Development of an Unmanned Aerial Vehicle (UAV) for Episodic Air Pollutant Measurements

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Aim

- Using UAVs to collect three-dimensional time series data of pollutants such as particulate matter (PM) and CO_2.
- Develop data driven methodologies to design/build plume models.

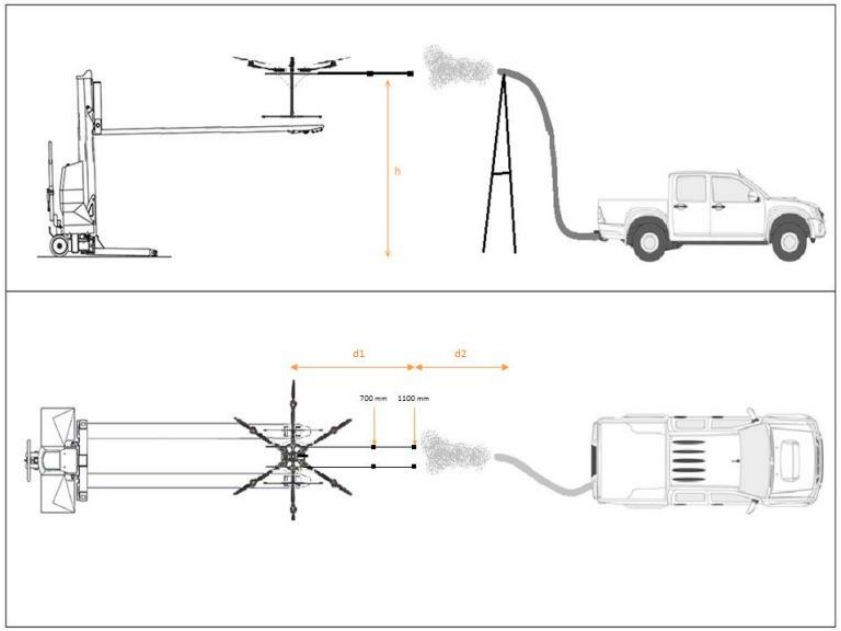
Motivation

- Plume Detection
- Estimating the area of impact caused by wildfires, chemical explosions and refinery pollution.
- Quantitative and qualitative data collection of invisible plumes.
- Fugitive VOC emissions from sources such as refineries.
- Source estimation of wildfires/chemical leaks.

State of the Art

Villa, Tommaso, Farhad Salimi, Kye Morton, Lidia Morawska, and Felipe Gonzalez. "Development and validation of a UAV based system for air pollution measurements." Sensors 16, no. 12 (2016): 2202.

- **Development and Validation of a UAV based system for Air Pollution Measurements**
- Characterization of the Particle Emission from a Ship Operating at Sea Using Unmanned Aerial Vehicle
- A Multipollutant Smoke Emissions Sensing and Sampling Instrument Package for Unmanned Aircraft Systems: Development and Testing



State of the Art

Villa, Tommaso F., Reece A. Brown, E. Rohan Jayaratne, L. Felipe Gonzalez, Lidia Morawska, and Zoran D. Ristovski. "Characterization of the particle emission from a ship operating at sea using an unmanned aerial vehicle." Atmospheric Measurement Techniques 12, no. 1 (2019): 691-702.

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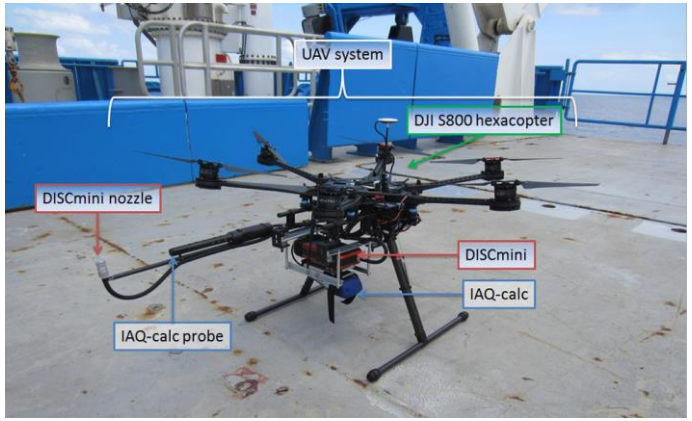

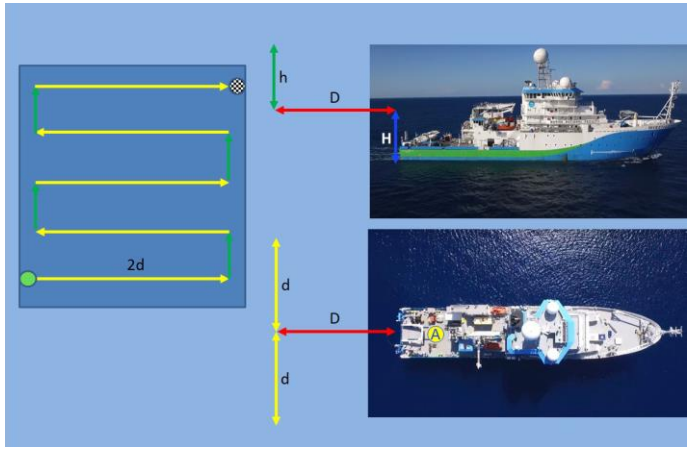

State of the Art

Nelson, Kellen N., Jayne M. Boehmler, Andrey Y. Khlystov, Hans Moosmüller, Vera Samburova, Chiranjivi Bhattarai, Eric M. Wilcox, and Adam C. Watts. "A Multipollutant Smoke Emissions Sensing and Sampling Instrument Package for Unmanned Aircraft Systems: Development and Testing." Fire 2, no. 2 (2019): 32.

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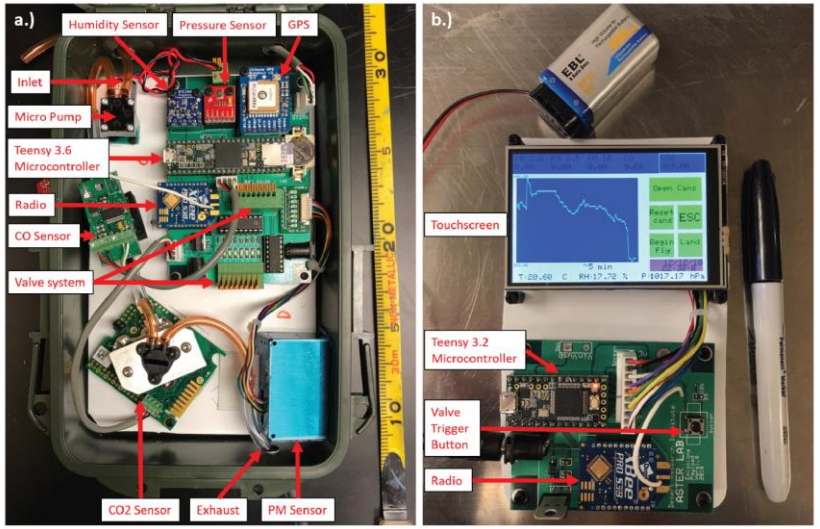


