Drones, Trucks, and Grids: Development of a 4D Terrestrial Sensor Network for Data Assimilation

Current Research and Prospects for Terrestrial Instrumentation for CH_4 Monitoring at OU

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GeoCarb Science Team Meeting
University of Oklahoma

May 11th, 2022

NOTES from presentation

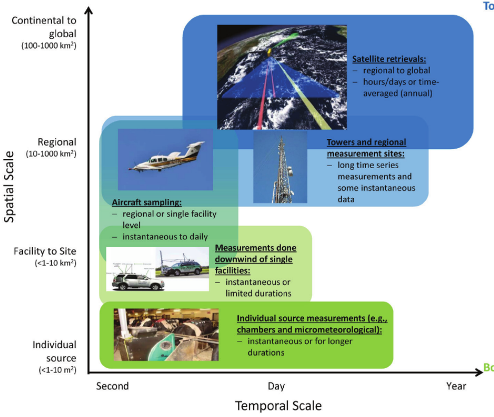
What was spoken about on each slide

I will include slides like this which follow slides with content to note what was discussed during the presentation.

Top-Down and Bottom-Up; Spatio-temporal Scales

- Atmospheric measurement
- Transport models
- Climate Reports

- Output inventories
- Point measurements
- Flux models



NOTES from presentation

Top-down/Bottom Up Arrows

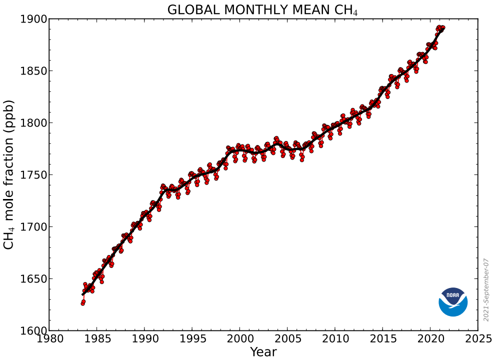
Generally speaking, we sense things as "top-down" and we estimate using inventories as "bottom-up". Some examples are included in the arrows. Both are ways of guessing the gas in the air, and neither are perfect.

Scales

The way we perform top down measurements depends on the spatial and time scale we intend to measure. Nothing captures everything.

Top-Down: Global Levels

May 2021: 1891.6 ppb
May 2020: 1874.4 ppb
Last updated: September 07, 2021



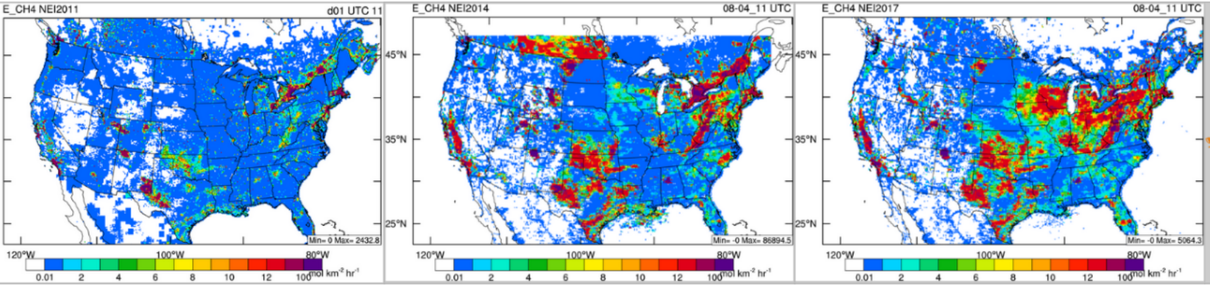
Dlugokencky, E., 2020. Trends in Atmospheric Methane. NOAA/ESRL.

NOTES from presentation

Mauna Loa Measurements

The atmospheric baseline is determined by column measurements at Mauna Loa, Hawaii. These are not *in situ* measurements but a complete stock of the full column of air into space. Note 2 ppm background result.

