Characterizing Mine Methane Emissions Using Airplane-, Vehicle-, and Drone-Based Measurements

36th Annual Kentucky Professional Engineers in Mining Seminar

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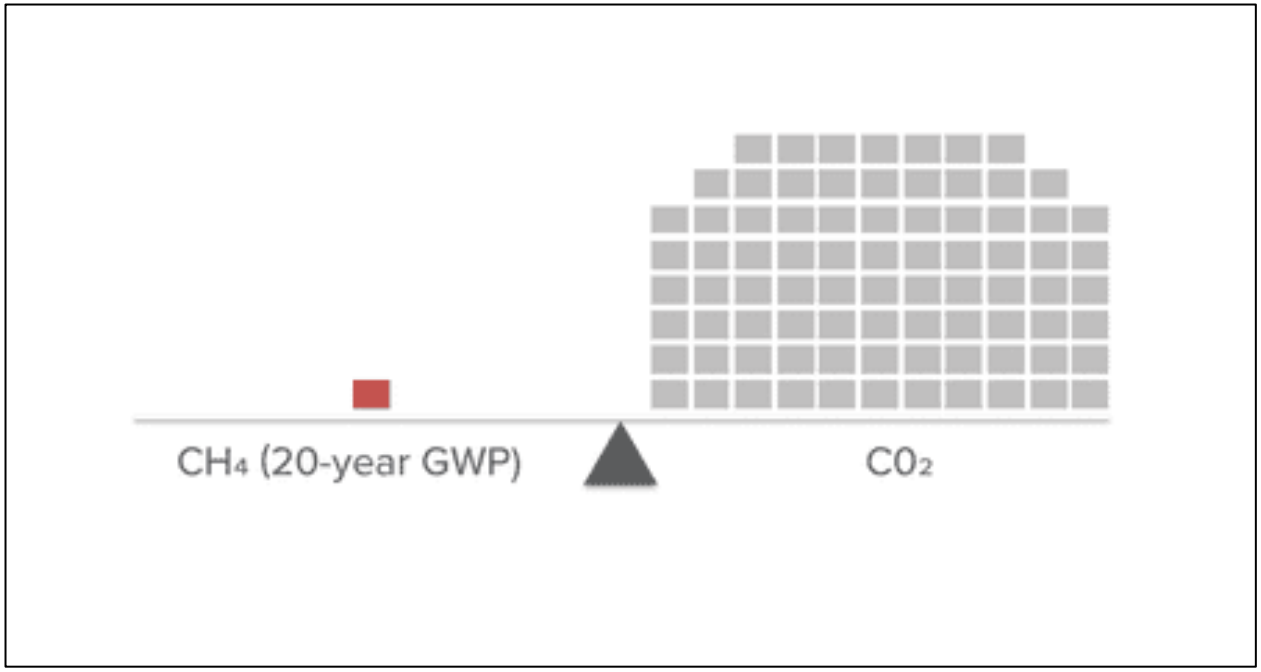
The Study

- Funded by the KY Energy and Environment Cabinet, analyzed methane emissions from underground coal mines over an 11-month period from late 2021 to 2022
- Evaluated coal production and methane emissions as reported to the MSHA and EPA Greenhouse Gas Reporting Program
- Completed methane surveys over 22 underground coal mines in eastern and western KY using sensors deployed on vehicles, an airplane, and a drone
- Evaluated performance of different measurement platforms

Methane, Why Does it Matter?

- Main component of natural gas and relatively clean source of energy
- Responsible for 25% of increased radiative forcing since pre-industrial times

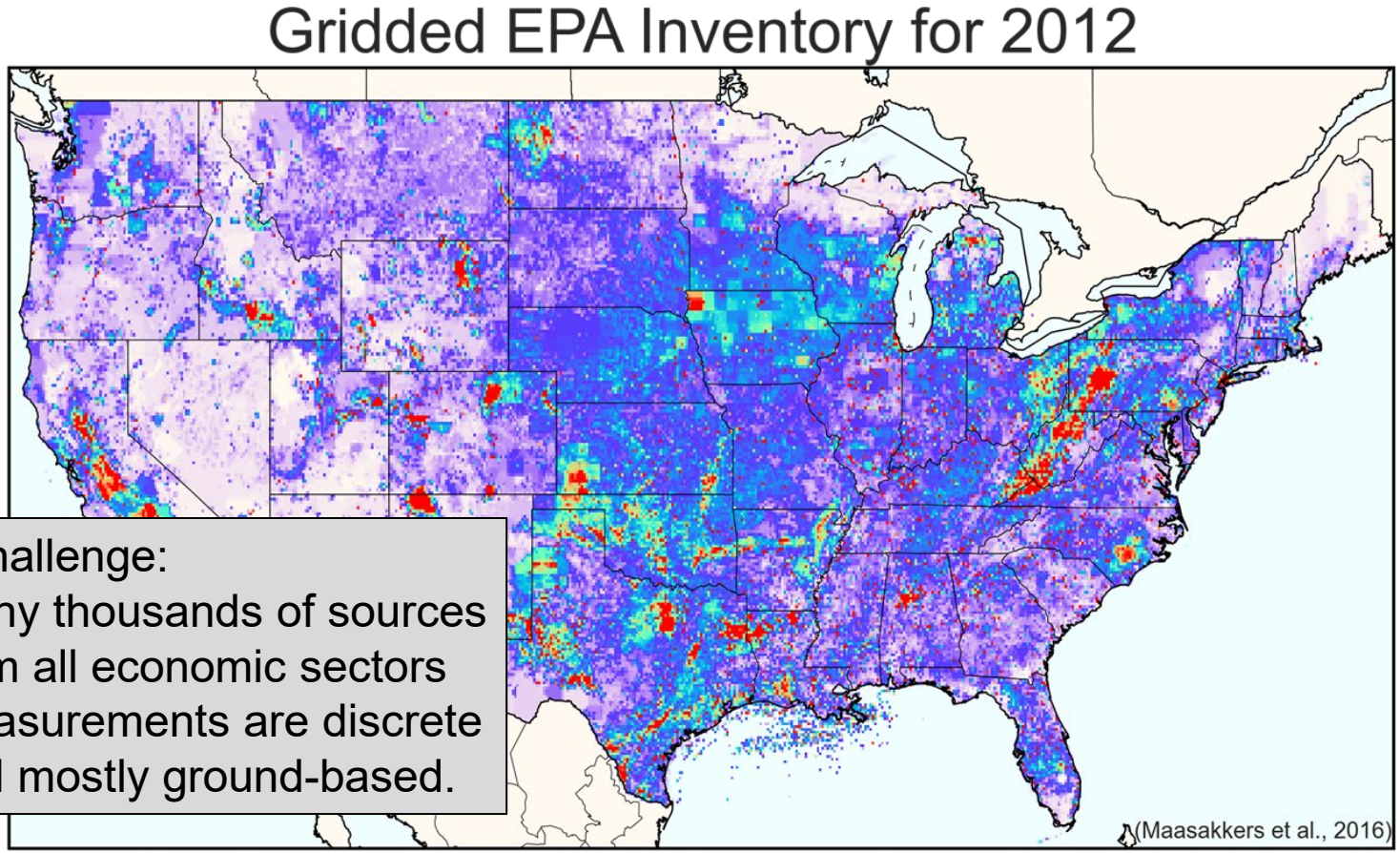


Methane has a global warming potential 84X greater than CO_2 over 20-year time period

