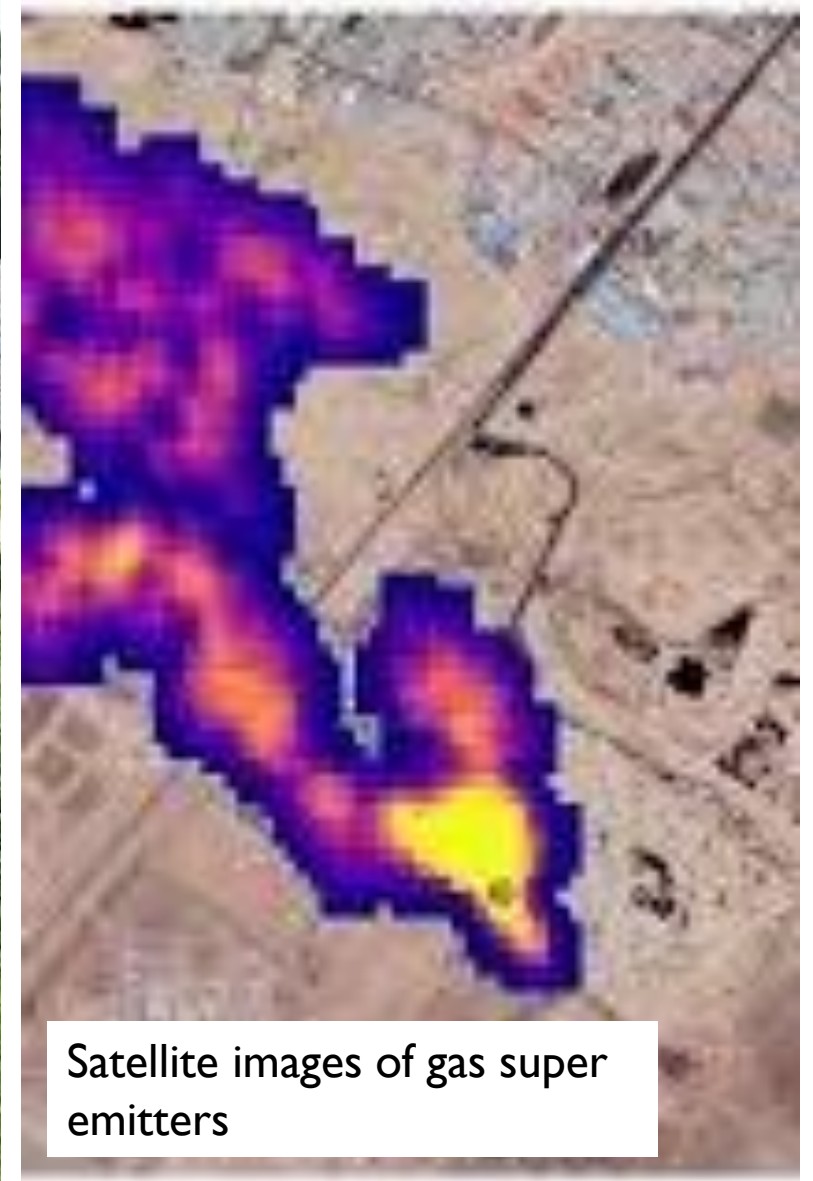


BIOGAS PLUME CHARACTERISTICS AND MEASUREMENT

WHY IS IT DIFFICULT /
DIFFERENT TO MEASURE
THE EMISSIONS FROM A
SLURRY STORE COMPARED
TO A VENT PIPELINE LEAK?

Andy Atkins, IFEAA
Chris Mann, Bennamann



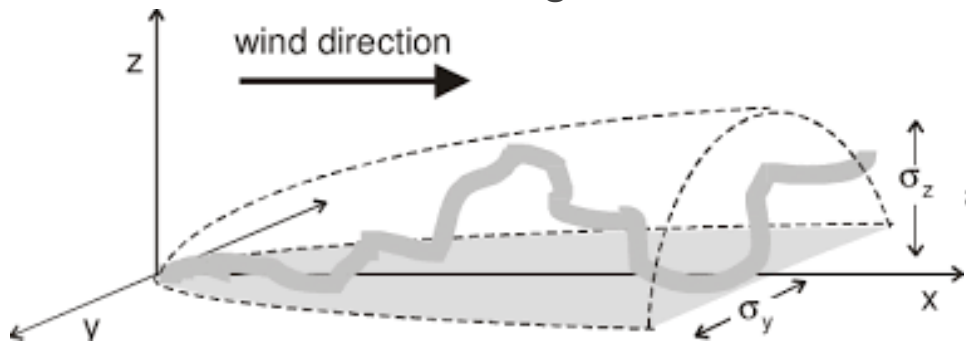
WHY IS IT INTERESTING?



USING LASERS 3 METRES OF THE GROUND YOU CAN'T DETECT METHANE....

PLUME MODELLING: AT HEART OF IT IS A SIMPLE EQUATION

- Equation for dispersal from Yang et al.
- If that W_* is in the range from 1.1 to 2.1.
 - This is from Ventatram (1979)
- Results shown in ranges as per slide 1 with W_* at either end of the range



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DISPERSION FROM AN ELEVATED SOURCE IN A CONVECTIVE BOUNDARY LAYER

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Air Resources Branch, Ontario, Canada

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Modification and validation of the Gaussian plume model (GPM) to predict ammonia and particulate matter dispersion

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Laura L. McConnell^a, Peter M. Downey^c, Cathleen J. Hapeman^{c,*}

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$$C(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \left[\exp\left(\frac{-(z-h)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+h)^2}{2\sigma_z^2}\right) \right] \quad (1)$$

where x , y , and z are the downwind, crosswind, and vertical coordinates (m), h is the release height from the ground (m), Q is source strength (g/s), u is wind speed (m/s), σ_y and σ_z are the standard deviation of the distribution concentration in y and z axis (m). For small distances, where $x < 1000$ m, σ_y and σ_z can be calculated from wind speed, u (m/s), distance from source, x (m), and the convective velocity scale, w_* (m/s), following the equations given by Venkatram (2015):

$$\sigma_y = \frac{0.6w_*}{u}x, \quad \sigma_z = \frac{0.6w_*}{u}x \quad (2)$$

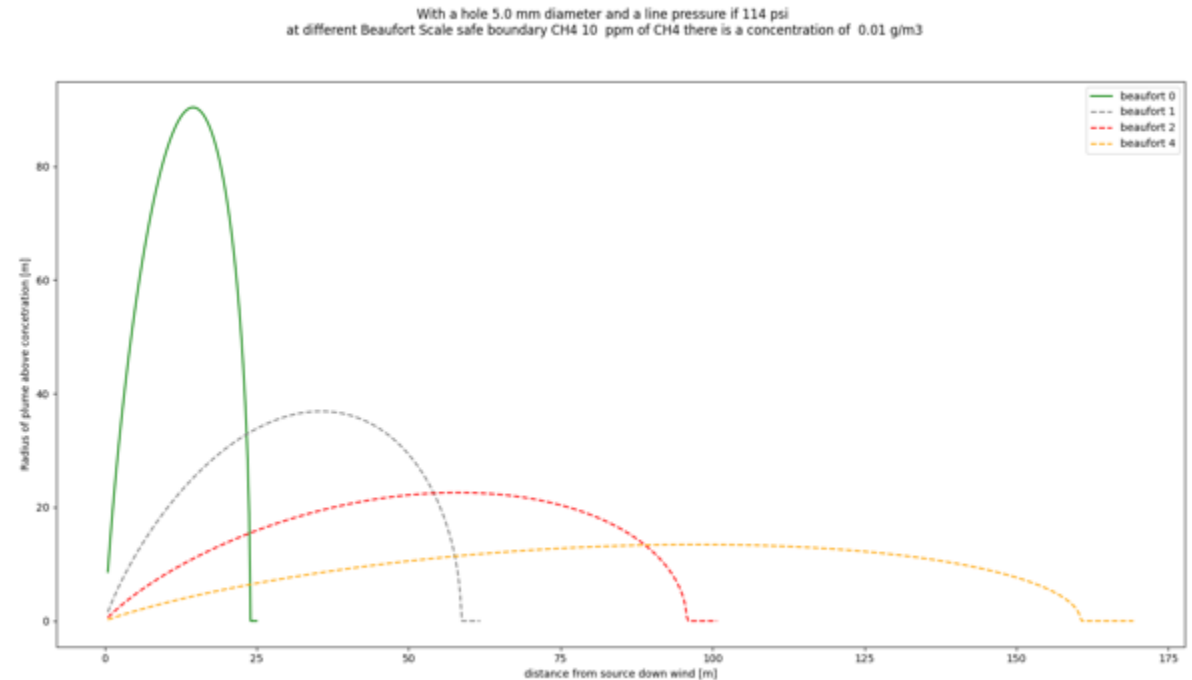
PLUME MODELLING

FOR A GAS LEAK FROM A HIGH-PRESSURE SUPPLY 114 PSI (7.6 BAR (ABS)) THROUGH A 5MM HOLE → CONE 80m RADIUS AND LENGTH 150m.