Top-Down: Atmospheric Predictive Models



Courtesy of Xiao-Ming Hu at OU CAPS

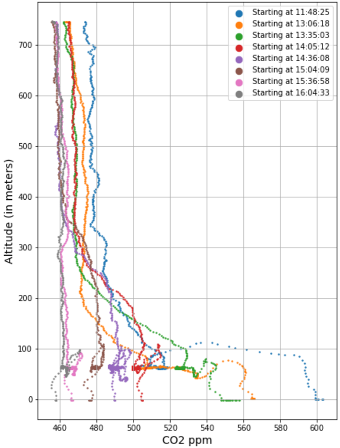
NOTES from presentation

Predictive models

We use predictive tools from weather to guess at future concentrations as a form of top-down inventory. These predictions are based mostly on bottom-up inventories, meaning that the quality of the models is driven in part by the honesty of emitters. This is problematic.

Does this match reality?

The Column Problem



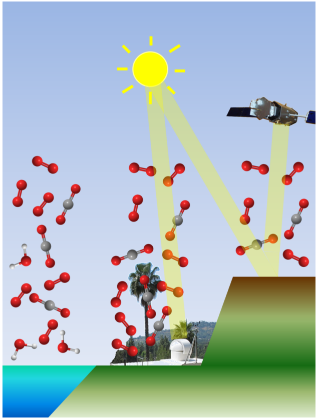
Pillar-Little, Elizabeth A. (2022) [In Preparation]

NOTES from presentation

Very Low Boundary Layers

In a test sensing CO_2 using a UAS, we see that the column makes huge jumps below 100m. If you notice reading many of the papers and presentations from modelers and folks that claim to measure the "boundary layer", they usually omit the bottom 500m out of convenience. It is hard to measure. But we see a huge spike there.

Total Column Measurements Average Constituents



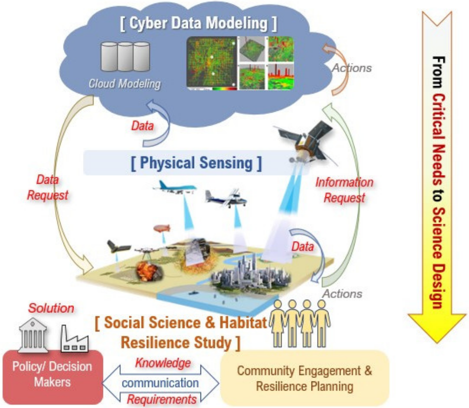
Graphic borrowed from Wikipedia

NOTES from presentation

Column Assumptions

When we measure using ground-based and satellite-based solar sensors, we measure full columns. This averages out and misses some of the very low boundary layer information. These big fancy tools simply are not made to measure air where the people live.

We Need an Integrated Approach



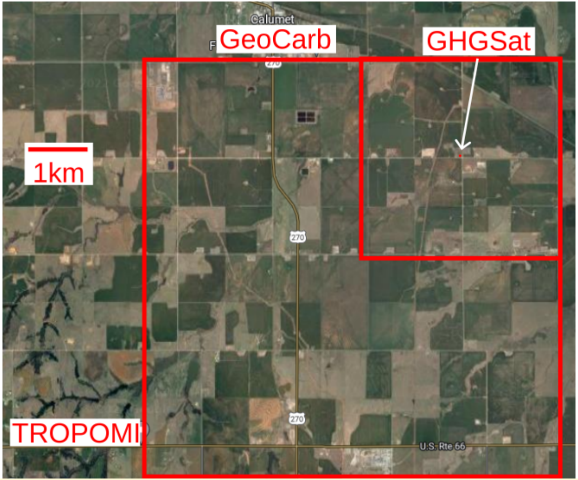
Honeycutt, W.T., 2021. On Sustainability as a Cyber-Physical-Social System: The XGEM Initiative Multiscale Integration of Methane Monitoring for Impact Characterization and Mitigation.

