Quantifying Methane, Ethane, and VOC Emissions from the Denver-Julesburg Basin Using Aircraft Mass Balance in Fall of 2021.

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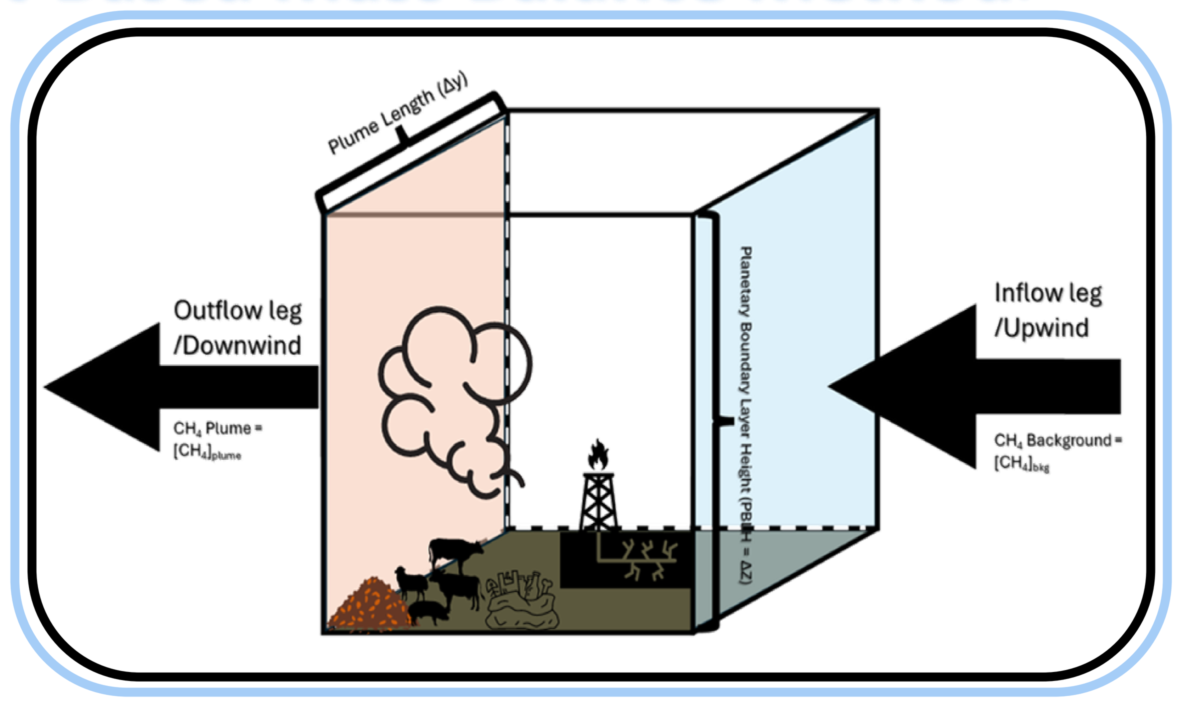
Intro:

Methane, a potent greenhouse gas and primary component of natural gas, requires quantification of emission rates and their temporal changes to assess its climatic impact. In the Denver-Julesburg Basin (DJB), particularly the Wattenberg field area of Colorado, methane emissions predominantly originate from oil and natural gas (O&G) operations (>18,000 active wells in 2021), agricultural activities at concentrated animal feedlot operations (CAFOs), and landfills (Figure 2). During Fall 2021 (9/17–10/5), our research group conducted nine flights over this region in a fully instrumented Cessna aircraft (Figure 1), measuring CH_4, C_2H_6, acetic acid, and other trace gases, with four flights deemed sufficient for mass balance emission rate determination. Since CH_4 and C_2H_6 are co-emitted from O&G operations, and CH_4 and acetic acid (but not C_2H_6) from CAFOs (Figure 3), we determined methane emission rates, source apportionment, and emission intensity for each flight normalized by O&G production (Figure 4).

