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Interactive comment on "Quantifying alkane emissions in the Eagle Ford Shale using boundary layer enhancement" *by* G. Roest and G. Schade

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The authors' responses to Anonymous Referee #2 are below. Each response is provided below the Referee's original comments.

General comments

"This paper provides an emission estimate from a region with extensive oil and gas production whose emissions are not well known, and would therefore be an important addition to the body of knowledge concerning methane and alkane emissions from oil and gas production regions in the U.S. However, I have some concerns regarding the analysis that I think must be addressed before this paper is ready for publication. My main concerns are discussed in the next two paragraphs. Some lesser concerns are brought up in the Other Comments section."

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Discussion paper

"I am concerned with using Barnett tank alkane ratios to represent tank emissions from the Eagle Ford. First, the alkane ratios could be significantly different from the two regions. My understanding of the Eagle Ford shale is that produces a very wet mixture of hydrocarbons. Do the authors have data from any other oil producing regions in the U.S., like the Bakken or a traditional oil producing region? If they used those ratios, how would that affect the analysis results? I think more work will need to be done to show the effects of this assumption, especially since it plays such a large role in the results."

Response: We agree that using alkane ratios from liquid storage tank emission samples from the Eagle Ford Shale would be the most appropriate data to use in this study. However, we are not aware of such data publicly available for the Eagle Ford. While we have inquired about non-public data with two possible sources, our requests were unsuccessful. The available data, i.e. the sampled emissions from liquid storage tanks in the Barnett Shale are variable in composition and this is incorporated into our Monte-Carlo error analysis. The composition of emissions from oil and condensate storage tanks in other areas of Texas (Hendler et al., 2009) are also largely variable. We assume that the average composition of liquid storage tank emissions in the Eagle Ford falls within that variability of the Barnett Shale samples, although this assumption does introduce an uncertainty in our analysis. The text has been updated to emphasize this assumption and the associated uncertainty.

"Another concern I have is with the use of ground-based sampling to represent the entire vertical extent of the planetary boundary layer. I think some discussion of the location of possible sources of methane relative to the sampling sites is necessary. This is especially true for the Floresville site, which may be influenced by emissions that have not mixed completely through the planetary boundary layer on more days than just 18 March 2015."

Response: We agree that vertical measurements of alkane mixing ratios would validate the assumption that upwind emissions have been mixed through the planetary bound-

ary layer (PBL). An aircraft campaign in the Barnett Shale has shown that methane emissions were thoroughly mixed downwind [Karion et al., 2015]. While we do not have alkane measurements in the vertical, the assumption of well-mixed upwind emissions is defensible. Our analysis shows that the long-term increasing trend in ethane enhancement between Corpus Christi and San Antonio parallels the development of the Eagle Ford Shale, suggesting that the Eagle Ford is responsible for the emissions that have led to said increase. Furthermore, the Eagle Ford Shale is sufficiently upwind of Floresville such that a discrete plume from a nearby source should be thoroughly dispersed in the afternoon PBL before it reaches Floresville. This is based on the finding that the nearest potential source is approximately 12 km upwind (a well pad south of the site), while all other sources are at least 15 or more kilometers upwind. Under typically conditions used in this study with boundary layers of 1.5-2 km depth and convective velocity scale values of 1-2 m s-1, vertical dispersion occurs within approximately 30 minutes, while horizontal transport at typical wind speeds of 5 m s-1 will require more than 30 min to reach the Floresville site.

Other comments

"p. 1, Line 25, is carbon monoxide a HAP? I don't see it here: https://www.epa.gov/haps/initial-list-hazardous-air-pollutants-modifications"

Response: This has been addressed in the text.

"p. 2, Line 10, please add Olaguer et al. to the References"

Response: Olaguer (2012) is already included in the references.

"p. 2, Line 14, How does the 5750 Gg of methane compare to the EPA GHG inventory? If they are the same, I'd cite the GHG inventory. If they are different, I'd still use the GHG inventory, but note the difference. Also, does this number include emissions from petroleum production as well as natural gas? Since you included associated gas in the leak rate calculation for the Eagle Ford on p. 11, line 27, the national leak rate should

also include emissions from petroleum production."