NOTES from presentation

Integrated Approach

If we rely on one technology, we will shoot ourselves in the foot. We need a full stack. This was discussed in a recent talk I gave suggesting policy tools for urban planning. This is also the goal of the OU XGEM project, where this figure is from.

Space and Time



- The GeoCarb pixel here has 20 well-pads
- Optimizing satellites for regional or single-site scale has left a deficit for the space in between.

NOTES from presentation

Pixels

Single pixels (simplified cartoon example overlayed in NW OK) from most satellites are too big to be useful for identifying emitters on their own. Specialized satellites like GHGSat are actually too small to be useful too, as they cannot cover the ground the others can. There is no perfect spacial resolution.

Covering Ground

$$C_{LOD} = 16.7\text{ppm}$$

$5

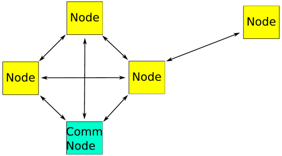
Honeycutt, W.T., Ley, M.T., Materer, N.F., 2019. Precision and Limits of Detection for Selected Commercially Available, Low-Cost Carbon Dioxide and Methane Gas Sensors. Sensors 19. urlhttps://doi.org/10.3390/s19143157

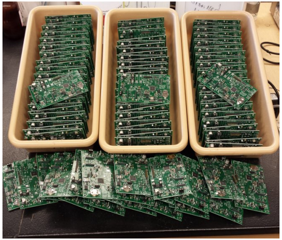
NOTES from presentation

2D Network

My previous work when I was at OSU was used to design a high-density terrestrial grid of sensors to address these spatial issues. Note the sensor on the right, which performs extremely poorly. This is not a quantitative study.

Multi-Tier, Self-Assembling Sensor Network





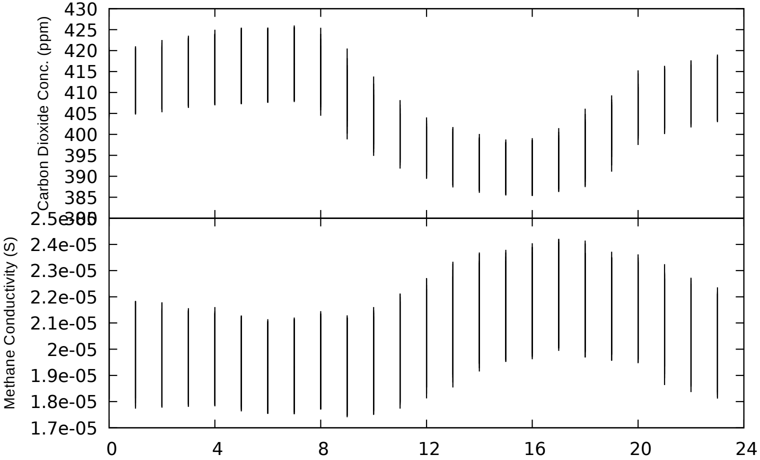
Honeycutt, W.T., Kim, T., Ley, M.T., Materer, N.F., 2021. Sensor array for wireless remote monitoring of carbon dioxide and methane near carbon sequestration and oil recovery sites. RSC Adv. 11, 6972–6984. https://doi.org/10.1039/D0RA08593F