- Shape is dependent on wind speed
- Within this plume area the CH₄ has rich areas where buoyancy will cause it to rise.
 - Velocity therein produced will drive mixing increasing reaction with OH groups in atmosphere.



- While this model applies well to gas emitted at choked flow from a pipeline where it is at 90% concentration Does it apply to a bubble which is well mixed with CO₂?



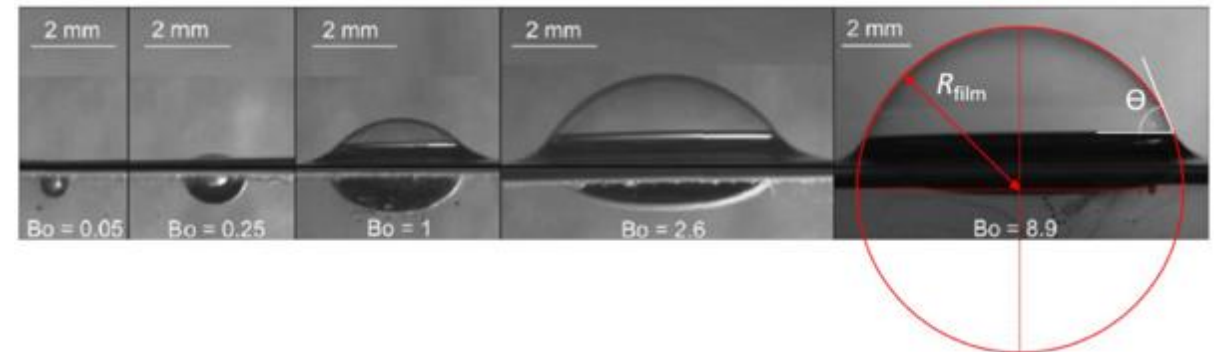


WITH A BUBBLE IT IS DIFFERENT – MUCH LOWER PRESSURE AND EXIT VELOCITY

- Gas emitting from a liquid.
 - Forms as a bubble beneath the surface then grows with more gas increasing buoyancy force as it lifts across the barrier
 - When the buoyancy force equals breaking strain of the surface the gas is released.
 - The breaking strain falls with bubble size, so R_{film} is dependent on liquid and gas quality.
 - Research into this for slurry liquor would be a useful way of calculating the number quality of the gas.
 - A 100mm diameter bubble releases at $\sim 0.1 \mu\text{bar} \rightarrow 76,000,000$ lower than a gas pipeline



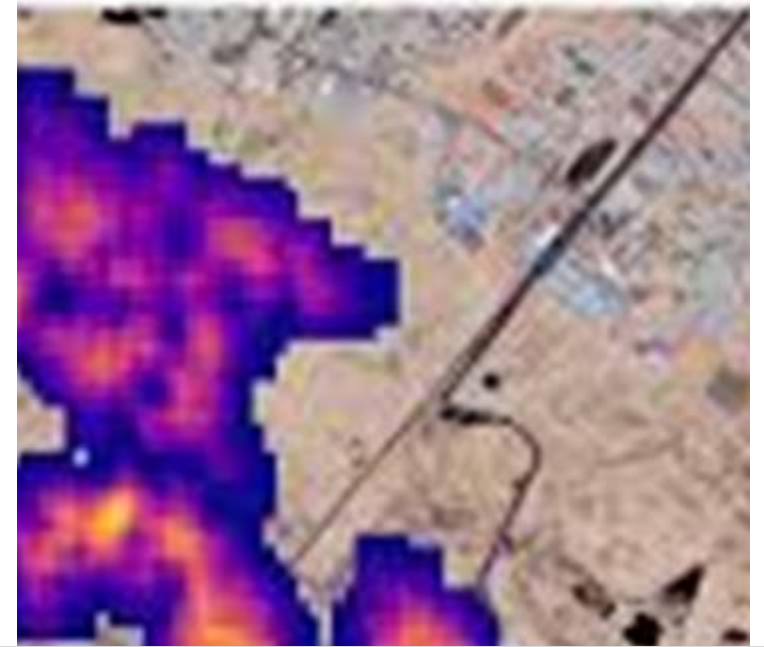
- This suggests the gas is not dispersed by release process
- AND no real lift on the gas



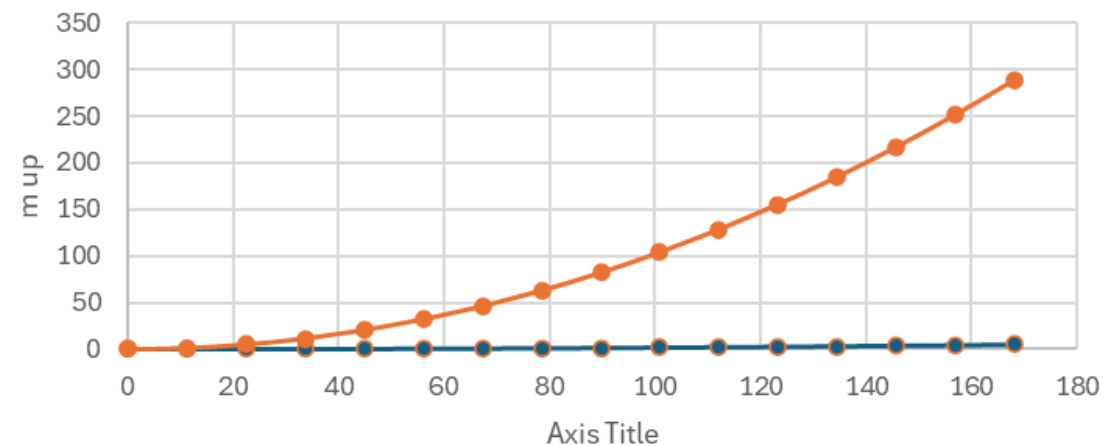
GAS BUOYANCY AND MIXING AS CO2 CONTENT RISES IT TRAVELS SIDeways FASTER THAN IT TRAVELS VERTICALLY

- 90% methane from gas main is buoyant $\sim 2/3$ the density of air $\rightarrow$ hence rises quickly.
- The CO₂:CH₄ mixture does not rise quickly
 - NB 50:50 has negative buoyancy
- 90 % methane experiences ≈ 6 times the lift of CO₂ [45%] :CH₄ [55%] mixture from slurry
- Slurry gas also close to same density (99%) the density.
- $F=M.a \rightarrow$ vertical acceleration of the CO₂:CH₄ slurry gas $\approx 1/60$ th of methane.

Slurry gas is Slow to rise by the time 55:45 mixture has risen 5m
90% methane has risen 289m and they have both travel 170m
laterally



Effect of bouyancy on lift and distance travelled in
Force 4 Wind over 15 seconds



METHANE CO2 SEPARATION

IT WILL ACCELERATE AS IS SEPARATES → BUT THIS IS SLOW

- Buoyancy becomes a bigger effect as you get regions of purer gas.
- The gas therefore has to separate first !!!!
- At molecular level the Kinetic energy to potential energy ratio is key
 - Kinetic energy $\approx 3/2 kT$ (k is Boltzmann's constant)
 - Potential energy $\approx mgh$ (h is layer of mixed gas assume 1m)
- → at 300K ~ 8000:1 Mixing wins
- **Separation is by diffusion is slow to diffuse apart a bubble ~ 1100 secs → 7.7km sidesways motion in F4**



- So:
 - The higher the CO2 content of the gas the slower it rises with 50:50 achieving negative buoyancy in dry air
 - The slurry gas will slowly separate and then be buoyant this is why it rises and is seen dispersed in the upper atmosphere
 - It will probably travel a long way sideways before this happens, so we want to measure down wind of the store
 - If one measures above the store as one would with a high pressure natural gas leak you probably won't see much
 - Counting bubbles if there is no crust is potentially a good way of measuring quantity and quality of the gas.

HOW DOES THIS AFFECT MEASUREMENT STRATEGY?

