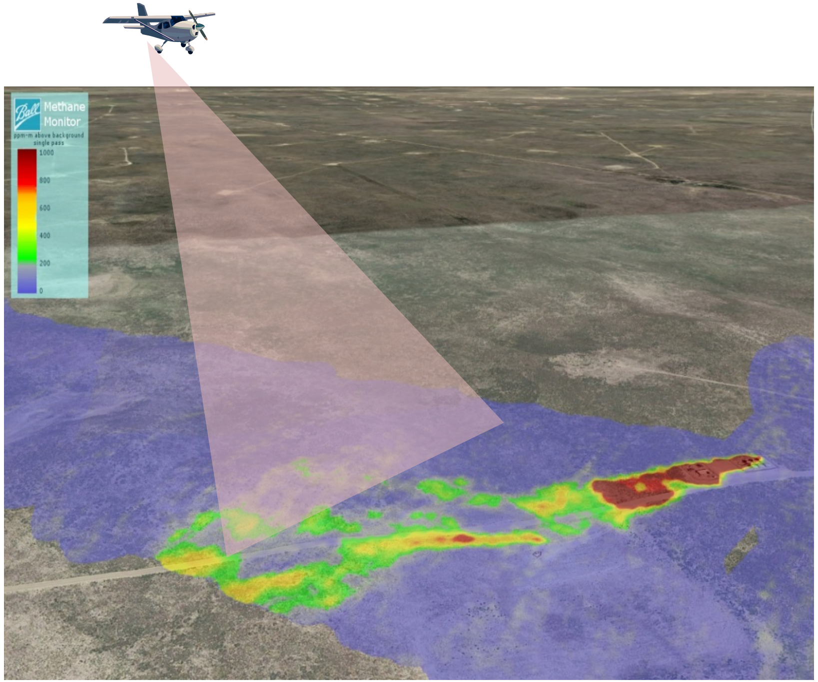
Improving Methane Emission Estimates with Airborne Active Remote Sensing



Ball Aerospace & Technologies,
Boulder, CO 80301

Betsy Farris

Systems Engineer

bfarris@ball.com

Jarett Bartholomew (PI), Orion Esch,
Lyle Ruppert, Carl Weimer, Phil Lyman,
Steve Solga, Jeremy Craner, Mats Bennett

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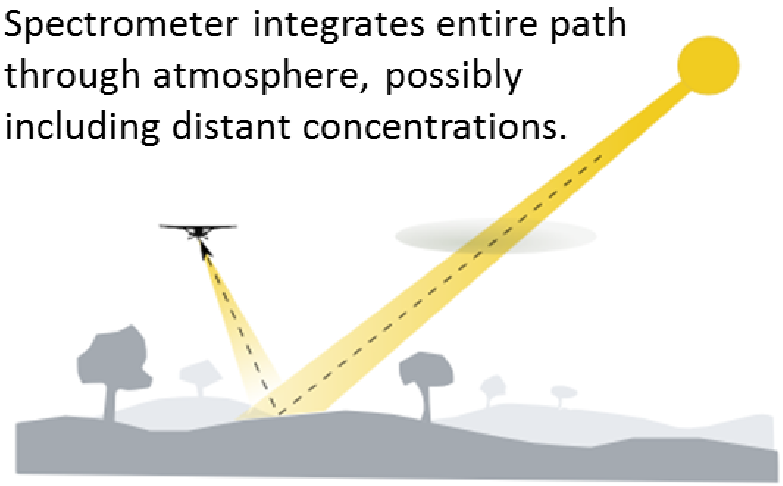
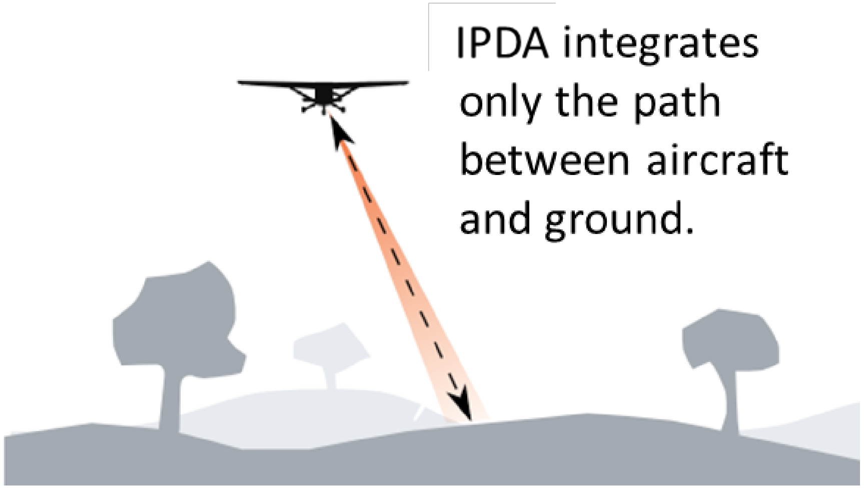
Outline