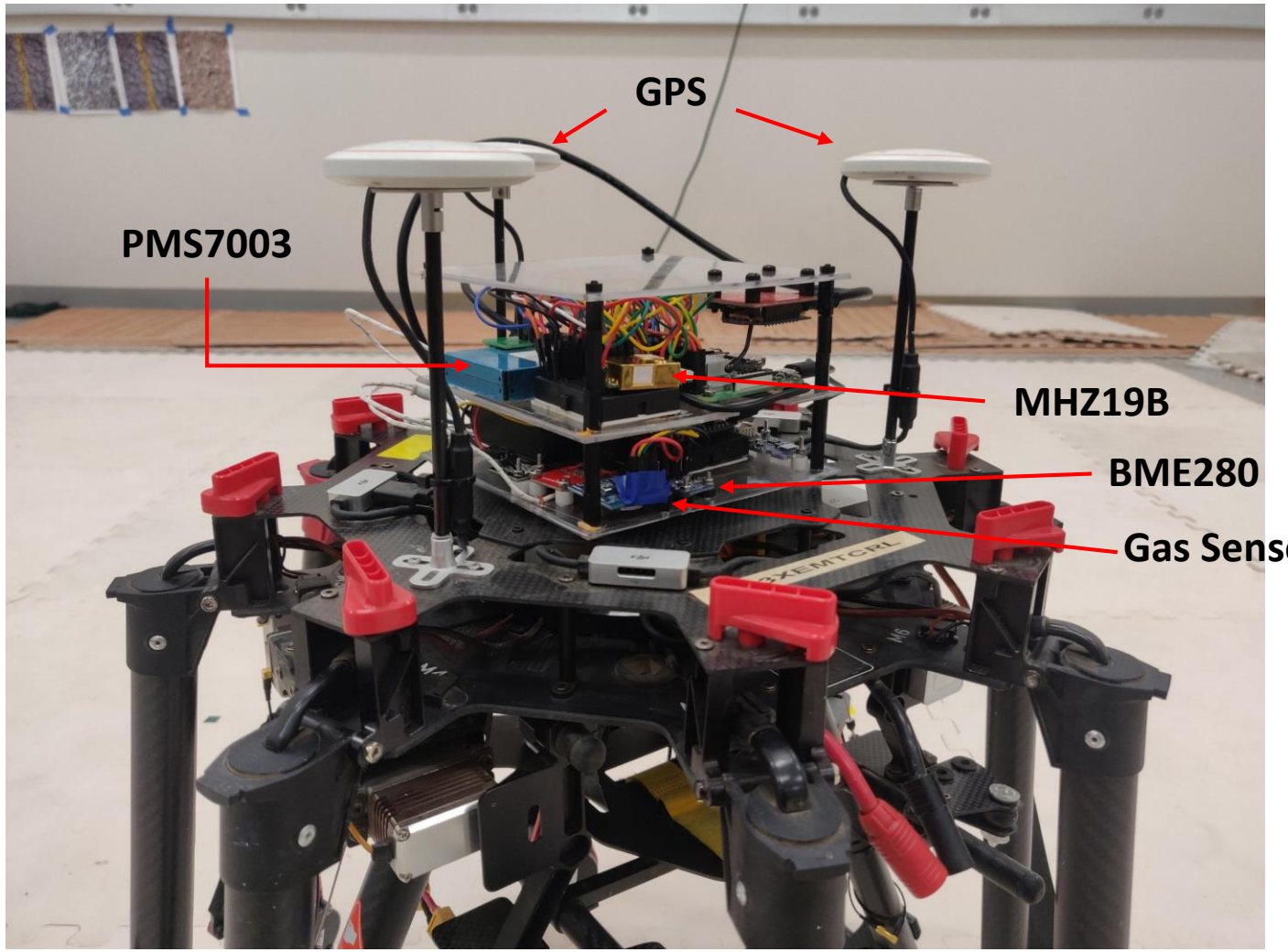
The measurement device houses the main circuit board. The CO and CO_2 sensors are plumbed in line with a micropump and the particulate matter sensor is exposed to ambient air through a window on the side of the enclosure.

Sensor Package

Our sensor package consists of non-regulatory grade low cost sensors.

They consist of:

- PMS7003: PM Sensor (size and mass)
- MH–Z19B: CO_2 Sensor (NDIR)
- Grove Multichannel Gas Sensor (NO, CO, NH_3, CH_4)
- MAX31855 Thermocouple
- DS18B20 Thermistor
- BME280: Pressure/Temperature/Relative Humidity Sensor
- (External) ResponseONE Ultrasonic Anemometer



Controlled Burn – Plume Detection

Our site for this experiment was near the town of Winters, California.

We conducted a controlled burn of agricultural waste in a large area of land away from agricultural fields and human population.

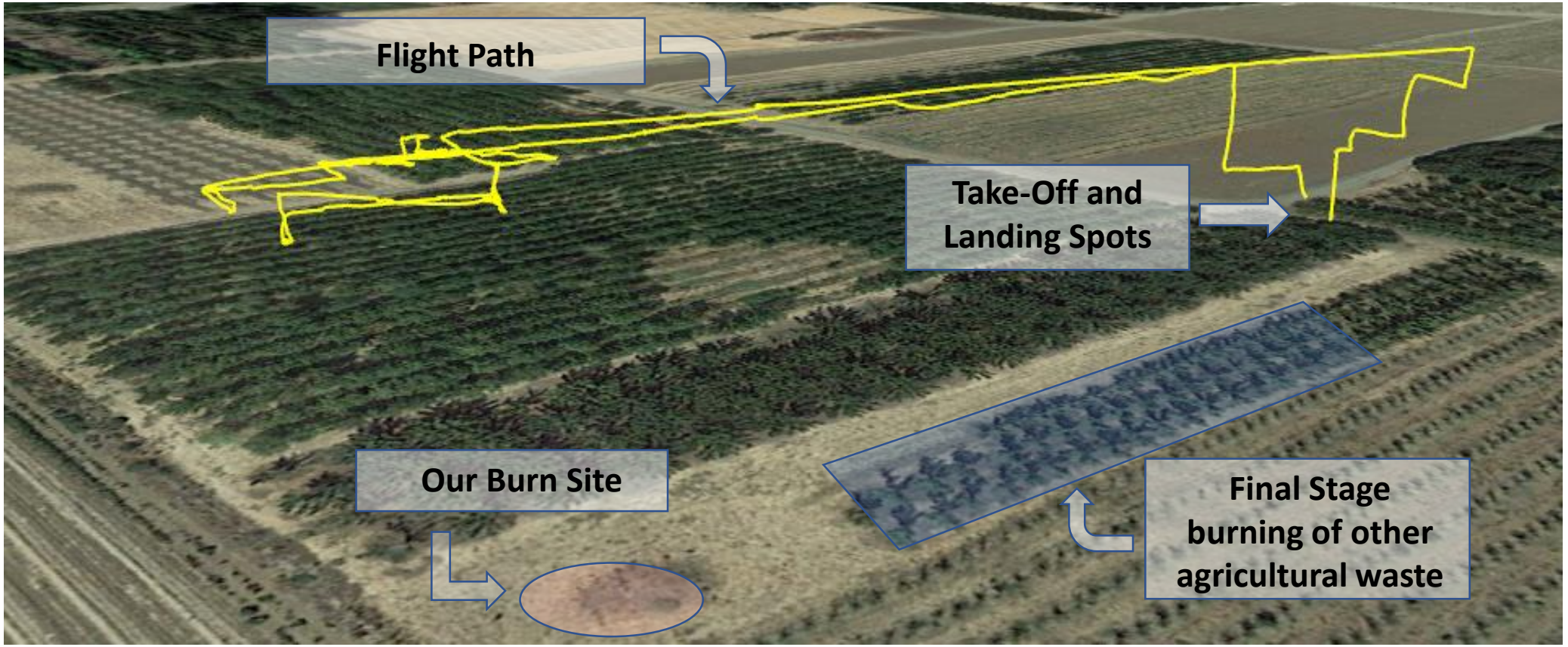
We flew the drone into the plume and tried to keep it centered at the smoke despite changing wind speeds and direction.

