Review of Orak et al.

The authors present several months of near-continuous monitoring of a suite of air quality metrics including NOx, CO, CO2, CH4, and VOCs at site located near a natural gas well in the Marcellus Shale region of West Virginia. The measurements were conducted throughout the key phases of the drilling process, including hydraulic fracturing and flowback of a horizontally-drilled well. The authors present the observed mixing ratios for select species during different well-activity periods and use positive matrix factorization (PMF) to identify "three factors impacting air quality at the site" which basically boil down to the background air, flowback/natural gas fugitive emissions, and engine exhaust.

The measurements are valuable but the analysis could use a more thoughtful/through approach and attention paid to similar studies that were not cited. I recommend publications after major revisions/additions.

General comments:

Measurement details – there isn't much information included on the distance/direction between the measurement site and the drilling activities. Other than a wind rose (Figure 2), how often was the measurement site directly downwind? Do any of the PMF factors or other chemical parameters relate to the windspeed and direction?

The authors left a lot of useful analysis out regarding the VOC measurements, which are a key component of air quality measurements and are relatively scarce in the literature making these all the more important to expand upon. The authors should report the ethane/methane ratio for comparison (see Yacovitch et al. 2014) as it is a key metric to defining natural gas emissions from other methane sources and is important for emissions modeling purposes. Also, the iso- to n-pentane ratio that is used to separate gasoline related sources from raw oil and natural gas (see Gilman et al. 2013). Gasoline/traffic is an important source that I'm surprised the PMF didn't pick out as the measurement site looks to be in close proximity to an interstate highway. The basic statistics of all VOCs should be reported for the flowback portion at a minimum.

Lastly, this isn't the first study of its kind (L117). Please refer to and include discussion of Hecobian et al. (2019). Whenever possible, please use the correct engineering terms such as "hydraulic fracturing" instead of "frac" or "fracking" to be more precise.

Other comments in order of appearance:

Line 72: Simulated what? Drilling, the economy, …?

Line 73: By the public of the potential public health impacts…

Line 74: hydraulic fracturing, referred to as "fracking"

Line 82: Add Hecobian et al. 2019

Line 97: Add reference Gilman et al. 2015

Line 117: Hecobian et al. 2019. Not the first/only but likely so if limiting to Marcellus.

Line 157: hydraulic fracturing fluid

Line 270: Did you see any instances of NOx titration? Often, with sharp NO spikes in concentration from local sources, you will see an equally sharp decrease in ozone.

Line 272: The reference to Edwards et al. takes on several different forms throughout the manuscript – be consistent.

Line 317: How is natural gas only 1% methane??? This doesn't make any sense. Also, you expect the n-alkane isomers to be more prevalent in natural gas than the branched isomers; however, you are reporting iso-pentane > n-pentane which sounds more like a mobile source emission. These percentages aren't consistent with other oil and natural gas studies. How does this composition compare to the Swarthout paper or any other source in the Marcellus?

Line 323: This sounds more like a regional background. How do you know it's transport or active chemistry?

Line 334: Toluene is also a known component of oil and gas extraction and is often in hydraulic fracturing fluid.

References:

Demonstration of an Ethane Spectrometer for Methane Source Identification. T. I. Yacovitch, S. C. Herndon, J. R. Roscioli, C. Floerchinger, R. M. McGovern, M. Agnese, G. Petron, J. Kofler, C. Sweeney, A. Karion, S. A. Conley, E. A. Kort, L. Naehle, M. Fischer, L. Hildebrandt, J. Koeth, J. B. McManus, D. D. Nelson, M. S. Zahniser and C. E. Kolb. *Environmental Science & Technology*, 48(14), 8028-8034, doi:10.1021/es501475q, **2014**

Source Signature of Volatile Organic Compounds from Oil and Natural Gas Operations in Northeastern Colorado. J. B. Gilman, B. M. Lerner, W. C. Kuster and J. A. de Gouw. *Environmental Science & Technology*, 47(3), 1297-1305, doi:10.1021/es304119a, **2013**

Air Toxics and Other Volatile Organic Compound Emissions from Unconventional Oil and Gas Development. A. Hecobian, A. L. Clements, K. B. Shonkwiler, Y. Zhou, L. P. MacDonald, N. Hilliard, B. L. Wells, B. Bibeau, J. M. Ham, J. R. Pierce and J. L. Collett. *Environmental Science & Technology Letters*, 6(12), 720-726, doi:10.1021/acs.estlett.9b00591, **2019**