- Biogas plumes will tend to stay low and not rise unless there is air lift
- Little mixing as there is no sonic dispersal as there is from a point source such as a natural gas leak from a pipe or vent
- Methane and CO₂ are very slow to separate
- A lagoon source is large and the biogas is dispersed with no pressure over the entire surface and so it starts as a very dilute cloud
- The vertical behaviour of the resulting biogas cloud will be dependent on its make up i.e., 50:50 CH₄ : CO₂ is neutrally buoyant in air

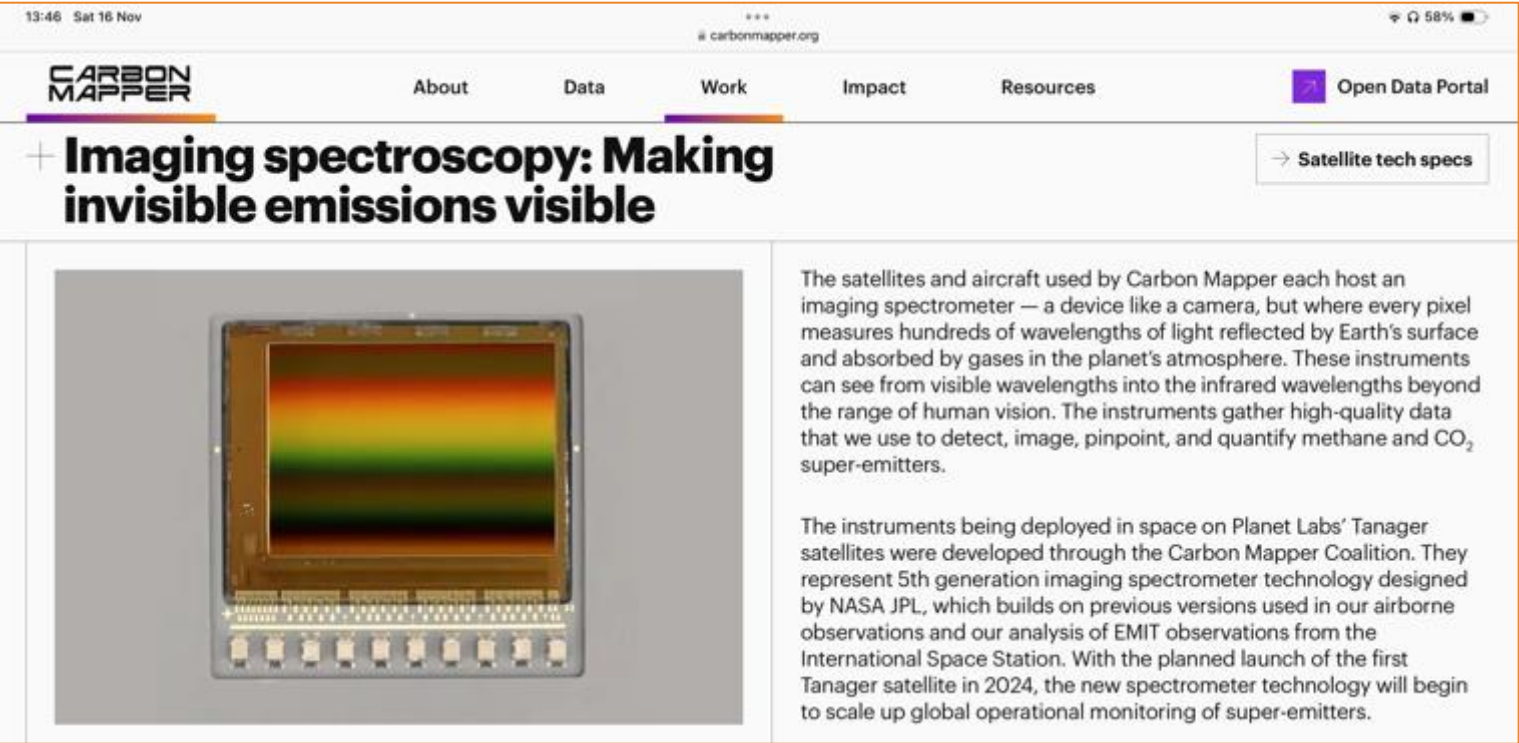


REMOTE SENSING BIOGAS FROM SPACE

RECENT NEW CAPABILITIES

CARBON MAPPER: TANAGER – I (launched 16th August 2024)

ENVIROMENTAL DEFENSE FUND: METHANE SAT - (launched 4th March 2024)



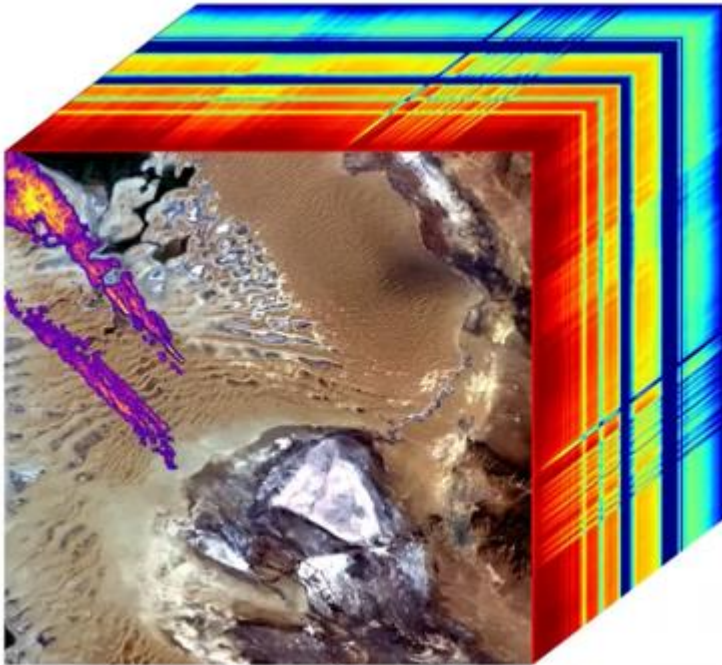
Hyperspectral imaging capability developed for atmospheric mineral dust imaging aboard EMIT on the International Space Station

Expected to have some methane and CO2 detection capability but have been found to exceed expectations

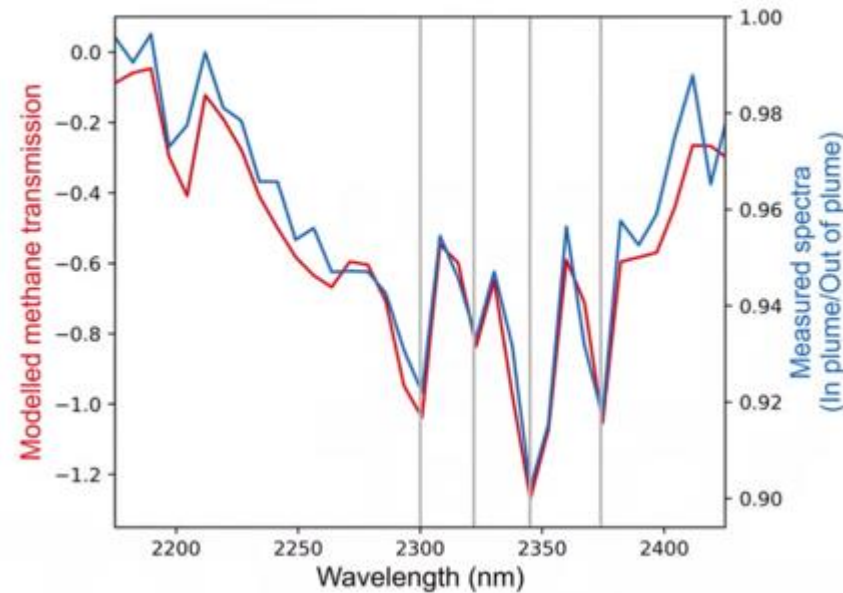
Now embedded into the Tanager series of satellites funded by Carbon Mapper

Very recent powerful methane detection capabilities

JPL Hyperspectral Imager:



Methane spectral fingerprint



Quite a recent remarkable technological breakthrough

As well as retrieving high resolution optical imagery

Each pixel captures the spectral information for each spatial position

The result is a data cube that can be interrogated for specific signatures such as methane