NOTES from presentation

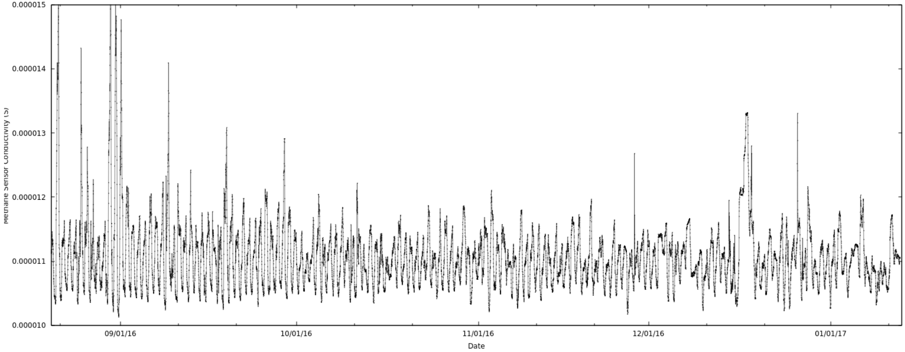
Devices in 2D Network

The network is composed of multiple device echelons which self-assemble as hybrid networks. All of the little nodes have sensors and self-distribute data over line-of-sight radio. Each of these subnetworks includes 1 big unit. The big unit regularly transmits the data from the network back to home base over cell data.

Network Capabilities

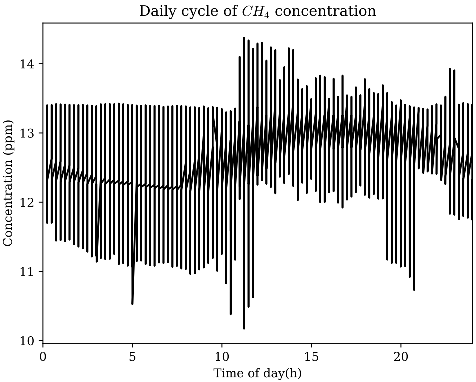


Network Capabilities



Honeycutt, W.T., 2017. Development and Applications of Chemical Sensors for the Detection of Atmospheric Carbon Dioxide and Methane (Dissertation). Oklahoma State University, Stillwater, Oklahoma.

Network Capabilities



Honeycutt, W.T., 2017. Development and Applications of Chemical Sensors for the Detection of Atmospheric Carbon Dioxide and Methane (Dissertation). Oklahoma State University, Stillwater, Oklahoma.

NOTES from presentation

Sensor Quality Matters Less en Masse

With enough units in our network, we can overcome the poor quality sensors. Pictured here is our daily cycling of gases with high temporal resolution. This measures every 30 minutes.

Field Data

The next plot shows data collected from a carbon sequestration site. Our network detects notable increases in the concentration. Sadly, the corporate partners in this case renegged on their agreement to share data when they heard we detected something, so I cannot tie peaks to real events. There was no significant relationship between spikes we observed and earthquakes, the original purpose of the study.

Daily Cycle vs. 2ppm Background

Our network did detect a notably higher concentration of gas in Stillwater above the baseline CH_4. We do not draw conclusions from this: it was near a wet area, a distillation plant, cattle yard, and concrete lab. There is such a difference in these data that we need to look much more carefully at total column data near the ground

Along the Fenceline

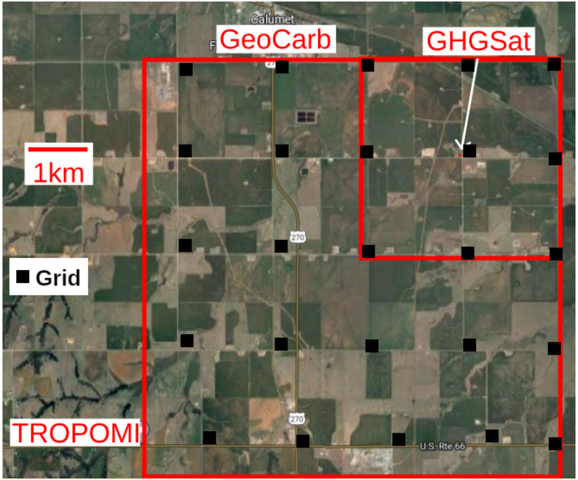
Jacob, J., Mitchell, T., Honeycutt, W.T., Materer, N.F., Clark, P., 2016. Monitoring of Carbon Dioxide and Methane Plumes from Combined Ground-Airborne Sensors, in: Convection and Boyancy Driven Flows: Environmental, 20. Presented at the 69th Annual Meeting of the APS Division of Fluid Dynamics, APS.