Aircraft-Based Mass Balance Method:



$$CH_4\ ER = \iint_{z_0=surface;y_0}^{z_1;y_1} \left([CH_4]_{plume} - [CH_4]_{bkg}\right) * WS_{\perp} * (GS * \Delta t) * N(P,T,Z)\, dy\, dz$$

$$WS_{\perp} = WS*\cos(WD\perp\text{-}TA)*k$$

For each mass balance flight, outflow legs were determined based on the visual plume enhancement and confirmed with 10hr HYSPLIT to be from the source region. Subsequently a flight footprint was defined by the curvilinear quadrilateral formed by the outflow leg, plume edge back trajectories, and the upwind portion of the flight path. The background concentration was either determined by the average concentration of the inflow region (where outflow leg back trajectories intersect with forward trajectories from the inflow leg) or by a linear interpolation from the edges of the plume. The planetary boundary layer height (PBLH) was determined from vertical profiles typically in the center domain. Emission uncertainties were assessed through a propagation error analysis of 10 variables: adjusted PBLH, methane concentration ($[CH_4]_{plume}$), methane background ($[CH_4]_{plume}$), wind speed (WS), track angle (TA), wind speed correction factor (k), wind direction (WD), groundspeed (GS), temperature (T), and pressure (P).

Emission Intensity Determination:

Multivariate linear regressions were used to determine the CH_4 fraction from O&G based on corrections of methane with ethane (O&G tracer) and acetic acid (CAFO tracer). Thermogenic methane emission rates were normalized by production, in total barrels oil of equivalent (BOE) within each flight footprint. Data provided by well-pad production statistics for 2021 provided by the Colorado Energy and Carbon Management Commission (ECMC)

$$Emission\ Intensity\ (EI) = (CH_4\ \text{fraction from O\&G})*(CH_4\ \text{mass balance kg/hour})/(\text{BOEh})$$

As **oil and gas production** in the D-J Basin **increases, methane emission intensity decreases.**

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Methane and Ethane Emission Results:

Date	C2H6 Emission Rate (tn/hr)	CH4 Emission Rate (tn/hr)	O&G%	Total BOE/hr	Methane Emission Intensity	Ethane Emission Intensity
9/24/2021	2.24 ± 0.49	17.7 ± 4.3	51.4	36925	0.26	0.06 ± 0.1
9/27/2021	1.83 ± 0.50	17.9 ± 2.9	63.2	27951	0.40	0.07 ± 0.02
10/1/2021	1.96 ± 0.52	19.5 ± 7.3	71.2	17949	0.77	0.11 ± 0.04
10/5/2021	3.71 ± 0.59	28.5± 3.1	67.1	29337	0.65	0.13 ± 0.02
Average	2.44 ± 0.80	20.9 ± 5.0	63.2 ± 8.7	28041 ± 7800	0.56 ± 0.19	0.09 ± 0.02

3 Take away points:

1. Methane and Ethane Emissions: From four flights conducted in Fall 2021 (9/24–10/5), the methane emission rate was quantified as **20.9 ± 5.9 tons CH_4/hr**, while the ethane emission rate was **2.44 ± 0.80 tons C_2H_6/hr**.

2. Source Apportionment Using Tracers: Acetic acid proved to be a valuable tracer for agricultural methane emissions. Combining acetic acid and ethane tracers, we attributed **63.2 ± 8.7%** of methane emissions to oil and gas (O&G) operations.

3. Emission Intensity Trends: By determining flight footprints, we achieved a more precise estimation of O&G production captured during each leg/flight. This enabled calculations of a methane emission intensity of **0.56 ± 0.19 kg thermogenic CH_4/BOE/hr** and an ethane emission intensity of **0.09 ± 0.02 kg C_2H_6/BOE/hr**. Methane emission intensity has declined linearly by **0.05 kg/BOE/hr per year** since 2012, while ethane emission intensity has significantly decreased > 70% since 2015 (Pieschl, 2018; Ngulat/Daley/Fried et al., in prep.).