https://www.unenvironment.org/resources/emissions-gap-report-2019

https://rmi.org/what-is-methane-and-why-does-it-matter/

Methane Spatial Distribution



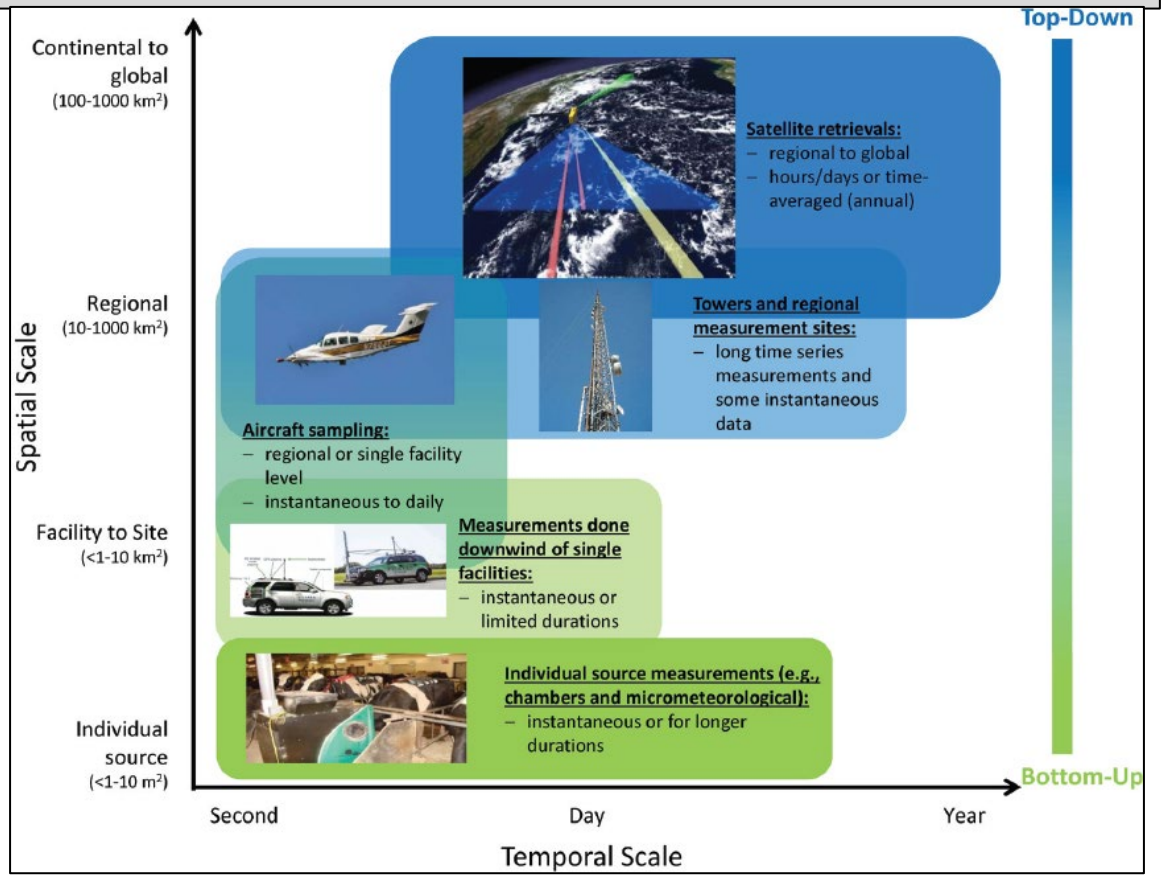
The Challenge:

1. Many thousands of sources from all economic sectors
2. Measurements are discrete and mostly ground-based.

Includes all methane emissions included in the National Greenhouse Gas Inventory.

Methane Emissions—Scales of Observation

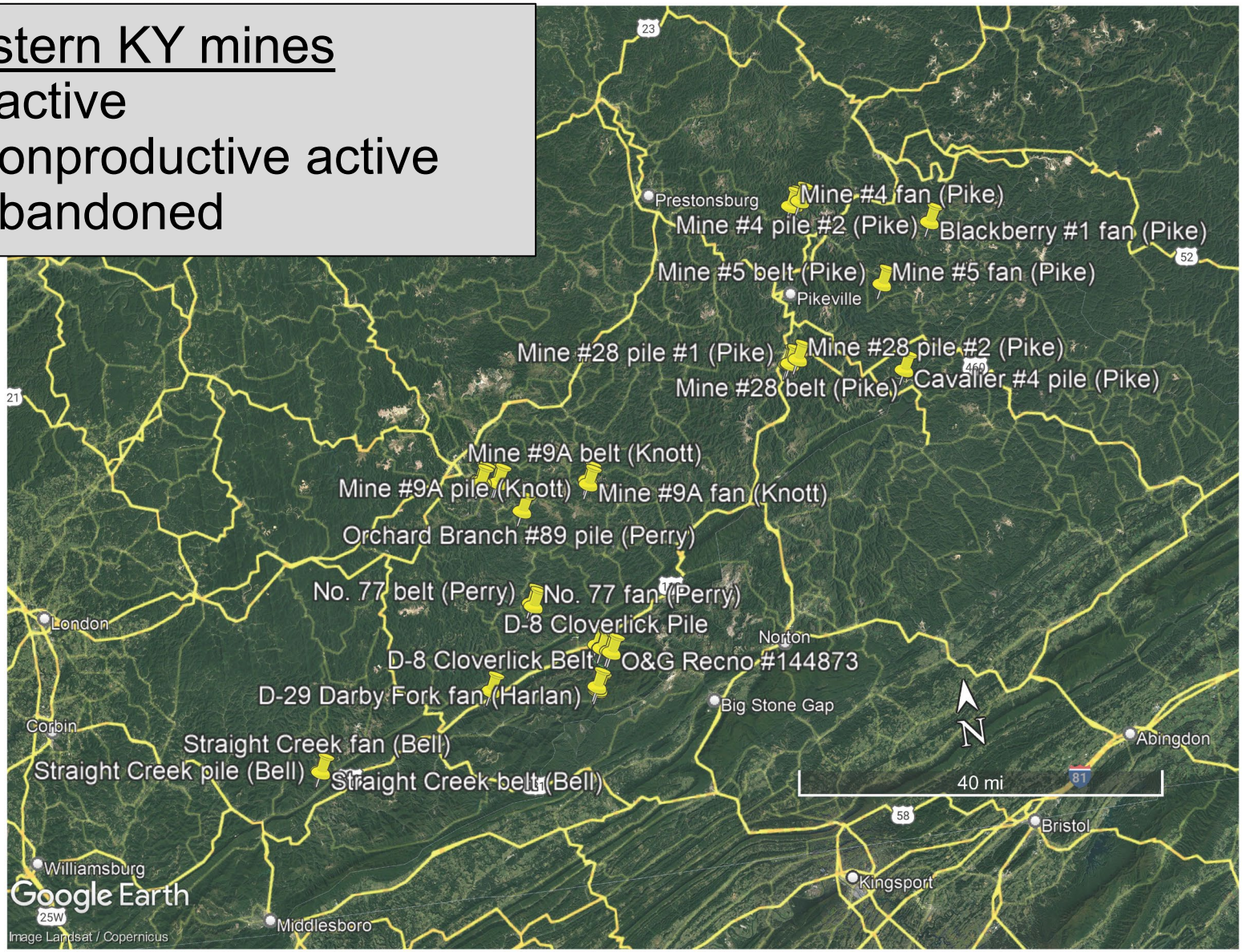
- As observed in the gridded methane map, emissions sources are nearly ubiquitous (e.g. ~3,000,000 miles of gas transport pipelines in the U.S.)
- Therefore attempts to characterize emissions will always be limited by frequency and distribution of sample campaigns
- Adds to uncertainty about whether measurements are representative and if some sources are missed entirely



https://www.nap.edu/catalog/24987/improving-characterization-of-anthropogenic-methane-emissions-in-the-united-states

