern Hemisphere mid-latitudes (and hence more plausibly with a substantial fossil share). This paper doesn’t address this issue, and while it doesn’t contribute new knowledge in this area it would be good for the reader to have a short discussion of results from this line of inquiry and how those compare with the conclusions drawn here. For example, Nisbet et al claim their box model suggests much of the increase is from tropical or Southern latitudes. The Rice et al study (already cited) found conflicting results, however. Similarly, at least some studies using satellite observations have suggested that increases are largely at mid-latitudes (e.g. Schneising et al; Turner et al). Additional References: Nisbet, E. G., et al. (2016), Rising atmospheric methane: 2007–2014 growth and isotopic shift, Global Biogeochem. Cycles, 30, 1356–1370, doi:10.1002/2016GB005406. Turner, A. J., et al., Geophys. Res. Lett., 43, 2218, 2016.”

This is a good suggestion, and I will bring this information into the revised manuscript as I rewrite, including the two satellite papers (Schneising et al. and Turner et al.), the Nisbet et al. (2016) paper and also a new Nisbet et al. (2019) paper. Regarding Rice et al., please note that their analysis ends in 2009, just at the time the shale gas revolution was starting, and so their findings are not applicable to my paper; I will make mention of this in my revised manuscript.

ADDITIONAL COMMENTS:

“P1, L22: UNFCC should be UNFCCC”

Thanks, correction made.

“P1, L29: This is the first mention of Fig 1A. This has an error in the y-axis labels, which show 1880 where it should be 1800.”

Correction made.

“P2, L1: There should be a space before the delta symbol, here and hereafter (e.g. P2,L21; P3,L18, etc.).”

Oddly, the spacing is fine on my Word version, but obviously is wrong on the generated pdf. I will try to fix this.

“P3, L25: How are the 61 data points weighted, all the same? It there is uneven sampling, is it necessary to weight by geographic location to avoid bias (e.g. giving equal weight to the three regions mentioned previously)?”

Yes, all points were weighed equally. Since the different studies all had a similar number of points, this is not a large issue, although I agree with the reviewer it would be better to weight them. However, in response to a comment from reviewer #1, I am no longer relying on these 61 data points. Please see my second response to reviewer #1 (posted 3 June 2019).

“P4, L25: In the text reading DA-CG, the ‘A-CG’ portion should be subscript.”

Correction made.

“P5, L20-21: Should say something like ‘estimated based on satellite observations’ rather than ‘as measured from satellite data’ as the satellite cannot measure any specific source of methane emissions, only total methane concentration.”

Good point; I will make this revision.

“P8, L34-P9, L1: The text here states that “the model scenarios presented in the IPCC report emphasize reducing carbon dioxide emissions first, and these scenarios begin to reduce methane emissions only after 2030.” This is incorrect. The scenarios are designed to achieve long-term targets at least cost, and as methane reductions are often very cost-effective these occur fairly rapidly in most scenarios. For example, Figure SPM.3a shows methane emissions relative to 2010 in the 1.5C scenarios, and the midpoint of the range is about a 40% decrease by 2030. Reductions are indeed typically larger and more rapid for CO2, but methane drops quite substantially early on."

I have deleted this text.

"P8, L1-L2: The phrase 'This may reflect the belief of the IPCC authors that methane emissions are dominated by biogenic sources' is not an appropriate way to describe characteristics of the scenarios in the SR1.5. The scenarios do not reflect beliefs of the authors, but rather results from integrated assessment models that the authors analyzed. Language such as "This may reflect an overestimate of the fraction of methane emissions attributed to biogenic sources in the underlying integrated assessment models" would be much better."

I have deleted this text.

"P9, L7-11: Some related calculations were shown in Shindell, D., J. S. Fuglestvedt, W.J. Collins, The Social Cost of Methane: Theory and Applications, Faraday Disc., 200, 429-451, doi: 10.1039/C7FD00009J, 2017, which could be noted here."

Thank you for this lead.

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