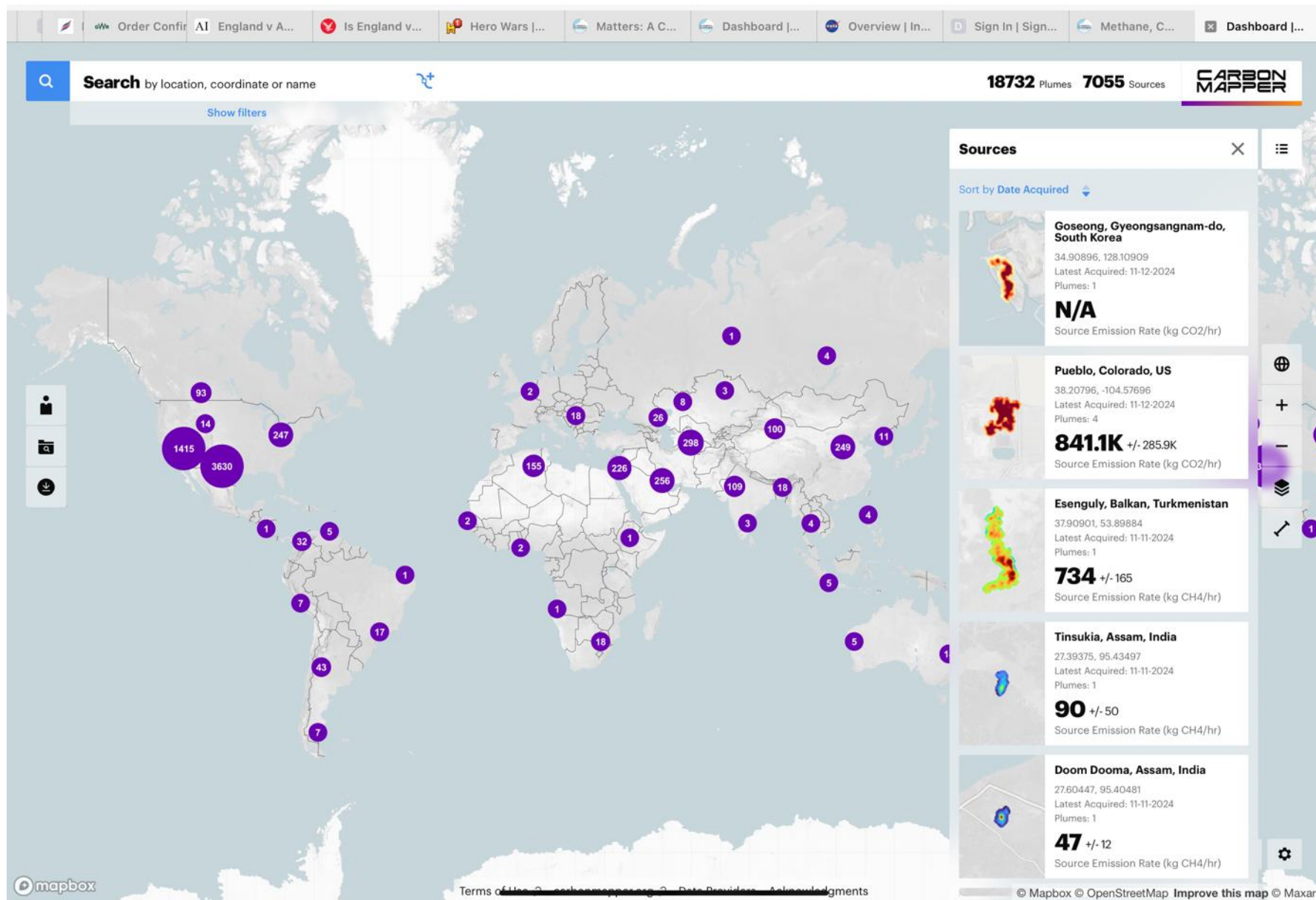
Some capability over sea and water but not current priorities



With the launch of the first Carbon Mapper Coalition satellites, Carbon Mapper will expand emissions observations from space. (Image: Planet Labs)

Tanager capabilities at-a-glance

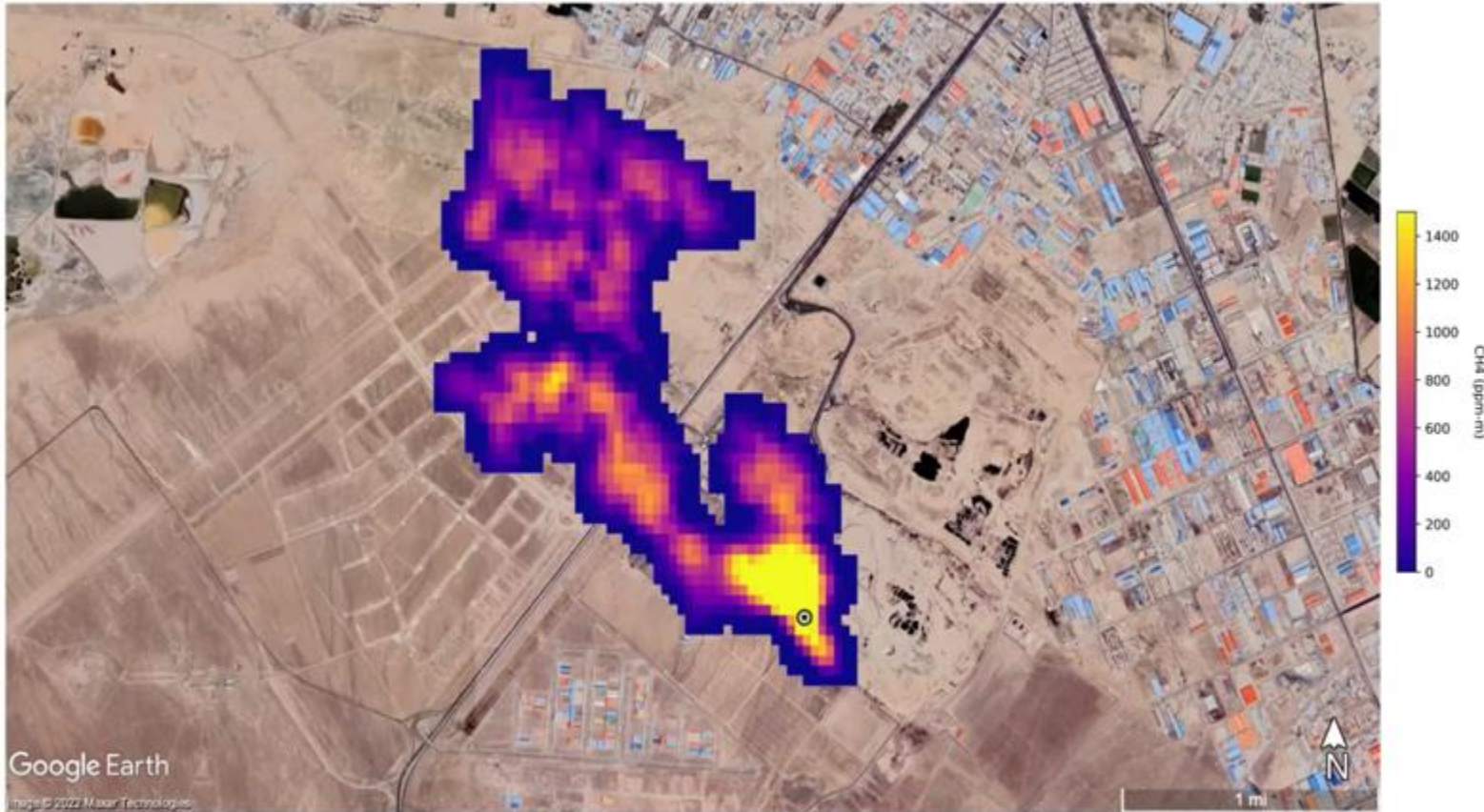
- **Detecting methane with high sensitivity:** Tanager satellites are designed to detect methane plumes from facilities or pieces of equipment (like pipelines or flares) with emission rates as low as 70 kg/hr under moderate conditions (predicted 90% detection limit of about 100 kg/hr).
- **Mapping high priority areas with high resolution:** The imaging spectrometer combines high-spatial resolution — 30 meters — with the ability to rapidly image large areas — upwards of 130,000 km²/day per Tanager. This allows for mapping major emitting regions to pinpoint the origin of methane or CO₂ plumes at or within individual facilities.