Smoke emission rate was also a very dynamic factor during our data collection.

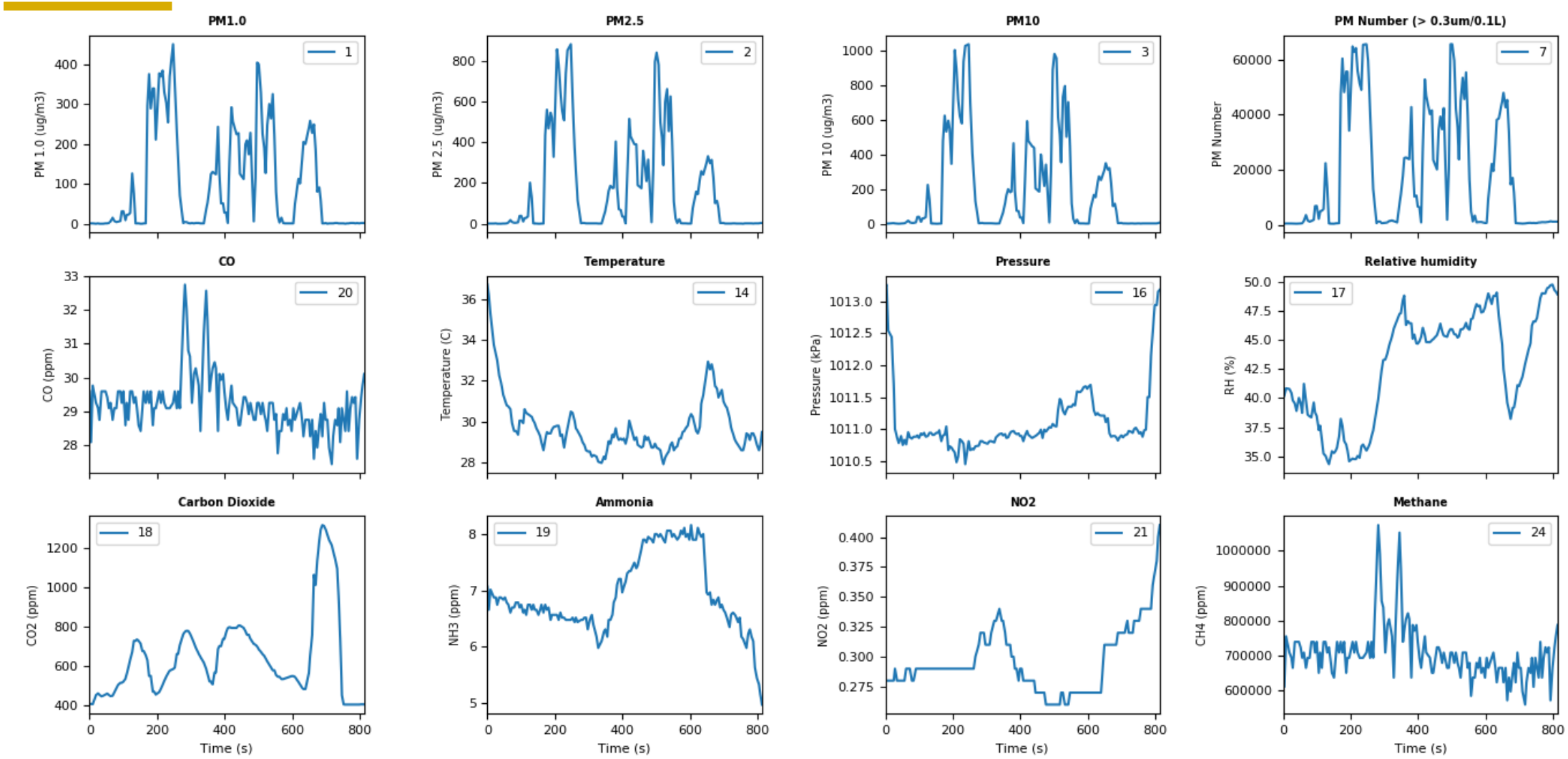
General Notes

- Since battery life of our drone was a limiting factor of the experiment, we collected the data in two sets during the burn:
  - Set 1 was collected as soon as the burn commenced.
  - Set 2 was collected once the battery from Set 1 had drained and replaced.
- In the following slides, the data is plotted against a common axis of time in seconds.
- Take-off and landing times of the drone can be inferred from the ‘Pressure’ sub-plot. Since Pressure and Altitude are inversely related, a decline in pressure corresponds to an increase in altitude and vice versa.