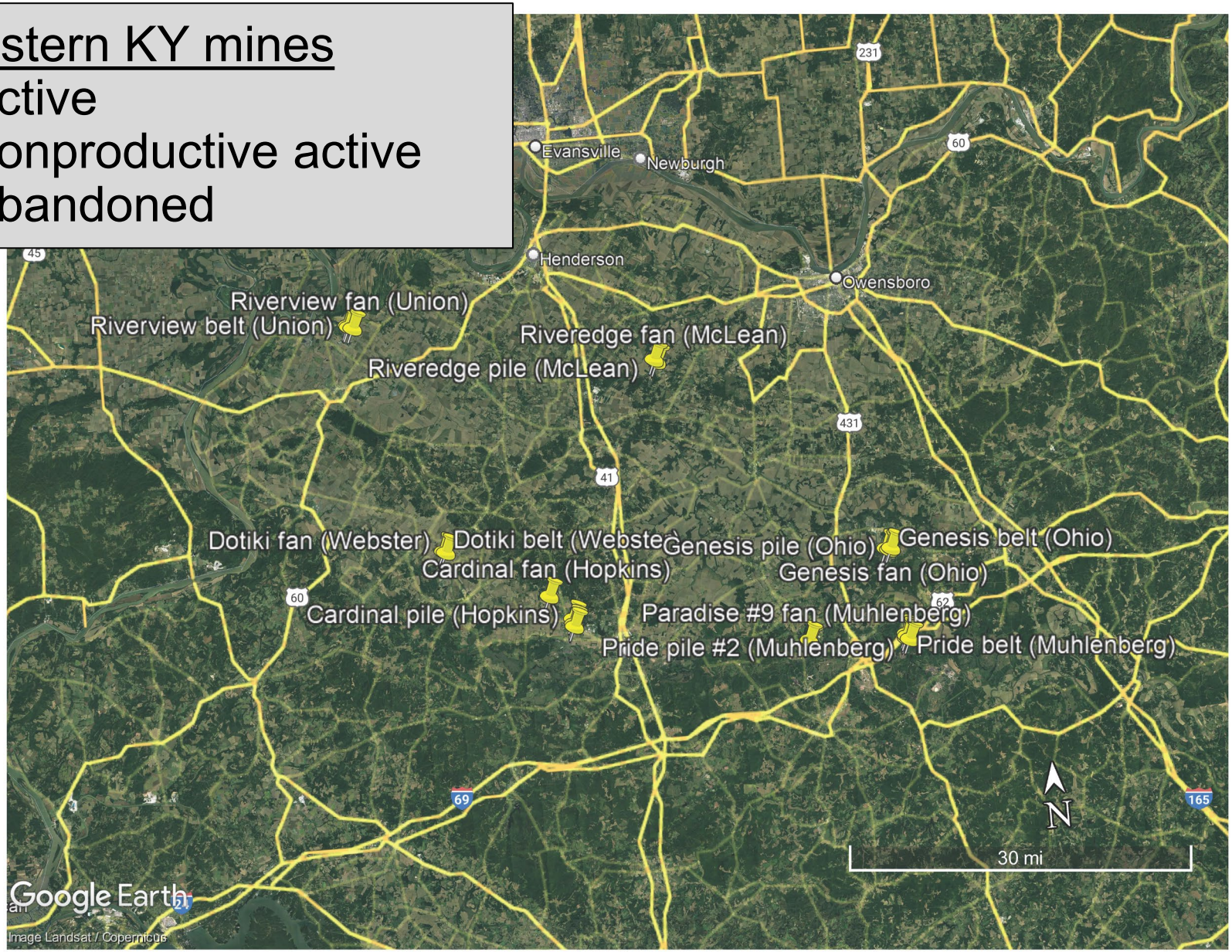
Eastern KY mines

11 active
2 nonproductive active
2 abandoned

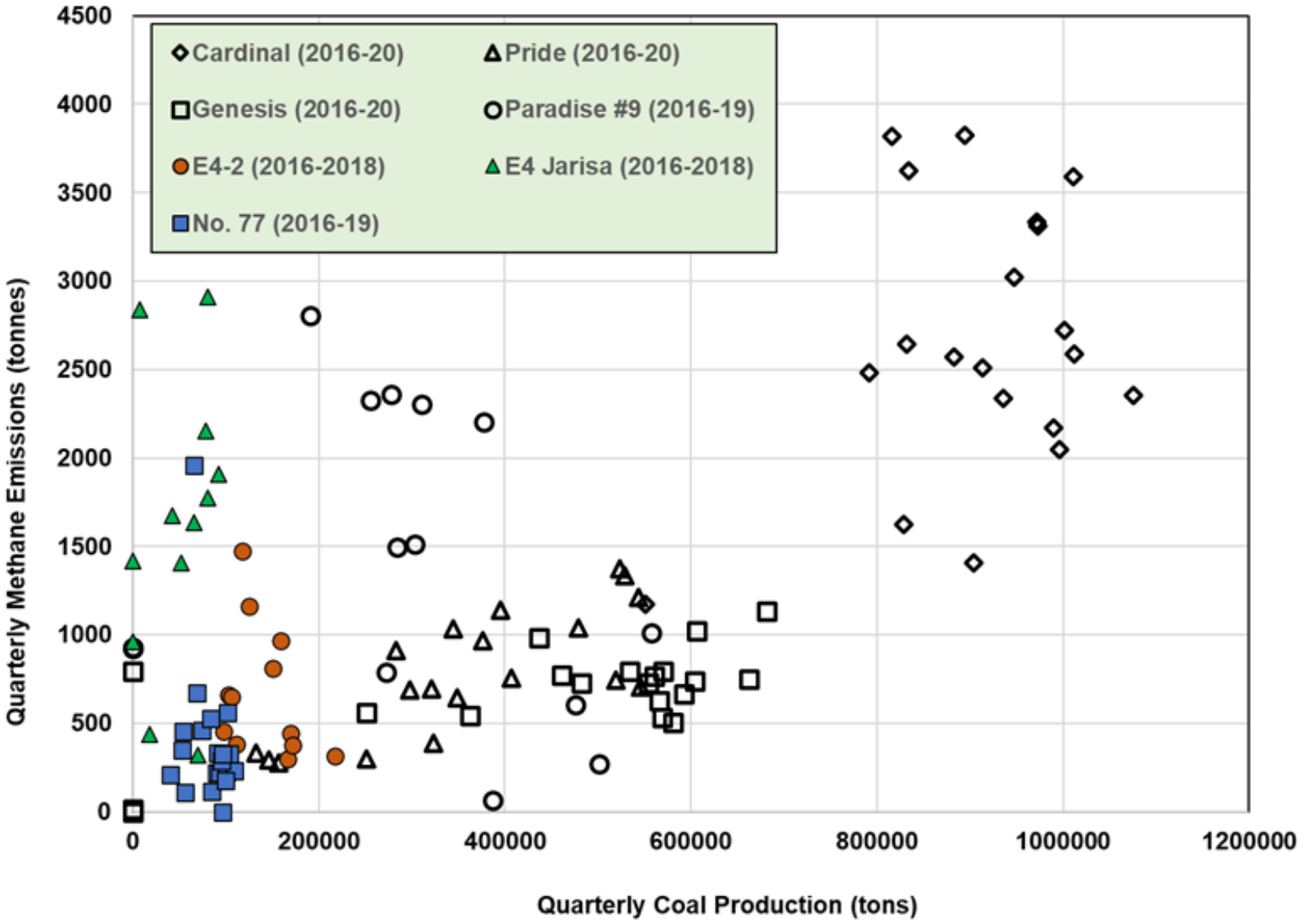


