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C3
Colorado Coordinated Campaign

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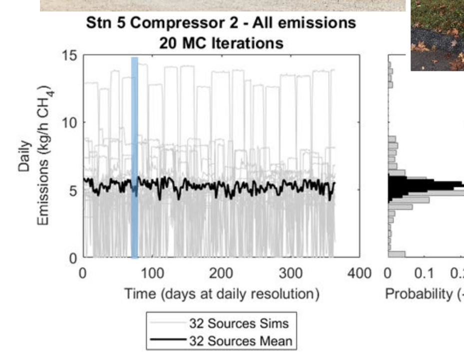
The CSU ‘METEC’ Group

What We Do

1. **METEC Test & Experimental Facility**
   - Test leak detection solutions … lots of them
   - Test/develop common methods
   - Safety-focused experiments on underground gas leaks
2. Make **field measurements**
   - Measured across most sectors of NG industry
3. Develop **emissions simulation software**
   - Methane Emissions Estimation Tool (MEET) – emissions simulator
   - Fugitive Emissions Abatement Simulation Tool (FEAST) – LDAR simulator

Pathway to Equivalence



The METEC$_{H_4}$ Facility

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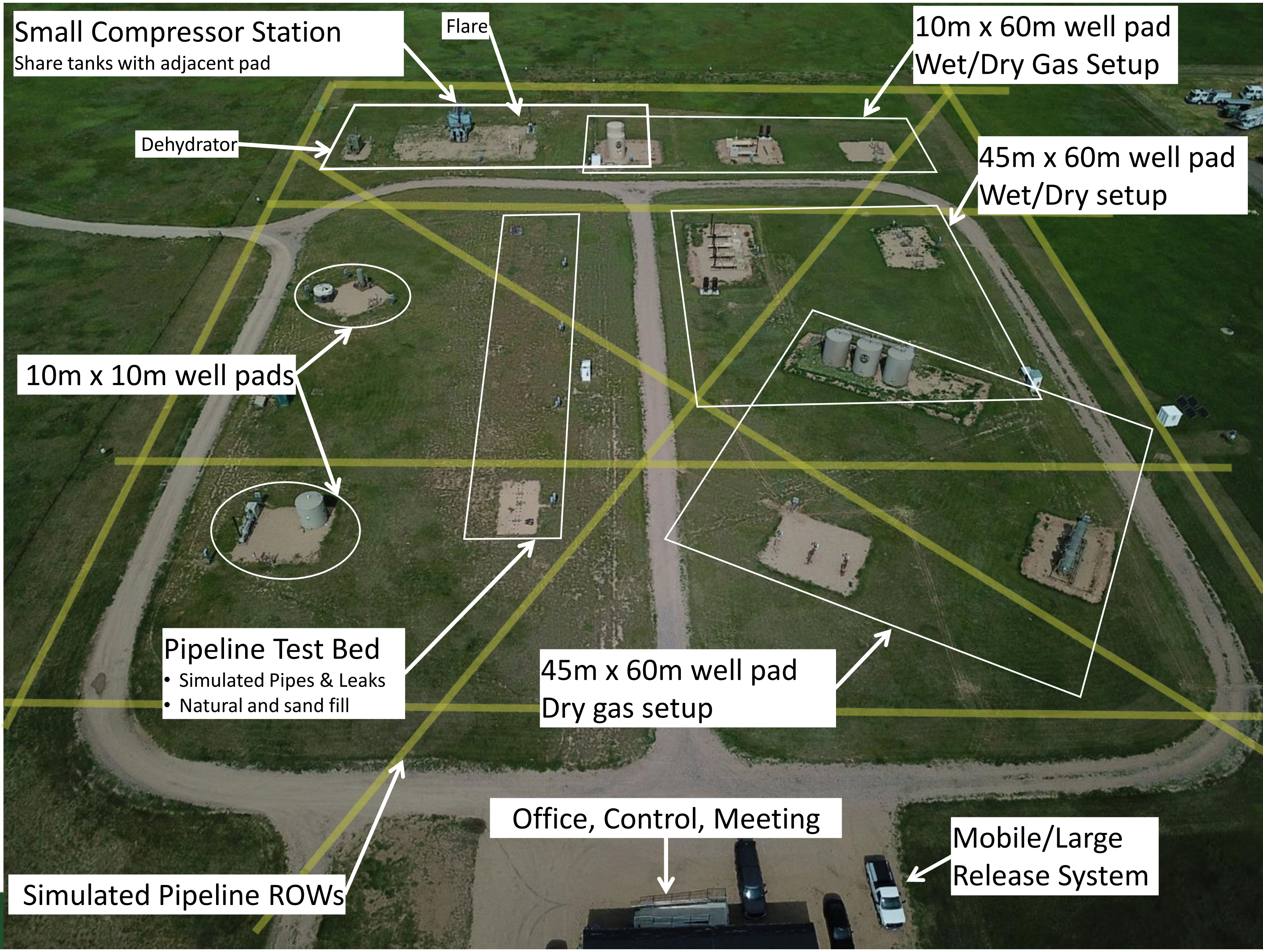
Methane Emissions Technology Evaluation Center

Major Facilities



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arpa·e CHANGING WHAT'S POSSIBLE

Note: More than one project …

- Colorado Coordinated Campaign (topic of this conversation)

- ADED field trials
  - DOE-funded trial for leak detection solutions in DJ, Permian, possibly Marcellus basins.

- RPLUME/UPSIDE Pipeline projects
  - Safety-focused pipeline work for leak detection
  - Trials of pipeline leak survey methods

C3: Colorado Coordinated Campaign

What is a 'Coordinated Campaign?'

- In short … coordinated sampling by
  - Top-down methods (aircraft, satellites, regional towers)
  - Bottom-up methods (facility or component)
- Targets a region – typically a production basin
- Measurements by multiple teams synchronized as much as possible

TD & BU measurements *disagree on emission rates.*

- Missing / undercounting large emitters in BU estimates
- TD methods sample large areas over short periods
- Causality is not generally available for TD methods

Top Down
More comprehensive

These disagree by ≈1.5x … and have for years

Bottom Up
Easier to update

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Why Interest in Coordinated Campaigns?

