Paper # A51J-2716

UAV deployment for CO_2 flux estimation in a mid-size city

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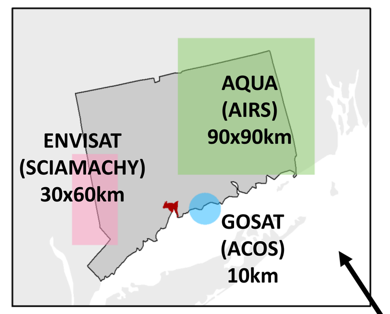
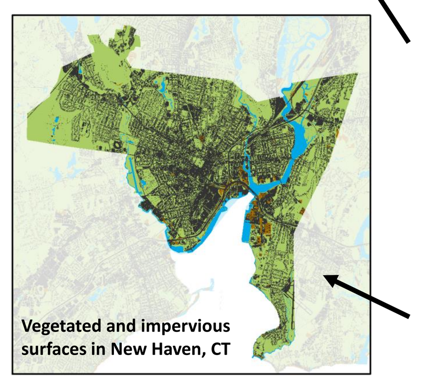
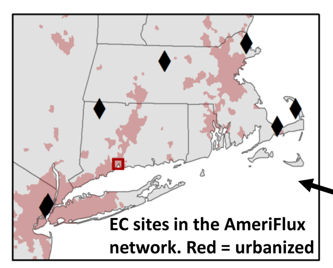
Background







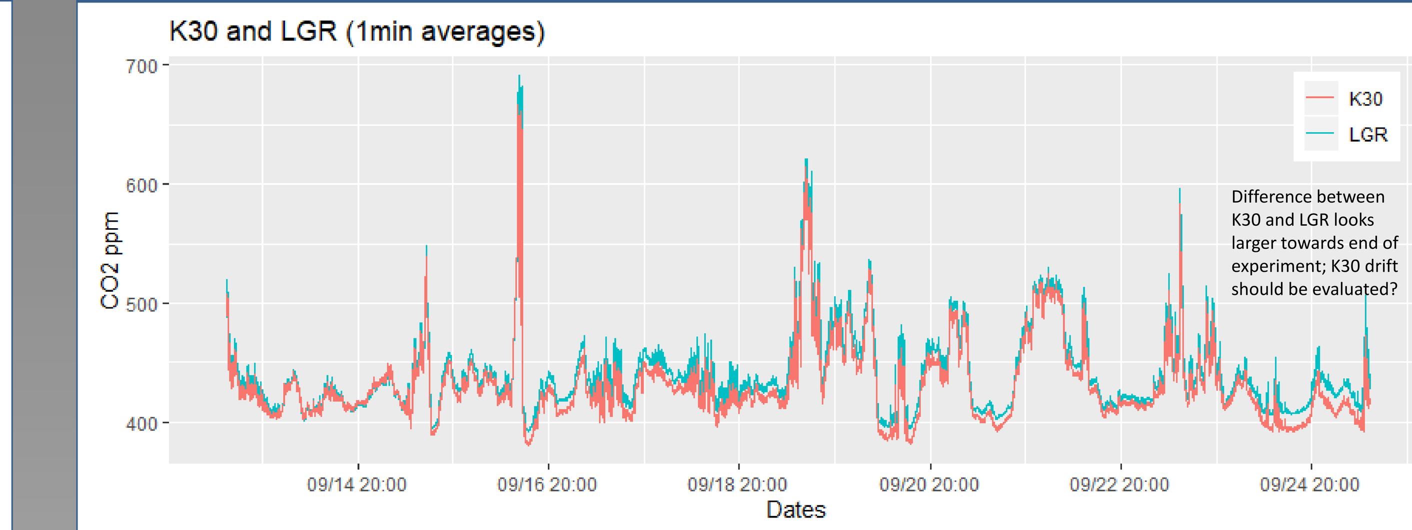
Urban areas produce a disproportionate amount of CO_2 emissions worldwide, and better understanding and quantifying these emissions is crucial to mitigating them. However, with current tools, ***scientists possess limited ability to quantify CO_2 emissions on small scales and to resolve intra-city variation in CO_2 flux.***

Existing satellites that measure atmospheric column CO_2 lack spatial resolution to de-aggregate CO_2 patterns within cities.