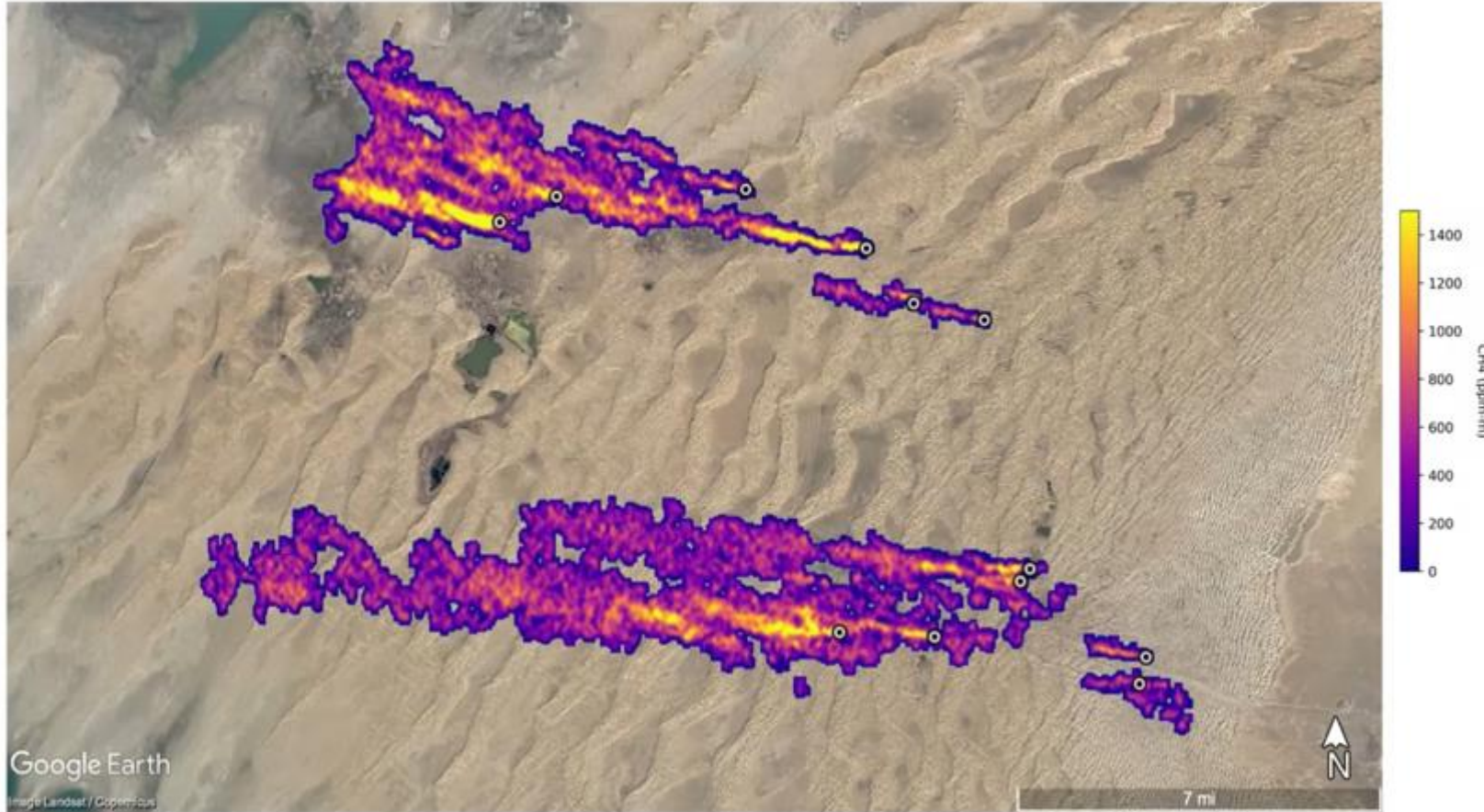
Total global super emitter plumes detected by Carbon Mapper

USA has 78% of super emitters

Predominantly vented natural gas from older oil fields and fracking sites



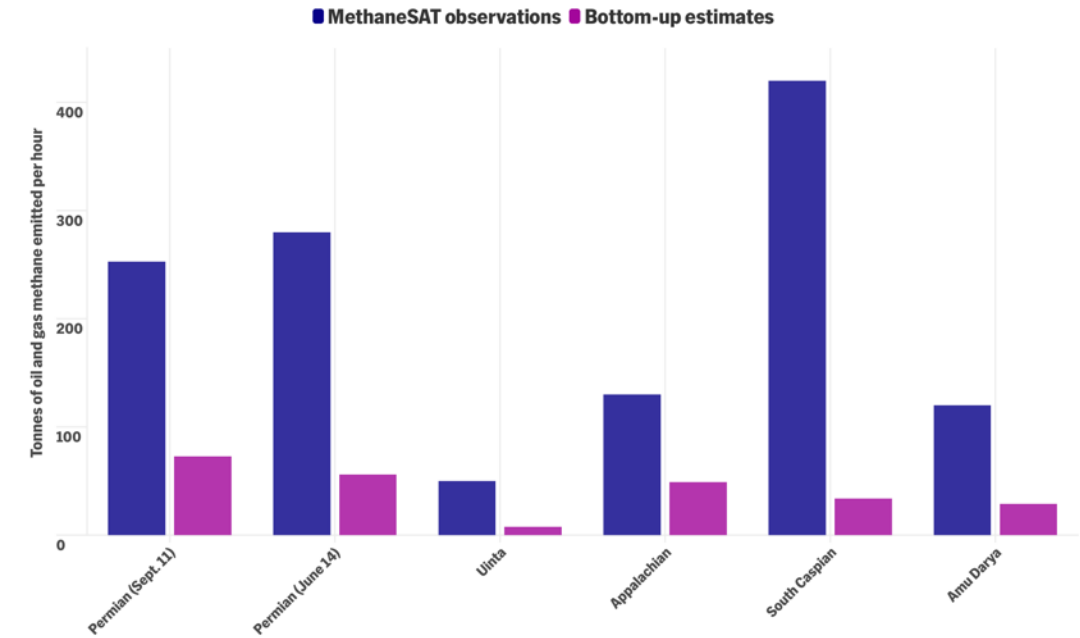
- South Permian USA
- 7 mile plume
- 18000kg hour
- Note point source



Turkmenistan

- 20 mile plume
- Note multiple plumes
- 55000kg per hour

These early observations suggest that emissions in North America and Central Asian production basins are significantly higher than currently reported in existing inventories built on engineering estimates. They also align with a growing body of research indicating that smaller emissions dispersed across wide areas are responsible for a substantial share of total oil and gas methane emissions.



Bottom up estimates derived from: [EDGAR \(Turkmenistan\)](#), [EPA \(U.S.A\)](#)



PROJECT UPDATE

New Data Show U.S. Oil and Gas Methane Emissions Over Four Times Higher than EPA Estimates

Methane loss rate is eight times greater than industry target

(July 31, 2024) New comprehensive aerial measurements show oil and natural gas producers across the U.S. are emitting methane into the atmosphere at over four times the rates estimated by the Environmental Protection Agency for those same areas based on industry-reported data. The results also show that operators are exceeding their own widely touted emissions goals eightfold.

Data was collected by [MethaneAIR](#), a specially equipped jet aircraft, measuring regions accounting for 70% of onshore contiguous U.S. oil and gas production. MethaneAIR uses similar technology to [MethaneSAT](#), a satellite developed by Environmental Defense Fund (EDF) and launched this year in March, which is scheduled to start delivering public data later this year, enter full operation in early 2025.

“Information used to track methane emissions today is based on extrapolations from very limited measurements. Now we can take robust, reliable measurements directly at an unprecedented scale,” said Dr. Ritesh Gautam, a Lead Senior Scientist on the MethaneSAT mission at Environmental Defense Fund. “These new findings represent a major advance over current methods, but also just a preview of the continuous high-resolution measurements that are coming soon from MethaneSAT and other satellites.”

Comparing methane emissions across major U.S. oil and gas basins

USED FOR LIVESTOCK METHANE EMISSIONS

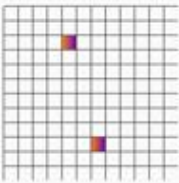
13:46 Sat 16 Nov carbonmapper.org

CARBON MAPPER About Data Work Impact Resources Open Data Portal



Attributing emissions at their source

The technology not only observes methane emissions, but also attributes them at a facility-scale level — often including specific pieces of equipment or infrastructure. These plume detection and attribution capabilities pinpoint emissions within individual sectors, including fossil fuel production and use, waste management, and large livestock operations.



Detecting methane with high sensitivity

The imaging spectrometers we use on aircraft can see plumes from methane super-emitters as low as 5-10 kg/hr under moderate conditions (90% detection limits are closer to 30 kg/hr). The Tanager satellites are designed to detect methane plumes with emission rates as low as 70 kg/hr under moderate conditions (predicted 90% detection limit of about 100 kg/hr).



More frequent sampling

With the launch of the first Tanager satellites targeting 2024, we plan to provide regular monitoring of high emission methane and CO₂ point sources. Depending on the sector, these emissions can be highly variable and, in some cases, intermittent. Because of this, sustained, high frequency monitoring is helpful to better understand the behavior and net impact of emission sources. Sample frequency is a function of the instrument field of view, satellite orbit, satellite agility and distribution of areas to be mapped.