Western KY mines

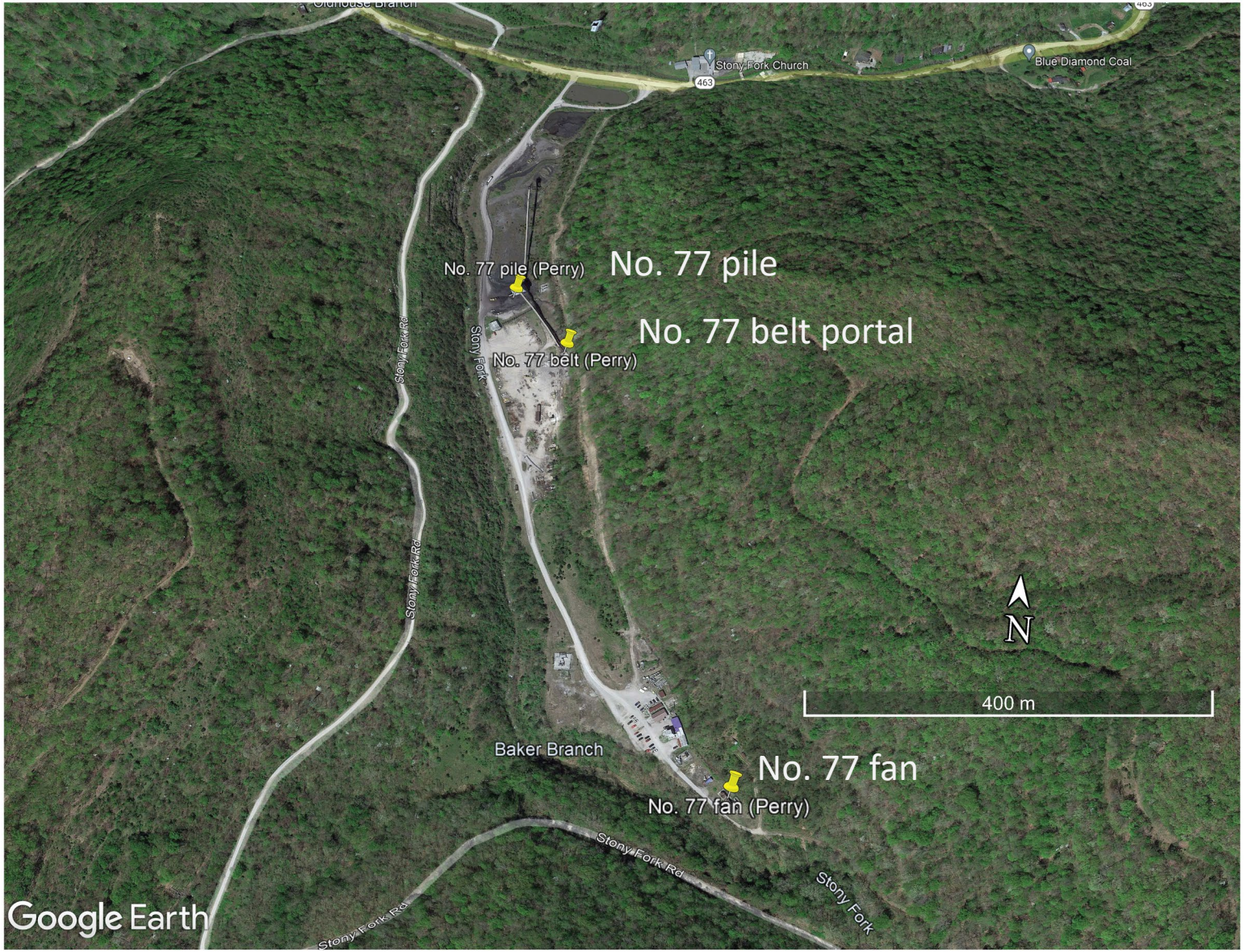
3 active
2 nonproductive active
2 abandoned



