Interim Report on Proposal Activities & No-Cost Extension Request:

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

Prepared by:

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To

Colorado Oil & Gas Conservation Commission (COGCC)

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The Colorado Air Pollution Control Division, Department of Public Health & Environment (CDPHE)

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1. Overview of Proposed Activities & Executive Summary of Results

This report summarizes results and preliminary conclusions from investigations of the emissions of methane, ethane, and associated pollutants including volatile organic compounds (VOCs) from oil and natural gas operations (O&G) in the Denver-Julesburg Basin (DJB) in September and October of 2021. As a fraction of the total production, methane emissions are down substantially and ethane emissions down dramatically.

Researchers at the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado Boulder (hereafter referred to as CU) in collaboration with Professor Russell Dickerson in the Department of Atmospheric & Oceanic Science at the University of Maryland (UMD), and Abigail Koss and Joel Kimmel at TOFWERK USA were funded by this proposal to deploy a fully instrumented aircraft for continuous measurements of ONG emissions during the DJB studies. Specifically, this payload successfully deployed the Maryland University Research Foundation's (URFs) Cessna 402B research aircraft to acquire continuous measurements of: 1) ethane (1 Hz) from the CU team employing their CAMS-2 (Compact Airborne Multispecies Spectrometer-2); 2) carbon dioxide, methane, and CO (0.3 Hz) employing the UMD Picarro analyzer; 3) nitrogen dioxide (NO_2) employing the UMD analyzer (0.1 Hz); 4) meteorological parameters of air temperature, pressure, relative humidity, wind speed and wind direction employing the UMD Vaisala instrument and differential GPS (1 Hz); and 5) TOFWERK's Vocus Elf Proton Transfer Reaction Time of Flight Mass Spectrometer (PTR-TOF) for continuous (1 Hz) measurements of benzene, toluene, xylene, acetone, acetonitrile, acetaldehyde and potentially other volatile organic compounds (VOCs). A total of nine flights were successfully carried from September 17, 2021 – October 5, 2021 over the DJB, and six of which were considered appropriate for mass balance analysis in deriving the flux for methane (CH_4), ethane (C_2H_6) and various volatile organic carbon (VOC) gases.

This report summarizes the procedures employed and data interpretation from two of these flights: October 1 and October 5, 2021. Although the title of this report indicates the word "interim", we consider these results as nearly final, as all the measurements have been QA/QC'ed, finalized, and submitted to a central archive located at:

https://www2.atmos.umd.edu/~rammpp/archives/2021data.html

Our final data analysis product may include small minor potential adjustments from: the analysis of additional flight days; the incorporation of additional HYSPLIT trajectory analysis runs; additional analysis procedures employing Lagrangian and Eulerian transport models; and updates to our error analysis, as examples. In this report, we only focus on emission fluxes from CH_4 and C_2H_6. However, our final report will also include additional results from the PTR-TOF VOC measurements. Our analysis here presents CH_4 source attributions based upon simple linear correlations with C_2H_6, which is co-emitted from the same oil and gas (O&G) drilling operations as CH_4 but not from biogenic sources of CH_4, such as from Concentrated Animal Feeding Operations (CAFOs). Such correlations provide approximate CH_4 emission rate estimates from O&G operations. As time permits, we hope to supplement this simple approach in our final report with more sophisticated analyses employing multiple linear regressions using Positive Matrix Factorization.

This interim report represents fulfillment of the contractual obligations of CU to COGCC. However, as indicated above, we are requesting a 1 year No-Cost-Extension (NCE) to carry out additional analysis in support of our preliminary findings herein, which we plan to publish in the

peer-reviewed literature. In addition, efforts are currently underway in the planning of additional flights in 2023 and 2024 employing the procedures and lessons learned from the present study. These studies and follow-up analysis will be funded under a separate proposal.

Based on the two flight days studied thus far, we derive **CH_4 emission fluxes of 19.7 ± 4.2 and 26.9 ± 7.9 tonnes/hour (1 tonnes/hour = $1x10^6$ grams/hour) for October 1 and October 5, 2021, respectively.** The error bars here represent the total uncertainty (random and systematic error estimates) at the 1σ levels. The corresponding results for **C_2H_6 are: 1.9 ± 0.6 and 2.2 ± 0.8 tonnes/hour, for October 1 and October 5, respectively.** We note that the flux values for the Oct.1 flight have increased slightly from those presented in our June 30 CDPHE presentation due to a reassessment of our background inflow time period.

2.0 Overview of the Denver-Julesburg Basin (DJB) and the Instruments Employed

The DJB, a large shale and sandstone basin, extends over areas of northern Colorado from Colorado Springs up through lower Wyoming and southwest Nebraska. 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. Figure 1 provides an overview of this region along with the many sources of CH_4 and the major highways. The active wells in Weld and Larimer Counties, which by the end of October 2021 are 18,538 in number, are highlighted by the light gray dots. The additional CH_4 sources, denoted by the inset key, are also indicated on this map along with the flight track outlines from the 2012 Pétron's study (Pétron et al., 2014) and the 2021 University of Arizona study.

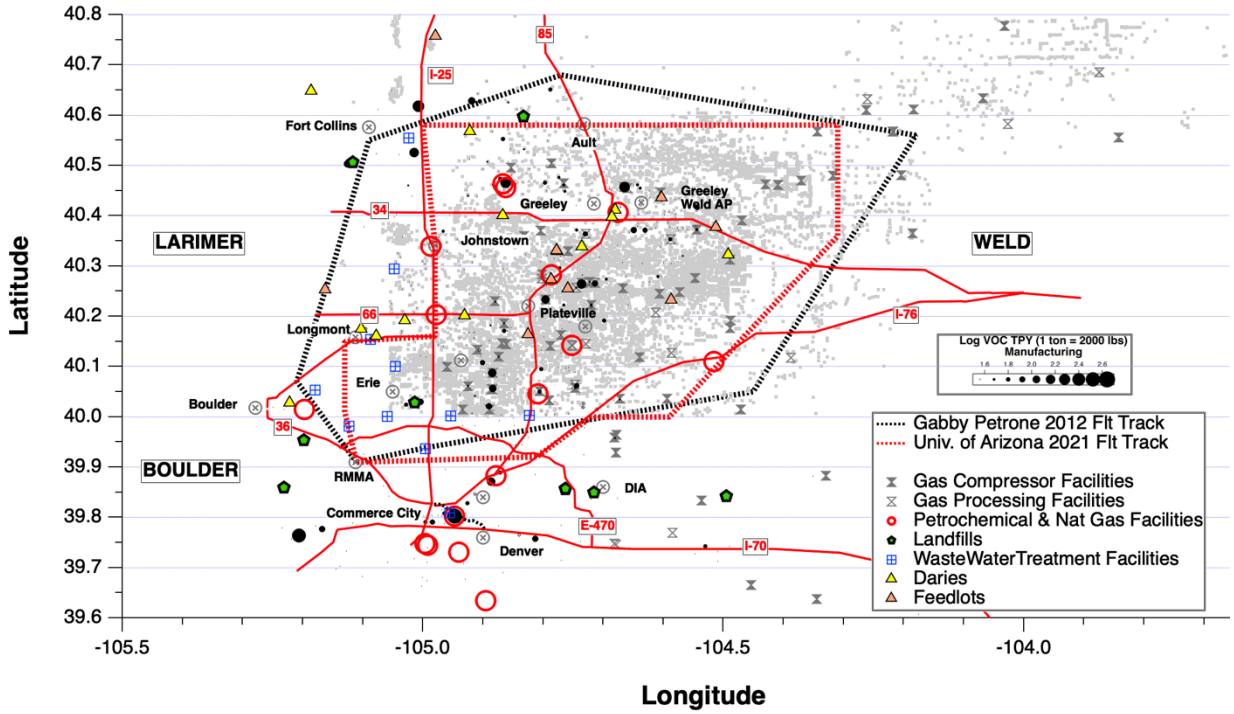


Figure 1: Map of the DJB study area, highlighting various sources of CH_4. The airplane base of operations for the present study was located at the Rocky Mountain Airport (RMMA). The filled black circles show various manufacturing facilities, which are sized by the yearly VOC emission estimates. Each small gray square represents an active or capped O&G well. The three counties (Boulder, Weld, and Larimer) are highlighted in boxes on this map.