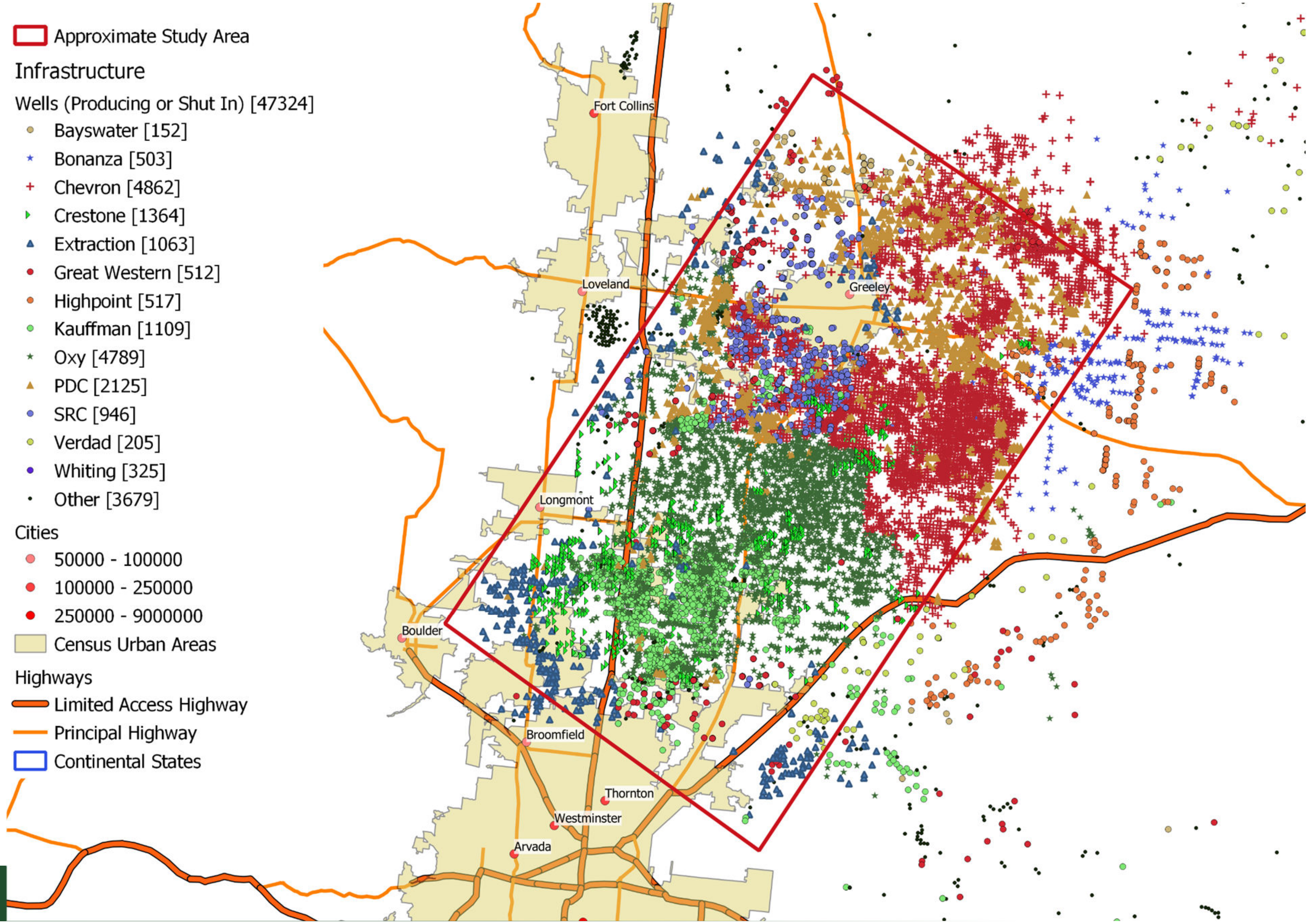
- *Coordinated campaigns are the 'research preview' to 'tiered observation systems'*
  - Regular observation … at regional level … at several different scales
  - Coordinated action … i.e. dispatch … from detections
- Examples:
  - Satellites → large emitter 'count' → basin emissions updates
  - Aircraft regional flights → large emitter ID → OGI dispatch → repair
- **Key Points:**
  - **Tiered observation is coming … and 'here to stay'**
  - **Best to engage, understand and practice than to avoid … for all stakeholders**
  - **Tiered methods are not 100% settled yet … now is the time to learn & tune**

Study Region

COGCC data from 1st 10 months of 2020

Producing or shut-in.