Set 1 Flight Path



Set 1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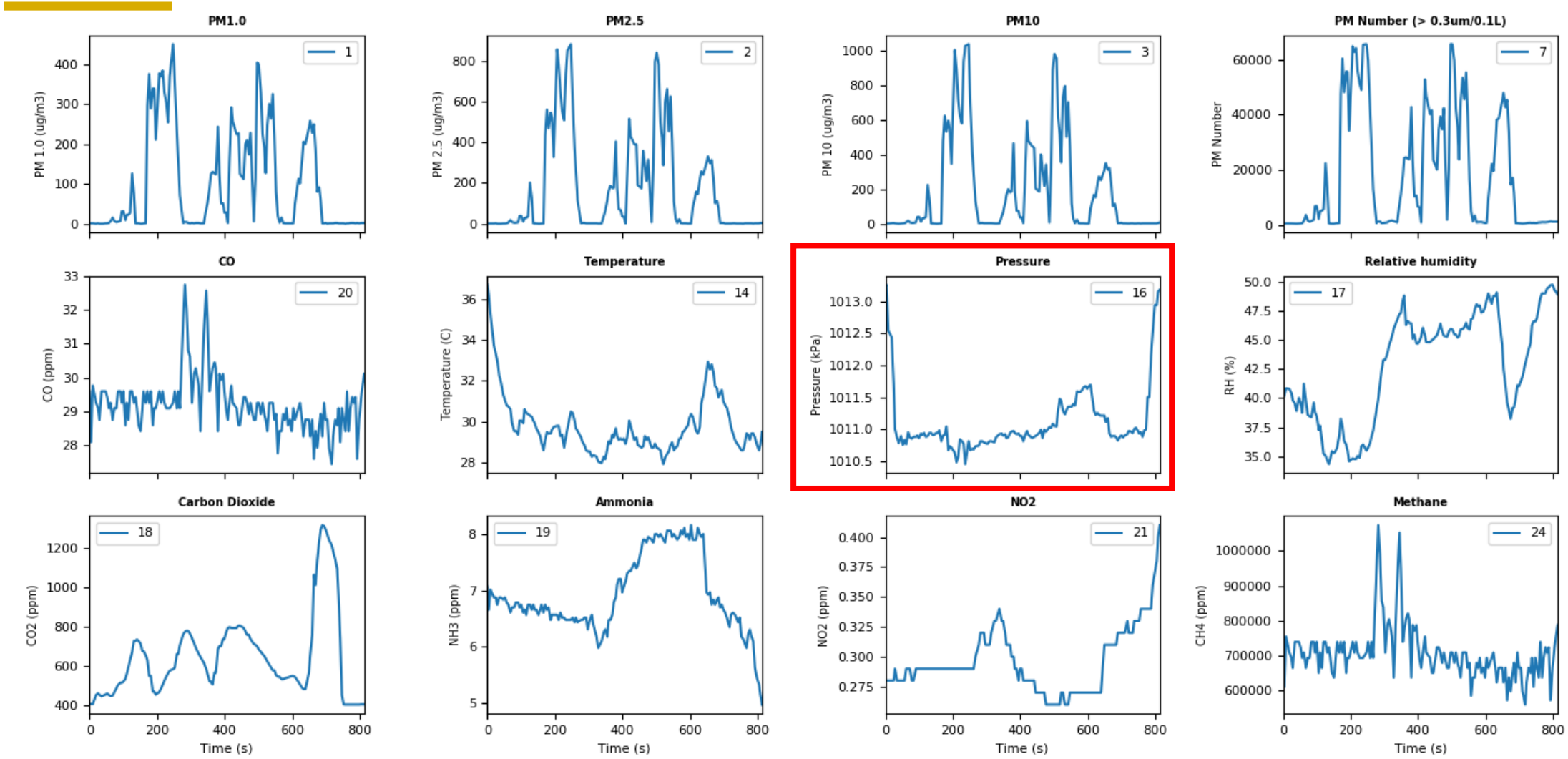
PM 1.0 (ug/m3)
1
PM2.5
PM 2.5 (ug/m3)
2
PM10
PM 10 (ug/m3)
3
PM Number (> 0.3um/0.1L)
PM Number
7
CO
CO (ppm)
20
Temperature
Temperature (C)
14
Pressure
Pressure (kPa)
16
Relative humidity
RH (%)
17
Carbon Dioxide
CO2 (ppm)
18
Ammonia
NH3 (ppm)
19
NO2
NO2 (ppm)
21
Methane
CH4 (ppm)
24
Time (s)

Set 1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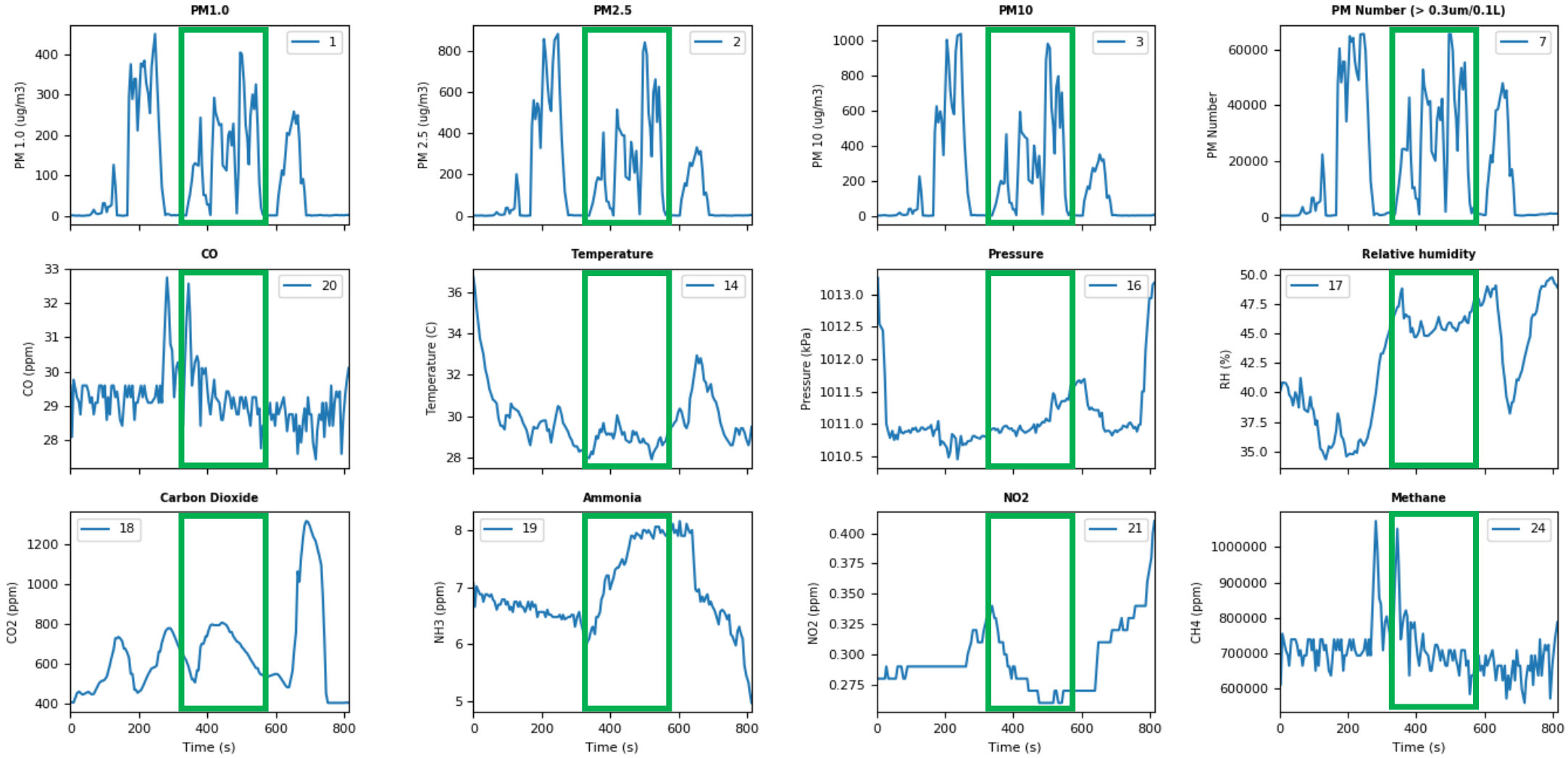
NO2 (ppm)
21
Methane
CH4 (ppm)
24
Time (s)