The 2015 Peischl et al. study (2018) over the DJB spans this same region, and as will be shown in figures 3, the measurements of the present study covers this same region. Over the DJB, the two largest CH_4 sources are from O&G operations as well as from CAFO sources, which are located in close proximity, especially around Greeley.

Figure 2 provides photographs of the UMD 402B Cessna Research Aircraft along with the various instruments employed. The UMD instruments are part of the normal aircraft instrument package employed on this aircraft for east coast ozone studies. The CAMS-2 instrument, which successfully acquired ethane measurements on the NASA King Air aircraft, was repackaged to reduce size, weight, and power, specifically for these studies on the smaller Cessna aircraft platform. The TOFWERK's Vocus Elf Proton Transfer Reaction Time of Flight Mass Spectrometer (PTR-TOF), mounted behind the UMD instruments, was also modified to fly on this aircraft platform.

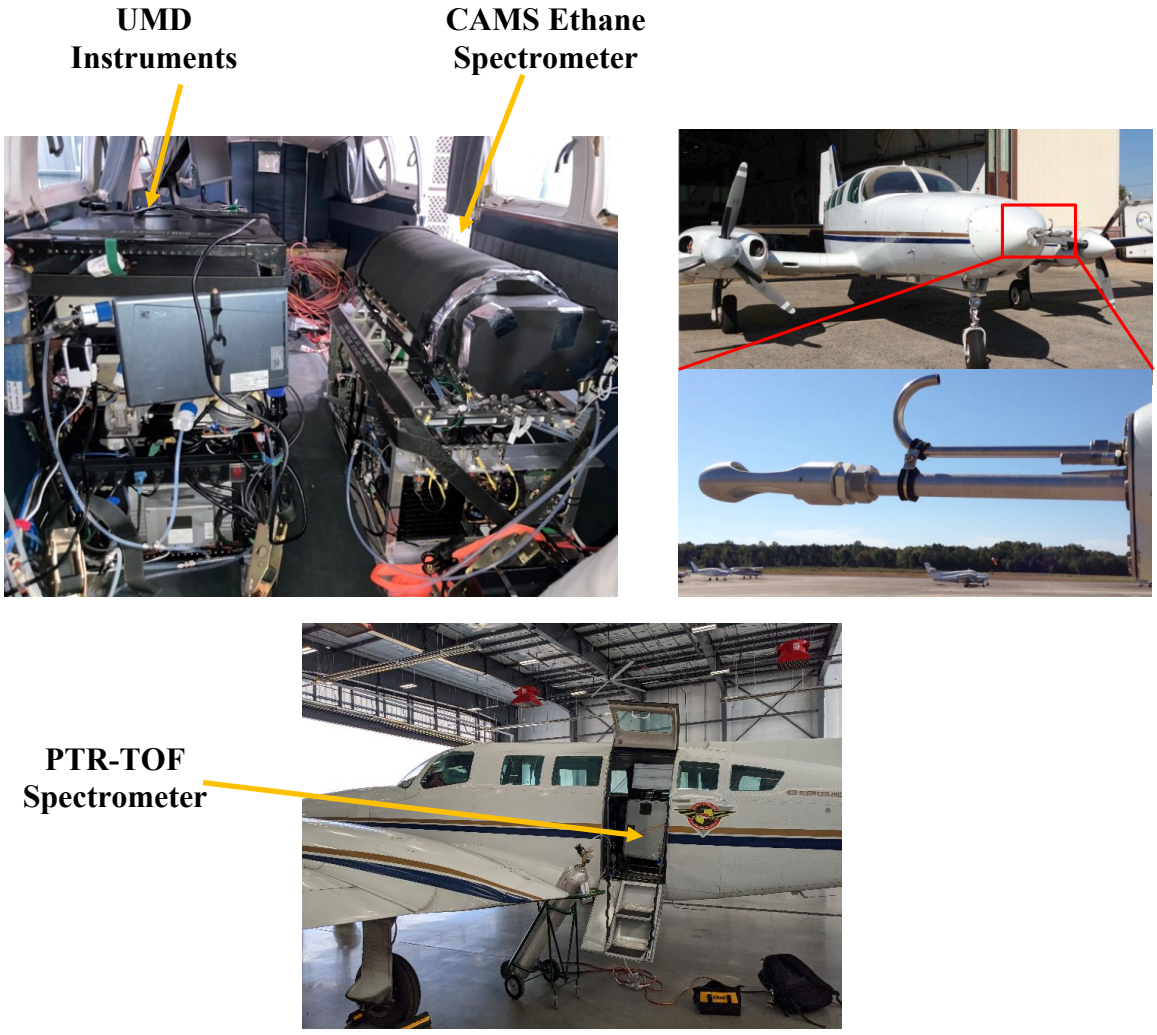


Figure 2: (Top left) photograph of the interior of the airplane viewed from the pilot's seat. The CAMS-2 ethane instrument is located on the right side of the cabin next to the door and the various UMD instruments, extending from behind the co-pilot seat to the middle of the airplane, are located on the left side. The PTR-TOF spectrometer, which is hidden in this view behind the UMD instruments, can be seen in the bottom photograph just inside the aircraft door. The **(right figures)** show the 402B aircraft and the reverse-facing *"candy-cane"* gas inlet in the nose of the aircraft.

3.0 October 1, 2021 Mass Balance Flight Results

Figure 3 reproduces the DJB map of Fig. 1 with the Oct. 1 flight tracks, colored and sized by measurements of CH_4 (Fig 3a) and C_2H_6 (Fig 3b) superimposed. The very high CH_4 emissions from the two large landfills near Erie and Fort Collins are highlighted. Figure 3b shows that C_2H_6 measurements are not elevated here, which emphasizes the utility of employing simultaneous C_2H_6 and CH_4 measurements in discriminating sources of CH_4. Since background C_2H_6 concentrations are typical in the 1 – 3 ppb range in the absence of O&G sources, the elevated levels up to 22 ppb shown Figure 3b highlight the O&G emissions from the DJB. Figure 4 shows the corresponding Google Earth map of these flight tracks, colored by CH_4, with the background inflow (IF) and plume outflow (OF) regions highlighted by the colored rectangular boxes.