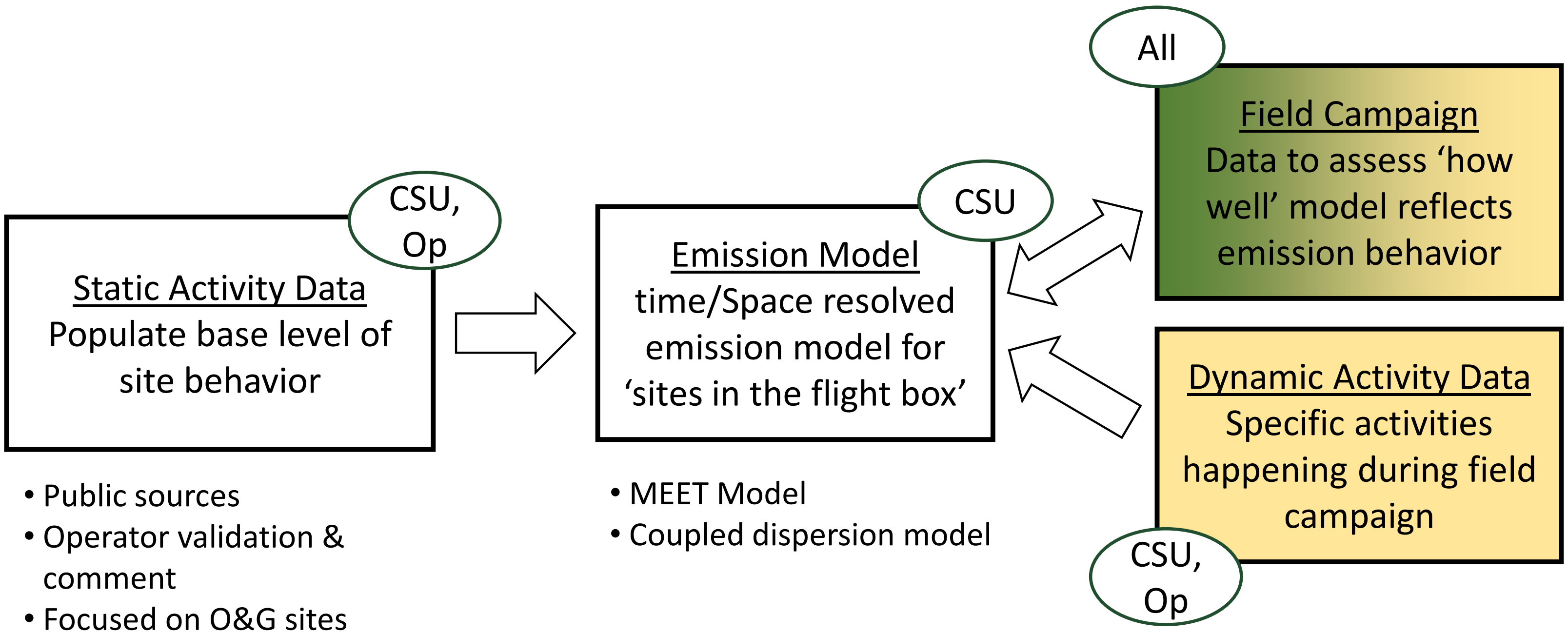
Producers with >100 wells in Weld & nearby counties



Objectives of study

- Develop better *model* of air emissions from the DJ basin O&G operations
  - Understand frequency and size of large emitters
  - Understand how well current emissions data reflect emissions from the basin.
  - Measure methane and sample VOCs
- Create model CDPHE, industry & others can use to
  - Understand emissions & mitigation opportunities
  - Compare to update sampling campaigns
- Note:
  - Currently does not include regional 'total basin emissions' comparisons
  - Investigating possibilities of comparing to regional satellite estimates
  - CDPHE assembling non-O&G emissions data

Conceptual model of the study



- Coordinated aircraft & ground meas.
- Collect 'drive by' concentration profiles
- VOC canister samples

- Operator site access
- Capture 'major known events' with emissions impact

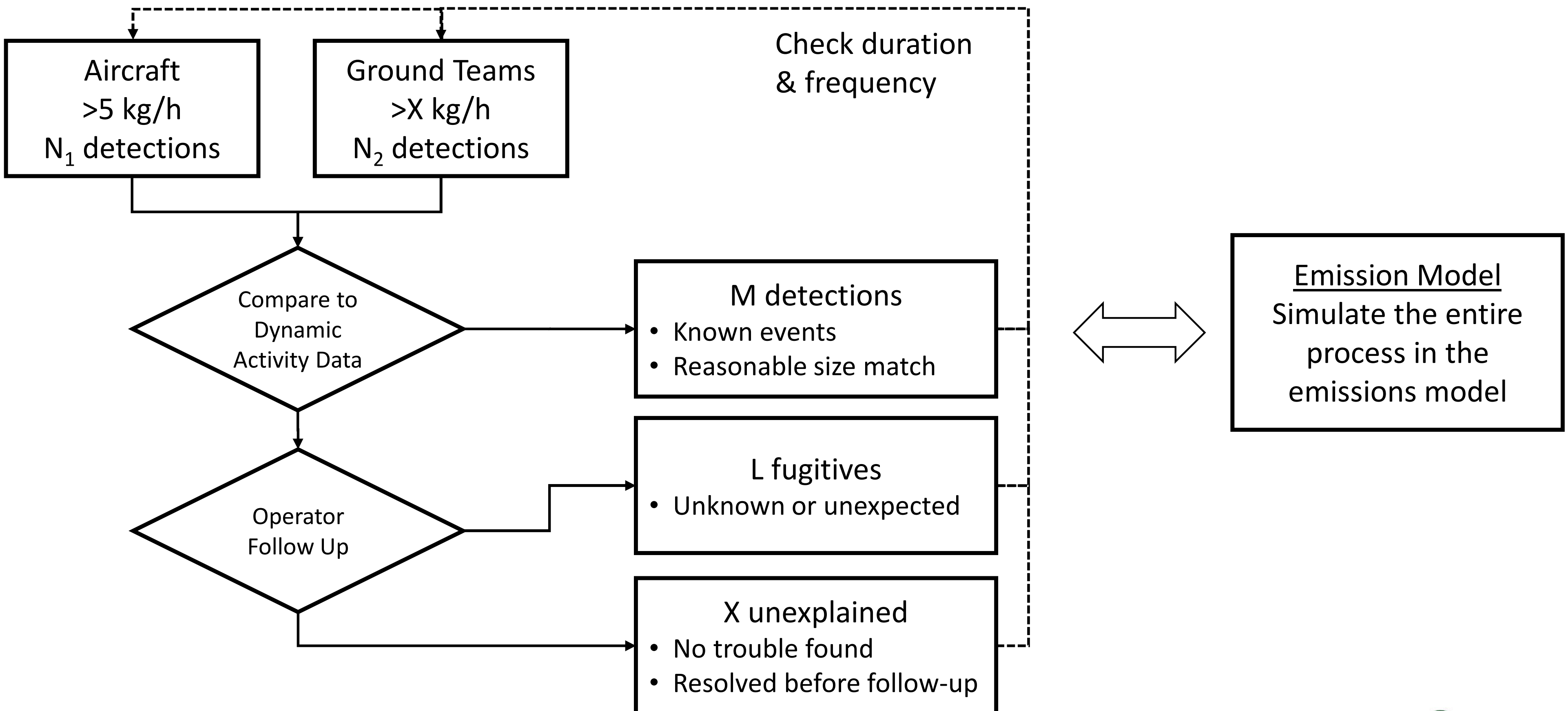
- Public sources
- Operator validation & comment
- Focused on O&G sites
- Track non-O&G methane sites if possible