- Active Sensing of Methane Emissions
- Methane Monitor
- Demonstration Case Study
- Applicability to Emissions Inventories
- Next Steps

Active Sensing of Methane Emissions

The Methane Monitor is a Integrated Path Differential Absorption Lidar (IPDA) system that measures methane total column density from an airplane flying 1,000 meters above the ground.

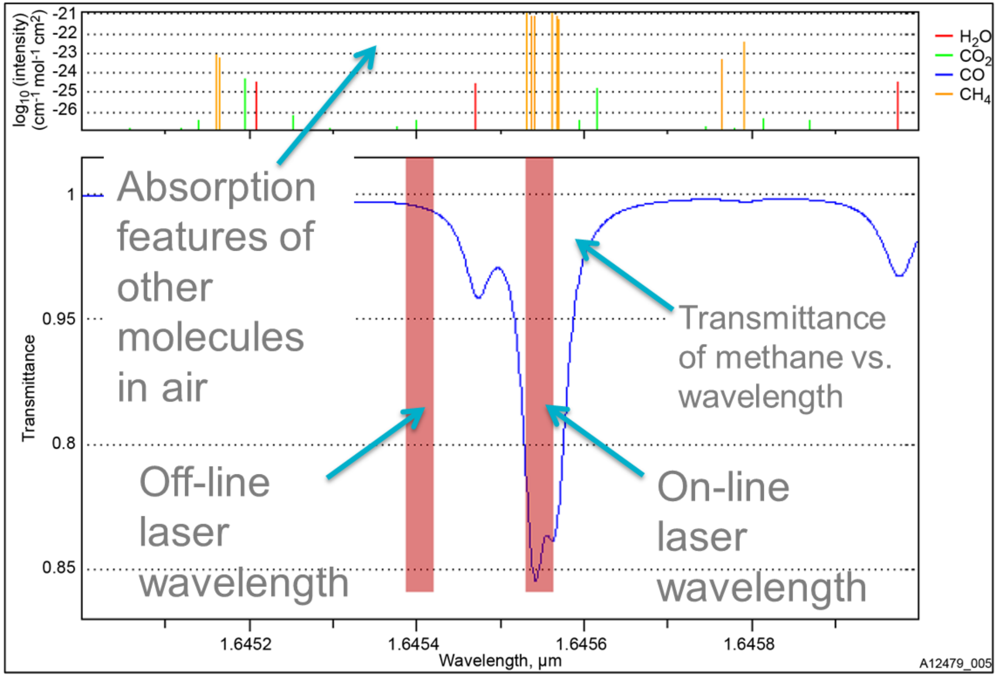




Active Sensing of Methane Emissions

IPDA: Integrated Path Differential Absorption Lidar

- Two lasers form a pulse pair
- One pulse is absorbed by methane (on-line)
- One pulse is absorbed less by methane (off-line)
- All pulse intensities measured at transmission and return