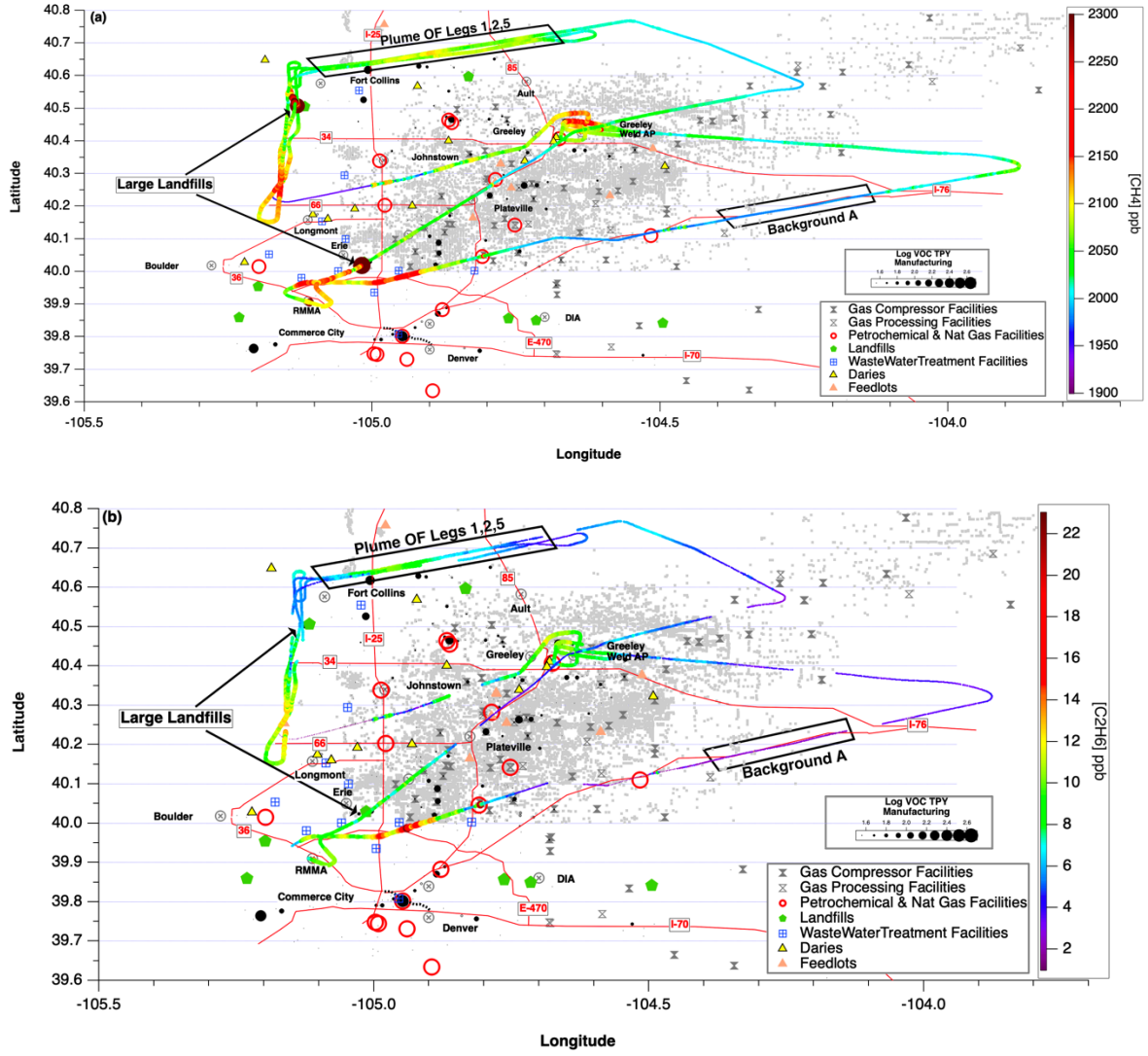


Figure 3: October 1 Cessna flight track over the DJB **(a)** colored and sized by the measured CH_4 and **(b)** by C_2H_6. The CH_4 scale in (a) is restricted to 2300 ppb to preserve resolution even though the CH_4 concentrations attained values of 2892 ppb and 2763 ppb over the landfills near Erie and Fort Collins, respectively. The C_2H_6 scale is not restricted. Note that the green landfill symbols in Fig. 3a near Erie and Fort Collins are mostly obscured by the very large CH_4 measurement symbols but not in the C_2H_6 measurements of Fig. 3b. Both figures show the Background A IF region and the Plumes 1,2,5 OF region.

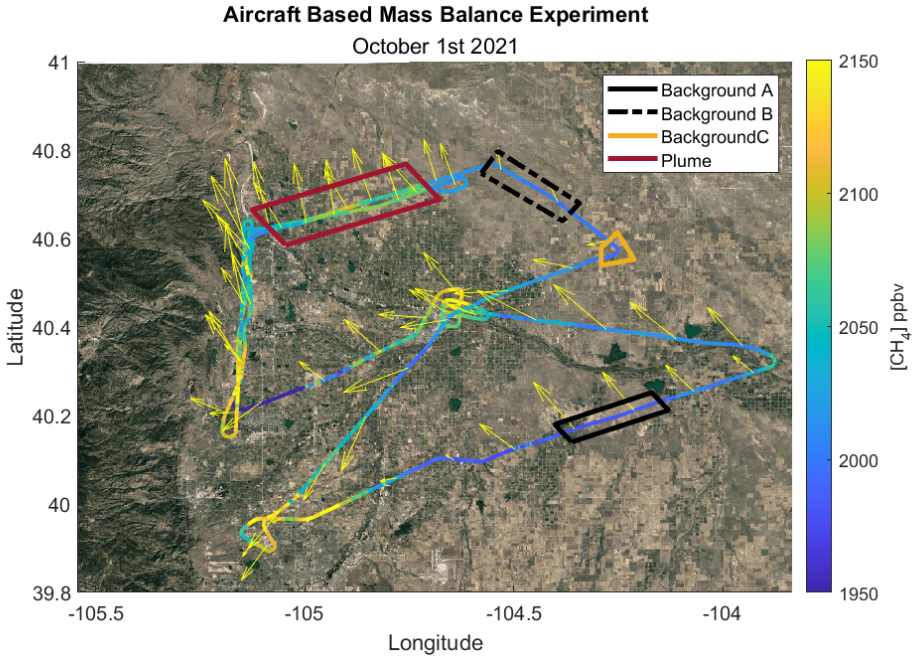


Figure 4: Google Earth image for the Oct. 1, 2021 flight track colored by the measured CH_4 concentrations. The color scale has been adjusted here to better highlight the inflow and outflow outflow regions. Likewise, the size of the wind vectors have been adjusted here to better show the general SE-NW wind flow.

We employ NOAA's HYSPLIT forward and back trajectories using HRRR (High Resolution Rapid Refresh) model, which employs 3 km meteorology, as one means to identify the background IF and plume OF regions. Figure 4 depicts three potential background regions that could be employed in the analysis, two of which depict backgrounds (B & C) at the eastern edge of the sampled region and one shows region (A), which represents inflow at the entrance of the sampling region. Based upon the trajectories as well as the C_2H_6 measurements as an additional guide, Background A was employed in this analysis. Accurate determination of the true background IF region is particularly critical in the mass balance approach. For example, a change of only 10.7 ppb in the CH_4 concentration employed for the mass balance background value yields a change in the CH_4 emission rate of 14%. Table 1 shows the averaged CH_4 and C_2H_6 concentrations for the 3 different potential backgrounds. In the boundary layer below 1317 m (to be shown in Fig. 7) for all data collected over the entire Oct. 1 flight, the lowest 5% values for CH_4 and C_2H_6 are 1981.5 ppb and 2.462 ppb, respectively. These values closely align with those of Background A. The rectangle labeled Plume in Fig. 4 depicts the 3 plume outflow legs, sampled over the same region at three discrete sampling altitudes of 287 m (Plume 1), 434 m (Plume 2) and 595 m (Plume 5), above ground level. Figure 5 shows these three outflow legs with corresponding HYSPLIT 6-hour back trajectories. The mid times of these three legs are: 21:22, 21:34, and 22:06 GMT, and Table 2 tabulates additional information for these legs.