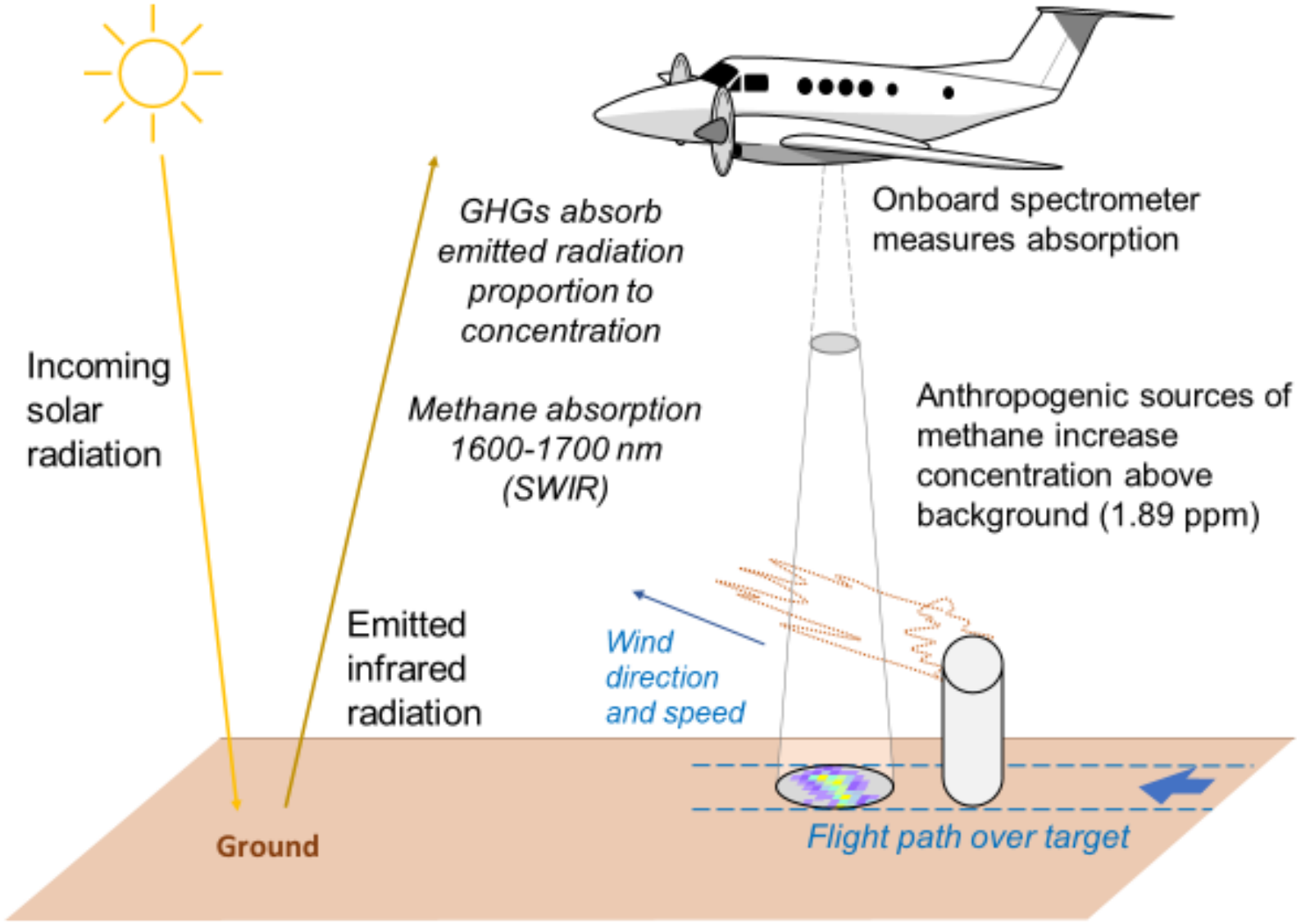
Mine Screening and Selection



No. 77 Mine Infrastructure Targets



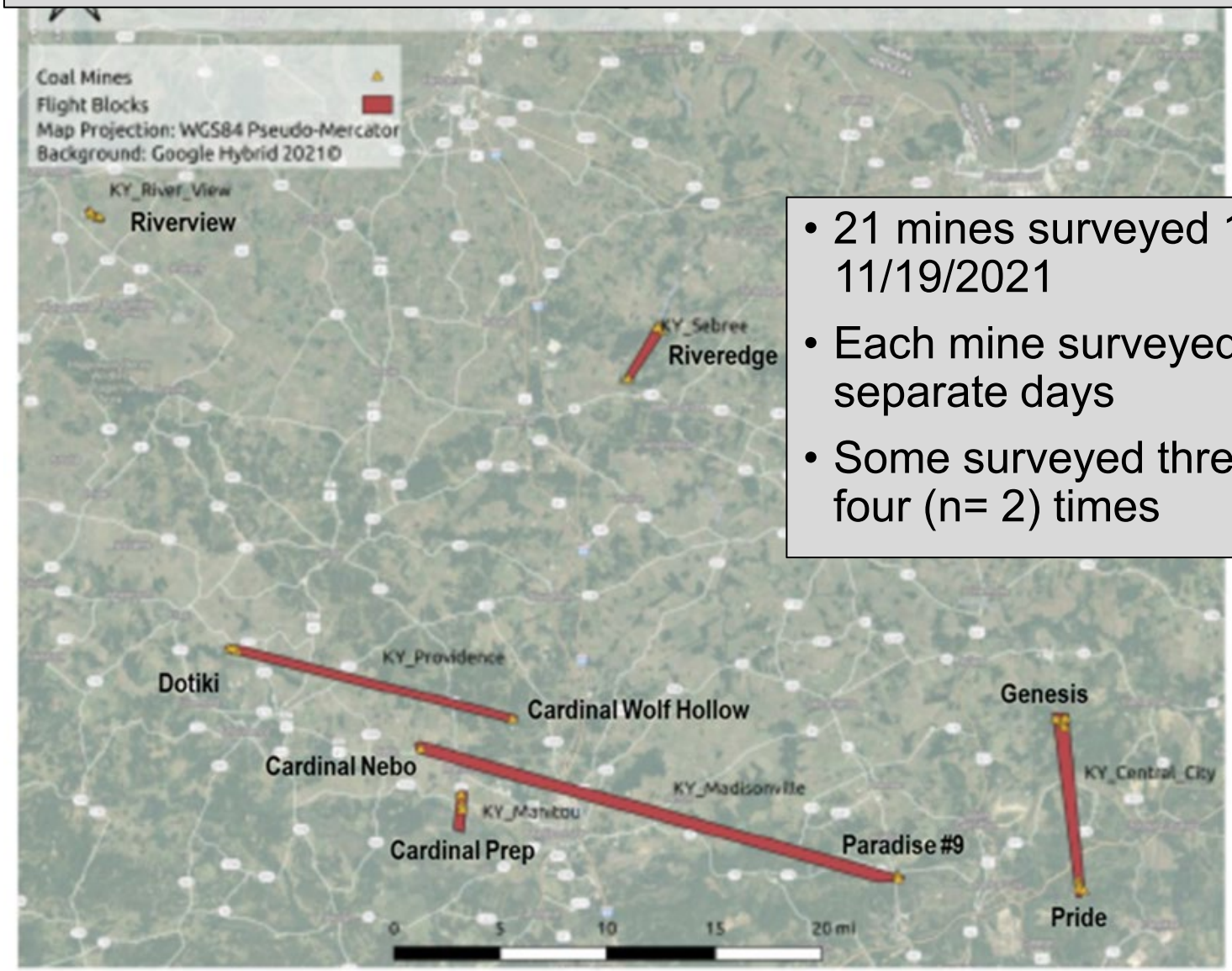
Measuring Methane in a 3,000 m Air Column