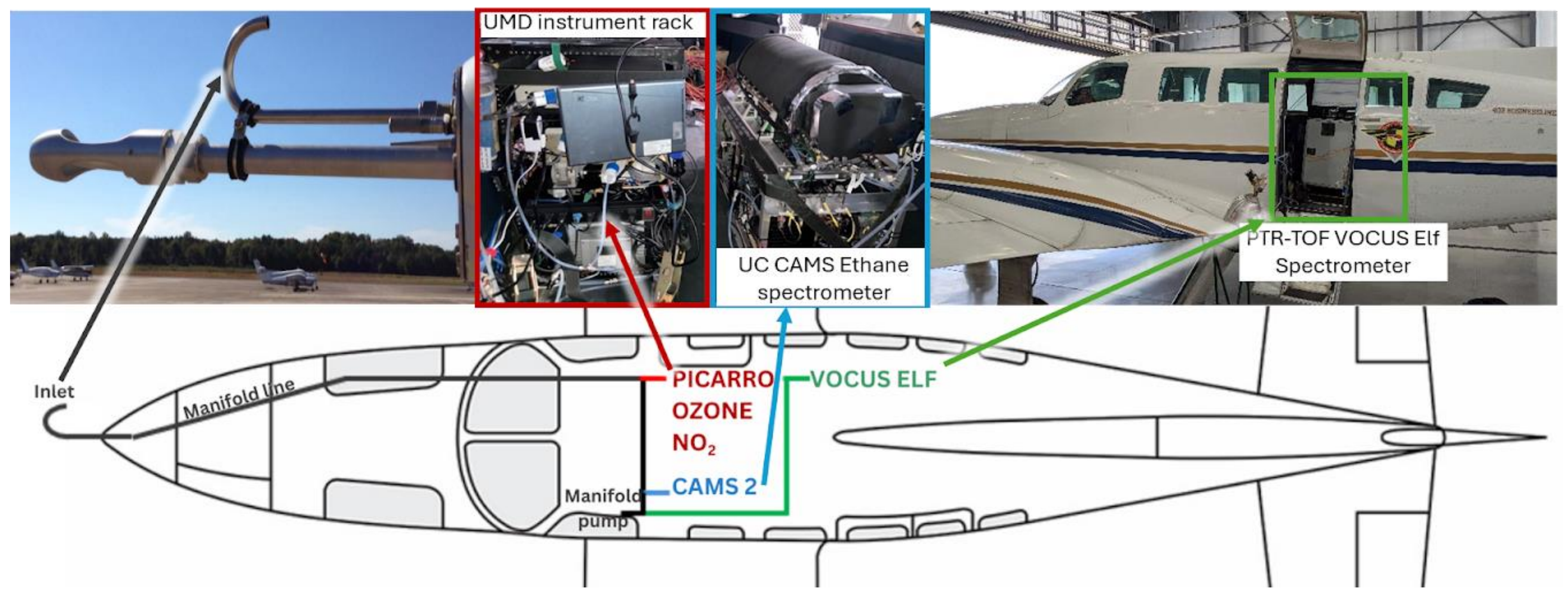

Figure 1. (Top left) The 402B aircraft and reverse-facing gas inlet, along with pressure/temperature/humidity sensors. (Top middle) Interior view showing the UMD instrument rack and CAMS-2 ethane instrument. (Top right) The PTR-TOF spectrometer inside the aircraft. (Bottom) Schematic of instrument placements relative to the aircraft size.