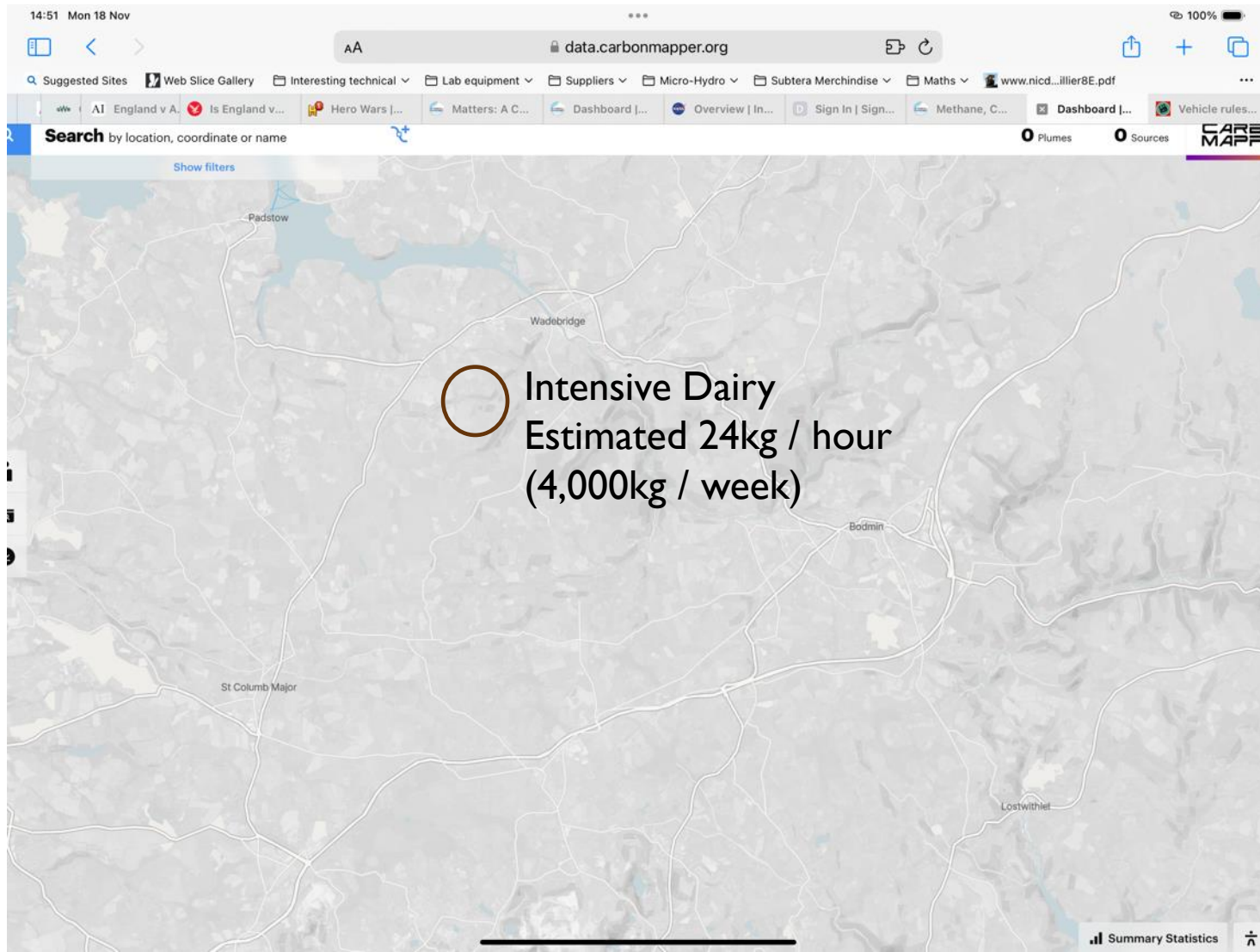


High resolution, wide area coverage

The imaging spectrometers we use on aircraft and satellites combine high-spatial resolution (typically < 5 meters for aircraft and typically 30-40 meters for satellites) with the ability to rapidly image large areas (typically 2500-5000 km²/day with an aircraft and upwards of 130,000 km²/day per Tanager satellite). This allows us to pinpoint the origin of methane or CO₂ plumes at or within individual facilities. Geolocation accuracy ranges from 5-15 meters for aircraft to 30-50 meters for Tanager satellites.

How large?

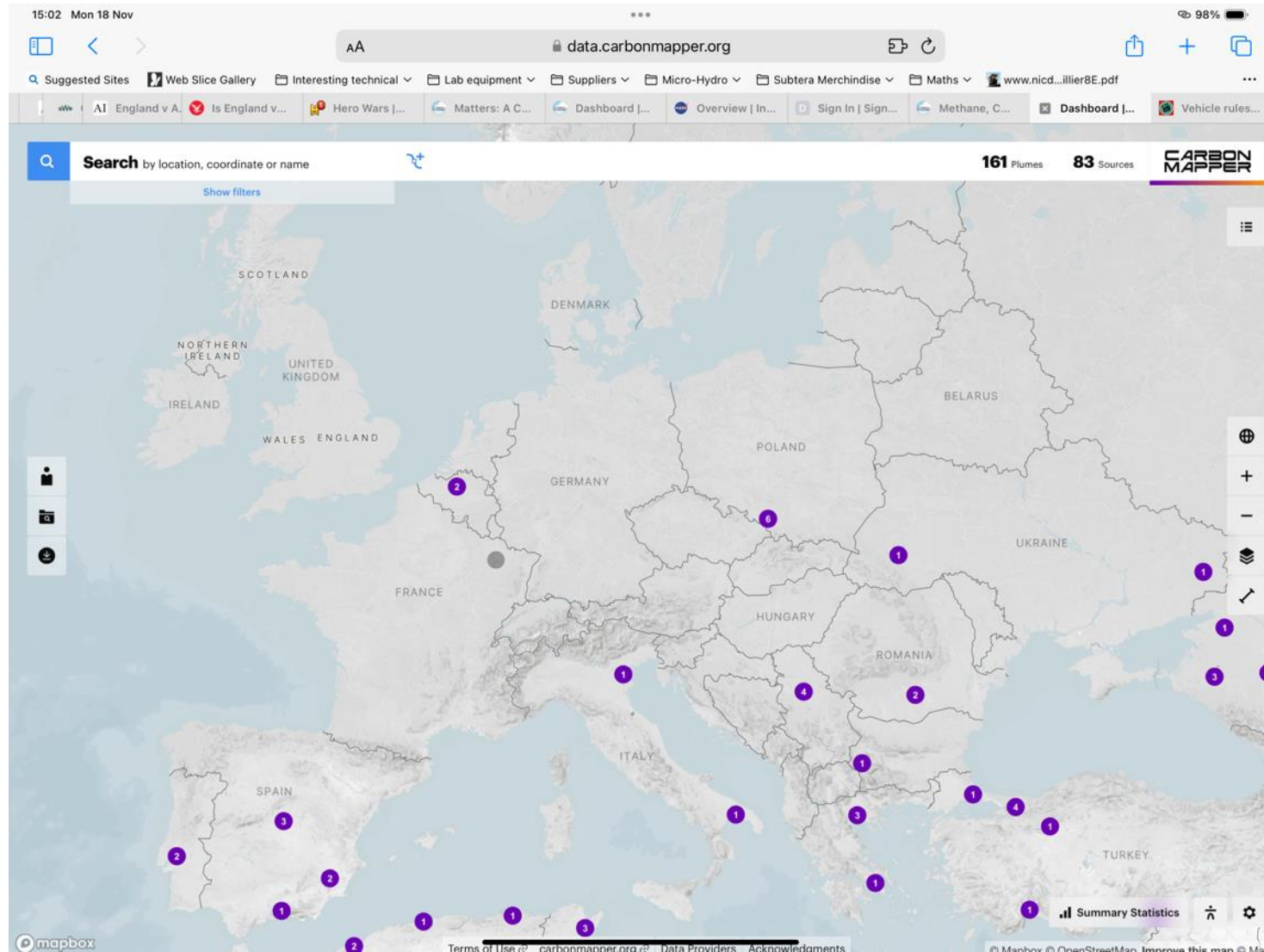
- Minimum detection emissions 100kg/hr
- Assumes point sources
- Assumes methane not biogas
- Typical 500 head dairy would be 30kg/hr of low altitude biogas not methane
- Well below detection threshold