Methane Monitor

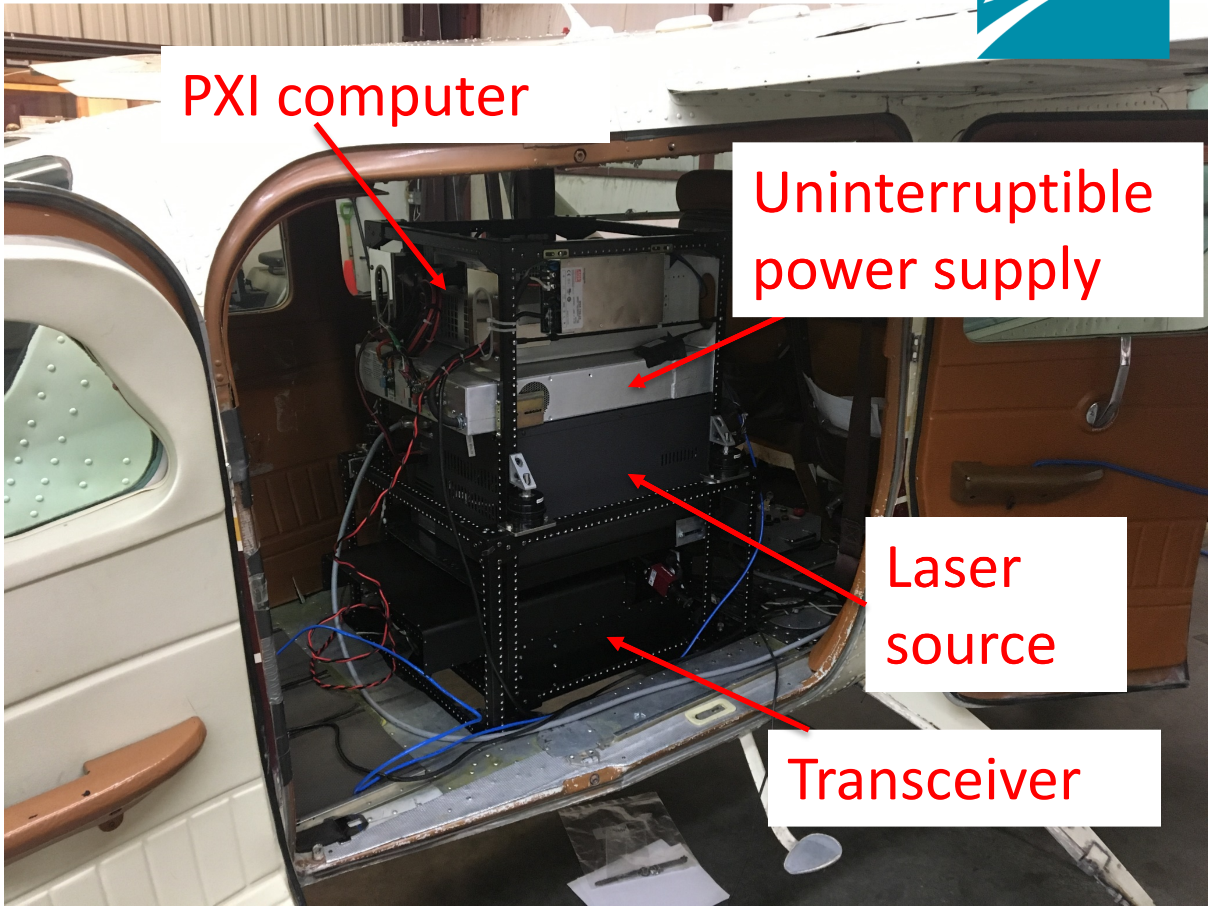
Upstream oil and gas operations
Distribution networks
Natural seeps
Landfills
Agriculture

Cessna TU206 with Camera Port

Methane Monitor

Sensor Integration

- Vibration isolated rack installed over the camera port
- Weight: 240 lbs
- Power consumption: 650 W
- Rack dimensions: 20”x20”x32”