NOTES from presentation

Airport

This network deployment at an uneventful site in cow country did not see much. The video on the right (omitted for PDF) shows the glowing of the diurnal cycle for each point on the grid.

Space and Time

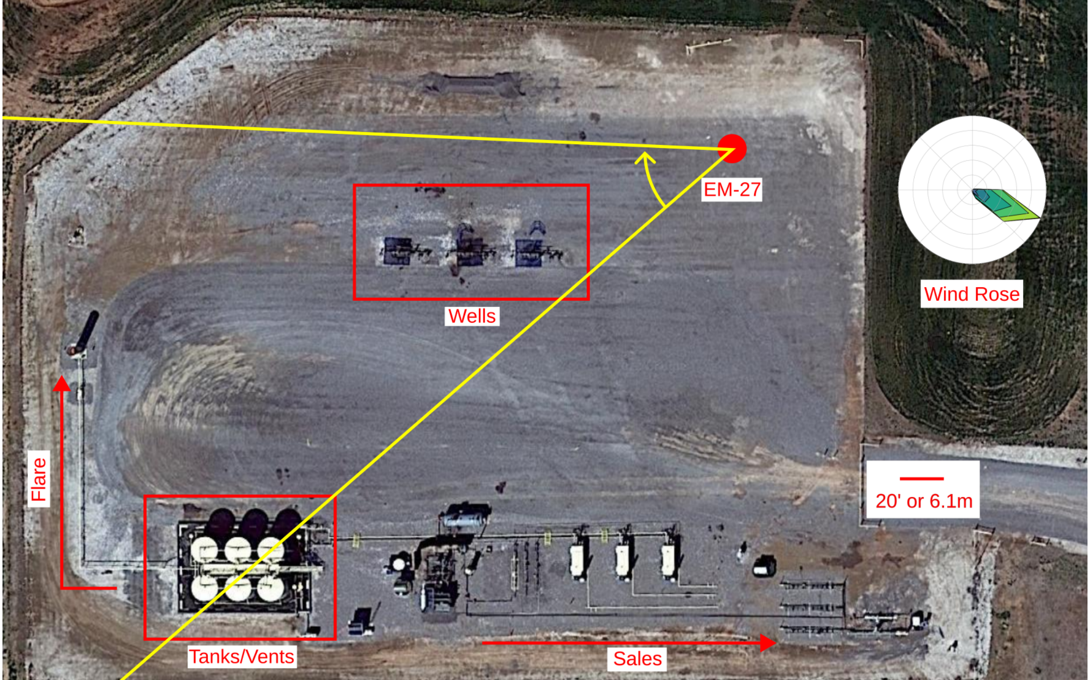


- 25 nodes, country road mile marker.
- Low-cost ($19,650 for pictured network).

NOTES from presentation

Grid Overlay

We should overlay terrestrial sensors with satellite grids. Here is a cost guess based on pre-COVID supply chain cost increases. We can improve the satellite measurements at the site with an inexpensive array.

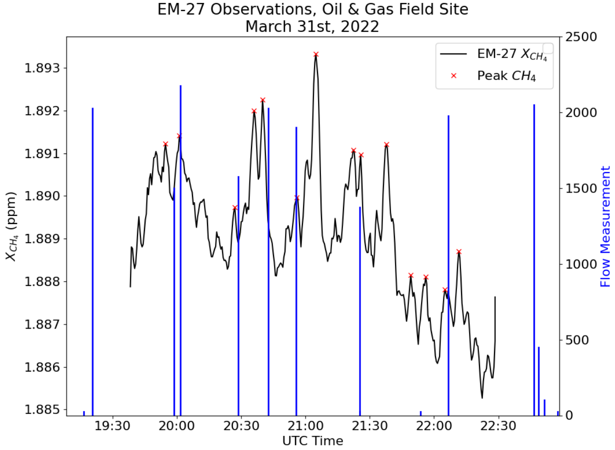

EM-27
Wind Rose
Wells
Flare
20' or 6.1m
Tanks/Vents
Sales

NOTES from presentation

What about a good sensor?

