Executive Summary of Interim Report

"Continuous Airborne Measurements and Analysis of Oil & Natural Gas Emissions During the 2021 Denver-Julesburg Basin Studies"

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Oil and gas operations (O&G) generate substantial amounts methane (CH_4) and other volatile organic compounds (VOCs) that adversely impact local air quality and global climate. In September and October of 2021, we made direct measurements of these trace gases and meteorology in the Denver-Julesburg Basin (DJB) in order to quantify the strength of these emissions and their dependence with time. Determining the flux of O&G methane is complicated by other nearby or collocated sources including cattle, landfills, wastewater treatment facilities, and urban areas. To separate emissions from O&G, we made simultaneous measurements of ethane (C_2H_6) – a tracer for fossil fuels and not emitted by biogenic sources. Based on best available data, our O&G emissions for 2021 were about 18 metric tonnes (10^6 g) of methane per hour – a value similar to measurements from 2012 and 2015. As a fraction of production, however, this represents a substantial decrease because production was roughly twice as high in 2021 as in 2015. Ethane was down from ~7 to 2 metric tonnes of per hour suggesting substantial improvements in engineering.

Our Interim Report provides comprehensive details and preliminary conclusions from airborne investigations of the emissions of CH_4, C_2H_6, and associated pollutants including volatile organic compounds (VOCs) from O&G sources in the DJB in September and October of 2021. As shown by the associated maps, the most productive O&G section of this basin is the Wattenberg field, which encompasses much of Weld County and portions of Larimer County in Colorado. By the end of October 2021 there were 18,538 active wells in this region, and these are highlighted by the light gray dots. These maps also show the numerous additional sources of CH_4 in this region, which are not sources of C_2H_6 from: Concentrated Animal Feeding Operations (CAFOs); landfills; waste water treatment facilities; and dairies. An overview discussion of these maps is presented with the maps.

The University of Colorado (CU) and the University of Maryland (UMD) in collaboration with TOFWERK USA successfully carried out a total of nine flights from September 17, 2021 – October 5, 2021 on the University Maryland University Research Foundation's (URFs) Cessna 402B research aircraft over the DJB, and six of which were considered appropriate for mass balance analysis in deriving the flux for CH_4, C_2H_6, and various VOC gases. Based on two flight days extensively studied thus far over the DJB (Oct. 1 and Oct. 5, 2021), we derive an average **total CH_4 and C_2H_6 emission flux of 23.3 ± 4.5 and 2.1 ± 0.5 tonnes/hour (1 tonnes/hour = $1x10^6$ grams/hour), respectively.** The error bars here represent the total uncertainty (random and systematic error estimates) at the 1σ levels. Table 1 provides a comparative summary of our 2021 results along with those from other DJB studies, which includes: the University of Arizona airborne measurements acquired over the same period; the 2015 studies by Peischl et al. (2018) and the 2012 studies by Petron et al. (2014). Our analysis includes preliminary DJB CH_4 flux estimates due to O&G operations only based upon correlations of methane with ethane, which only

highly correlates for O&G operations. A more sophisticated analysis approach based upon Positive Matrix Factorization will be carried out in the near future in an attempt to derive this information.

Table 1: Summary of DJB Mass Balance Results. The Study period represents the period of the actual measurements and not the published paper.

Study Period	Total CH_4 Flux 10^6 g/hr	O&G CH_4 Flux Estimates 10^6 g/hr	Total C_2H_6 Flux 10^6 g/hr
Petron May 2012	26.0 ± 6.8	19.3 ± 6.9 (74 ± 33%)	
Peischl April 2015	24 ± 5	18 ± 8 (75% ± 37%)	7.0 ± 1.1
Univ. of Arizona Sept/Oct 2021	25 ± 7	19.8 (79%)	
CU/UMD Oct 1, 2021	**19.7 ± 4.2***	**14.4** (73%)**	**1.9 ± 0.6***
CU/UMD Oct 5, 2021	**26.9 ± 7.9***	**22.3** (83%)**	**2.2 ± 0.8***
Averaged CU/UMD	**23.3 ± 4.5**	**18.4**	**2.1 ± 0.5**

*The total uncertainty calculated from an error propagation analysis.
**Estimates from the correlation coefficients in the present study

This comparative summary table shows four important points: 1) the averaged CU/UMD total CH_4 flux is in agreement with the total basin CH_4 flux from the University of Arizona carried out over the same time period; 2) the CU/UMD O&G CH_4 flux estimate is also in agreement with that from the University of Arizona; 3) the total basin CH_4 flux and the flux estimate due to O&G activities have not changed over 9 years, despite a factor of ~ 2 increase in natural gas production over Weld County from 2015 to 2021, based upon COGCC data production statistics; and 4) the C_2H_6 flux has decreased by a factor of 3.3 over the 6 year period from 2015 to 2021.

The reason(s) for the rather significant decrease in the C_2H_6 flux is(are) still unclear. The mass flux ratio of ethane/methane from the Peischl study, 7/18 = 39%, does not match the 2021 CDPHE composition downstream data for statewide gas plants, which indicates an ethane/methane weight ratio of 9.9%. The present estimated ratio of 2.1/18.4 = 11% is more in line with the CDPHE composition statistics. This apparent inconsistency, which clearly warrants additional investigation, could imply that the 2015 Peischl study may have been preferentially sampling enhanced C_2H_6 emissions from leaking storage tanks where the CH_4 has been largely removed at the well head. An alternative explanation being investigated is that the design of production well pads have changed substantially between 2014 and 2022, resulting in more C_2H_6 recovered without escaping to the atmosphere.

The data acquired by the CU group using a similar C_2H_6 spectrometer on NCAR's C-130 during the 2014 FRAPPÉ study and the Aerodyne group on NASA's WP3 aircraft during this same 2014 time frame during the DISCOVER-AQ study, both over the DJB, provides additional evidence for enhanced C_2H_6 emissions during the earlier studies. Despite the fact that mass balance flights were not carried out in these 2014 studies, Table 2 shows that the median boundary layer C_2H_6 values in 2014 relative to 2021 were ~ 36% to 52% higher, and the average values were nearly a factor of 2 higher. It is also worth noting, that with the exception of the one very large enhanced C_2H_6 emission source measured near Greeley airport during 2021, the 99 percentile 2014 C_2H_6 data range between a factor of ~ 3 to 4 times higher than those in 2021.

Table 2: Comparison of C_2H_6 measurements employing similar IR spectrometers in the boundary layer over the DJB. The 2014 C130 and 2021 Cessna measurements employed similar CU IR spectrometers, calibration, and zeroing methods. The 2014 WP-3 measurements were carried out by Aerodyne Inc.

Measurement	Avg ± Std ppb	Median
2014 C-130	6.801 ± 7.098	4.356
2014 WP-3	7.629 ± 9.713	4.870
2021 Cessna	3.888 ± 3.152	3.202

Whatever the cause of the decrease C_2H_6 emission flux between 2015 and 2021, if substantiated by additional measurements and analysis, this could represent a significant improvement in the air quality over the DJB and neighboring communities as C_2H_6 decomposition produces ozone and a series of reactive compounds, including peroxyacetylnitrate (PAN).

References

Peischl, J., et al., (2018), Quantifying Methane and Ethane Emissions to the Atmosphere From Central and Western U.S. Oil and Natural Gas Production Regions, *J. Geophysics. Res.*, **123,** 7725 – 7740, doi: 10.1029/2018JD028622.

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