Ms. Ref. No.: acp-2019-90

Title: Measuring methane emissions from oil and gas platforms in the North Sea

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Dear Editor,

We thank Mr Varon for his comments. As suggested, we have amended the manuscript to address the reviewers' comments and suggestions.

Please find our detailed responses below.

Yours sincerely,

Stuart Riddick (corresponding author)

Stuart N. Riddick, Denise L. Mauzerall, Michael Celia, Neil R. P. Harris, Grant Allen, Joseph Pitt, John Staunton-Sykes, Grant L. Forster, Mary Kang, David Lowry, Euan G. Nisbet, and Alistair J. Manning

Reviewer: Daniel Varon

Specific comment #1
Page 2, Lines 13-14: To my knowledge, the studies cited (Zavala-Araiza et al., 2015 and Schwietzke et al., 2017) do not directly discuss methane emissions from offshore platforms. Perhaps this sentence could be broken into two sentences or parts, the first citing these studies as evidence that public inventories often underestimate methane emissions, and the second suggesting that the same may be true for offshore oil and gas platforms.

Author's response:
As suggested this sentence has been edited.

Change to manuscript:
P2 L19
"However, recent studies indicate public inventories in the United States underestimate CH_4 emissions including from the oil and gas supply chain (Alvarez et al., 2018; Zavala-Araiza et al., 2015, Schwietzke et al., 2017). This leads to the question: Could CH_4 emissions from offshore oil and gas platforms be higher than previously estimated?"

Specific comment #2
P2, L17-19: Nara et al. (2014) quantified methane emissions from offshore platforms in Southeast Asia using a mass balance approach, but the authors describe that study as qualitative rather than quantitative. It would be helpful to clarify this comparison in the manuscript.

Author's reply:
As suggested a comparison between the findings of this study and Nara et al. (2014) have been made and included in the introduction and the discussion.

Changes to manuscript:
P3 L6
"However, a mass-balance approach identifies CH_4 emissions from offshore oil and gas operations off the coast of South East Asia as having a large regional median (range) emission of 99 (4 – 427) g CH_4 s^{-1} $platform^{-1}$ for the Malay Peninsula and 15 (2 – 46) g CH_4 s^{-1} $platform^{-1}$ for Borneo (Nara et al., 2015)."

P11 L29
"Moreover, the median value of this study (6.8 g s^{-1}) is much smaller than the regional median emission estimate of 99 g s^{-1} for the Malay Peninsula and 15 g s^{-1} for Borneo (Nara et al., 2015), which suggests that the ambient leakage rate may be lower in the North Sea than other regions of the world."

Specific comment #3
P3, L19-20: I would recommend removing this novelty claim, because the study is clearly original. Targeted measurement of methane emissions from individual oil and gas platforms is an impressive contribution. This sentence could be replaced with a one- or two-sentence comparison to the previous work of Nara et al. (2014).

Author's comment:
Thank you for the endorsement of our work. As suggested, we have removed the sentence about novelty.

Specific comment #4
P4, L24: The maximum horizontal distance from the platforms is reported to be 1500 m, but some platforms in Table 1 have distances of 2000 m.

Author's reply:
This was a typo and has been corrected.

Change to manuscript:
P4 L21
"and 2 km horizontal distance"

Specific comment #5
P8, Figure 3: Peak enhancements (2160-2230 ppb) do not match the value reported in Table 1 (2290 ppb). Can the authors clarify in the table caption (or elsewhere in the manuscript) whether the downwind methane concentrations reported in Table 1 represent peak concentrations, or something else?

Author's response:
This should have been platform ID #6 instead of # 5. The caption has been corrected.

Change to manuscript:
P8 Caption Figure 2
"Minute-averaged CH_4 mole fraction measurements made upwind and downwind of production platform, ID # 6, on the 24th of August."

Specific comment #6
P8, L11-14: The total emission from the 8 platforms should not be compared to the total production from only 6 platforms unless there is good reason to believe that the missing production rates are small. Indeed, if one of platforms #1 or #2 produced as much gas as platform #4, the calculation would be quite different. One solution to this problem would be to compare emissions and production rates only for platforms #3-#8. Another option would be to impute the production rates for platforms #1 and #2 from the average (or median) of the other platforms' rates.

Author's response:
As suggested we have changed the calculation to only include platforms 3 to 8. Text has been included to the caption of Table 1 and the manuscript to reflect this.

Change to manuscript:
P7 Table 1 caption
"The calculation of the "Median", "Mean" and "Total" only use data from platforms #4 to # 8. Platforms #1 and #2 did not have production data available for the time of measurement. During the measurement of Platform #3 the height of the PBL was calculated as zero (GFS, 2019) making the Gaussian plume modelled emission estimate ambiguous."