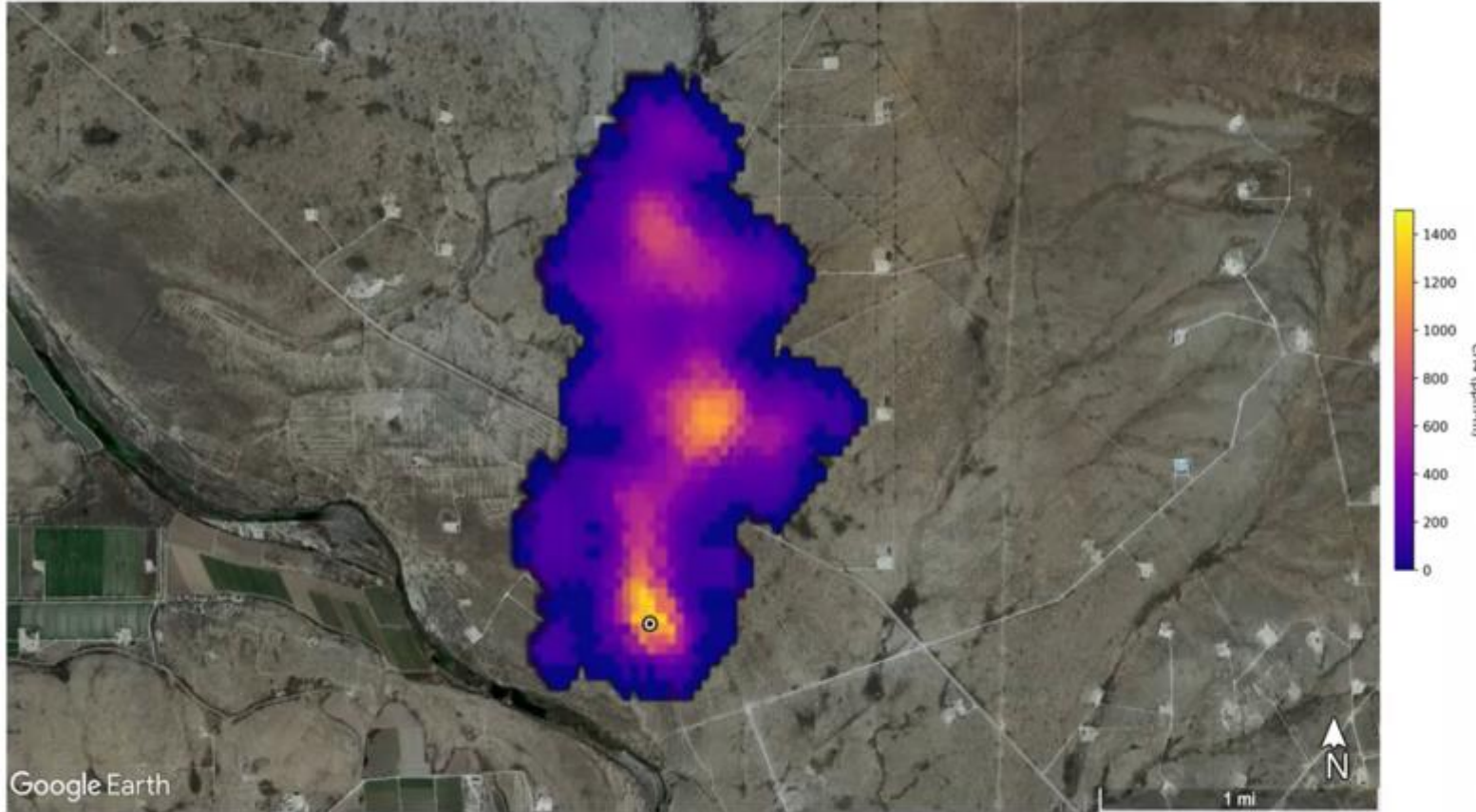
So even a large dairy by UK standards is below the detection threshold.

Why?

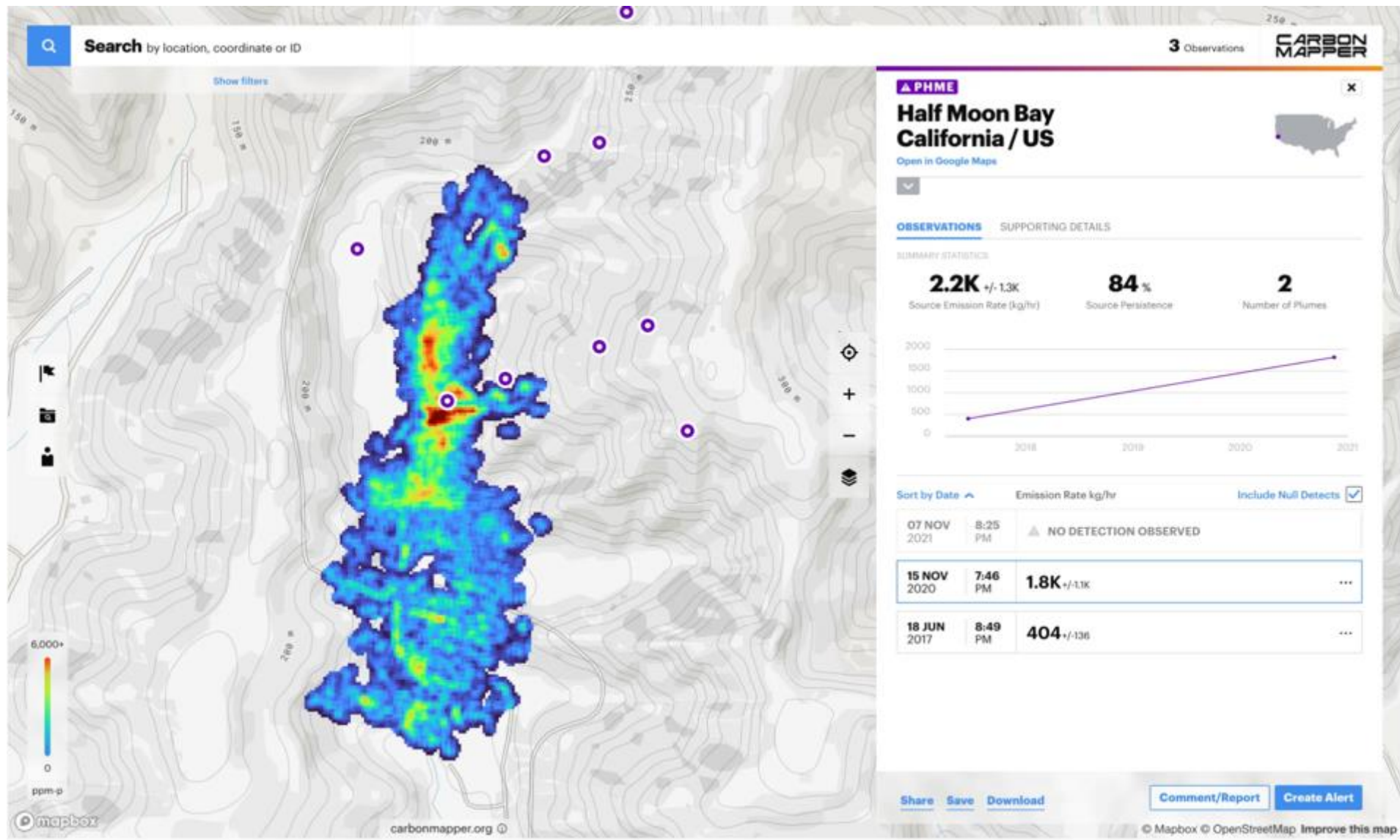
1. Biogas not methane therefore doesn't disperse upwards
2. Tanaka specifically targets point sources i.e., open vent stacks typically 0.5 – 2 and therefore extremely concentrated plumes
3. Lagoons are 10's of metres in spatial dimension therefore very diffuse clouds not plumes
4. Specific spectral information can be lost in the background noise