- MEET Model
- Coupled dispersion model

Legend

- Spring & summer '21 (white)
- July '21 field campaign (green)
- Sept '21 field campaign (yellow)

Example of Tiered Observation in Practice



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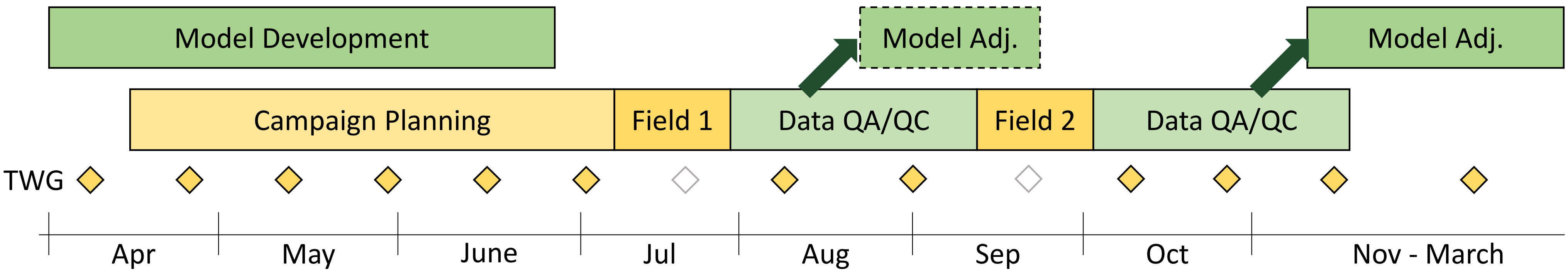
Campaign Timing & General Plan

Schedule Overview



- Main Aircraft Windows
  - July 8-21
  - September 17-30
- Ground teams may be active before/after

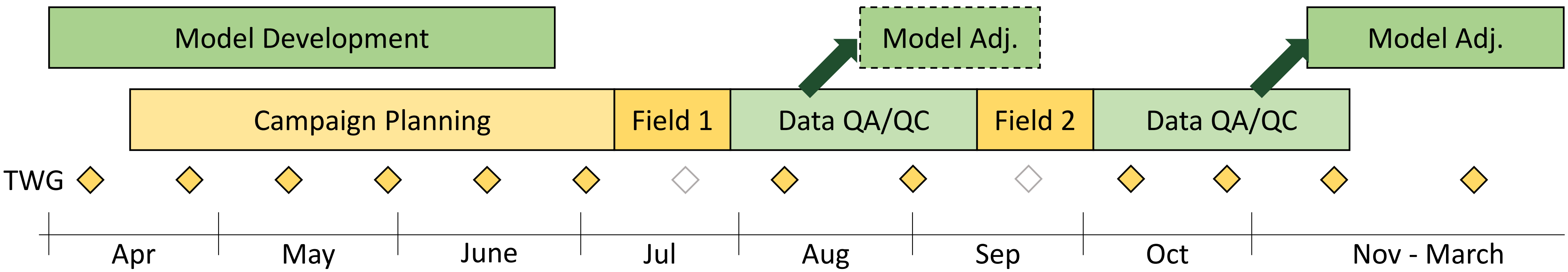
Operator Involvement

Study Team Only

Measurement Methods

- Aircraft:
  - Imaging spectrometer (U. Arizona)
  - Methane/ethane concentration (U. Colorado, September campaign only)
- Ground
  - Tracer flux (CSU, U. Wyoming)
  - Area concentration mapping (CSU, under consideration)
  - Flux-plane using drones (Scientific Aviation)
  - VOC canisters (CSU)

Planning Details: Operators



<u>Technical Working Group</u>

- Study team + operators
- Develop uniform processes
- Review preliminary results
- Educate study team on operational processes
- ≈biweekly, dropping down after field measurement

<u>Campaign Planning</u>

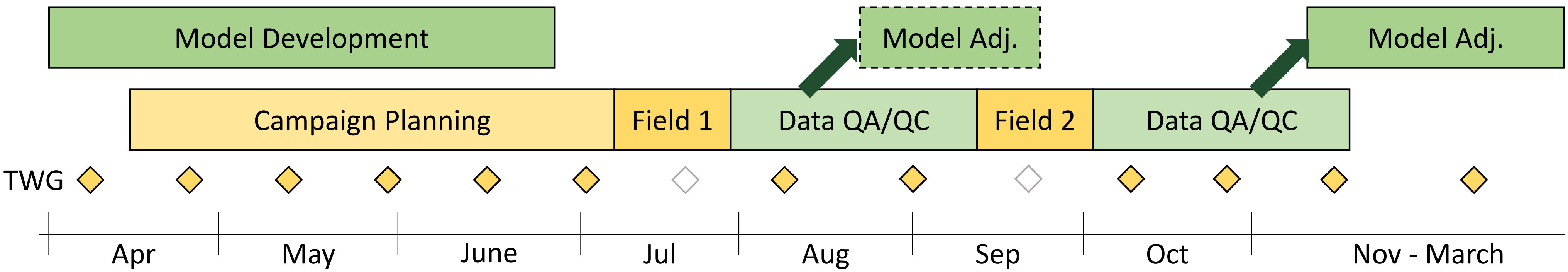
- Study team + operators
- Who goes where & when
- Plan activity data collection
- Site access & non-disclosure agreements

- Is a 'governance agreement' required?