Municipal emission inventories present difficult-to-quantify uncertainties, and many inventory methodologies do not account for carbon sinks (like green spaces) that may affect a city's CO_2 flux.

Gas flux models based upon eddy covariance (EC) calculations often assume homogenous surfaces, which clearly does not hold in complex urban topography. Perhaps as a result, EC data are most often collected on undeveloped land.

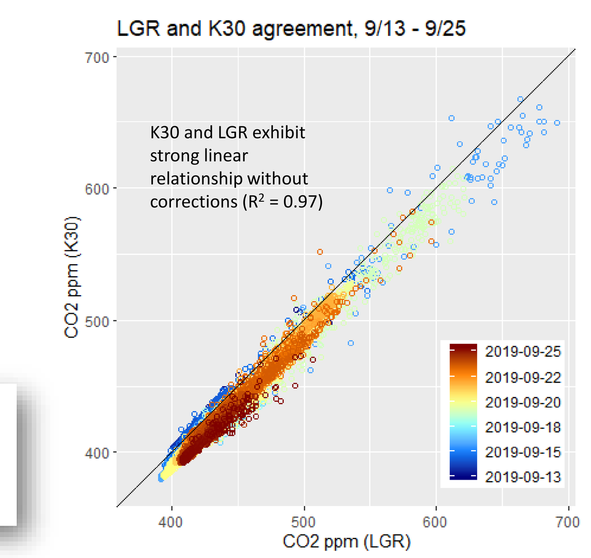
Calibration of Low-Cost CO_2 Sensor



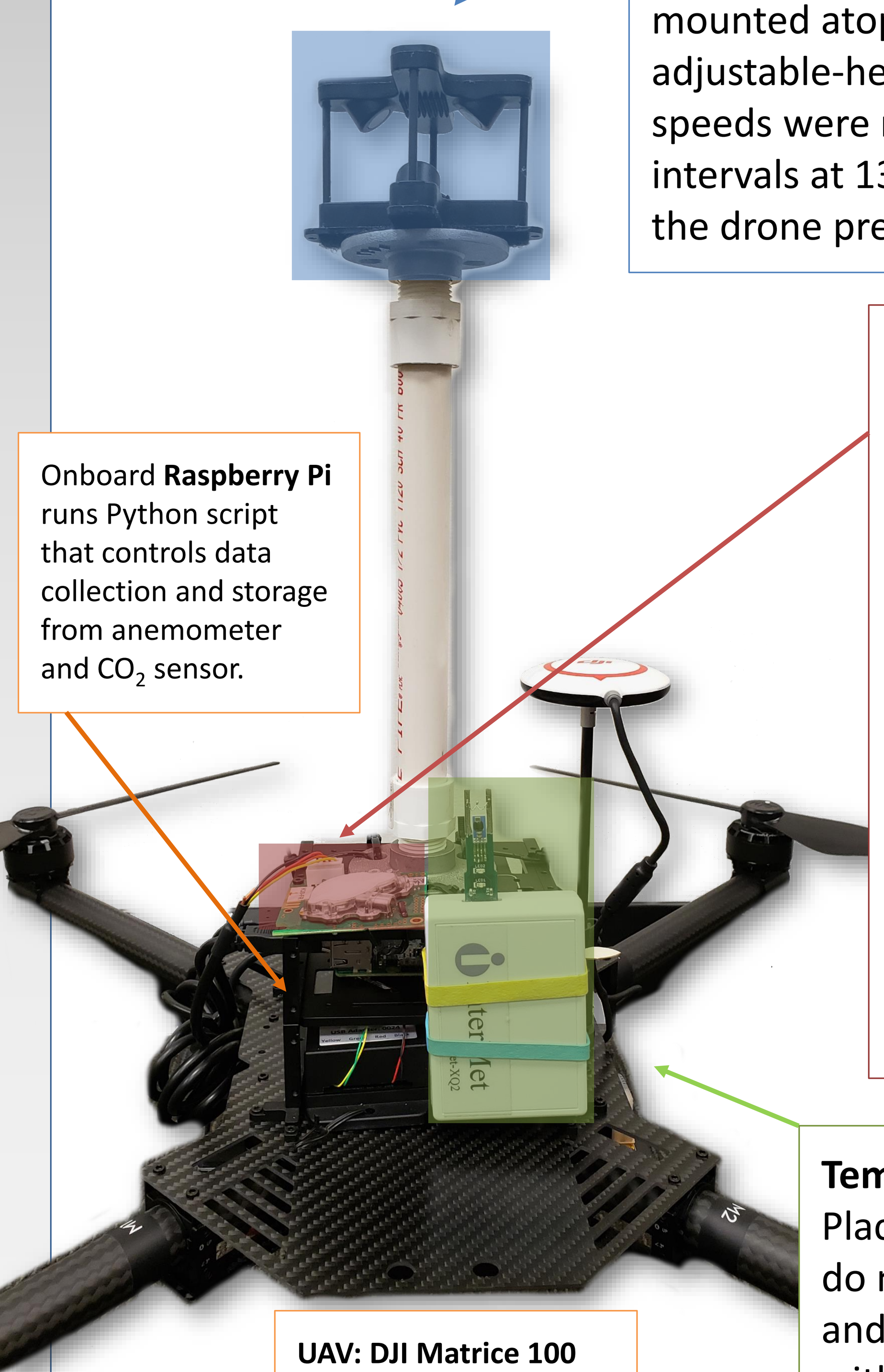
Calibration data collection: The K30 was placed adjacent to a high-precision CO_2 analyzer (Los Gatos Research analyzer) and a meteorological instrument (iMet XQ2) and left undisturbed in an unoccupied room for 13 days to record ambient air from a propped-open window. K30 values appeared *lower* than LGR values by 8.61ppm on average in this period.