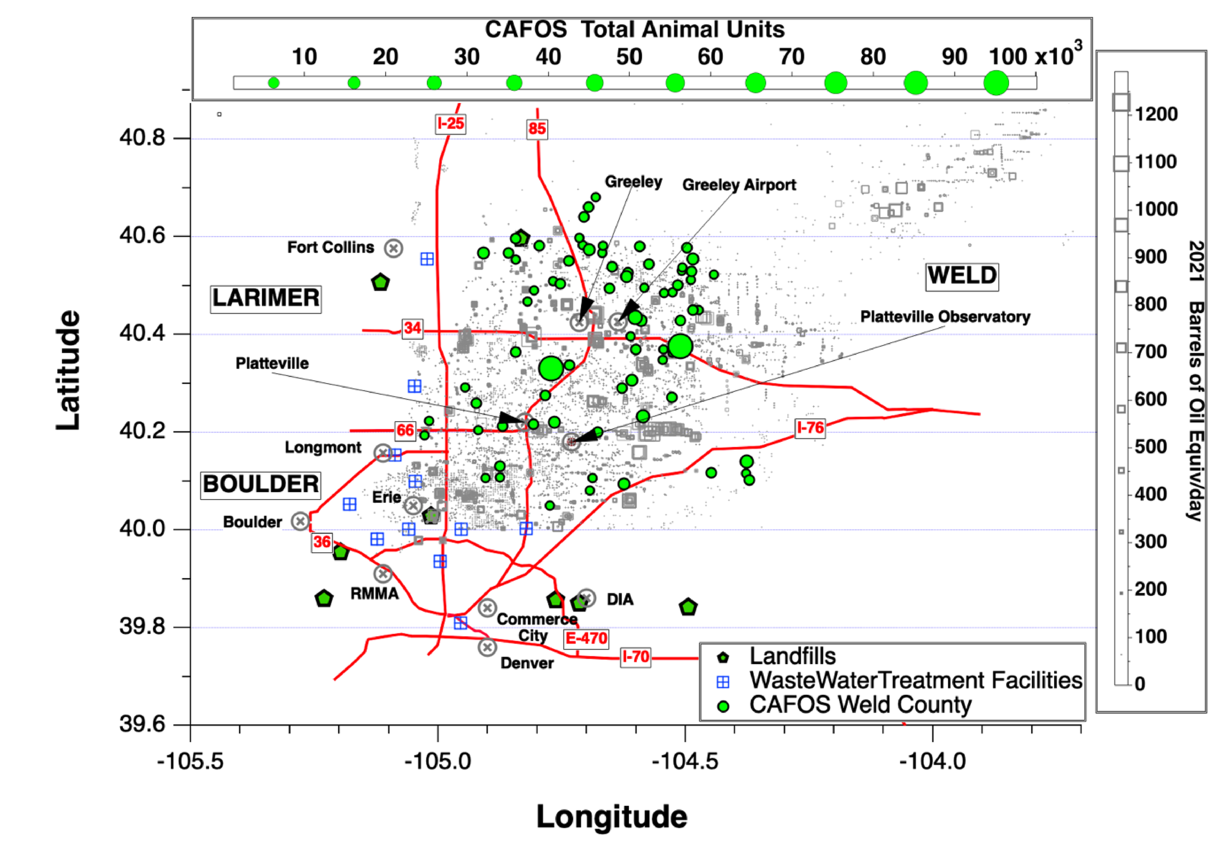

Figure 2. Map of the Wattenberg Field portion of the DJB in Weld and Larimer Counties showing CH_4 sources, with O&G facilities sized by daily BOE production and CAFOs sized by animal units (AU).