<u>Field Campaigns</u>

- Study team + operators
- Report dynamic activity
- Site escorts for measurements
- On-the-fly coordination, if needed

Planning Details: Teams



<u>Model Development</u>

- Study team (some operator)
- Finalize model features
- Populate static activity & emissions data
- *Validate models with operators*
- Set up model to run by field campaign

<u>Data QA/QC</u>

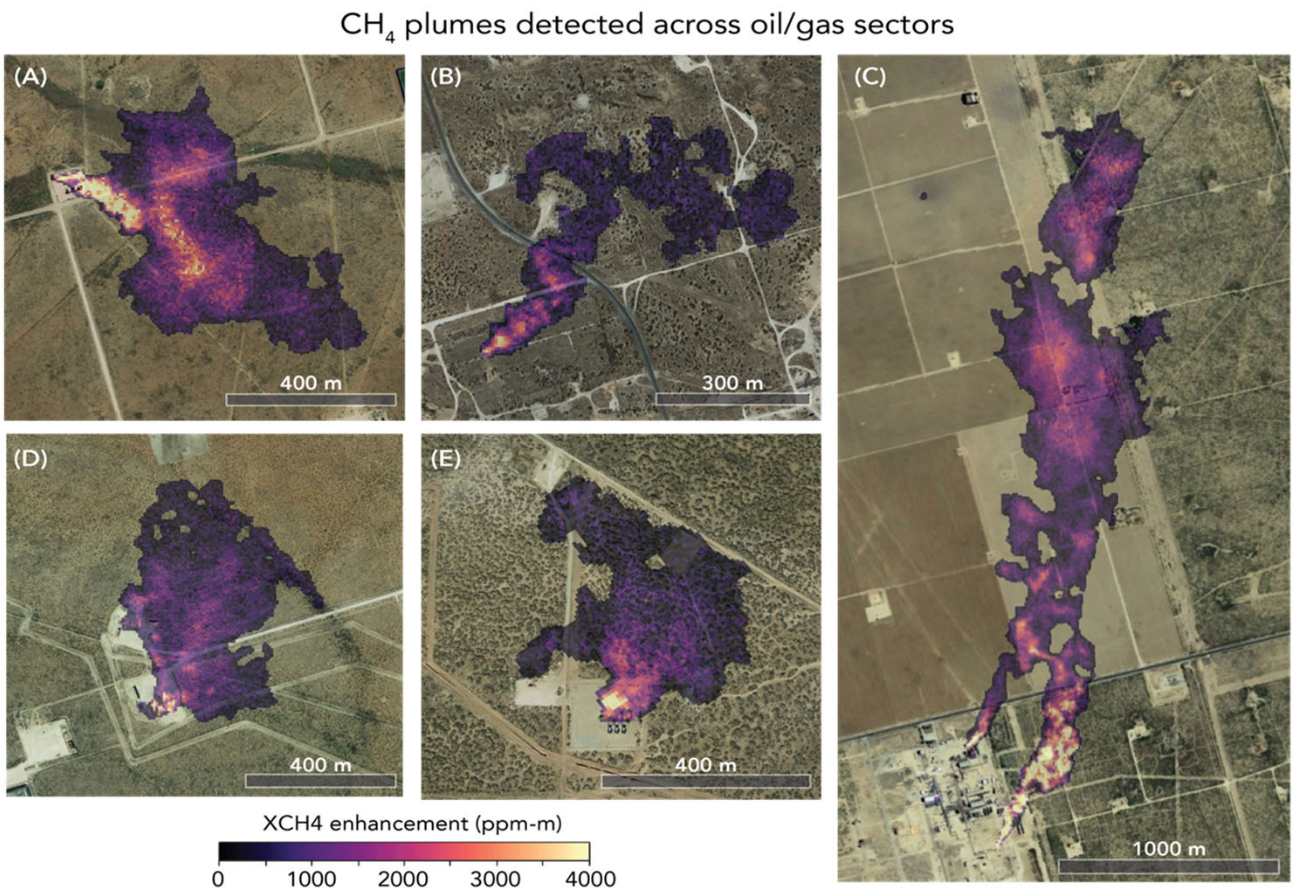
- Study team
- Consolidate & review data
- Prepare preliminary presentations

<u>Model Adjustment</u>

- Study
- Two-way feedback – data into model and model into field plan
- Test tiered observation experiment
- Develop guidance for model maintenance

Measurement Methods

Aerial Spectrometer:
Representative CH_4 point sources in the Permian basin



Example CH_4 plumes detected by AVIRIS-NG and GAO imaging spectrometers from oil/gas infrastructure, including emissions from (A) a tank battery , (B) gathering pipeline, (C) a gas processing plant*, (D) a production site, and (E) a compressor station.

Detection threshold 5-10 kg CH_4/h

*2 sources at same facility: 1 flaring and 1 TBD
Images courtesy of Riley Duren, U. Arizona

Note on ‘Fast Ground Screens’

- With site access …
  - Ground team drives onto site & *safely* around site
  - If no plume detected, site is classified as ‘no emissions detected’
- Advantages: Fast identification of zero-to-low emitting sites
  - Increases site count
  - Provides more accurate representation of ‘non-tail’ emissions
  - Spot checks more sites with aircraft (non) detections

Image from Shane Murphy, U. Wyoming
From Fayetteville Campaign

Tracer Measurement: In Theory

$$\frac{\Delta CH_4}{\Delta tracer} = \frac{Flow_{CH_4}}{Flow_{tracer}} \quad (1)$$

By measuring the concentration enhancements of methane and the tracer gas(es) above background (ΔCH_4 and $\Delta tracer$), and knowing the flowrate of the tracer gas being released ($Flow_{tracer}$), the flow of methane from the site ($Flow_{CH_4}$) can be determined readily.

