

Interactive comment on “Volatile organic compound emissions from the oil and natural gas industry in the Uinta Basin, Utah: point sources compared to ambient air composition” by C. Warneke et al.

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Received and published: 21 August 2014

We thank both reviewers for their insightful comments. Reviewer #1's comments particularly helped to bring the paper more in line with industry standard terms and reviewer #2's comments to clarify the discussion of the various emission sources in the basin. In the following we respond to all comments raised by the reviewers and describe the changes to the manuscript in detail.

Reviewer #1

C6101

1. The presented data adds to an emerging body of data that considers the variation of VOC emission from oil and gas emission sources. The paper provides a useful contrast between different source types and product types. The difference between VOC emission compositions from dry gas, wet gas and oil well is of critical importance for a variety of air quality issues.

2. The paper would benefit from additional grammatical review. A case in point is the first sentence of the abstract; “Emissions of” rather than “The emissions of”. However this is not critical as the paper clearly explains the presented data. Also some loose statements are made, e.g. p11897 line 20: “was very small” needs clarification. We have changed the wording as suggested. We also replaced “very small ozone production” with “no ozone exceedances”.

3. The use of the terms “dry-gas collection” and “wet-gas collection” are confusing given the importance of the produced hydrocarbon composition. The definitions given in the paper conflict with the industry standard definitions of “wet gas” and “dry gas”. Also perhaps “consolidated from multiple wells” versus “single well.” Then perhaps the best-associated term is “collection and dehydration.” We have replaced the term “wet and dry gas collection” in the paper to “well pads with and without dehydration” as the reviewer suggests. We also used the term “consolidated from multiple wells” where appropriate.

4. The use of the terms “gas wells” and “oil wells” is also confusing. Given that the paper is measuring not just wells but also additional emission sources then “wells” should be replaced with “well pads.” We have now also used the term “well pads” instead of just “wells” in the paper where appropriate.

5. The paper relies upon comparison of ambient mixing ratios with some measurements in close proximity to emission sources. However there is no quantification of identified emission sources. This limitation is acknowledged in a couple of locations including the conclusions. However the paper should refer to existing and emerging

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techniques that can provide quantification; namely tracer release methods and remote geospatial Gaussian methods. We have added a sentence to the conclusion about the various possibilities for emission measurements of well pads as suggested. There is as of yet very little available in the literature about the tracer releases and the Gaussian method for oil and gas exploration. These methods are now frequently used and will be very helpful in future studies. We have added the reference to Allen et al (2013), who determined emissions from many parts of the well pads.

6. Given that there are likely to be considerable truck traffic emissions associated with well pads is there any influence noted in the VOC measurements? We have only measured well pads that had no truck traffic in the vicinity in order to have no interferences. We have added that to the text as well.

7. While the lack of correlation with methane is noted p11907 line 10 this is an important finding that merits more discussion. It points to fugitives being dominated by processing (dehydration) as opposed to handling (pneumatic valves/well heads). The reviewer is correct. It seems that the handling emits the raw gas and the processing emits heavier compounds. We have added this more clearly to the discussion of Figures 5 and 6 that show the measurements of the individual well pads and also to the comparison with the WRAP emission inventory.

8. While the authors note that sample sizes are limited the paper compares data to inventory information. I cannot find an exact indication of the number of pad measurements performed that are shown in figures 2, 7, 8 and 9. This is important as were 9 out of 1000 gas wells sampled? The number of measured well pads and other point sources is given on page 11903 in line 15.

9. Section 3.4 is a little confusing and hard to follow. On p11909 sentence starting on line 23 is that what the data shows? I would place a period after dehydrators and a separate sentence that notes the most important inventory categories for VOC. Given that sources were not quantified what is the metric to state "broadly consistent" p11909

C6103

line 29. We have reworded this paragraph and made clearer what we know from the inventory and what specific measurements can be used for confirmation.

10 and 11. Given the title of the paper I do not understand why sources (5) and (6) are noted but then excluded from analysis. Also while other sources are noted (7) these are not really discussed. How can the flow back pond source be included in the conclusions when detailed discussion of this source (5) is noted as being published elsewhere? Indeed should these sources be included in the figures (and paper) and/or be given full discussion. In the paper we clearly focus on the oil and gas well pad measurements, because they are by far the most common point sources in the basin and we also have the most measurements of them. In addition, the WRAP inventory has VOC compositions for well pad emissions, which were compared to the measurements. Other point sources (e.g.: flow back ponds or evaporation ponds) are far less common. We have very few measurements of them and also little information from the inventory about them, such that meaningful comparisons are difficult. Nevertheless, we think it is important to show that these other point sources have similar mixing ratios associated with them and not many orders of magnitude larger, which could offset the small number of point sources compared to the oil and gas well pads. Therefore we would like to keep the relatively short discussion about the other point sources as is in the paper. We have changed the title of the paper to better reflect our focus on oil and gas well pads in the paper and removed the sentence about the flow back pond from the abstract as suggested by the reviewer.