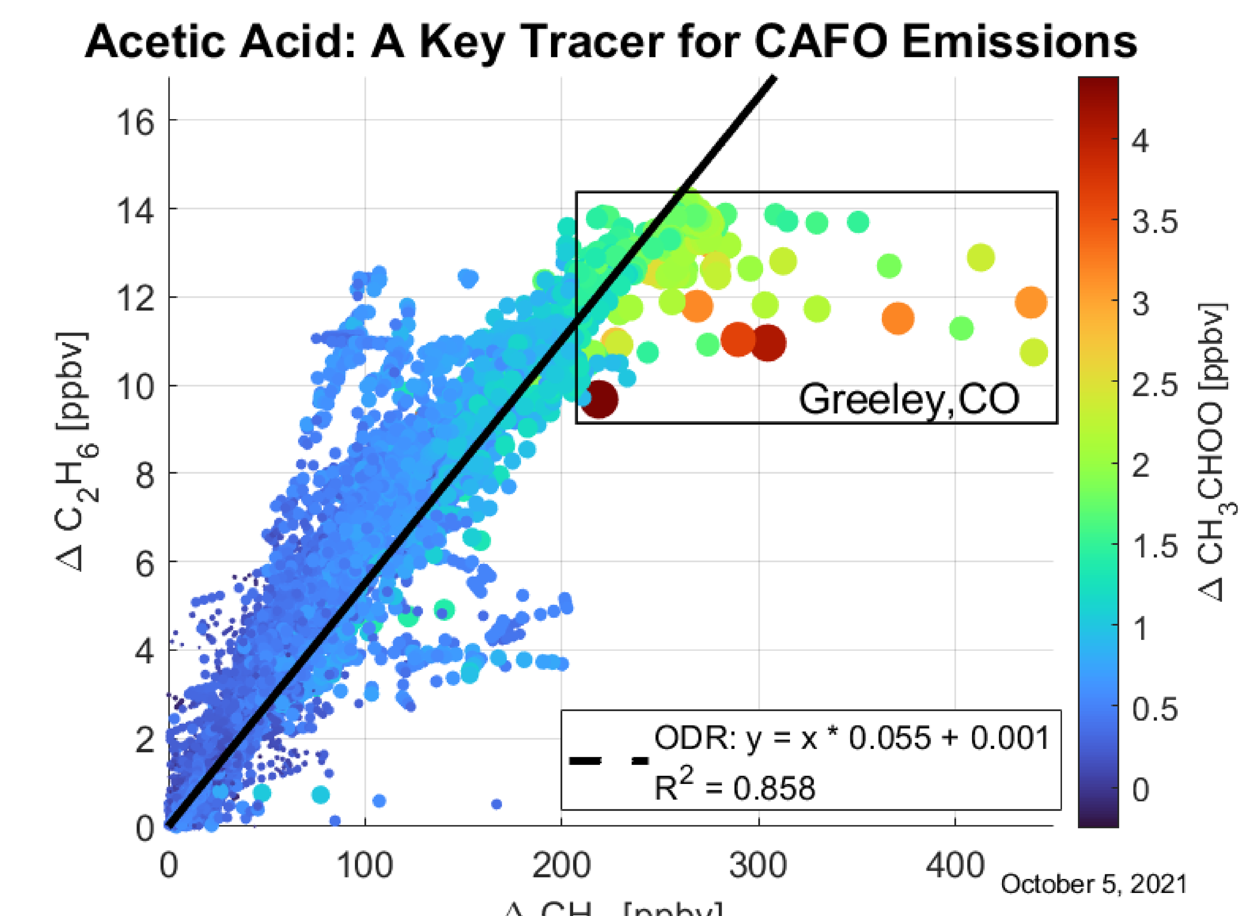

Figure 3. Plot of 1s ΔMethane vs. ΔEthane, colored and sized by Δacetic acid concentrations. Background values represent 5% of values within the PBLH. The box region highlights Greeley, CO, a major CAFO area. The figure shows a ΔEthane/ΔMethane ratio of approximately 5.5% and a strong correlation between CAFOs and acetic acid.