Set 1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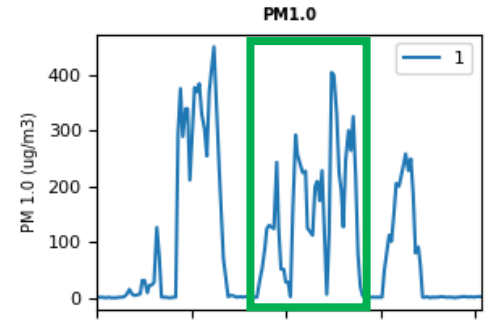
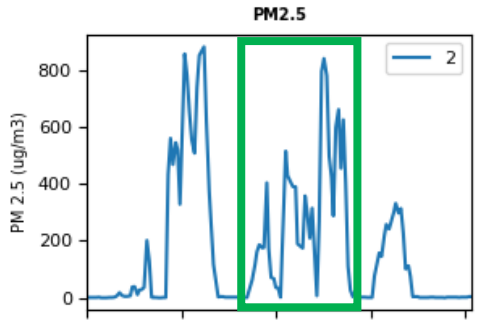
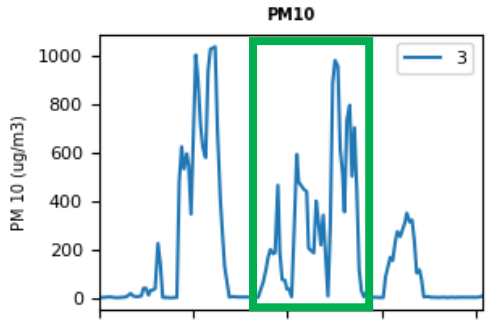
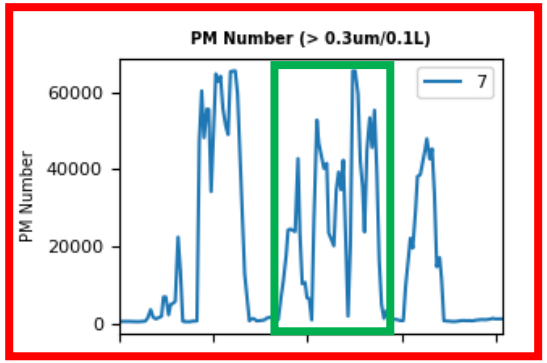
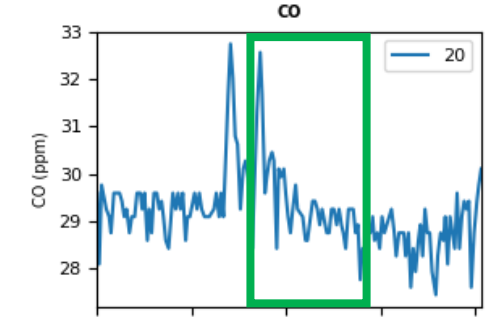
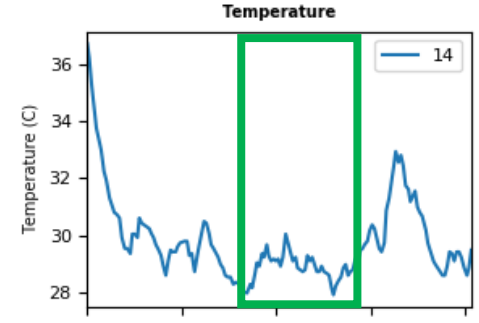