Methane Monitor

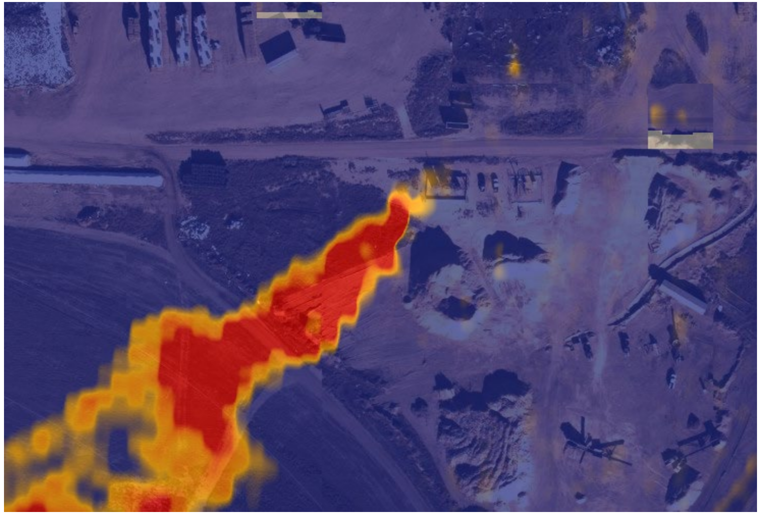
Operating Parameters

Parameter	Performance
Operating Wavelengths	1645.40 (off) 1645.55 (on)
Sensing Swath	Up to 400 m (¼ mile)
Altitude	800-1800 m (2,600-6000 ft) AGL
Methane Emission Rate Detection Threshold	50-100 SCFH depending on wind speed
Spatial Resolution	~3 m
Geo-location Accuracy	2-5 m depending on altitude
CH_4 Error	50-60 ppm-m

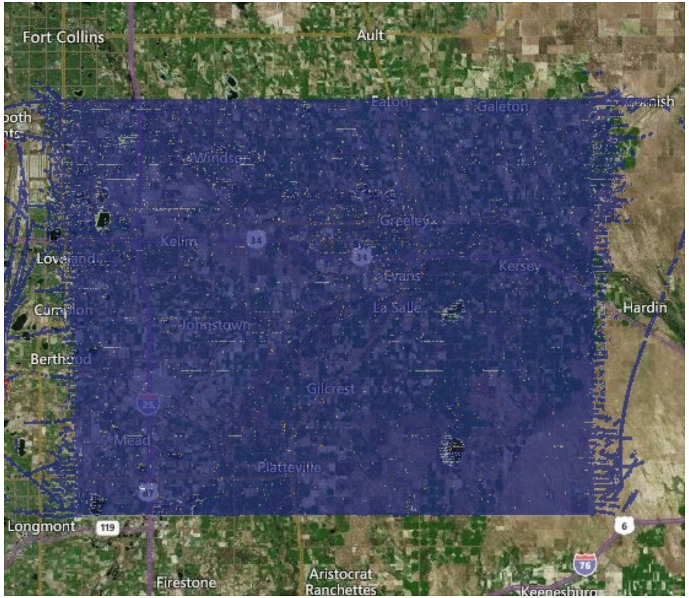
Demonstration Case Study

Denver-Julesburg Basin

- 720 sq. mi. of survey data collected in 8 days
- Pinpointed location of 63 sources of methane emissions