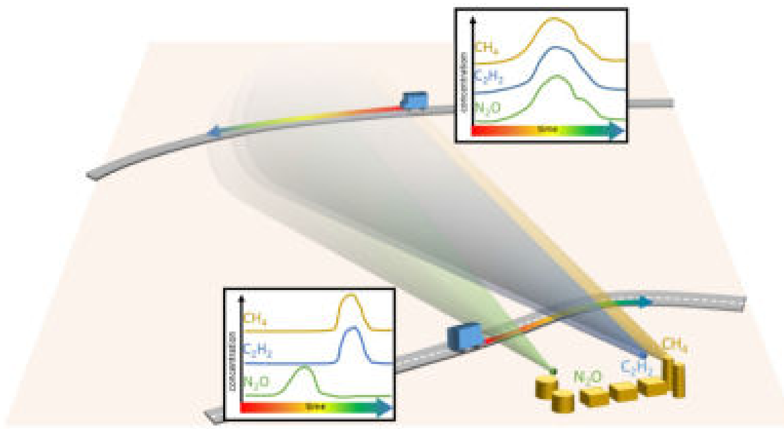
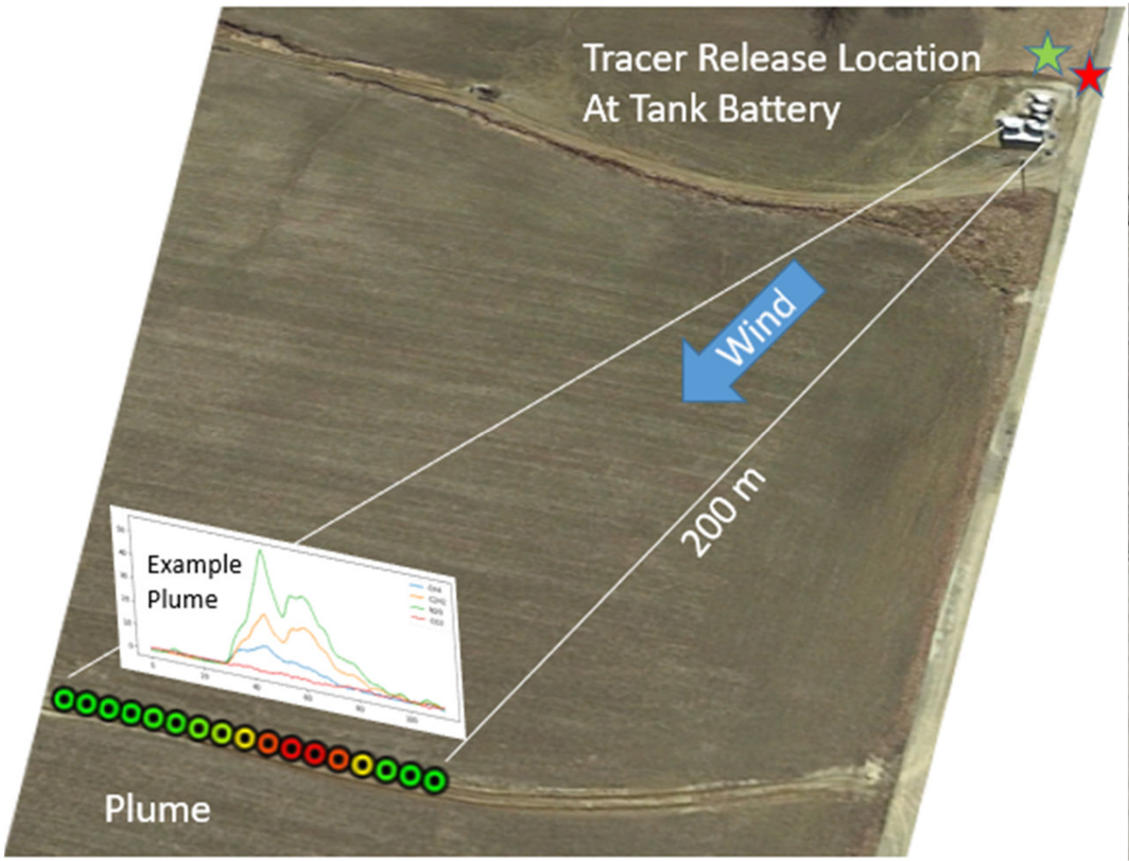
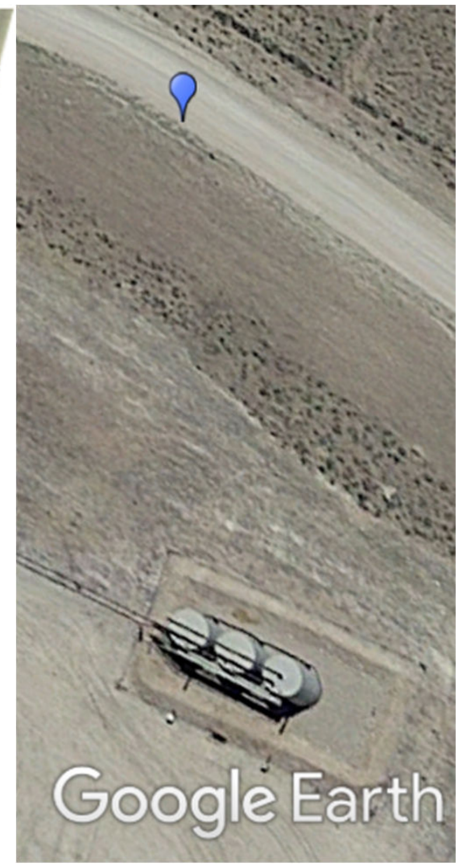


Figure 1: Dual tracer flux measurement setup from Roscioli et al.[3]. Tracer gases (N_2O and C_2H_2) are released on-site at known flow rates near suspected emission sources (CH_4). Mobile measurements of atmospheric enhancements of both the emission source and tracer gases are made downwind. The mass emission rate of the source can be deduced from the measured downwind enhancements and the known mass emission rates of the tracer gases.