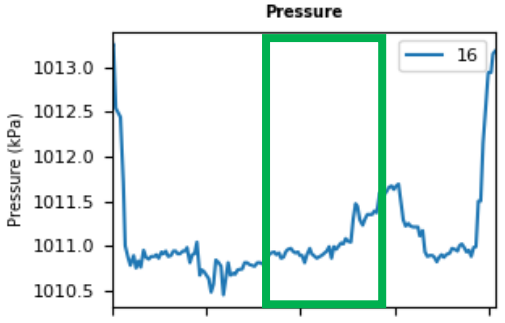


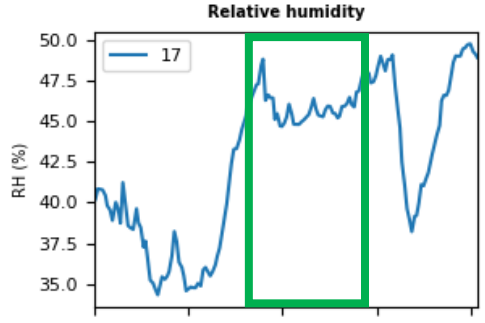


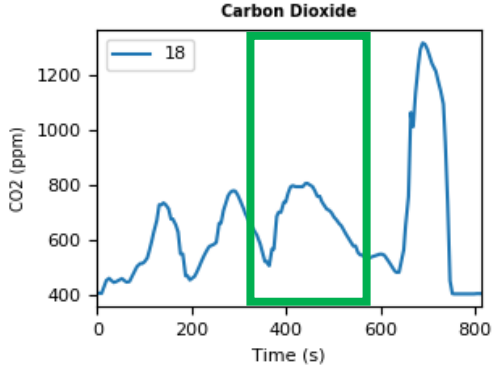


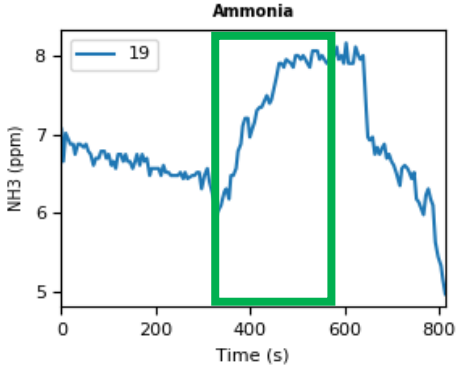


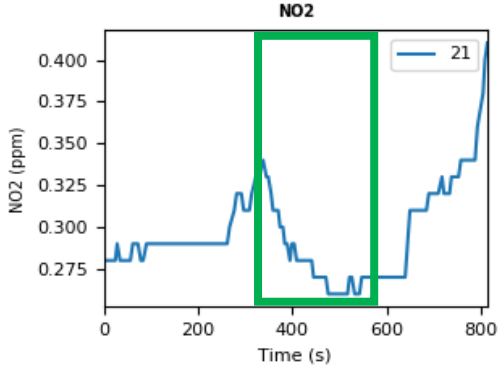


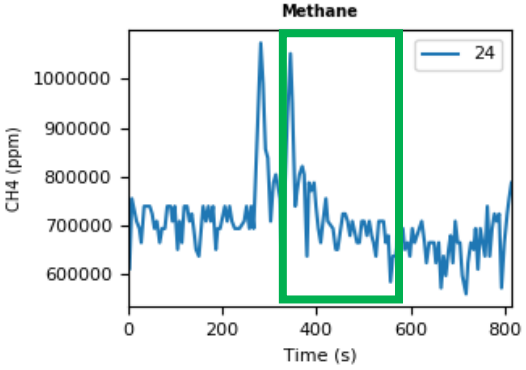






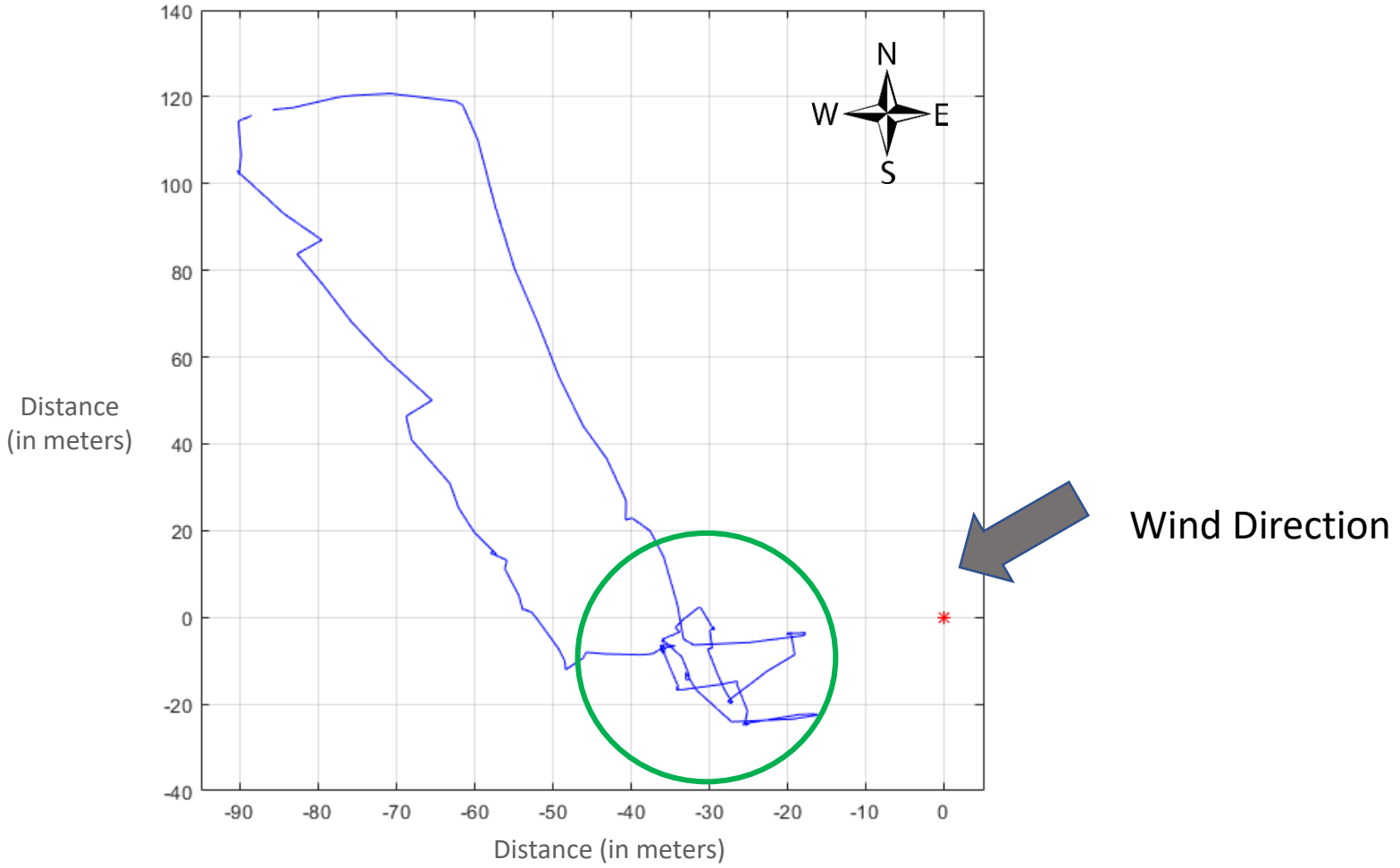




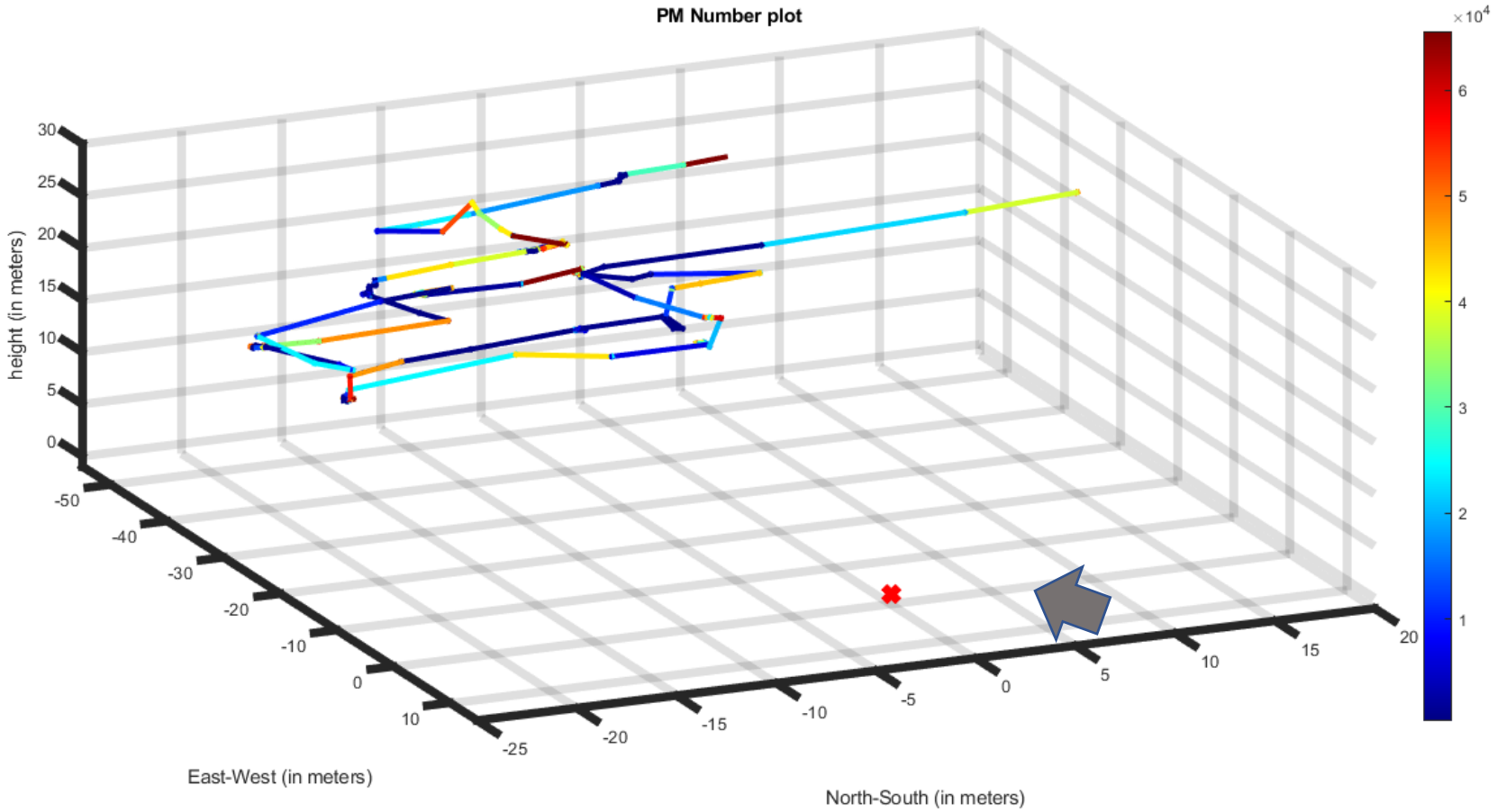