Cloud-based analytics tools give methane contour map visualization over imagery



Demonstration Case Study

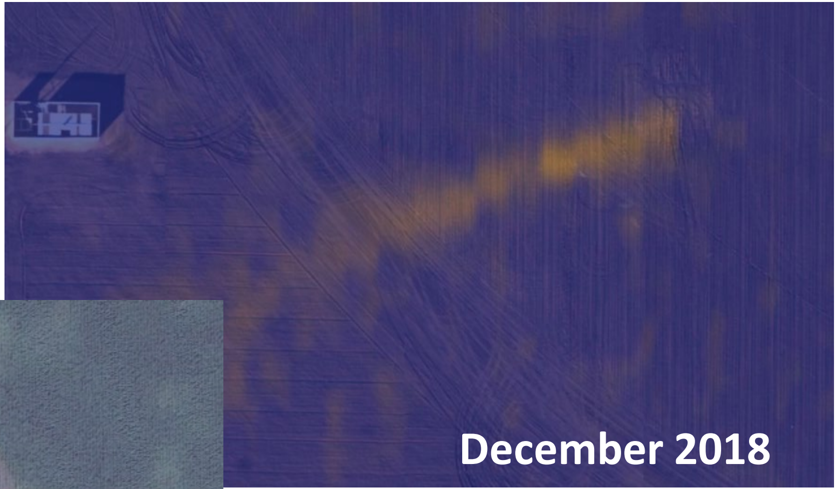
Identified 4 broken gathering lines outside of the oil & gas operators' fenced facilities

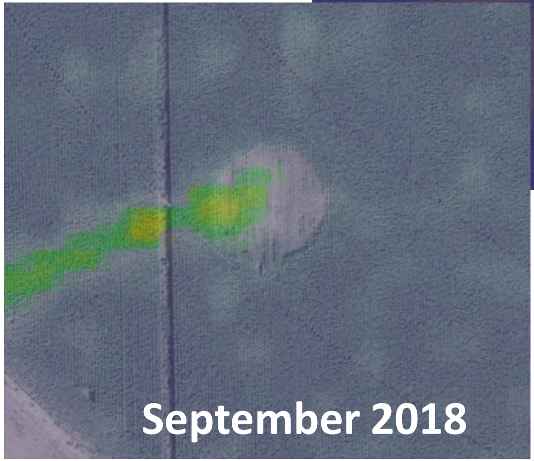
- Leaks escaped detection, in some cases for years, with inspections performed using routine optical gas imagery
- Entire area dataset analyzed for leaks in ~5 hours using Ball's cloud-based, scalable big data analytics tool set hosted on Amazon Web Services
- All four leaks were communicated to the pipeline operators and subsequently repaired

Demonstration Case Study

Smallest of the 4 flow line leaks was in a center-pivot irrigation corn field

- 80 ft. diameter circle of dead corn from methane emission
- Difficult to find with handheld sensor
- Landowner notified



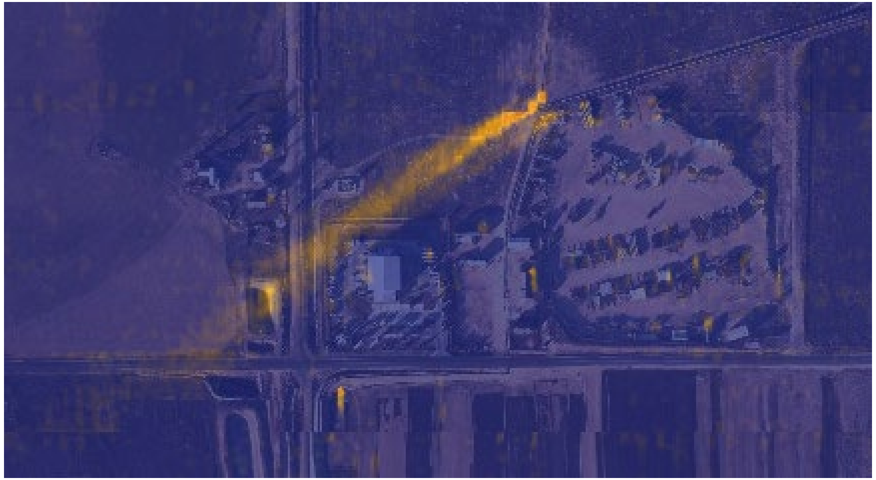


Note: the graphical displays are at different spatial scale and use different color scales for the methane concentration.