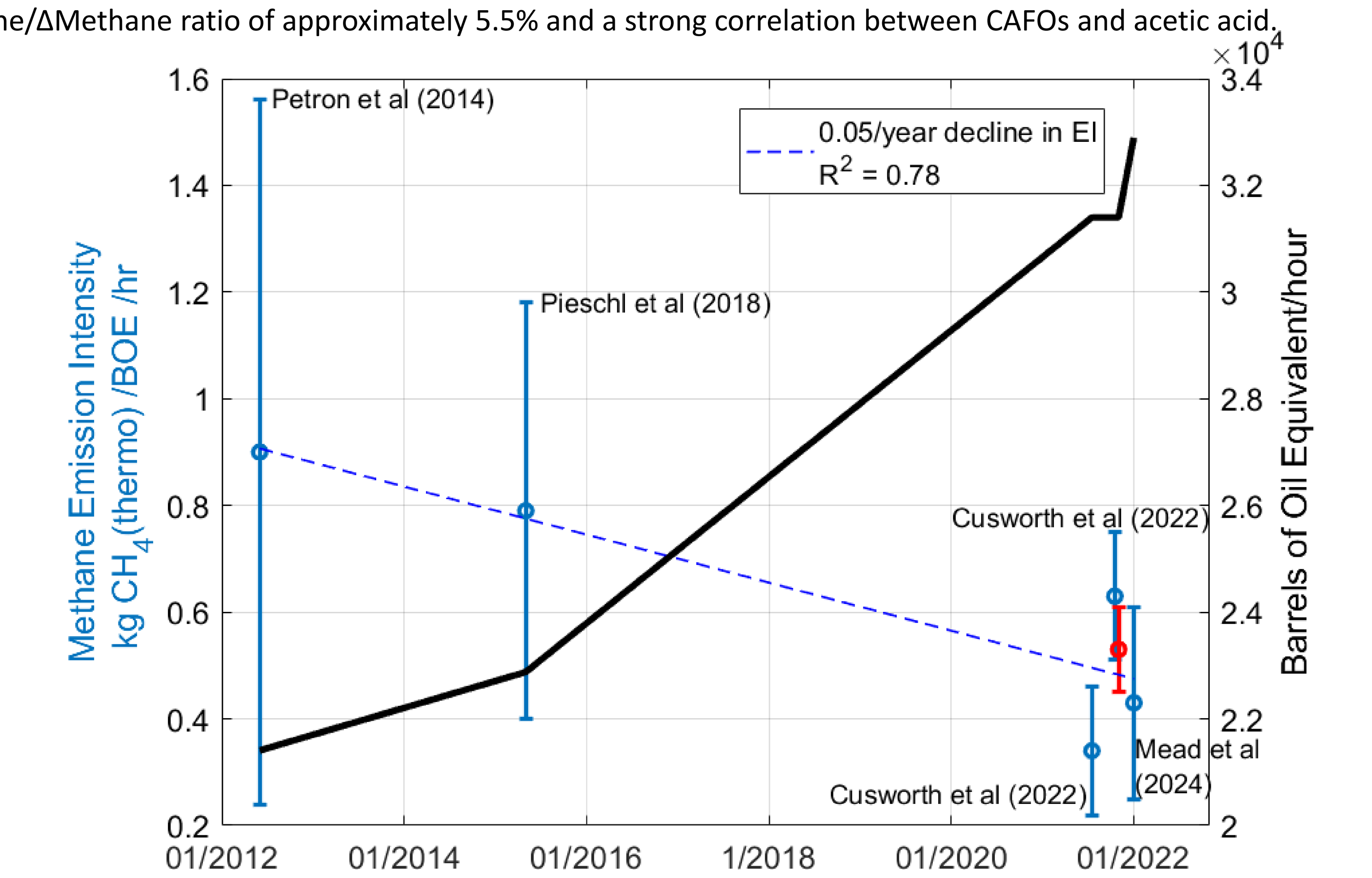

Figure 4. Methane emission intensity (blue) and Barrels of Oil Equivalent (BOE, black) for six studies conducted in the Denver-Julesburg Basin from 2012–2021. BOE increased by 146% from 2012 to 2021 and 137% from 2015 to 2021. The trendline (r^2 = 0.78) indicates a decrease in emission intensity of approximately 0.05 EI/year, where EI is kg CH_4/BOE/hr.