Tracer Flux (Downwind, With Site Access)





Requires site access

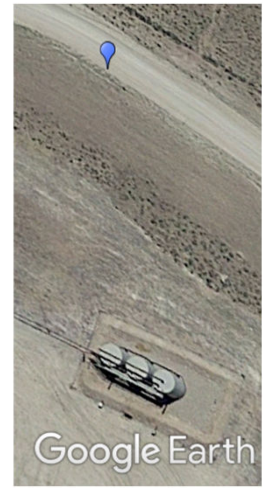
Well developed & recognized method

Does not require dispersion assumptions

±20-30% Precision

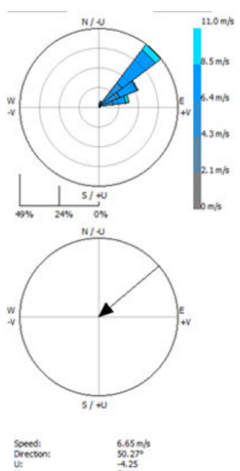
OTM33a

EPA "Other Test Method 33a"

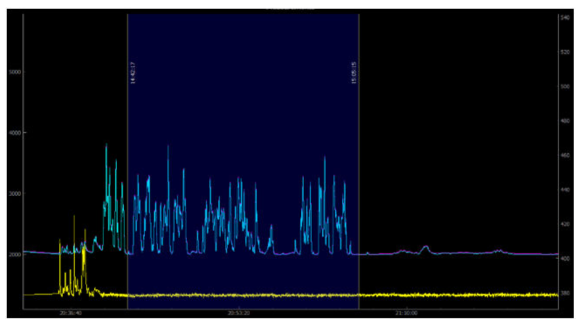


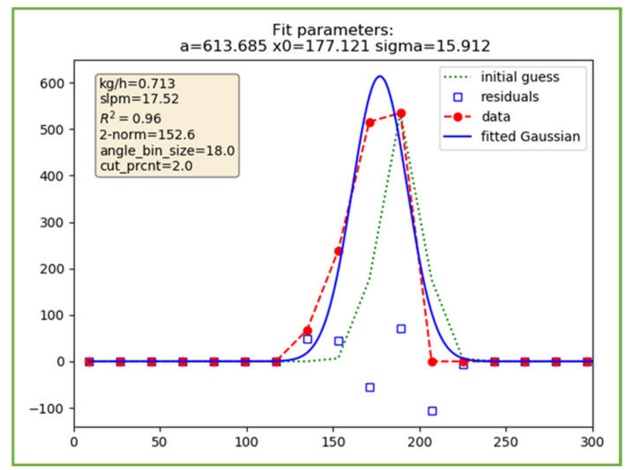
Wind Direction

Wind Speed & Direction



Concentration Log





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SciAv's Drone Platform

Aeris Pico Mid-IR
Methane/Ethane Instrument

Gas canister sampling

Drone Flux-Plane Method

SCIENTIFIC AVIATION

Quantifying emissions sources from the air

Concentration measurement + Accurate on-board wind speed and direction

- On-board wind system developed at Sci Av *(Conley et al., 2014)*
- Emissions calculation is based on the principal of mass conservation *(Conley et al., 2017)*

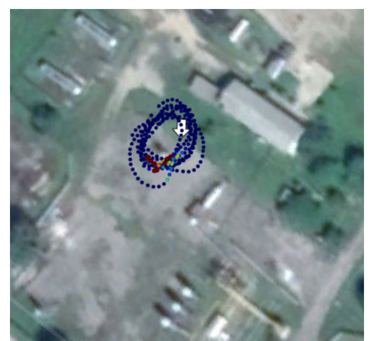
$$\text{Emissions} = E_{Out} - E_{In}$$

$$E_x = \sum \langle \text{wind vector} \rangle \bullet \langle \text{concentration} \rangle$$

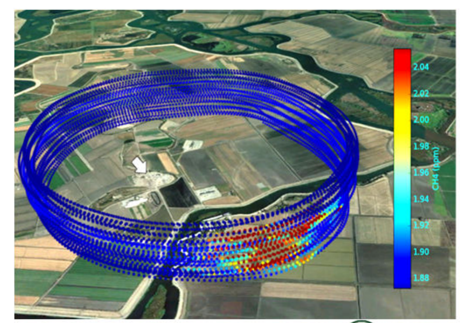
- Notes:
  - No major competing upwind sources
  - Drone uncertainty $\pm$10 – 50% of emission
    - Stronger the better
    - Difficulty measuring flares
  - Need to be around 30 m downwind of the emissive component. Max 50 m.
  - Can measure up to 10 sites per day

Site quantification:

Component-level quantification:



Manned flight example:



Canister Samples for VOCs

- Evacuated canisters will be deployed with field measurement teams
  - Fill canisters when making another measurement
  - Return canisters to CSU atmospheric sciences for speciation
- VOCs emission rate estimated by comparing concentrations X measured methane flux