Calibration correction equation: Raw K30 data were fed into a multivariate regression model ($K30_{raw}$ ~ *LGR + Pressure + Air Temp + Relative Humidity)* to quantify offset from the LGR and how weather factors affect instrument performance. Coefficients from the linear model were used to assemble a "correction equation" that could be applied to future K30 data collected in the field.

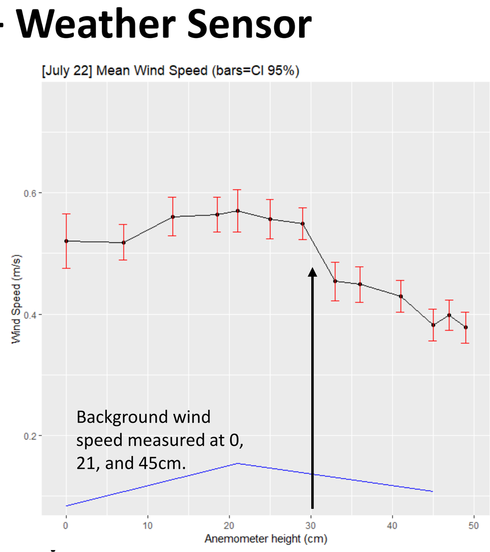
$$K30_{corrected} = \frac{[\,K30_{raw} - 606.364 - (0.581*Pressure) - (0.712*AirTemp) - (0.328*RelHumidity)\,]}{0.942}$$



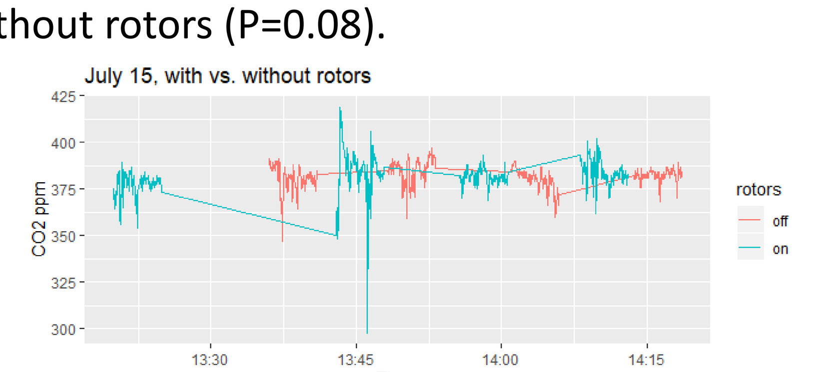
Instrument Testing & Placement



Anemometer: TriSonica Mini Wind + Weather Sensor
Rotor wind can interfere with measurements, but mounting an instrument on a boom too far from UAV's center of gravity may present safety hazards. Anemometer was mounted atop UAV on an adjustable-height platform. Wind speeds were recorded for 5 min intervals at 13 heights. 30 cm above the drone presented the best compromise.