Table 1: Average measured concentrations and 1σ standard deviations for the 3 backgrounds depicted in Fig. 4

Background Region	[CH_4] ppb	[C_2H_6] ppb
A	1981.6 ± 2.9	2.484 ± 0.125
B	2004.0 ± 4.9	5.514 ± 0.867
C	1992.3 ± 0.6	2.892 ± 0.143

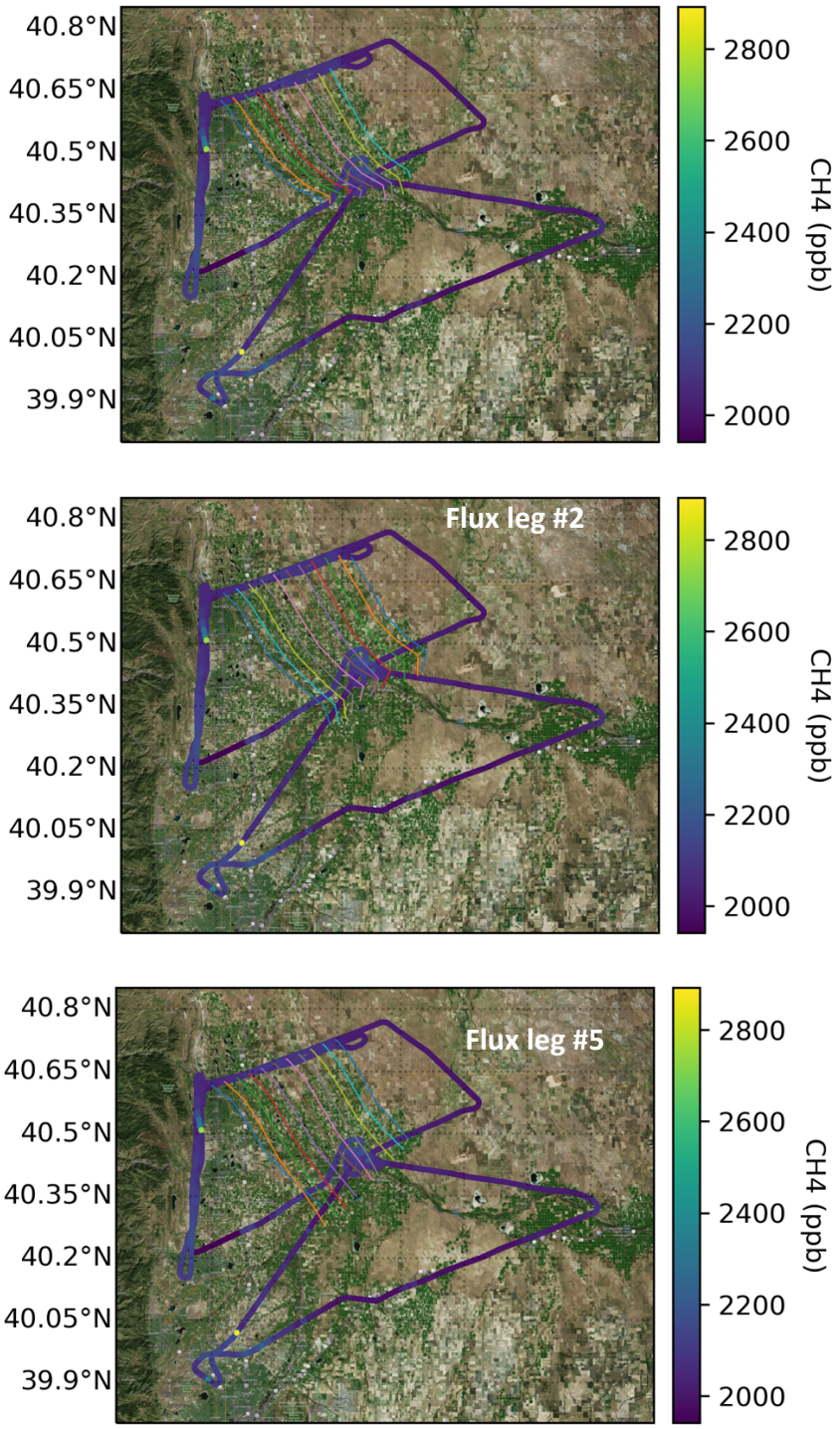


Figure 5: HYSPLIT 6-hour back trajectories for the 3 OF flight legs for the October 1 mass balance flight.

Table 2: Background and Plume outflow (OF) legs.

Flux Leg	Time Start	Time Stop	Lat Start	Lat Stop	Lon Start	Lon Stop	Avg. Alt AGL
Background A	20:18:49	20:24:08	40.158	40.236	-104.387	-104.136	579
OF 1	21:19:30	21:26:58	40.625	40.713	-105.084	-104.703	287
OF2	21:30:20	21:37:55	40.707	40.620	-104.671	-105.079	434
OF5	22:02:35	22:10:20	40.614	40.728	-105.097	-104.693	595

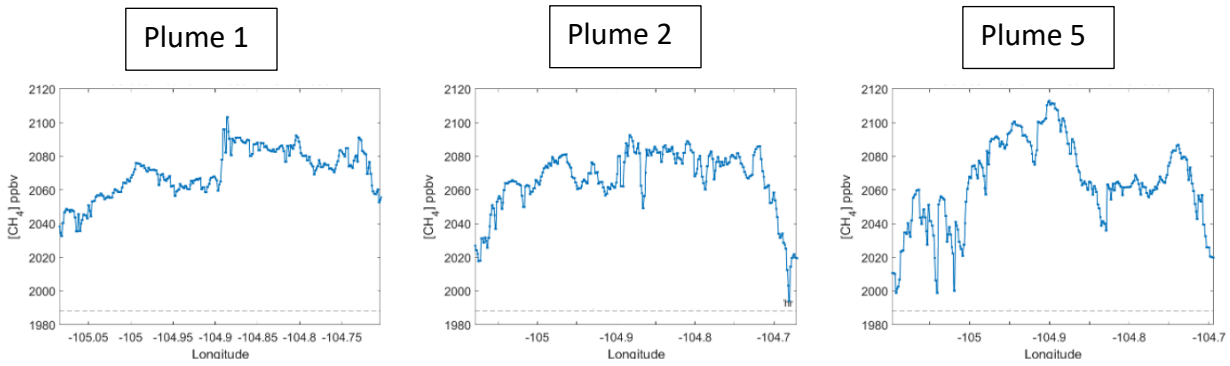


Figure 6: CH_4 timeseries for the 3 Oct. 1 plumes studied herein relative to the background A IF CH_4 levels of 1981.6 ± 2.9