Has very few super emitters due to smaller farm size and lack of fracking

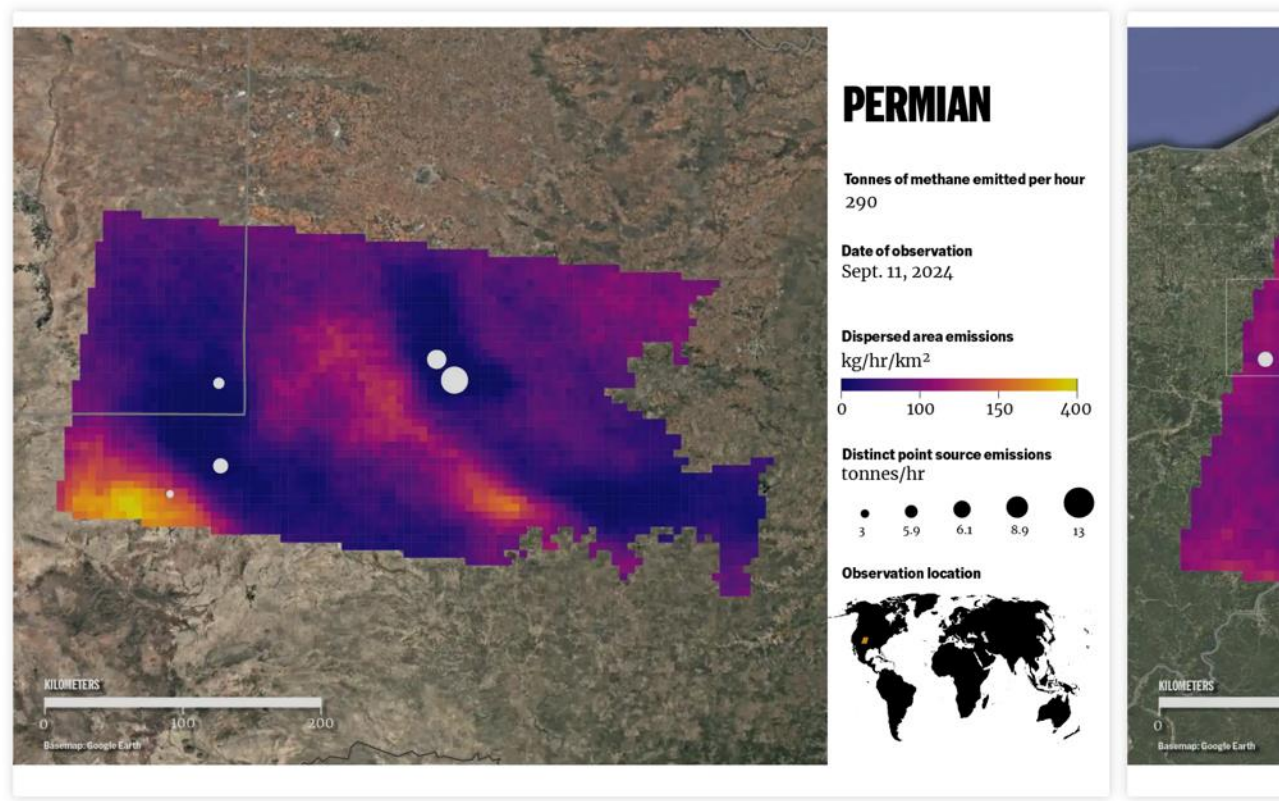


- Landfill site Iran
- Biogas not methane
- Extended source not point source
- 8000kg of methane per hour
- No vertical information
- Note distended cloud



MethaneSAT Emissions Images

Heat maps represent emissions over 5 km x 5 km areas



MethaneSAT
Launched 4th March 2024

Looking at large area swathes

Limited spatial resolution but
3ppb noise floor to detect
background methane
concentrations

Methane concentrations and distinct point source emissions rates captured over the Maturin basin of Venezuela

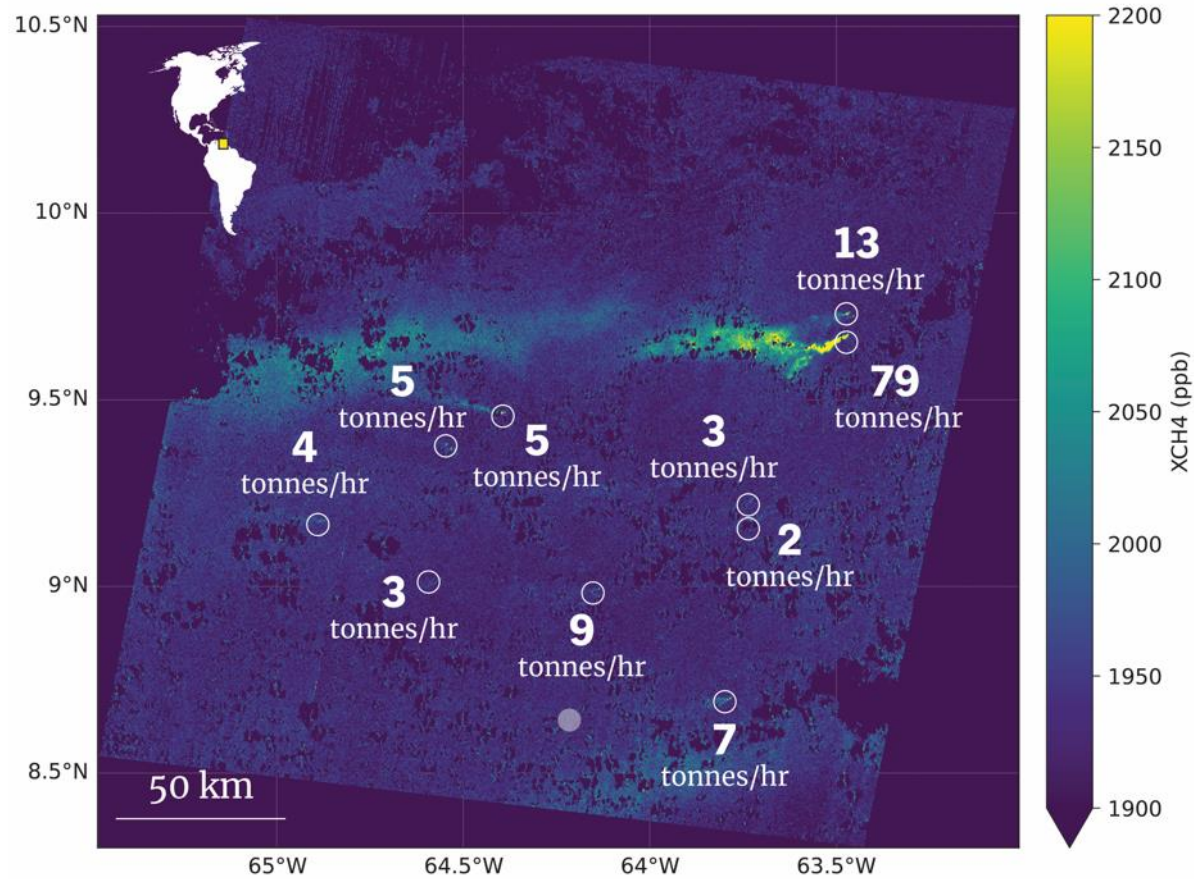
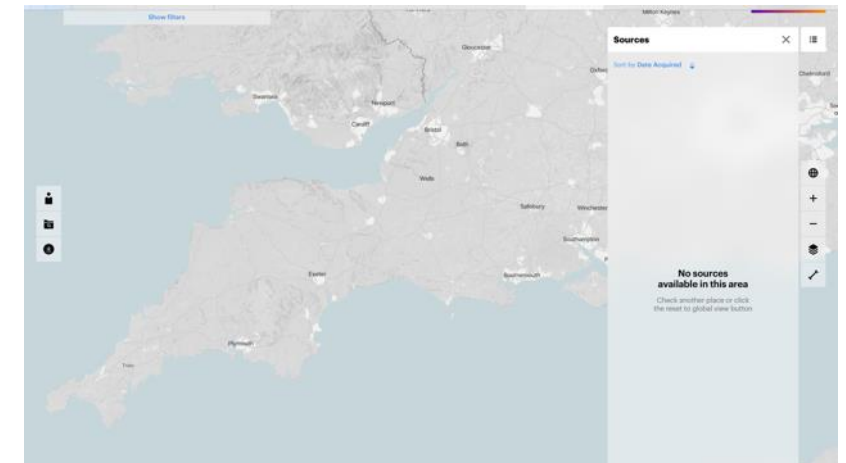


Image shows the powerful capability to provide regional emissions totals

Envisage Cornwall and Devon shown within a similar area that would highlight areas of high livestock concentrations and the associated fugitive methane and CO₂

Unable to identify individual farms





CONCLUSIONS

- New remote sensing capabilities are shedding new light on fugitive methane from oil and gas and large waste sites
- Measurements of fugitive methane from livestock farms are currently below the detection threshold
- Measurement on ground needs a different strategy and physical considerations
- Biogas from slurry stores starts diffuse, goes sideways and not up and doesn't separate
- Accurate quantification of fugitive biogas emissions has become a major area for IFEAA and others

A measurement open day will be arranged at a Bennamann site to test out different approaches