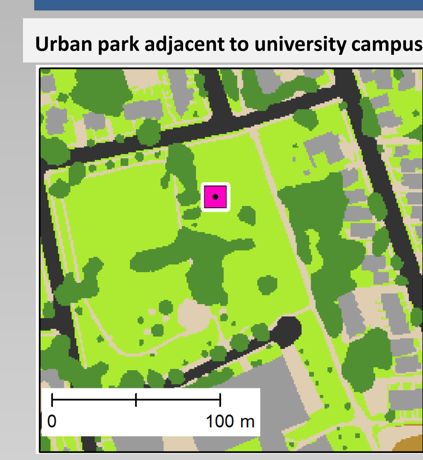


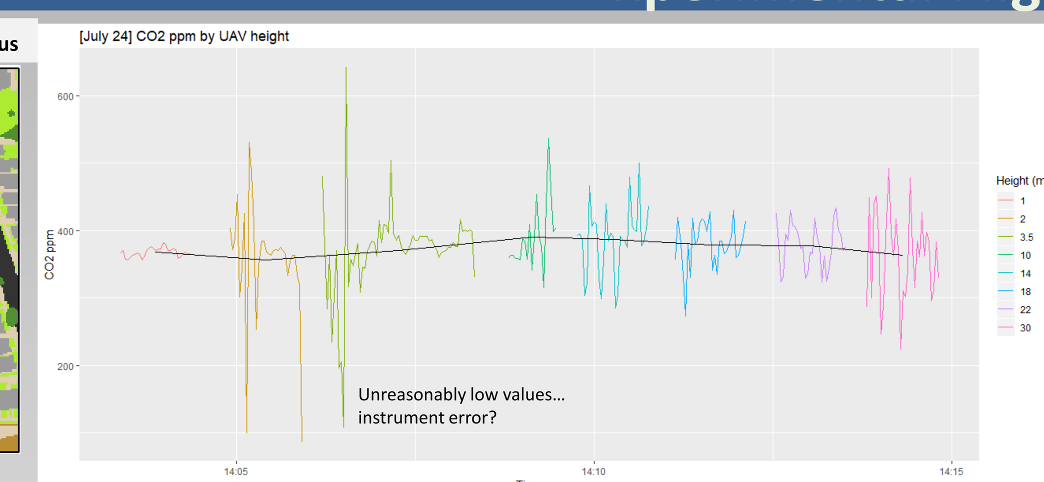
CO_2: K30 Fast Response Sensor
To estimate effect of rotor wind, sensor was mounted on a grounded UAV, and CO_2 data were collected while alternating rotors on-and-off for 5 min and 20 min intervals. Rotor wind increased the SD of CO_2 values (5.9 to 9.1), but mean CO_2 values were not significantly different with or without rotors ($P=0.08$).