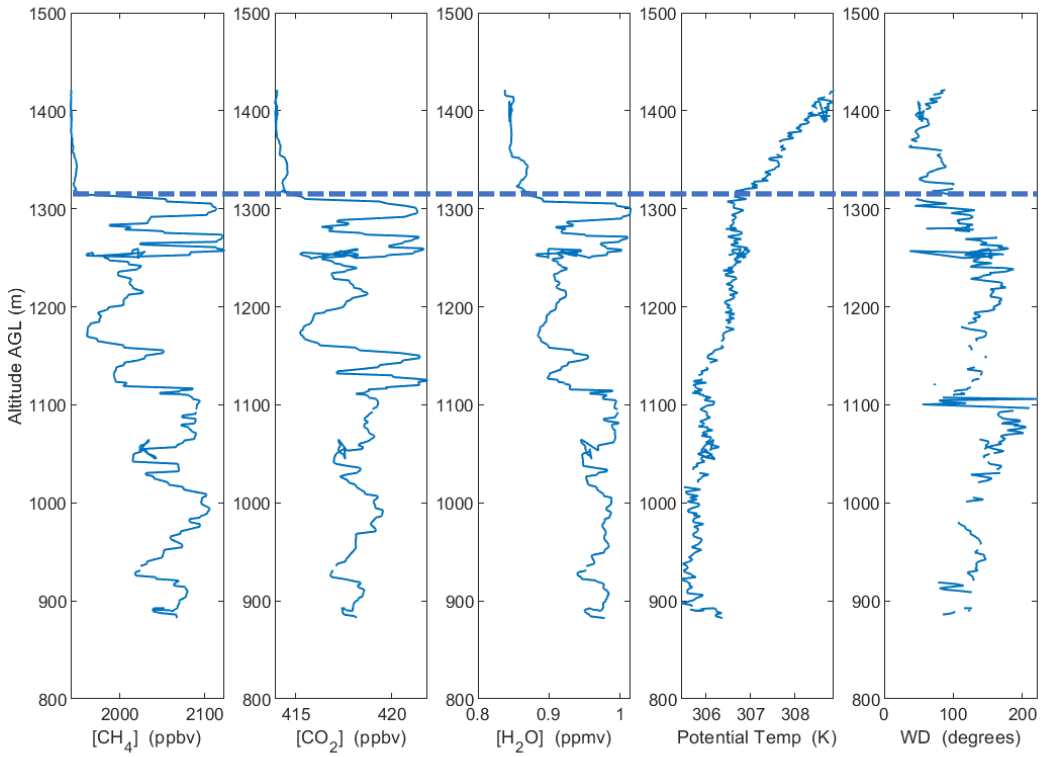


Figure 7: Vertical profiles acquired during the enroute flight ascend between Greeley and the western edge of the flight track near Longmont, CO, shown in Fig. 3. The dashed line indicates a mixed layer height (MLH) of 1317-m above ground level employed in our analysis.

The vertical profiles of CH_4, CO_2, H_2O, potential temperature, and wind direction shown in Fig. 7 indicate a mixed layer height (MLH, depth of boundary layer) of 1317 m above ground level. We conservatively estimate a maximum uncertainty of 150 m in this value.

We employ these various values in the following mass balance expression in calculating emission rates in terms of (ER) grams/sec, which is converted to metric tonnes/hour (10^6

grams/hour) by multiplying by 3.60 x 10^{-3} yields our final results. In this expression, which is pictorially represented in Fig. 8, the various terms are as follows: MLH (mixed layer height from z_0 to z_1 in units of m, also referred to as planetary boundary layer depth, PBL); ΔC (concentration difference between the plume OF (X_{Plume}) and the IF (X_{BKG}) in units of ppb), and this difference is multiplied by 10^{-9} to convert ppb to absolute mixing ratios and further multiplied by the molecular weight of the species under study to convert to grams; WS (wind speed in m/s); cos ($WD_{\perp}$ - Heading), the cosine of the angle between the normal to the wind direction (WD) and the aircraft heading (Heading); the aircraft ground speed (GS in m/s); the length of the plume (ΔT in s); the air number density (N(P,T)) corrected for the average density between the plume height and the surface in units of moles m^{-3}. The integration is calculated over the plume width (*dy* from -y to +y) and over the MLH (*dz* from the surface z_0 to the top of the boundary layer z_1). To improve measurement precision, all concentration and wind measurements are smoothed using an 11 point box car smooth and these values are employed in the following expression.

$$ER = \int_{z_0}^{z_1} MLH \} \int_{-y}^{y} (\Delta C)^* (WS)^* \cos (WD_{\perp} - Heading)\ ^*(GS^*\Delta T)^*\{N(P,T)\}\ dz\ dy$$

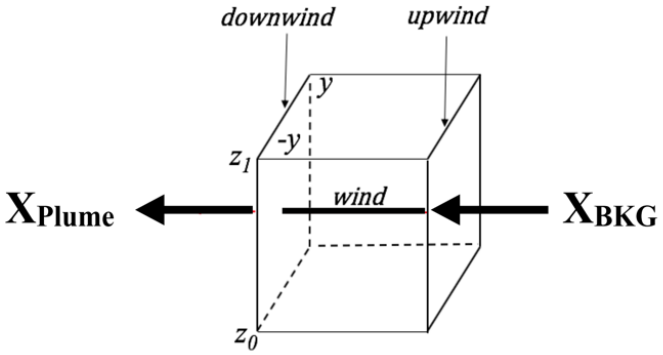


Figure 8: Pictorial representation of the mass balance approach.

Figure 9 reproduces Fig. 3a with the addition of a blue shaded region, which is drawn by eye to represent the DJB inflow and outflow regions under study. This takes into account the wind vectors shown, captures the IF and OF regions, and eliminates the large CH_4 sources to the west, particularly those associated with landfills, which due to the wind directions are not mixed into the OF plumes. We utilized this restricted dataset defined in the blue shaded region as one means of providing an estimate for the percentage of the total basin CH_4 flux due to O&G operations, and this is shown in Fig. 10. Here we plot the 5-second averaged CH_4 and C_2H_6 measurements for all the data acquired in the boundary layer (gray points), regardless of location, and for the restricted data set for boundary layer data residing in the blue shaded region. The large excursions from the non-restricted fit line (gray points) that are observable for C_2H_6 values in the 5.5 – 6.5 ppb range, highlighted in the light gray shaded region, reflect large CH_4 sources that are not C_2H_6 sources such as those from the two large landfills. The restricted boundary layer data does not show these large excursions.