P8 L11

"During the measurement of platform #3, the calculated boundary layer height was 0 m (GFS, 2019) making the emission estimate ambiguous and, even though presented in Table 1, has not been used further in the analysis. Using emission data from the five platforms with available production data and with a non-zero calculated PBL (platforms #4 through #8), the median CH_4 emission was 6.8 g s^{-1} (mean 11.2 g s^{-1})."

Specific comment #7
P9, L12-15: Why might the Pasquill-Gifford stability classes used to infer emissions from the platforms be too stable? What would cause the difference between stability at the receptor and stability at the source? Is it the difference in wind speed between the surface and 40-90 m altitude? If so, would this not suggest that the stability class as assessed at the surface might be too unstable (due to the winds being faster at altitude)? One additional sentence would probably clear this up.

Author's response:
The methane lost from the platform may be less stable as it has come from the subsurface and may be a warmer than the surrounding air and therefore less stable. As a test, we suggest this could be 1 PGSC less stable than calculated. To clarify this text has been added.

Change to manuscript:
P6 L11
"The uncertainty in the PGSC used reflects the possibility that the temperature of the natural gas leaving the subsurface could be hotter than air and therefore less stable."

Specific comment #8
P10, L8: Why are the estimated platform emissions larger than BEIS reported emissions of 0.13% by a factor of 2, but similar in magnitude to NAEI emissions? From page 6, line 1, it seems like the BEIS and NAEI figures should be similar, since the BEIS data "form the basis for emissions reported under category 1B2 within the National Atmospheric Emissions Inventory (NAEI; BEIS, 2018)." This can also probably be clarified in a sentence.

Author's reply:
The platform emissions are twice as large as the BEIS emission estimates but appear to be consistent with the NAEI because NAEI currently only accounts for venting and flaring not leakage. Here we present the leakage estimates only as venting and flaring were not taking place. It is only by coincidence that our leakage estimates are the same as the NAEI values.

Change to manuscript:
P10 L11
"neither of which was taking place during our measurements"

Specific comment #9
P10, L25-31: I am a bit hesitant to draw broad conclusions about global methane emissions from the oil and gas sector based on results from a small number of offshore platforms. It is interesting that the Oil and Gas Climate Initiative does not include ambient emissions in its global estimates when these emissions seem to be significant (as the authors illustrate), but I would expect their magnitude to vary greatly across geographies and industries. Indeed, the authors make note of this variability on page 2, line 15, and mention also the particularly harsh environment of the North Sea on page 10, line 20. I would recommend that the authors more

clearly qualify their extrapolation of ambient emissions from North Sea offshore platforms to ambient emissions from global oil and gas activities.

Author's reply:
The text has been amended to reflect the speculative nature of this statement. The idea of this paragraph was to merely represent the concept of emissions from leakage and the potential impact of these measurements.

Change to manuscript:
P11 L25
"If a global CH_4 emission from ambient leakage of 0.19% estimated by this study (0.8 Tg CH_4 yr^{-1}) is added to the current global estimate from flaring, venting and offshore oil loading (1.6 Tg CH_4 yr^{-1}) the total CH_4 emission from offshore oil and gas production would increase significantly. It should be noted that the value of 0.19% is based on a very small sample size using a method that comes with significant uncertainty."

Technical correction #1
Page 1, Line 4: The words "onshore" and "offshore" are spelled differently throughout the text, both with and without dashes.

Author's reply:
Have amended to be consistently "onshore" and "offshore".

Technical correction #2
P2, L10: The acronym "OGA" is not defined.

Author's reply
The acronym has been defined as the UK Oil and Gas Authority.

Change to MS:
P2 L16:
"(UK Oil and Gas Authority, 2018)."

Technical correction #3
P3, L11: The acronym "EEMS" is not defined.

Author's reply:
EEMS has been defined as the Environmental and Emissions Monitoring System.

Change to MS:
P3 L17:
"UK Government's Department of Energy and Climate Change Environmental and Emissions Monitoring System (DECC EEMS, 2008)"

Technical correction #4
P7, L10-11: Redundant use of the word "example."

Author's reply:
Deleted as suggested.

Technical correction #5
P9, L8: It seems like there might be a missing word here.

Author's reply:
Have amended the sentence.

Change to MS:
P8 L14
"As a sensitivity study, the median modelled emission is 2,658 g s^{-1} (mean 1,892 g s^{-1}) when we assume all CH_4 is emitted from the highest point of the platform, i.e. the flare."