In addition to the inexpensive array, what if we used a really good sensor at a local site. Here, we use an EM-27 at a superpad site. The path of the sun means that we measured the yellow region which passes over a leaky tank and flare. The wind rose notes that the plume would be flying through our scan area at the time.

EM-27 Plume Monitoring

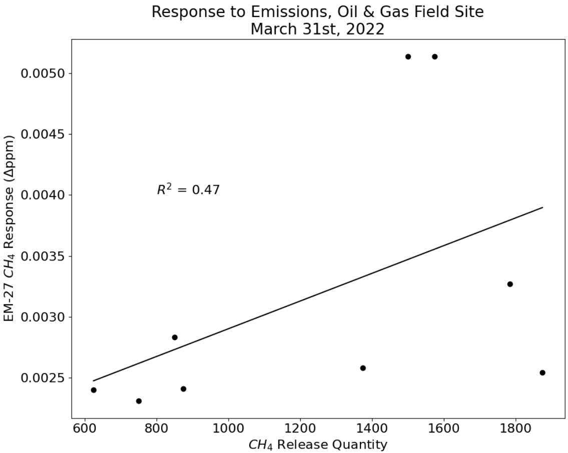


NOTES from presentation

Data

Data from one day are interesting. We see a cycle in concentrations observed by the EM-27. Speaking with the anonymous industry partner, we received information about gas leak timing at the site. Those peaks line up rather well, but there are too few data to claim significance. We plan to test more.

EM-27 Plume Monitoring



NOTES from presentation

Data

Plotting the change in observed methane by the EM-27 5 minutes after each peak with respect to the volume of release reported by the industry partner, we see the beginning of a relationship. It is likely that we are seeing the cycling of the wells at the site and the venting of the thief valve at the site.

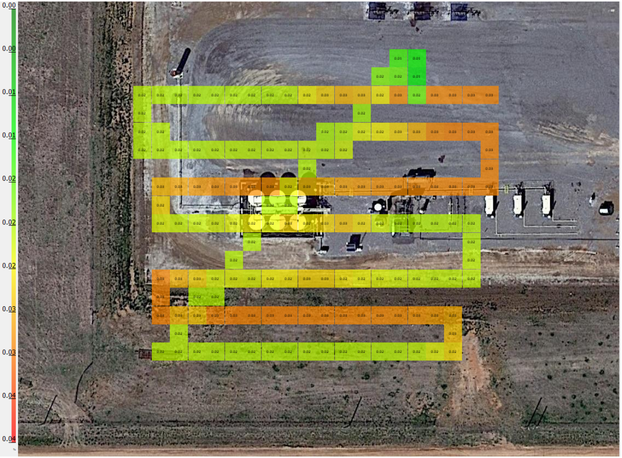
Flights at [REDACTED] Site

NOTES from presentation

Flights

In addition to the EM-27, we also flew a UAS above the tanks with a low-quality *in situ* sensor. The flight was 15m AGL, as close as I could comfortably get to the tanks without a hot-work permit.

Flights at [REDACTED] Site

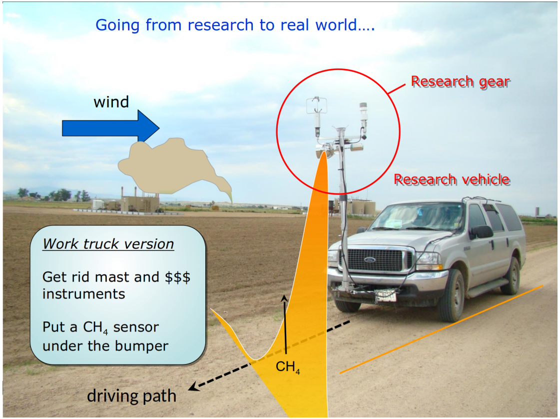


NOTES from presentation

Flights

Sure enough, we can see elevated concentration when we fly with the wind through the plume. Note, that I do not trust the sensor quality, so these are quantitative data only.