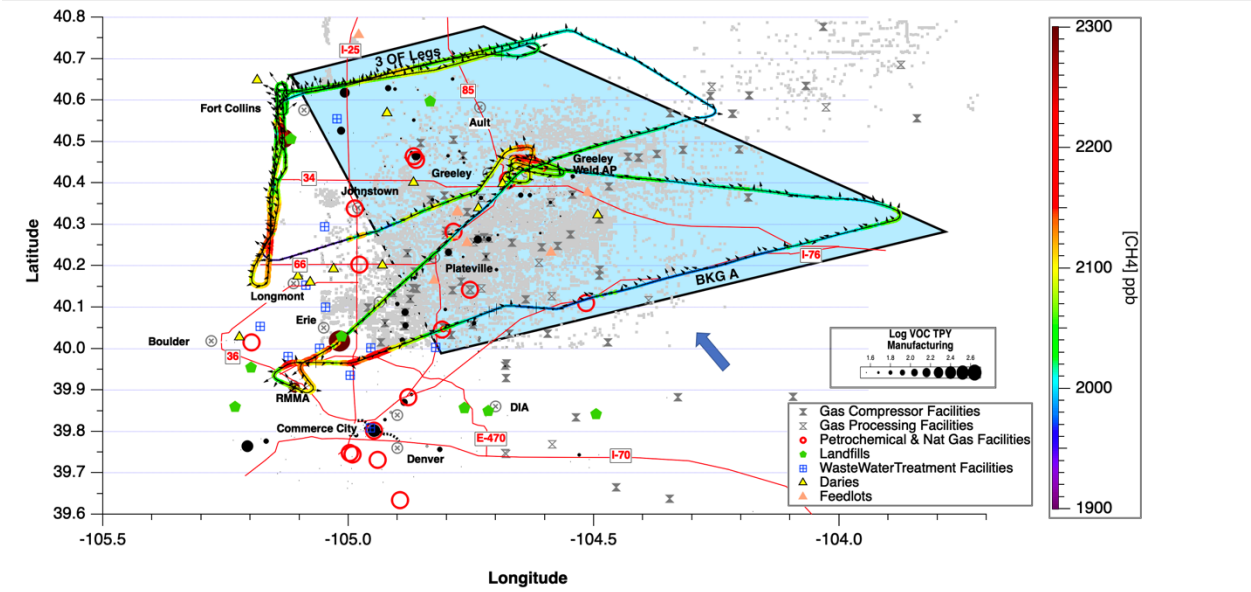


Figure 9: Reproduction of Fig. 3a with the addition of the blue shaded region to highlight the DJB area of influence for our Oct. 1 measurements. Wind vectors for select points are displayed by the small black arrows. The large blue arrow shows the overall general wind flow.

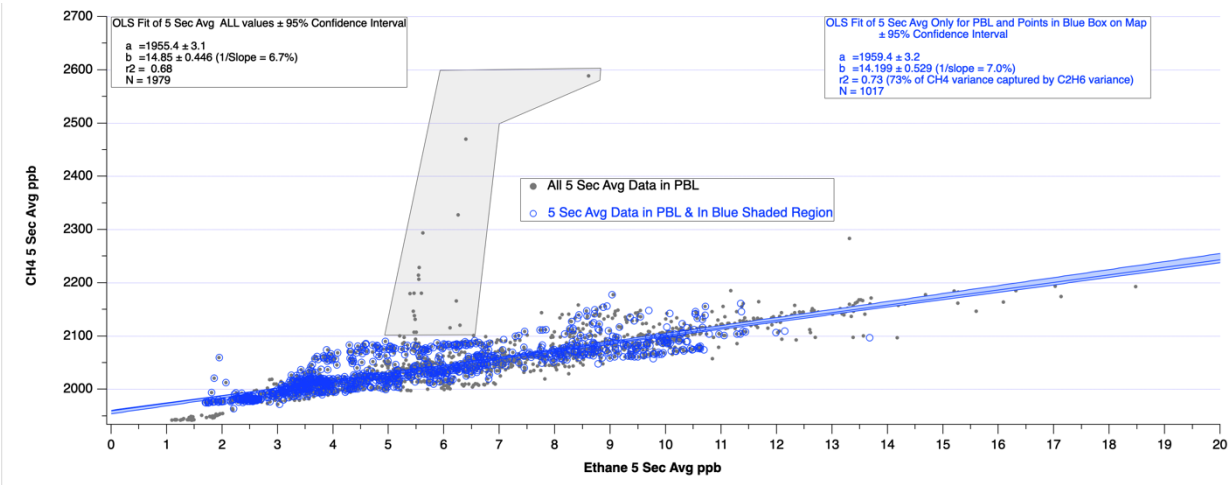


Figure 10: Ordinary Least Squares (OLS) linear regression fits of the 5-second averaged CH_4 and C_2H_6 data acquired in the boundary layer for all locations and for those data restricted to the blue shaded region of Fig. 9; the slope is about 14 ppb CH_4 per ppb C_2H_6 or about 7% of the emissions gas are ethane. The light gray shaded region highlights basin data with large CH_4 emissions without large C_2H_6 emissions suggesting a biogenic source.

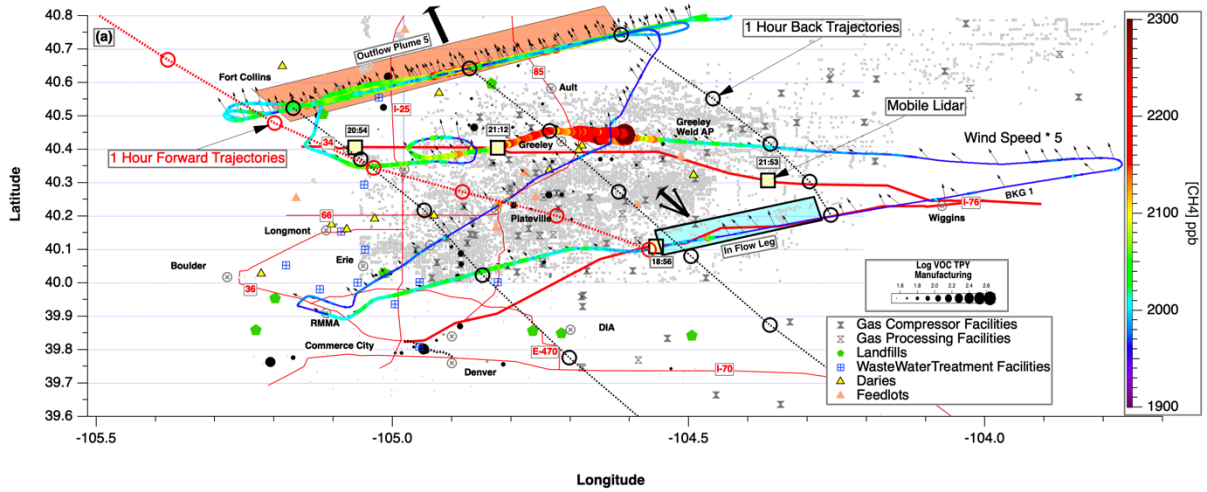
The r^2 values for both of these linear regression plots provides an approximation for the variance in CH_4 that correlates with the variance in C_2H_6, and this in turn represents an approximation for the percentage of the CH_4 observations in the DJB boundary layer that is associated with O&G operations. The r^2 value of 0.73 for the restricted boundary layer data indicates that approximately 73% of our measured DJB CH_4 emission rate is associated with O&G operations. Even the non-restricted data shows that a very high percentage (68%) of our CH_4

emission rate determinations are associated with O&G operations. As stated in Section 1, as time permits, we hope to supplement this simple approach in our final report with more sophisticated analyses employing multiple linear regressions using Positive Matrix Factorization (PMF).

Section 5 of this report will provide a summary of our CH_4 and C_2H_6 mass balance emission fluxes for the Oct. 1, 2021 flight as well as another flight analyzed herein, the Oct. 5, 2021 flight, which we now discuss.