$$\dot{m}_x = \frac{w_x}{w_{CH_4}} \dot{m}_{CH_4}$$

Mass flow of CH4 measured by field team

Concentration by species

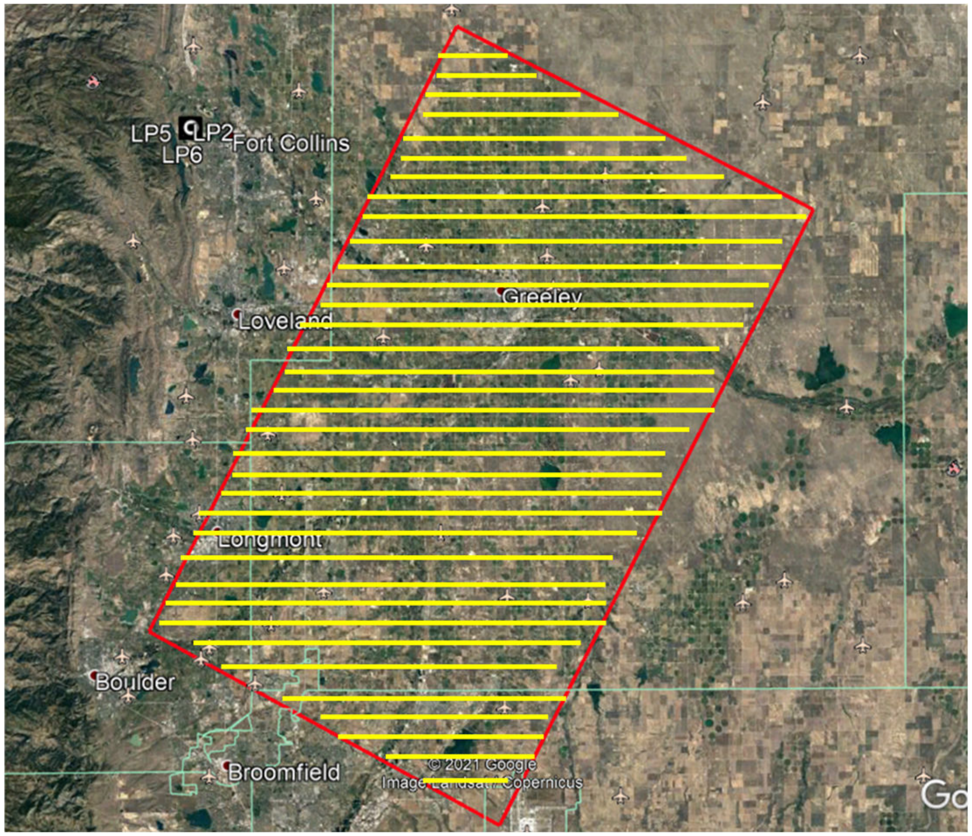
5-Channel GC

GC-FID-FID-FID-ECD-MS

List of Volatile Organic Compounds and statistics of calibration and system LOD

VOC	Calibration Curve Correalation (r^2)	LOD (ppbv)	Slope of Calibration Curve	Standard Range (ppbv)
ethane	0.999	0.105	137	0.4-3362
propane	0.999	0.02	1294	0.4-3203
i-butane	0.999	0.008	1682	0.4-3171
n-butane	0.999	0.01	1691	0.4-3140
i-pentane	0.999	0.009	2110	0.4-3171
n-pentane	0.998	0.007	2039	0.4-3108
2,4-dimethylpentane	0.992	0.004	4049	0.4-3330
2,3-dimethylpentane	0.998	0.013	1049	0.4-3362
2,2,4-trimethylpentane	0.998	0.018	1196	0.4-3298
2,3,4-trimethylpentane	0.999	0.009	1174	0.4-3299
n-hexane	0.999	0.012	2467	0.4-3267
2-methylhexane	0.999	0.01	1079	0.4-3299
3-methylhexane	0.999	0.014	1064	0.4-3299
n-heptane	0.995	0.009	3164	0.4-3299
2-methylheptane	0.999	0.022	1165	0.4-3299
3-methylheptane	0.999	0.016	1177	0.4-3267
n-octane	0.999	0.016	1115	0.4-3299
n-nonane	0.999	0.01	1165	0.4-3235
n-decane	0.999	0.011	1131	0.4-3299
cyclopentane	0.999	0.009	2097	0.4-3171
cyclohexane	0.999	0.015	895	0.4-3330
methylcyclohexane	0.999	0.019	1058	0.4-3299
ethene	0.999	0.053	945	0.4-3362
propene	0.999	0.009	1179	0.4-3203
t-2-butene	0.999	0.018	1662	0.4-3108
1-butene	0.998	0.013	1651	0.4-3104
c-2-butene	0.999	0.022	1756	0.4-3362
isoprene	0.998	0.012	2202	0.4-3171
t-2-pentene	0.996	0.014	1809	0.4-3203
1-pentene	0.998	0.023	1909	0.4-3076
cis-2-pentene	0.998	0.012	1917	0.4-3330
acetylene	0.999	0.013	1186	0.4-3362
benzene	0.999	0.01	903	0.4-3266
1,3,5-trimethylbenzene	0.999	0.012	1091	0.4-3235
1,2,3-trimethylbenzene	0.996	0.012	1074	0.4-3140
1,2,4-trimethylbenzene	0.997	0.0124	1077	0.4-3171
ethylbenzene	0.999	0.019	1066	0.4-3266
1,3-diethylbenzene	0.998	0.027	1136	0.4-3140
1,4-diethylbenzene	0.998	0.013	1133	0.4-3108
isopropylbenzene	0.999	0.011	1171	0.4-3140
n-propylbenzene	0.998	0.012	1157	0.4-3108
toluene	0.998	0.017	1028	0.4-3266
2-ethyltoluene	0.999	0.025	1128	0.4-3140
3-ethyltoluene	0.995	0.014	1084	0.4-3235
4-ethyltoluene	0.998	0.015	1102	0.4-3171
styrene	0.996	0.014	1008	0.4-3298
m+p-xylenes	0.995	0.014	1754	0.8-6596
o-xylene	0.999	0.006	1087	0.4-3203

Ground based ‘emission landscape’



- Drive in East/West transects @ 30 mph
- Identify concentration enhancements along the road
- Make a guess at the type and location of the source from:
  - Camera images
  - wind direction
  - [CH4], [C2H6], [N2O] and δ13C
- Estimate the emission using a Gaussian approach.
- Compare location/size of emissions with those detected by the aircraft.

Next Steps

Next Steps

- In/Out decisions by each operator → notify CSU (April 30)
- Set regular meetings for technical working group (start w/o April 26?)
- Start agreements
  - Preliminary discussion with one company → suggested a simplified governance agreement. Propose:
    - Work up agreement with that company (April 16)
    - Circulate to all others
  - Start NDA with each company as 'In' decisions received
  - Start site access as soon as TWG identifies ground team ←→ company alignment

    … or …
  - Site access with CSU and U Wyoming & SciAv covered as subcontractors of CSU?

Thank You

Contact

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