12. Where did the ethane (and other light NMHC) data come from that is used in Figure 13. These are data from the Horse Pool site measured by GC-MS as shown in 11909 line 17-20.

Reviewer #2

C. Warneke et al., present concentrations of selected volatile organic compounds and NO₂ measured in ambient air at a ground site in Unita Basin, Utah as well as concen-

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trations measured in the immediate vicinity of various sources related to the oil and gas industry. Interesting observations include variations of the VOC composition between different types of gas wells: with and without Dehydrators, oil wells, condensation and water tanks and other sources. Comparing the measured individual source profiles with the ambient air measurements the authors have concluded that the main emission sources in the Uinta Basin are individual wells, such that the observed VOC composition is a mixture of raw natural gas with oil and condensate tank flushing. These data are important for regional air quality.

P11899 L20: only NO₂ data were discussed in the text; do we need details of the O_x and NO_x measurements? The O_x measurements are an intricate part of the instrument and we would like to leave the discussion in the paper, even though we don't use them. Also this would only shorten the paper by a few words.

P11902 L3 "the mixing ratios observed at the site are characterized ... by very high mixing ratios during short-term spikes caused by local point sources." What are these local sources? Do they have any relation to the oil and gas industry? It would be useful to add to Fig. 2 a more detailed map of the sampling site with a scale showing closest wells and other possible sources. We have added another insert to Figure 2 that shows the many oil and gas wells surrounding the Horse Pool site. There are no other possible sources besides the oil and gas industry in the vicinity of Horse Pool. The whole Uintah Basin has only a few small towns and the Bonanza power plant, but the emissions are lofted with the stack outside the mixed layer in winter. This discussion has also been added to the description of Figure 2.

In Fig. 3 it looks like the methane concentration is sometimes lower than 2 ppm. Was the background level of methane subtracted? It would also be useful to include not just max and average concentrations, but minimum detected values too. Figure 3 was originally scaled from 1.5 ppm and now starts at 0 ppm. We also added a sentence about the lowest mixing ratios measured at Horse Pool, which were typical wintertime continental background values.

C6105

In Fig. 5 and 6 for some of the compounds there are elevated concentrations when the truck goes in one direction, but no spikes when it goes in the opposite direction at the pad entrance. Is there any explanation for this? In Figures 5 and 6 it can be seen that in a few occasions the plume was not measured on some of the transects, which is a result of the variable wind speed and direction and also of incomplete mixing so close to the emission sources. This is added to the text now.

P11906 L17 "Methanol was also one of the very few compounds that was not well correlated with the other hydrocarbons at Horse Pool (e.g. R₂ = 0.18 with benzene)". Does this indicate that gas wells are not significant sources of methanol in the area? Figure 5 shows clearly that gas wells are a major source of methanol, but there are also many other sources. Methanol is also emitted by different processes than the other hydrocarbons and as a result the degree of correlation with benzene is lower for methanol. We have added this to the text.

P11907 L8 "The Horse Pool data show good correlations for all compounds with benzene" It would be more informative to show a table with R₂ values for the correlation with benzene. The table can be added to supplement materials. We have added a lower limit for the correlation coefficient ($r^2=0.91$). We don't think it is necessary to add a table, since all the coefficients are so similar.

P11907 L11 "The slopes of the larger aromatics and the cycloalkanes with benzene in the oil well sector are clearly different from the gas well sector and the difference increases with the molecular weight of the compound." It would be much easier to analyze Fig. 10 if the author would draw linear fit lines similar to what is presented in the top right panel in all other panels. We have added all the lines for the linear fits to Figure 10. The slopes of those lines (and others not included in Figure 10) are then of course used for the analysis in Figure 11.

Fig. 13 Can relative contributions of raw gas and tank flashing to the total emissions be estimated from the available data? Using the measured VOC composition at Horse

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Pool and a linear combination of the VOC composition from WRAP for tank flashing and the raw gas could give relative contributions for the two sources. We don't have detailed enough VOC composition measurements from the mobile lab and at Horse Pool we are biased towards gas wells without dehydration. Furthermore the VOC compositions from the inventory are uncertain. Overall this would lead to such large uncertainties that we would not get useful results and decided to not add this to the paper.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 11895, 2014.

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