4. October 5, 2021 Mass Balance Flight Results

The winds for the October 5, 2021 flight were found to be favorable for another mass balance flight. Unlike the light winds for the Oct. 1 flight , which ranged between 2.2 and 3.0 m/s for the three plumes studied, the winds for the Oct. 5 flight ranged between 7.3 and 8.2 m/s for two flight legs further studied. This flight day utilized NOAA's mobile lidar system to assess the spatial, temporal, and vertical wind structure (wind speed and direction) at locations close to the plume outflow legs and inflow leg. Figure 11a, like Fig. 3a, provides a comprehensive view of DJB measurements acquired on this day, colored and sized by the CH_4 measurements. This plot highlights the region where outflow Plume 5 was acquired as well as the inflow flight leg. The inflow CH_4 and C_2H_6 here are 1969.7 ppb and 1.867 ppb, respectively. We include in this figure 1-hour HYSPLIT back trajectories (large black open circles) and one forward trajectory (large open red circles) that were employed in defining the inflow and outflow regions. We also show the location of the mobile lidar system (large, filled yellow-green squares) with the associated measurement times in boxes right above. This system continuously acquired vertical wind structure throughout this measurement day, along the path from Loveland on the extreme western edge on Route 34 to Wiggins on the east. At the beginning and end of the measurement period the mobile lidar system traveled along Route 76, in very close proximity to our inflow sampling box. These lidar measurements thus provided important cross checks on the wind measurements employed in our analysis, their vertical structure, and the stability across the basin from the time between inflow and outflow. For the sake of brevity, this analysis is not included in this report, but our final report will provide this information in detail along with additional analysis using the mobile lidar data to cross check the wind structure for the Oct. 1 flight.



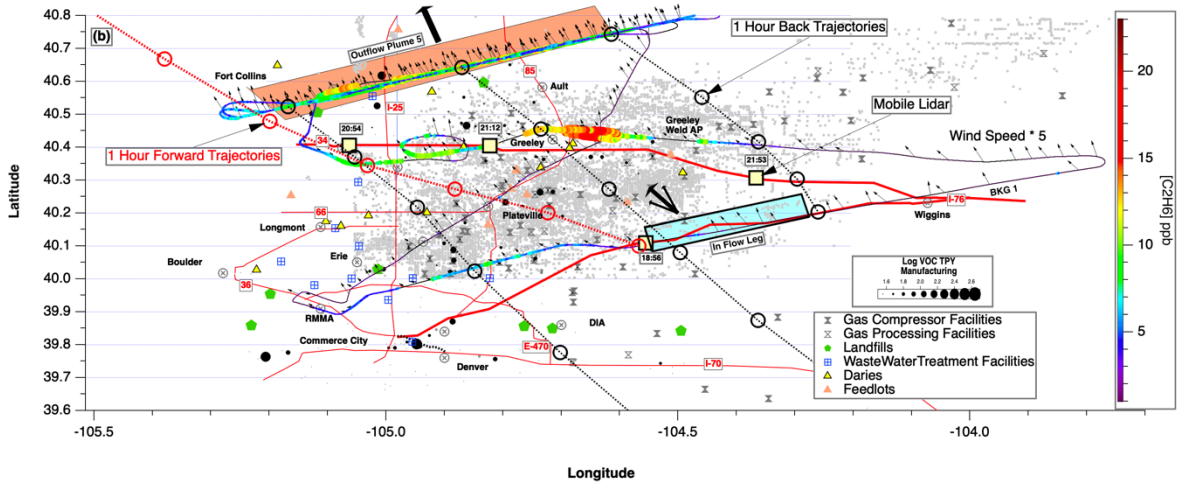
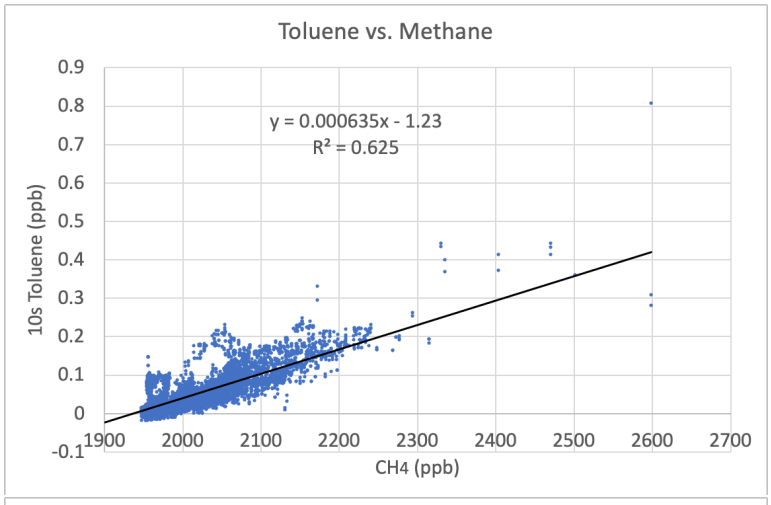


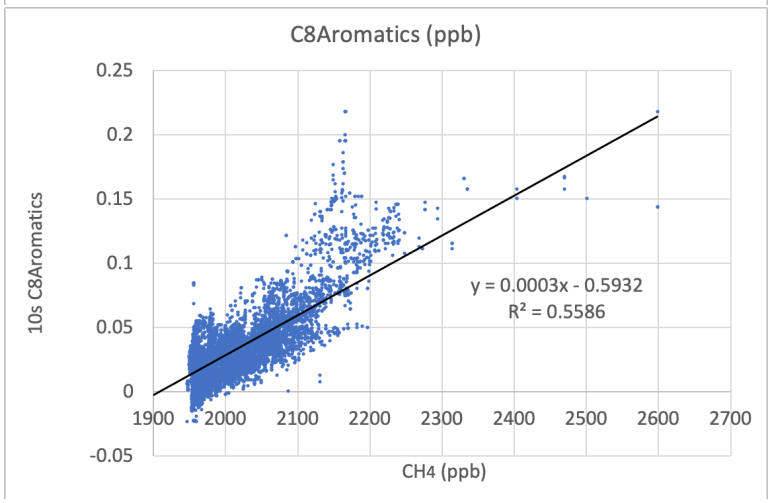
Figure 11: (a) Oct. 5 flight track colored and sized by the aircraft CH_4 measurements, restricted on this plot to 2300 ppb even though the large plume near Greeley exhibited CH_4 values as large as 2599 ppb; (**b**) corresponding flight track colored and sized by C_2H_6.

As can be seen in both the Oct. 1 and 5 flight tracks, and on other days not shown in this report, the area around Greeley and the Greely Weld County airport (AP) shows persistently high CH_4 and C_2H_6 concentrations. This area, near the center of our DJB study region, has a high density of O&G wells and processing facilities along with CAFOS activities.

4.1 VOC Correlations with CH_4

Several, more reactive hydrocarbons show strong positive correlations with methane. Because we can quantify the flux of methane, we can use the ratio of a VOC (measured by the PTR-TOF-MS) to CH_4 to quantify emissions of species involved in local air quality. Aromatic compounds such as toluene, C8 aromatics (the sum of xylenes and ethylbenzene) and C9 aromatics (such as trimethyl benzene) have short lifetimes in the atmosphere and contribute to both photochemical smog (ozone) and fine particulate matter. Figure 12 shows example data for 5 October 2021 as scatter plots, with least squares correlation coefficients (r^2), and slopes. Benzene, unfortunately, was not measured with sufficient precision to quantify its emissions. Note the periods when the Denver plume was detected were excluded from these analyses. In future work, we will quantify the flux of these substituted benzene compounds.