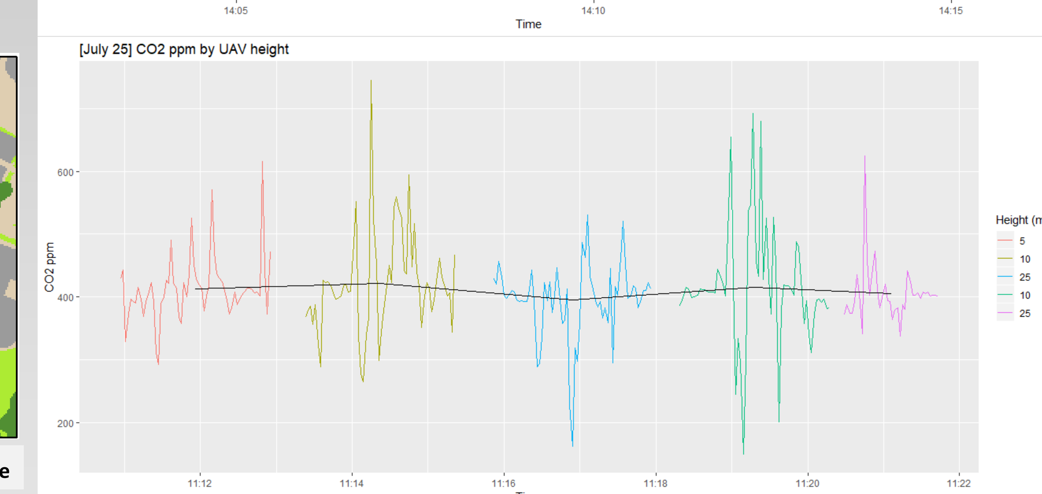


Temp, Humidity, & Pressure: iMet XQ2
Placed on the side of the UAV, pressure and humidity do not significantly differ when rotors are on ($p=0.62$ and 0.41). Air temperatures were significantly cooler with rotors-on ($p=0.00$), but this requires re-testing.

Experimental Flights

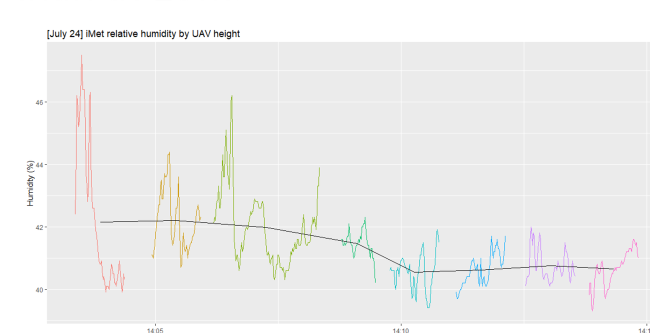


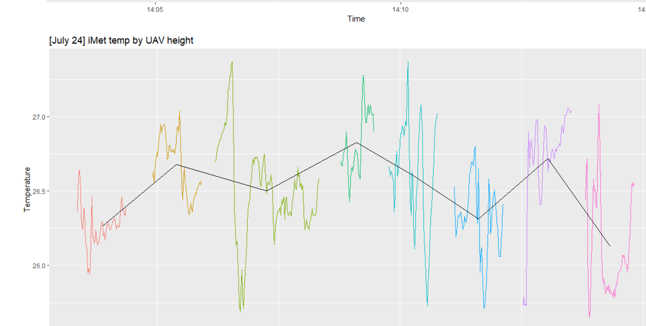




Influence of measurement height: Mean CO_2 concentrations were lower on average over urban parkland. The measured CO_2 gradient was smaller than expected—concentrations at 10m were ~20ppm higher than at 25m.

Relative humidity decreases with height, while temperature responds less linearly.