UCDAVIS

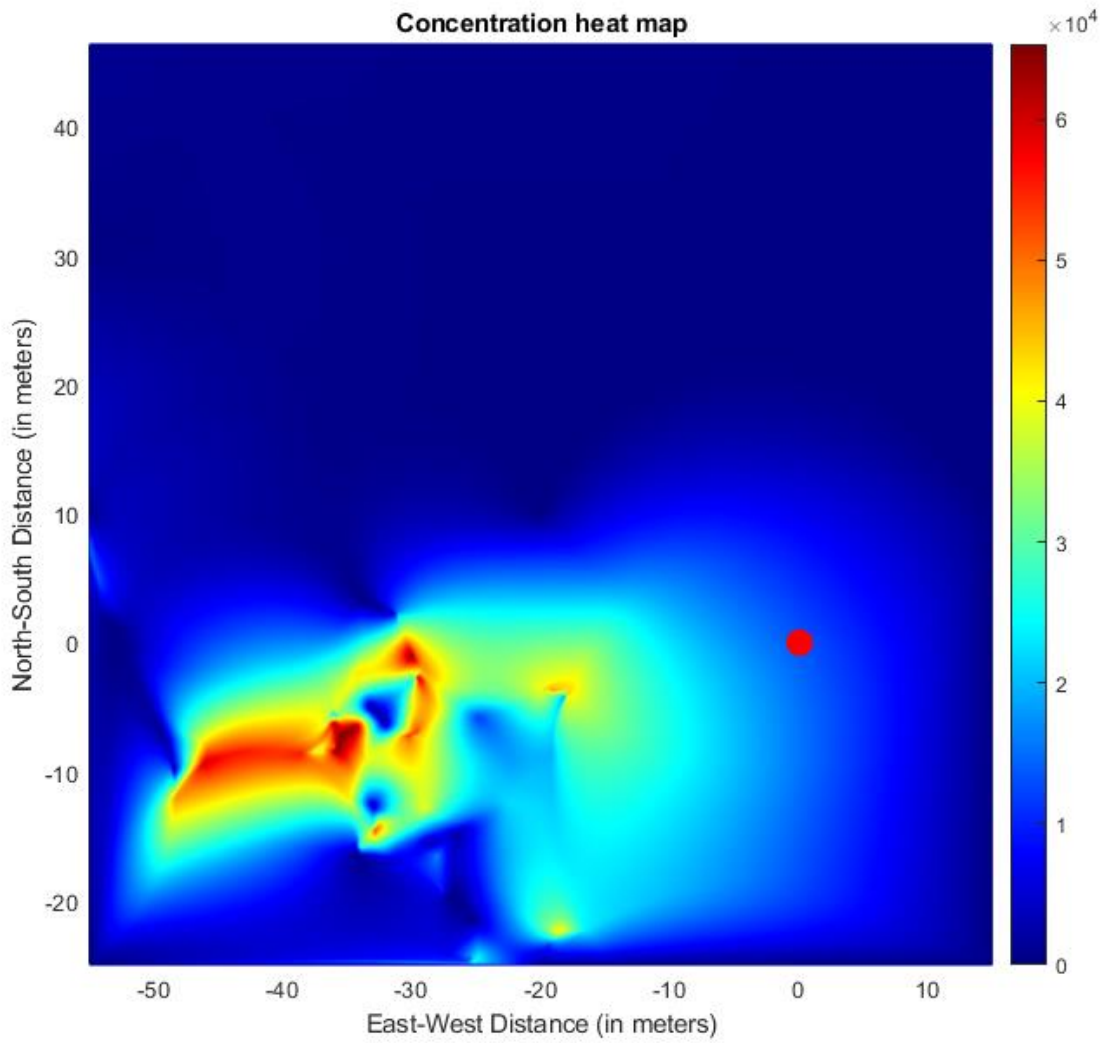
Set 1 2-D Path


Distance
(in meters)
140
120
100
80
60
40
20
0
-20
-40
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
Distance (in meters)
N
W
E
S
Wind Direction

Set 1 3-D


PM Number plot
height (in meters)
East-West (in meters)
North-South (in meters)
×10^4