GHGSat Airplane-Based Measurements

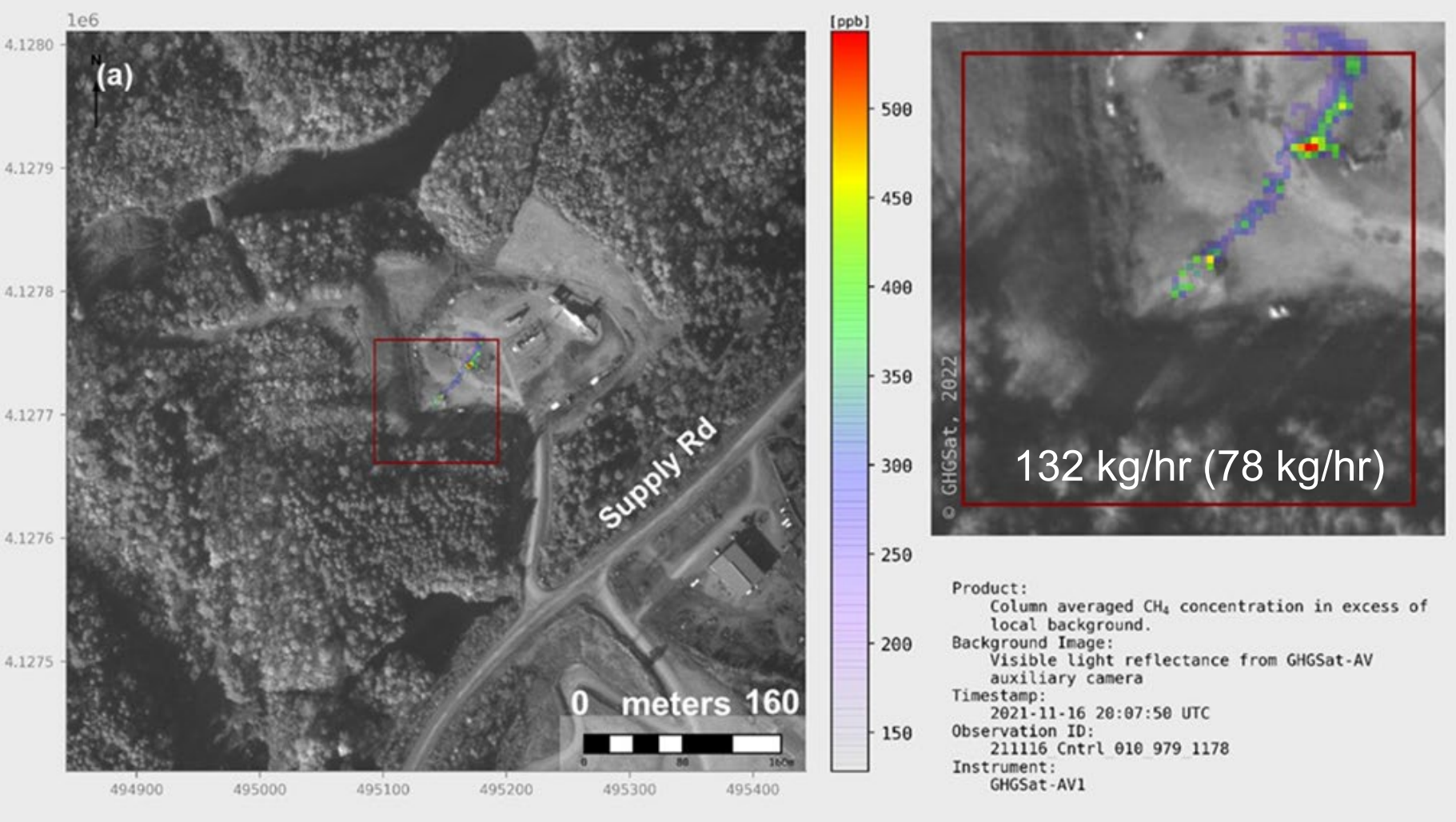
- Wide-angle fixed cavity Fabry-Perot spectrometer measures methane absorption in the near IR spectrum
- Flight altitude ~3,000 m
- Cross-track swath width of 750 m
- 0.75 m spatial resolution
- 100 ppb detection threshold

Western Kentucky Asset Overview

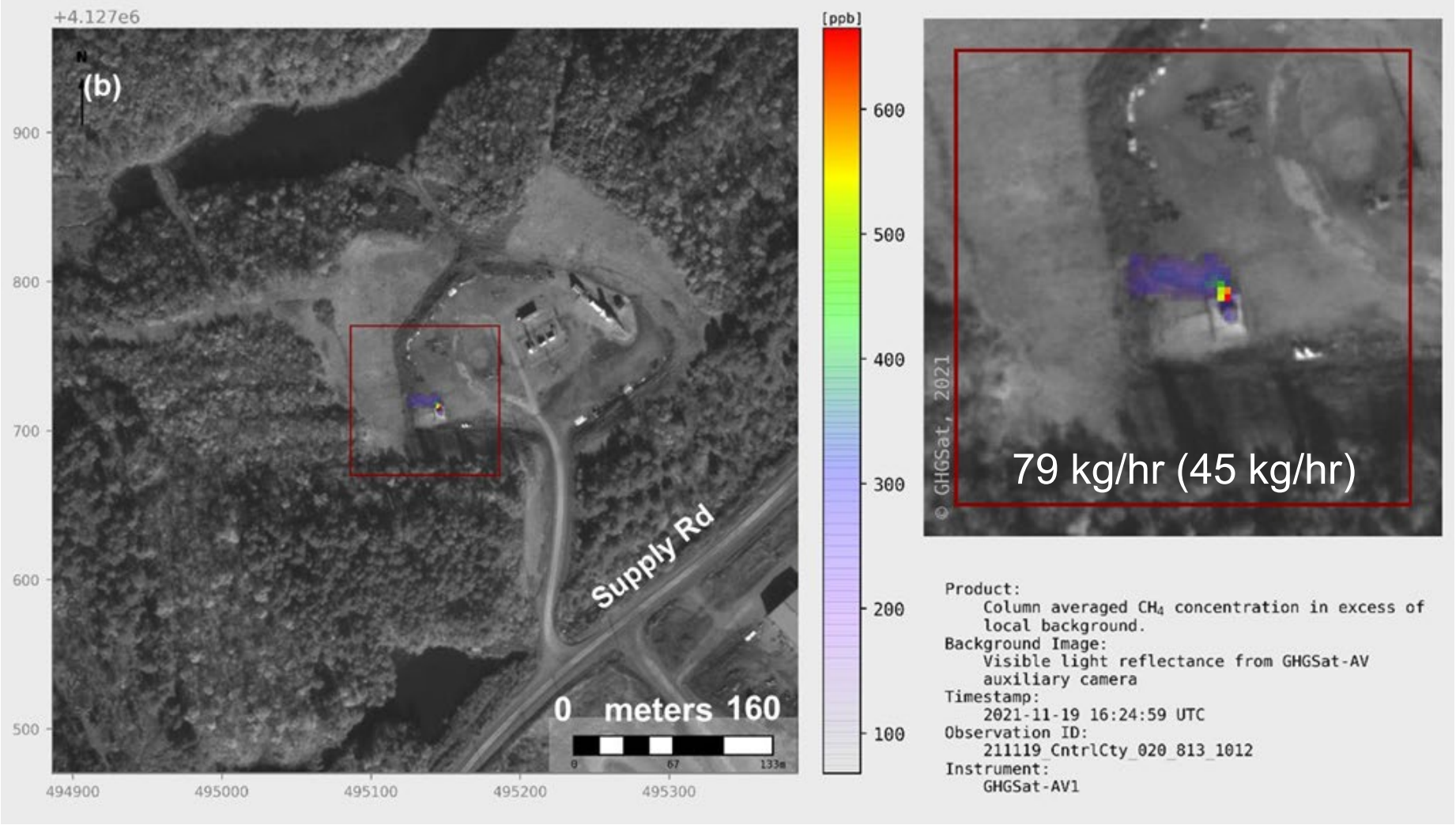


- 21 mines surveyed 11/12-11/19/2021
- Each mine surveyed twice on separate days
- Some surveyed three (n= 10) or four (n= 2) times