Open Path Sensors to Measure Methane



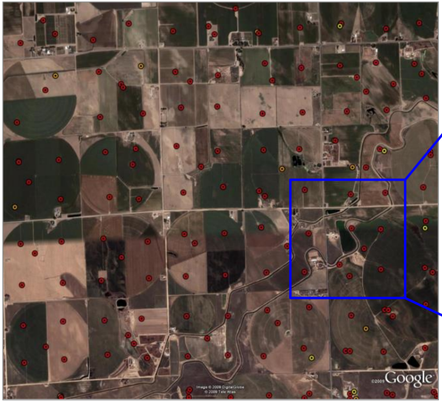
Thoma, E., Brantley, H., Albertson, J., 2014. Fugitive methane assessment with mobile and fence line sensors.

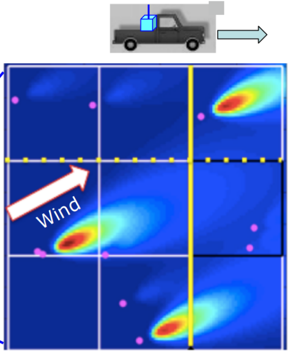
NOTES from presentation

Trucks

In addition to our current tools, we would like to add a truck to our toolkit. This is an example from other's research which mounted sensors on a truck. We have some ideas to improve this based on some expertise from the storm chasing crew at OU.

Open Path Sensors to Measure Methane





Thoma, E., Brantley, H., Albertson, J., 2014. Fugitive methane assessment with mobile and fence line sensors.

NOTES from presentation

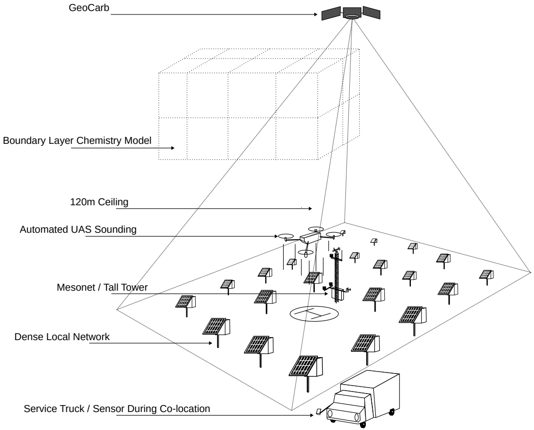
Trucks

The idea is that the truck can drive through a plume and detect gas. I'm not sure how much I believe this is useful in OK, as dirt roads would cause big problems with data acquisition. However, it is noted as an option which others have had success with.

What should we take from this?

- Currently, leak detection, site monitoring, and regional monitoring are separate:
  - **Leak**: GHGSat, aerial imagery, terrestrial networks
  - **Site**: UAS flights, IR imagery, long-path sensors
  - **Region**: TROPOMI, GeoCarb, WRF-CHEM
- Separable sensing regimes are less useful.
- We should correct this with extreme prejudice:
  - Coordinate technologies across siloed disciplines
  - Assimilation is a two-way street
  - New sensing regimes that cross boundaries

Proposal: 4D Integrated Super Site



NOTES from presentation

Overview and Future

The previous two slides discuss the overview of what needs to happen for better data acquisition and one super site which we are working very hard to create at OU. This would integrate tools from across campus expertise to perform measurements with high spatial and temporal resolution.

Contacts/Thanks

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Partners
Anon. Industry Partners
Cheyenne-Arapaho Tribe

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