Response: The methane emissions estimate from the EPA NEI Oil and Gas Emissions tool is lower than that of the GHG inventory because the GHG inventory includes emissions from federal offshore waters (the Outer Continental Shelf) while the EPA NEI Oil and Gas Emissions tool does not. Since the Energy Information Administration includes natural gas from federal waters in their U.S. natural gas production estimate, the emissions estimate of 5,750 Gg from the EPA NEI Oil and Gas Emissions tool has been replaced by the GHG inventory estimate of 6,616 Gg of methane emissions in 2011. This number includes emissions from both oil and gas wells.

"p. 3, Line 16, This emission rate is somewhat misleading. Schneising et al. reported an energy content leak rate, which is not the same as a natural gas leak rate. The energy content leak rate takes into account the oil produced as well as the natural gas. See Howarth [Energy and Emission Control Technologies, 2015, p. 48] or Peischl et al. [JGR-Atmospheres, 2016, p. 2] for a discussion on this issue."

Response: We agree that the context of an emission rate must be explicit. We chose to express the emission rate of natural gas as a fraction of produced natural gas to be consistent with most studies in other shale areas, including dry shale basins such as the Marcellus, as well as bottom-up greenhouse gas inventories (e.g. EPA GHG). We have revised the manuscript to clarify the context of the emission rate. If we were to compare the methane emissions to produced energy following Scheising et al., our emission rate would be lower as the produced energy in the Eagle Ford is largely in the form of oil. However, note that the combined emissions of ethane, propane, and butanes exceed the mass of methane emissions in our study. This suggests that a comparison of methane emissions alone to produced energy content may not be appropriate because it excludes the energy emitted in the form of non-methane VOCs. We consider this to be beyond the scope of this manuscript.

"p. 4, Line 21, Why did you use the EDAS 40 km dataset for meteorology over others?

Perhaps include a sentence explaining your choice."

Response: This dataset was chosen for computational efficiency while running the HYSPLIT trajectory model over a set of several years. Despite its relatively coarse grid, it will capture the general synoptic-scale flow, so it is sufficient to use to identify days with southeasterly flow. A sentence was added to the text. Note that a more robust meteorological dataset (the NARR) was used to calculate emissions.

"p. 5, Line 1, Please show a time series of the background upwind mixing ratios and the enhanced mixing ratios at Floresville. This will give the reader a sense of how well the background sites represent the background air impacting the Floresville site."

Response: A timeline of the ethane mixing ratios at the upwind site in Corpus Christi and the downwind site in Floresville has been added to the supplemental information document. This figure also shows the seasonality of ethane which was questioned in another comment.

"p. 7, Line 7, Please provide some discussion of the PBL height and what effect the uncertainty of the modeled PBL height has on the analysis. Has the modeled PBL height been verified using LIDAR or aircraft measurements?"

Response: The planetary boundary layer height does serve as a source of uncertainty. The uncertainty was estimated using the spatial variability of the PBL height in a subset of grid cells in between the upwind and downwind sites. Supporting Table S3 shows the height of the PBL for each afternoon and the standard deviation of the aforementioned cells. This standard deviation was used to introduce uncertainty into the Monte Carlo simulation. On average, the PBL height was 1789 m with a standard deviation of 164 m. This is a relative standard deviation of 9.2%. That is small compared to the relative uncertainty of the ethane enhancement and the alkane composition in the raw natural gas and tank gas samples. A few sentences have been added to the manuscript to emphasize the uncertainty in the meteorological variables. A reference has also been added for a study in which the NARR PBL heights were shown to have no strong

bias compared to objectively determined PBL heights from sounding data, though the correlations were moderate and seasonally dependent.

"p. 9, Line 1, Did you not see a seasonal change in background ethane due to greater chemical loss during the summer?"

Response: The timeline of the ethane mixing ratios at the upwind and downwind sites shows the seasonality of background ethane mixing ratios. A brief discussion has been added to the text.

"p. 11, Line 33, A comparison with the EPA inventory estimate from petroleum production would be a fairer one, considering how much oil is produced in the Eagle Ford shale."

Response: Please see the response for the comment pertaining to p. 3, Line 16.

"Conclusions section, Please include a time frame for your emissions estimates. Are they for the entire study period? If so, please state this explicitly in the Conclusions."

Response: The emissions were estimated for a set of 68 days from August 2013 through August 2015. This was added to the text.

Grammar suggestions:

"p. 3, Lines 7-10, This is a long sentence. Consider splitting it up into two."

Response: Done

"p. 10, Line 1, I'm not sure "constraint" is a verb, unless it is an old-timey past tense."

Response: This was fixed in the text.

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