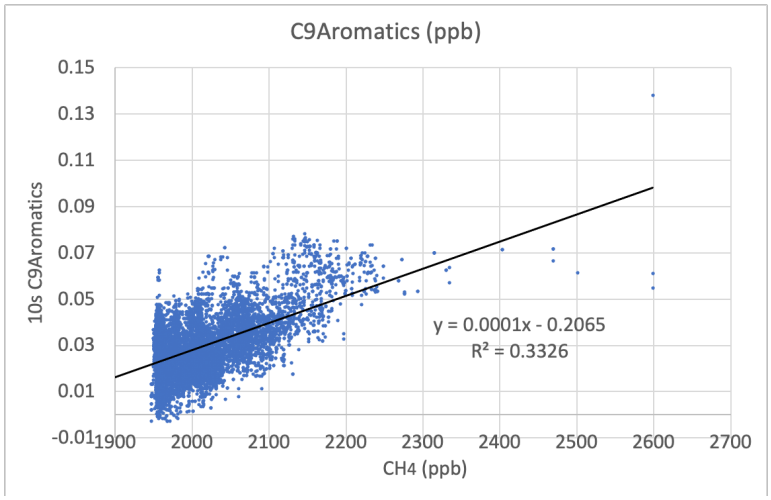


Figure 12. Scatter plots of observations from the aircraft on 5 October 2021. Aromatic pollutants such as toluene, xylenes, alkylbenzenes, and trimethylbenzene correlate well with methane. This suggests a common source and that the ratios can be used to estimate the flux of these more reactive species.

5. Summary of Mass Balance Results and Comparisons with Other Studies

Table 3 summarizes all recent measurements for CH_4 and C_2H_6 mass balance flux determinations over the DJB. It is notable that the averaged CU/UMD (University of Colorado/University Maryland) total CH_4 flux and O&G flux results of the present study are in agreement with those from the University of Arizona carried out over the same time period. A second item worth noting is that the total basin CH_4 flux and the O&G estimates have not changed over 9 years, despite a factor of ~ 2 increase in natural gas production over the DJB from 2015 to 2021.

Table 3: 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

However, the apparent C_2H_6 flux has decreased by a factor of 3.3 over the 6 year period from 2015 to 2021. The reasons for this are still unclear. However, 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. 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, may hint at such enhanced DJB C_2H_6 emissions. Despite the fact that mass balance flights were not carried out in these 2014 studies, one can view box & whisker C_2H_6 distributions in the boundary layer compared to those measured in 2021. Fig 13 and Table 4 present these results. The median boundary layer C_2H_6 values in 2014 relative to 2021 are 34% to 50% higher, and the average values are nearly a factor of 2 higher. It is also worth noting, that with the exception of the one very large enhanced C_2H_6 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. These 2021-2014 comparisons thus support the suggestion that the 2015 Peischl C_2H_6 results might be preferentially sampling enhanced C_2H_6 emissions from storage tanks. Clearly, more work in this area is warranted.

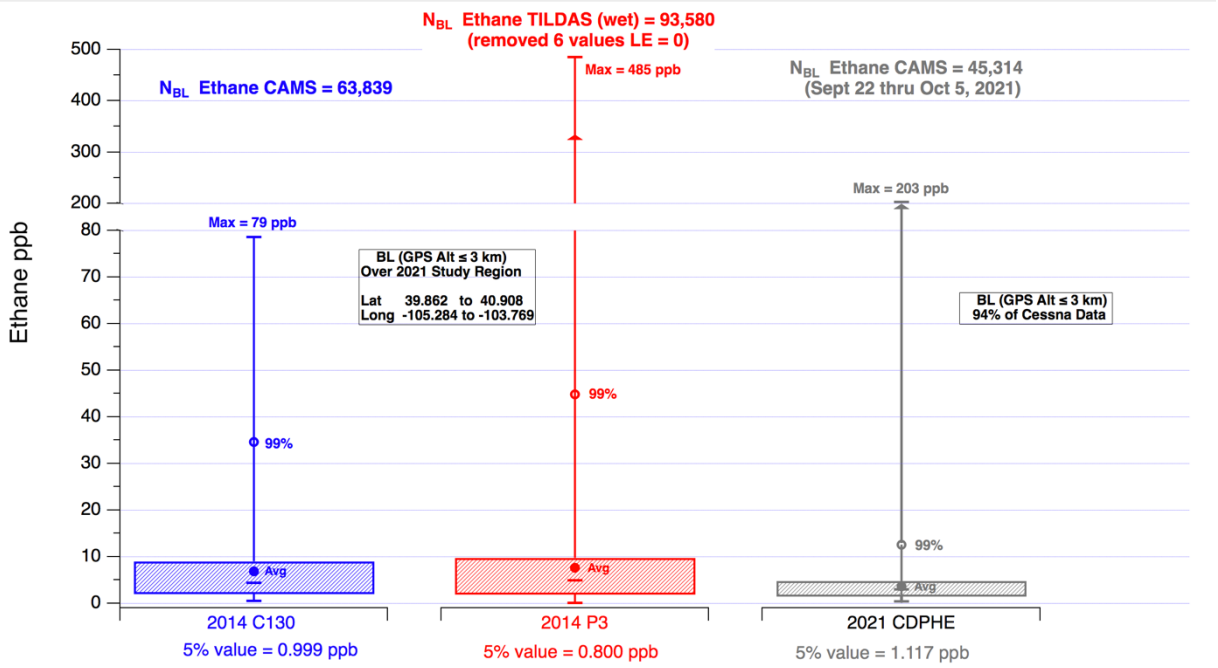


Figure 13: Comparison of C_2H_6 distributions in the boundary layer over the DJB. The boxes represent the 25 and 75% values while the medians are indicated by the horizontal lines in these boxes.

Table 4: 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

6.0 Request for No-Cost Extension Spanning the May 1, 2022 – April 30, 2023 Time Period

We will augment the mass balance approach in determining pollutant flux with two numerical simulation techniques. Although not in the original agreement, these additions allow use of a fuller data set and offers independent means of flux estimates. NOAA's Hybrid Single-Particle Lagrangian Integrated Trajectory dispersion model (HYSPLIT) will be driven with several different meteorological products such as the HRRR or WRF35 that includes several different PBL parametrizations and sources of initial and boundary conditions. With a Bayesian inversion framework, we will estimate emissions of CO_2, CH_4, and CO from the DJB to quantify the uncertainty, and its sources, in each day's emissions estimate and explain the cause for the observed daily variability in the estimated emissions. The modeling will be led by our colleagues at Stonybrook University). We will also use the Eulerian model CMAQ driven by WRF. This model has been used extensively to forecast changes in ozone and evaluate emissions). CMAQ provides three dimensional fields of trace gases that can be compared directly to aircraft observations to evaluate model meteorology, including PBL depth, until a faithful representation

is found – this usually requires nudging against observations and testing several different PBL schemes. Results are then compared trace gas concentrations until the most reliable emissions inventory is identified.

As stated previously, the data presented in this interim report are final. We will make adjustments to the interpretation in the next report at the end of the requested NCE period. This includes: the analysis of additional flight days; the incorporation of additional HYSPLIT trajectory analysis runs; additional analysis procedures employing Lagrangian and Eulerian transport models; and updates to our error analysis. In this report, we only focus on emission fluxes from CH_4 and C_2H_6. However, our final report will also include results from the PTR-TOF VOC measurements. Finally, our analysis here presents CH_4 source attributions based upon simple linear correlations with C_2H_6, which is co-emitted from the same oil and gas (O&G) drilling operations as CH_4 but not from biogenic sources of CH_4, such as from Concentrated Animal Feeding Operations (CAFOs). Such correlations provide approximate CH_4 emission rate estimates from O&G operations. As time permits, we hope to supplement this simple approach in our final report with more sophisticated analyses employing multiple linear regressions using Positive Matrix Factorization (PMF). Time permitting, we also plan to revisit our 2014 FRAPPÉ flights to see if any of the flights may be amenable for mass balance analysis in an effort to address the apparent C_2H_6 emissions reduction raised in the previous section.

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