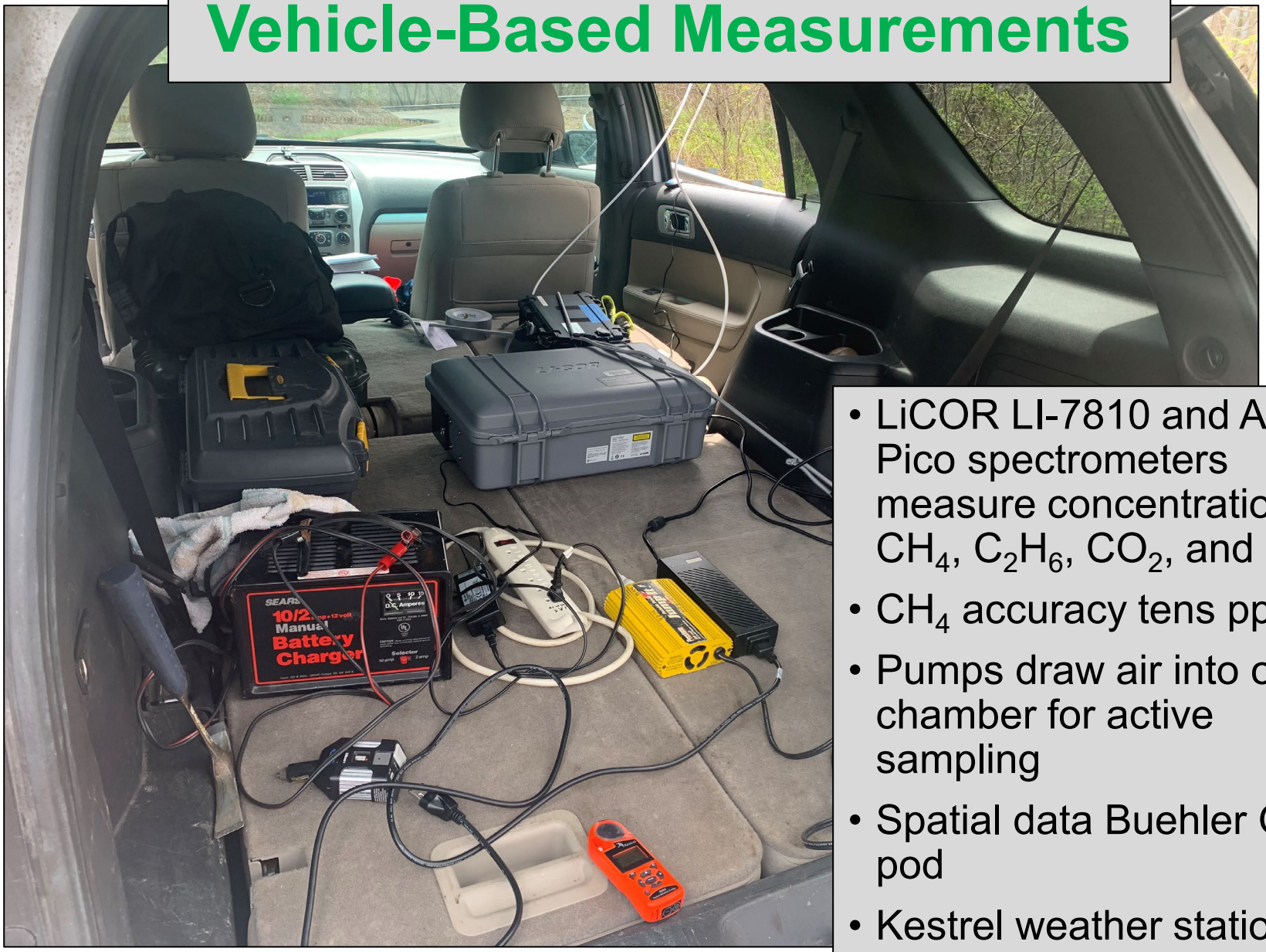
Pride Mine Example, 11/16/2021



Pride Mine Example, 11/19/2021

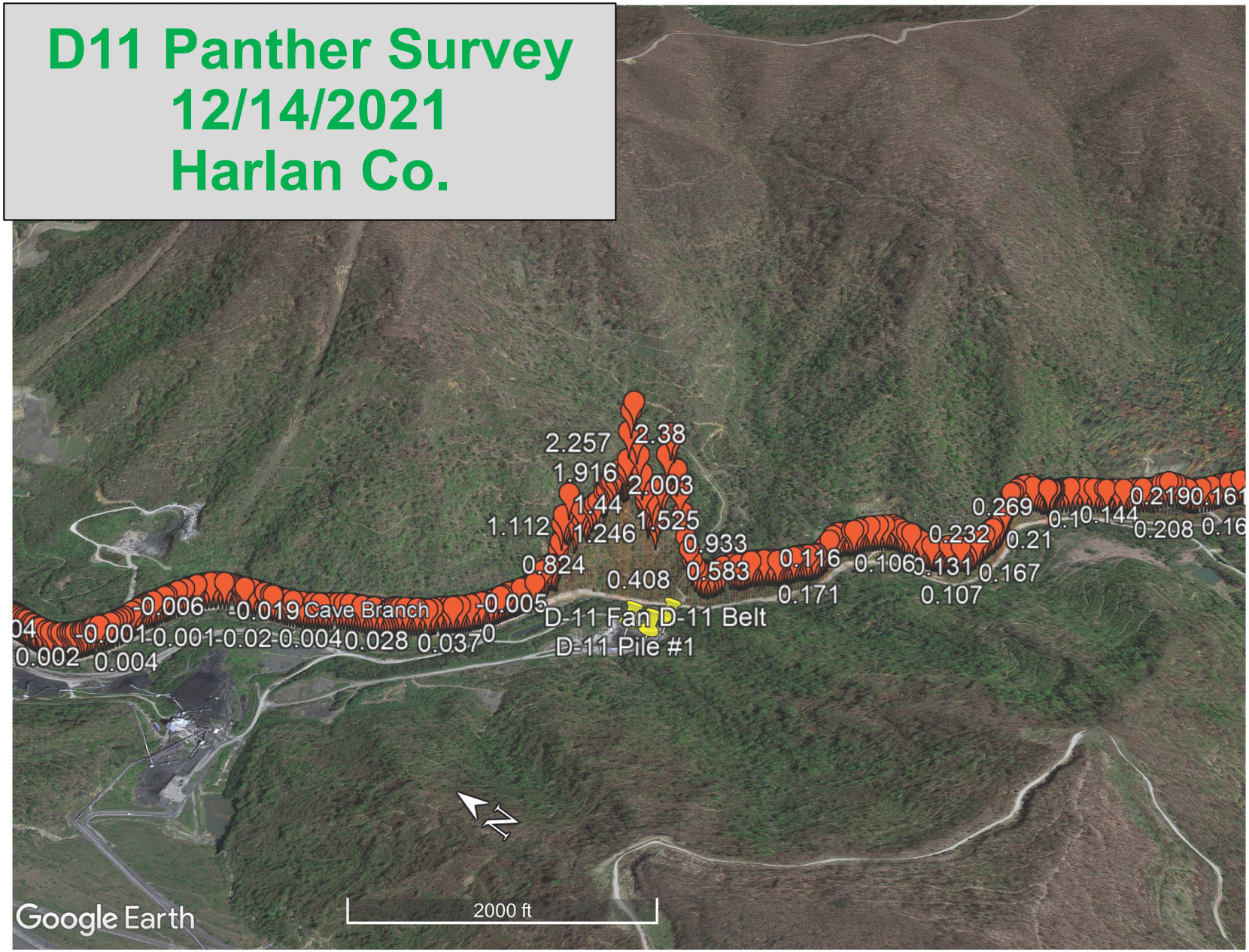


Vehicle-Based Measurements

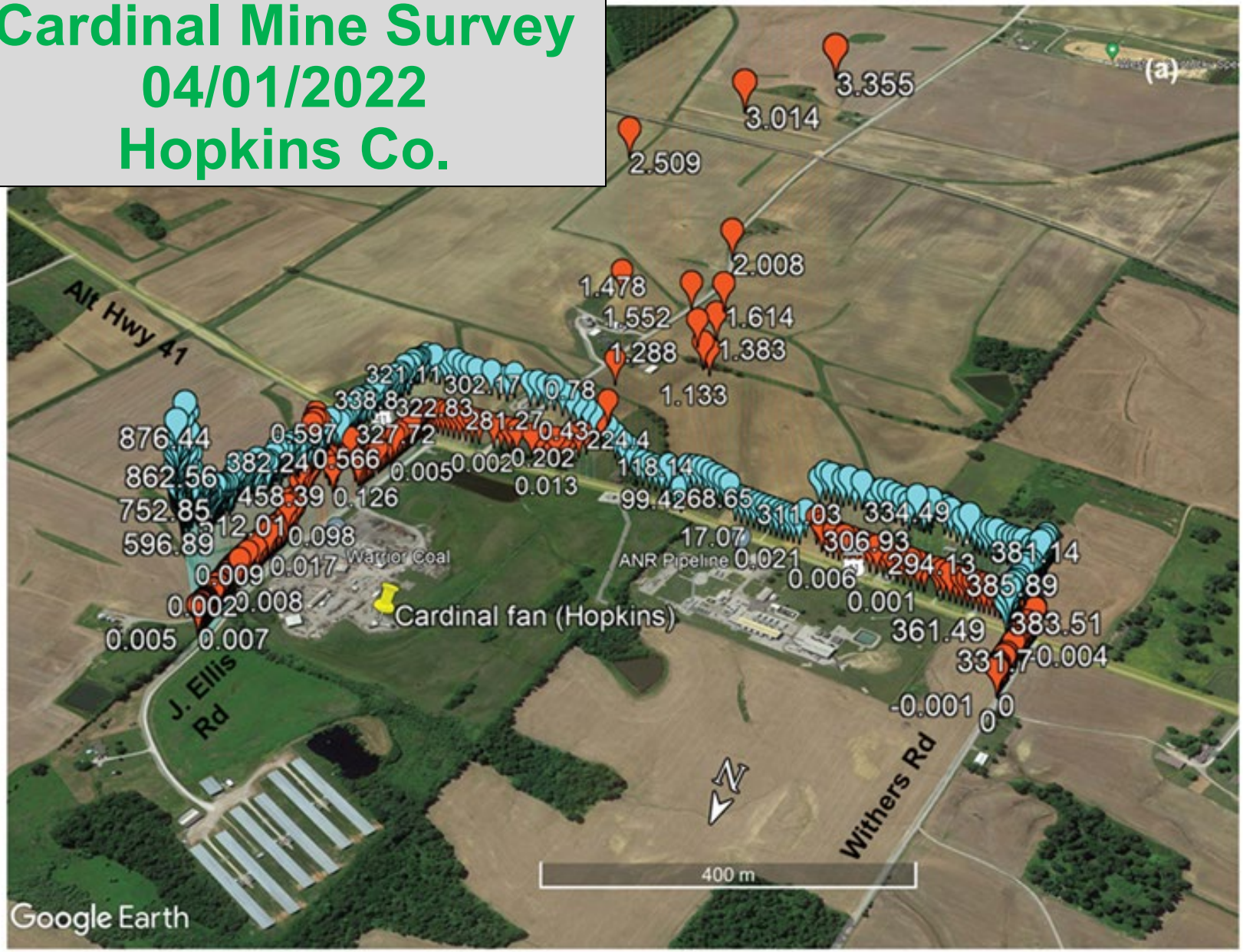


- LiCOR LI-7810 and Aeris Pico spectrometers measure concentrations of CH_4, C_2H_6, CO_2, and H_2O.
- CH_4 accuracy tens ppb
- Pumps draw air into optical chamber for active sampling
- Spatial data Buehler GPS pod
- Kestrel weather station

D11 Panther Survey
12/14/2021
Harlan Co.



Cardinal Mine Survey
04/01/2022
Hopkins Co.



MSHA ID	Mine Name	County	Basin	Report Years	Last Year Report	Q4 2021 Production	Mine Targets	Airplane Anomaly	Vehicle Anomaly
Active									
1519374							F, B, P	N	Y
1517216							F, B, P	Y	Y
1519744							F, B, P	Y	Na
1519015							F, B, P	N	Na
1502263							F, B, P	N	Y
1519859							F, B, P	N	Na
1518565							F, B, P	Y	Y
1519405							F, B, P	N	Na
1518911							F, B, P	N	N
1509636							F, B, P	N	Y
1519702							F, B, P	Na	Y
1518198							F, B, P	N	Y
1519280							F, B, P	N	N
1518001							F, B, P	N	N
Non-productive active									
1519535							F, B, P	N	Y
1517741							F, B, P	N	N
1519116							F, B, P	N	Na
1515215							F, B, P	N	Na
Abandoned									
1502132	Dotiki Mine	Webster	Illinois	>39	Q3, 2019	0	F, B, P	N	Y
1519424	Riveredge	Mclean	Illinois	5	Q3, 2019	0	F, P	N	Na
1519515	Mine #4	Pike	Appalachian	8	Q1, 2020	0	F, B, P	N	N
1519418	D-8 Cloverlick	Harlan	Appalachian	9	Q2, 2018	0	F, B, P	N	N

- ✓Airplane-based surveys detected methane anomalies at 21% (3 of 14) of active mines
- ✓Airplane-based surveys did not detect anomalies at non-productive active or abandoned mines.
- ✓Plume maps link all methane anomalies to exhaust fans
- ✓Inverse modeling of methane plumes suggests methane emissions rates from 79 kg/hr to 716 kg/hr