Demonstration Case Study

This leak had persisted for 6 years

- Source located near an operator's equipment yard and along an irrigation ditch
- Leak rate ~3,000 SCFH
- >300 ft diameter dead patch

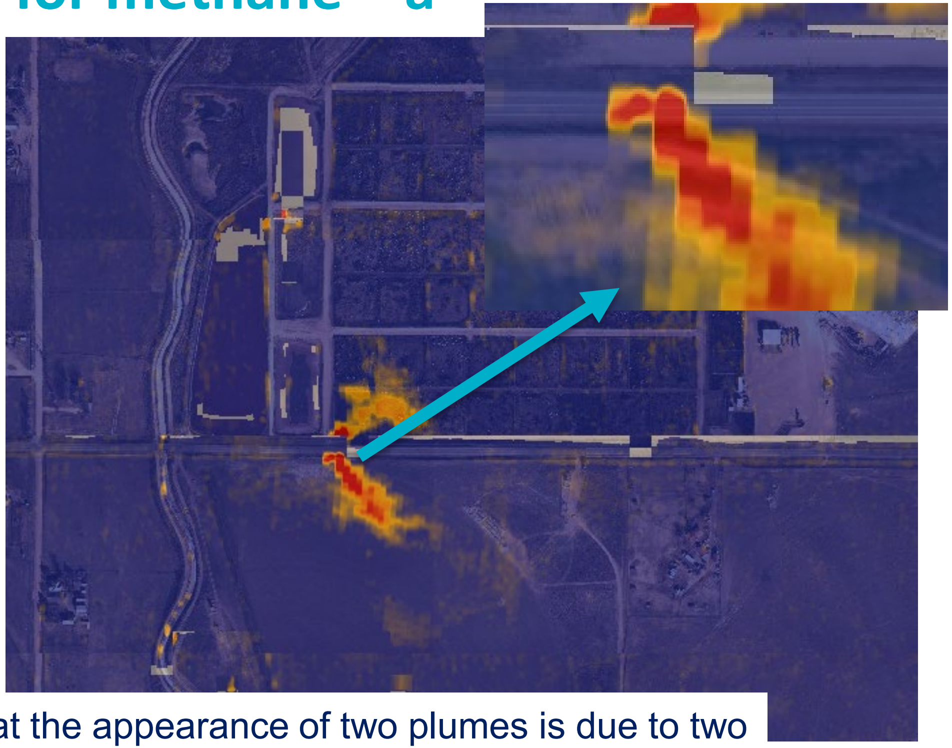


6/15/2010 8/18/2012 10/9/2015 9/7/2016 9/12/2018

Demonstration Case Study

This leak was along a dirt road and was well above the lower explosive limit for methane – a hazard

- Local rancher reported ground bubbles from leak location when it rains
- Largest leak found and could have been overlooked if erroneously attributed to the adjacent livestock operation