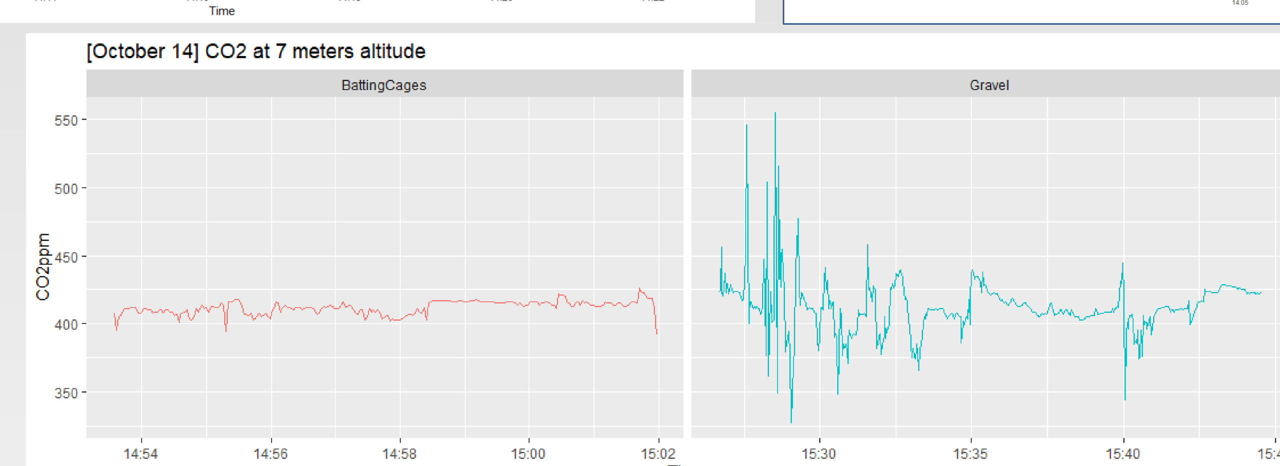


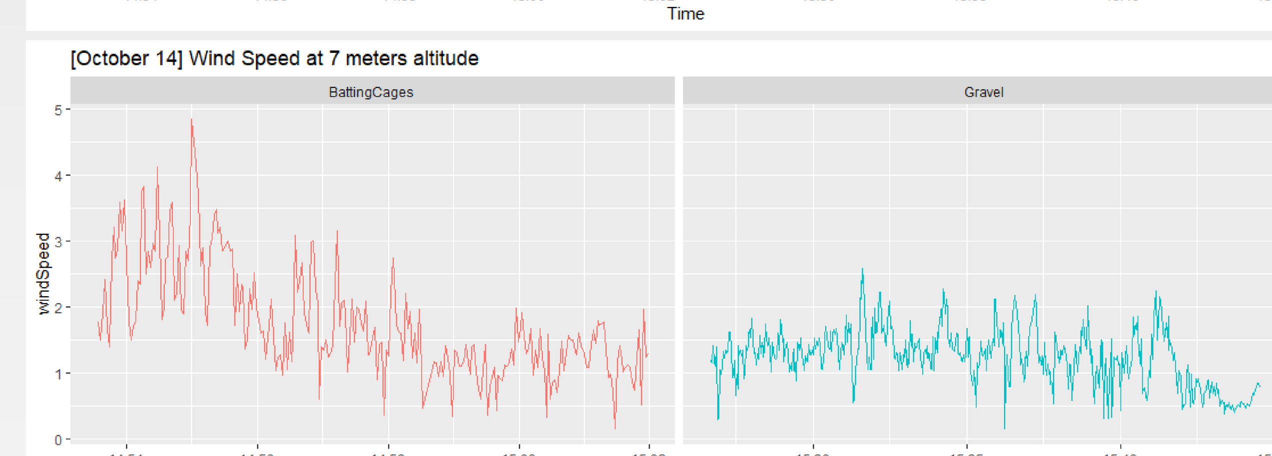


Measurement variation with wind:

Measured CO_2 concentrations exhibited more stability in higher ambient wind (SD 4.87 at the batting cages vs. 19.5 at the parking lot).

Both flights still produced very similar mean CO_2 values (411.9 vs. 412.1 ppm).





Conclusions

- When compared to a high-precision CO_2 sensor, our low-cost sensor originally exhibited a RMSE of 5.453 ppm. Factory-stated accuracy of the low-cost sensor is +/- 3% or 30 ppm.
- By calibrating our low-cost sensor against the high-precision LGR, and accounting for sensor response to weather variables, we reduced the RMSE of recorded CO_2 values to 3.806 ppm.
- Determining proper sensor placement on UAVs is high-priority for anemometers and temperature sensors, medium-priority for CO_2 sensors, and lower priority for humidity and pressure instruments.
- We observed a gradient of ~20 ppm between 10 and 25 meter altitude.

Future Work

- Fly transects over different land cover types, at different times of day, to compare CO_2 values
- Refine the assumptions used in calculating CO_2 flux from CO_2 concentrations
- Deploy platform adjacent to eddy covariance tower to directly compare flux estimates
- Estimate flux footprint areas, to analyze what mix of land cover types are included in the platform's source area

Acknowledgements

Special thanks to TC Chakraborty (Yale F&ES), Alex Du (Hotchkiss School), and John Campbell (Yale Environmental Health & Safety) for their assistance during Summer 2019. This project was funded by the Connecticut Space Grant Consortium.

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