- ✓Understanding lack of detections hard to pinpoint, but fan orientation and low signal to noise ratio under single-pass surveys may contribute to instrumental limitations in real world settings for low emitters

MSHA ID	Mine Name	County	Basin	Report Years	Last Year Report	Q4 2021 Production	Mine Targets	Airplane Anomaly	Vehicle Anomaly
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1517216							F, B, P	Y	Y
1519744							F, B, P	Y	Na
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1502263							F, B, P	N	Y
1519859							F, B, P	N	Na
1518565							F, B, P	Y	Y
1519405							F, B, P	N	Na
1518911							F, B, P	N	N
1509636							F, B, P	N	Y
1519702							F, B, P	Na	Y
1518198							F, B, P	N	Y
1519280							F, B, P	N	N
1518001							F, B, P	N	N
Non-productive active									
1519535	Genesis	Ohio	Illinois	9	Q1, 2020	0	F, B, P	N	Y
1517741	Paradise 9	Muhlen-berg	Illinois	23	Q1, 2019	0	F, B, P	N	N
1519116	#9A	Knott	Appalachian	11	Q3, 2019	0	F, B, P	N	Na
1515215	# 5	Pike	Appalachian	10	Q2, 2021	0	F, B, P	N	Na
Abandoned									
1502132	Dotiki Mine	Webster	Illinois	>39	Q3, 2019	0	F, B, P	N	Y
1519424	Riveredge	Mclean	Illinois	5	Q3, 2019	0	F, P	N	Na
1519515	Mine #4	Pike	Appalachian	8	Q1, 2020	0	F, B, P	N	N
1519418	D-8 Cloverlick	Harlan	Appalachian	9	Q2, 2018	0	F, B, P	N	N

- ✓Vehicle-based measurements detected anomalous methane at 70% of active mines surveyed (n= 10)
- ✓Most anomalies are associated with exhaust fans, which also have highest magnitude—up to 90.3 ppm
- ✓Vehicle surveys also detected methane anomalies from natural gas infrastructure near at least two mines. Natural gas methane anomalies are distinguished by lower methane:ethane ratios as compared to coal-derived methane

Thank You and Questions?

E4 Jarisa Survey, 11/12/2021
Perry Co.
415 kg/hr (252 kg/hr)