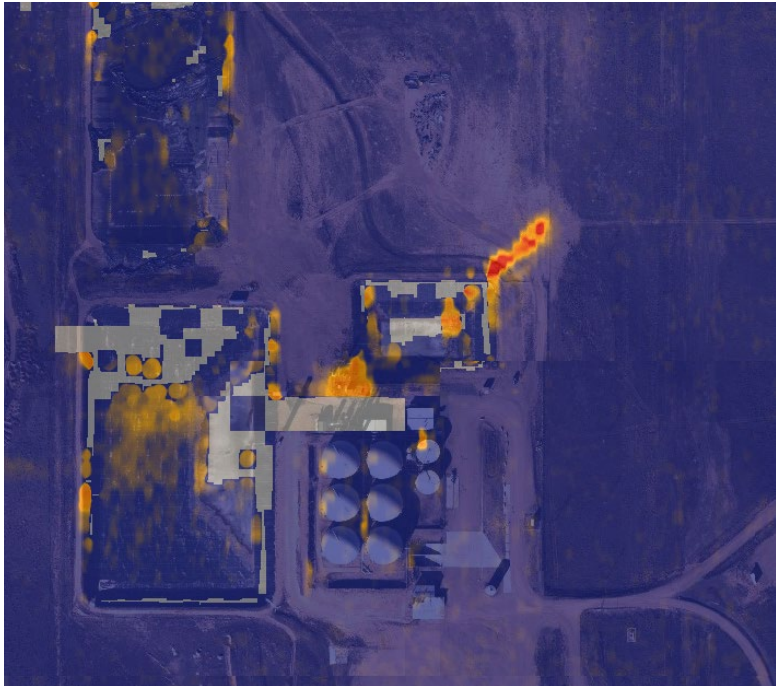


Note that the appearance of two plumes is due to two flyovers at separate times with different wind directions.

Demonstration Case Study

Last indication was from piping associated with a shuttered bio-gas production facility

- It was not clear if the emission was associated with the facility itself or the pipes that would have fed the bio-gas into the normal natural gas system
- Upon follow-up the plant facility foreman confirmed that it had been turned off



Demonstration Case Study

Summary

- Over 60 sources of methane emission identified with 8 days of survey covering over 700 square miles
- Cloud-based post-processing in <12 hours after collect
- Cloud-based tool enables detailed data review of >700 square miles in 5 hours by human analyst
- Four leaks from underground gathering lines found, verified, and reported to operators for remediation
- Emissions from agricultural operations readily discernable from oil and gas operations

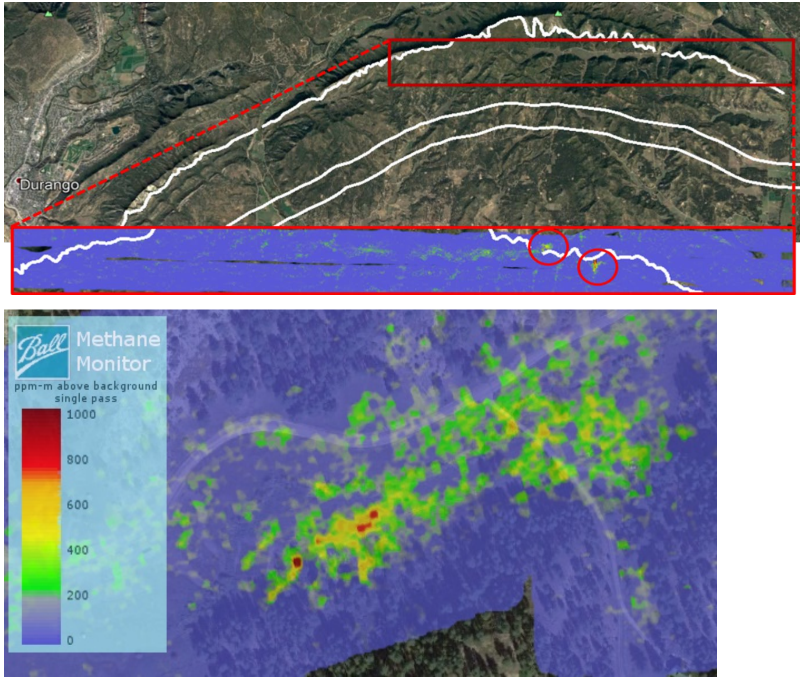
Active Sensing for Emission Inventories

Benefits and Advantages

- Identify and quantity Super Emitters
- Source agnostic
- Tracer for other species, VOCs

Limitations and Challenges

- Intermittent measurements
- Controlled airspace



Seep mapping in Fruitland Outcrop

Active Sensing for Emission Inventories

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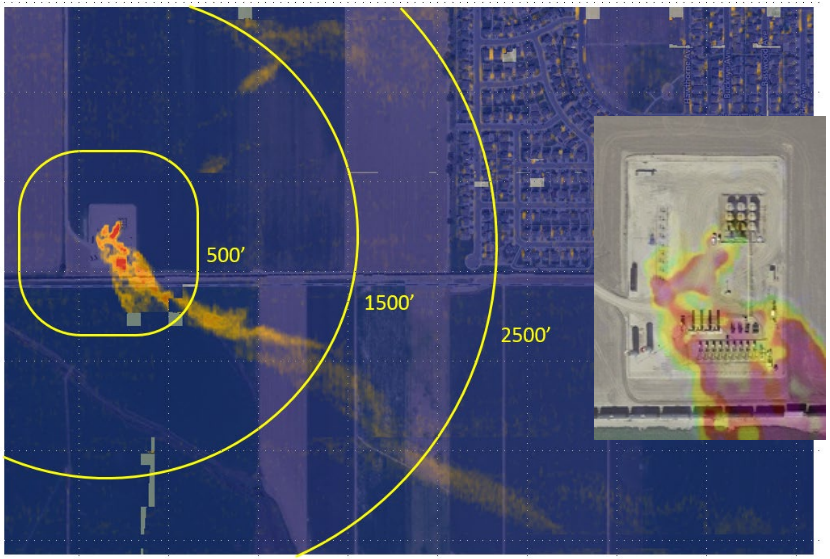
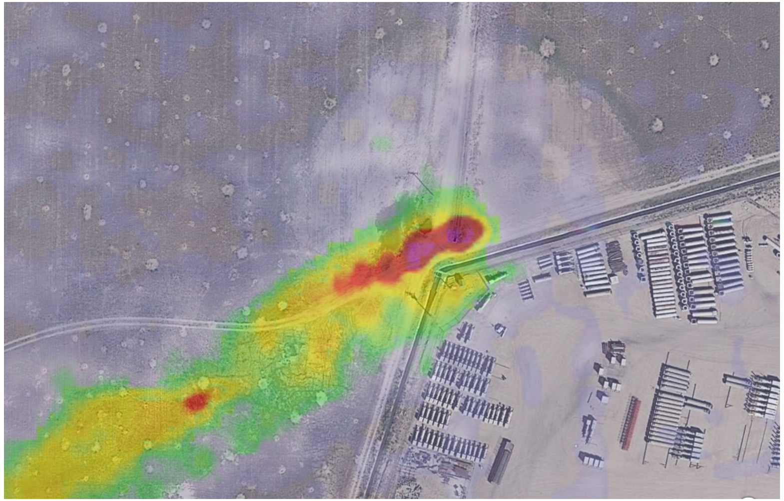


An example emission from a fenced production facility

Next Steps

- Improvements to target 10,000 ft operation for operation above Class B airspace
- Faster area coverage
- Sensitivity improvements
- Advanced emission quantification
- Persistent imaging platforms



Conclusions

- Active Methane Monitor is ready to save the world!
- How can we use this tech to improve inventories?

Acknowledgements

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Pipeline and Hazardous Materials Safety Administration

- Thanks also to API & PRCI for opportunities to learn about industry needs and share research results!

Thank You!

Active Sensing for Emission Inventories

The IPDA Equation

- Derived from the Beer-Lambert law:

$$log\frac{I}{I_0} = -\varepsilon[CH_4]l$$

- Adding a reference measurement to account for the unknown target reflectivity:

$$[CH_4]l = -\frac{1}{\varepsilon}\log\left(\frac{T_{off}R_{on}}{T_{on}R_{off}}\right)$$

Active Sensing for Emission Inventories

Wavelength Jitter Correction and Background Subtraction

- Transmission through a methane cell is measured for every pulse and the absorption coefficient is corrected for wavelength jitter:

$$\frac{1}{\varepsilon} = \frac{[CH_4]_{cell} l_{cell}}{-log\left(\frac{T_{off} C_{on}}{T_{on} C_{off}}\right)}$$

- Background methane is subtracted to yield exceedance:

$$[CH_4]l_{plume} = [CH_4]_{measured} l - [CH_4]_{background} l$$

Cloud Based Data Processing and Viewing

Methane Monitoring as a Service

- Cloud based data processing using Amazon Web Services
- Web based data viewing and delivery
- Less than 24 hour delay from data collection to web viewing
- Context imagery displayed with methane overlay
- Plume analytics, emission rate