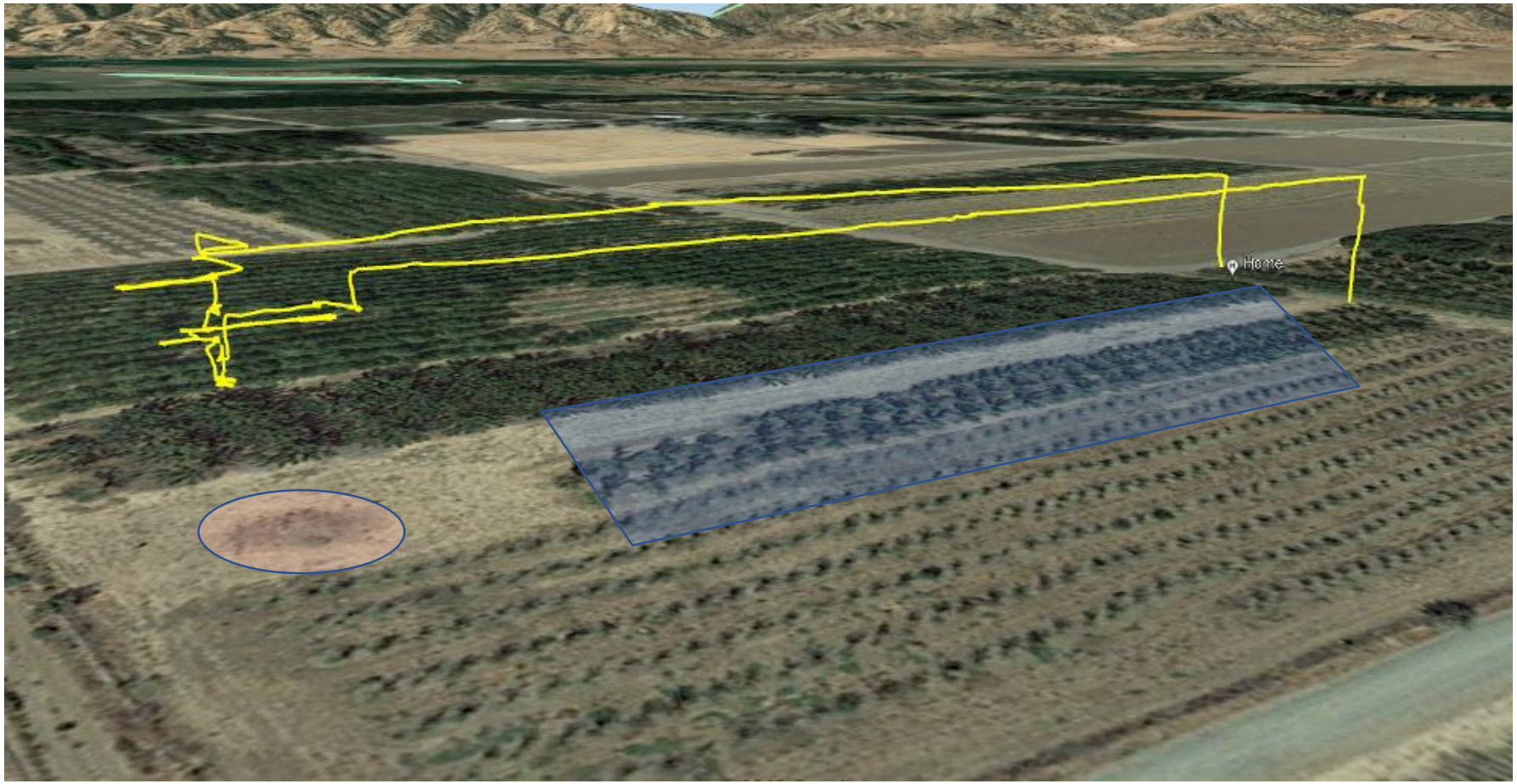
Set 1



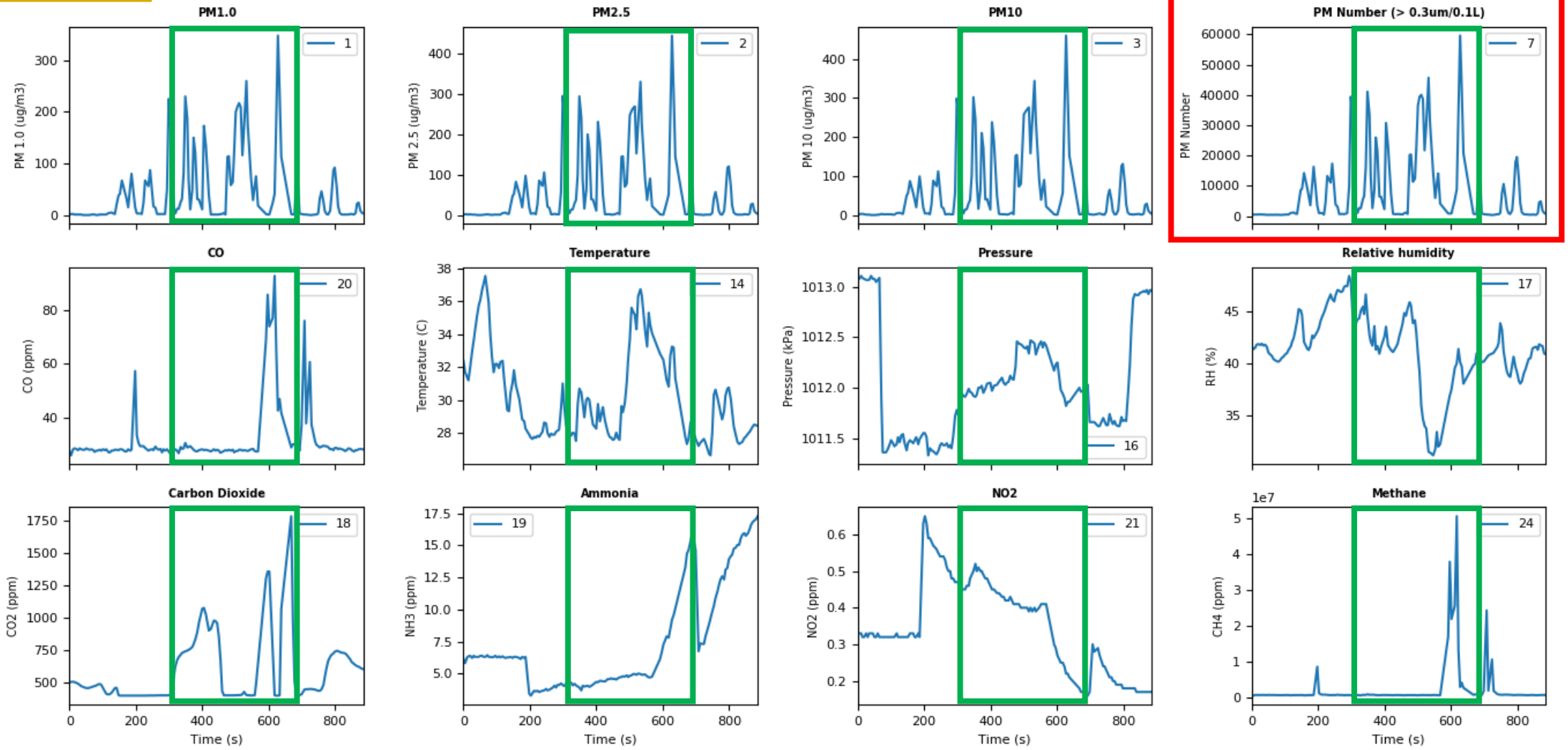
Wind Direction

Set 2

Set 2 Flight Path



Set 2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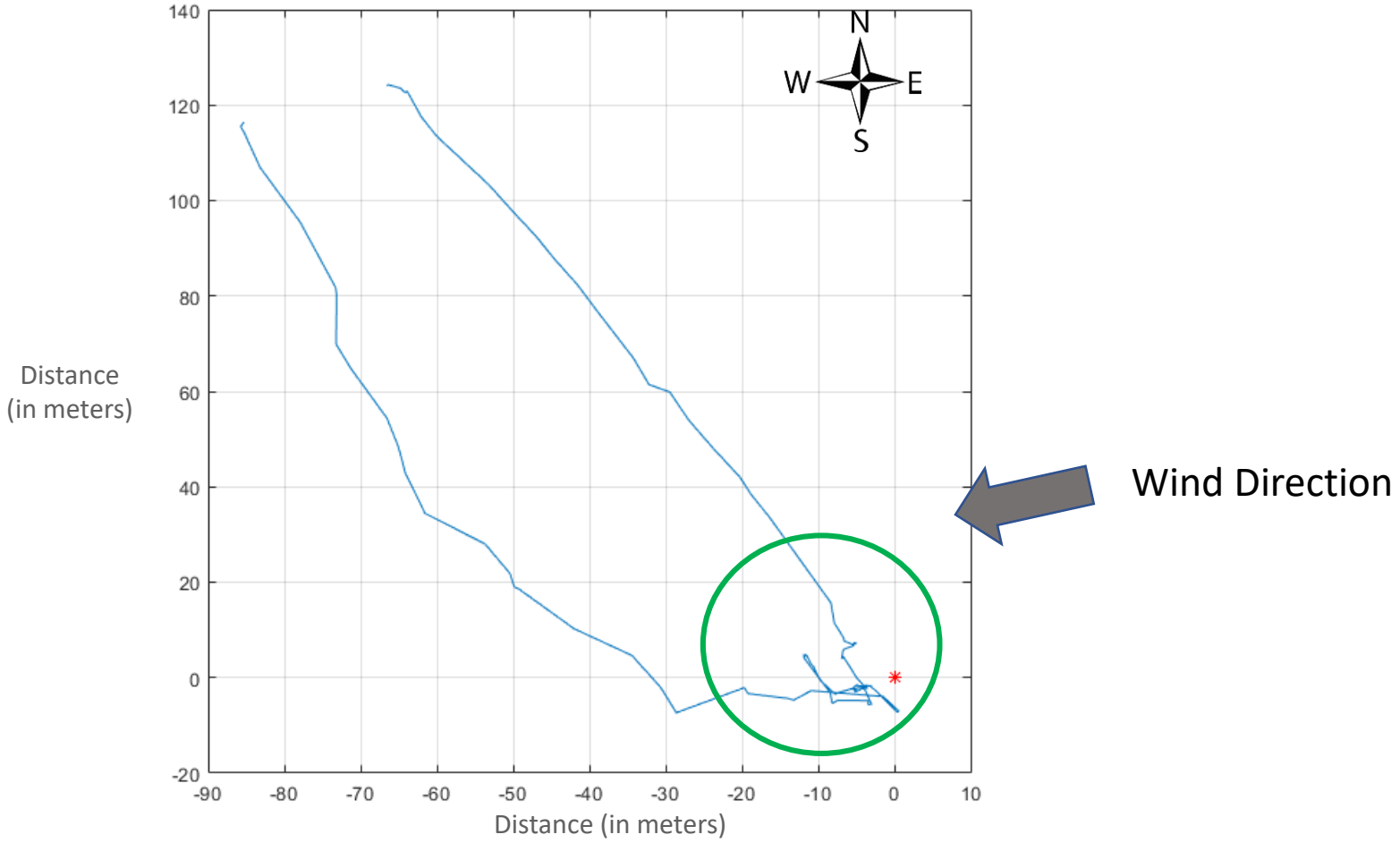
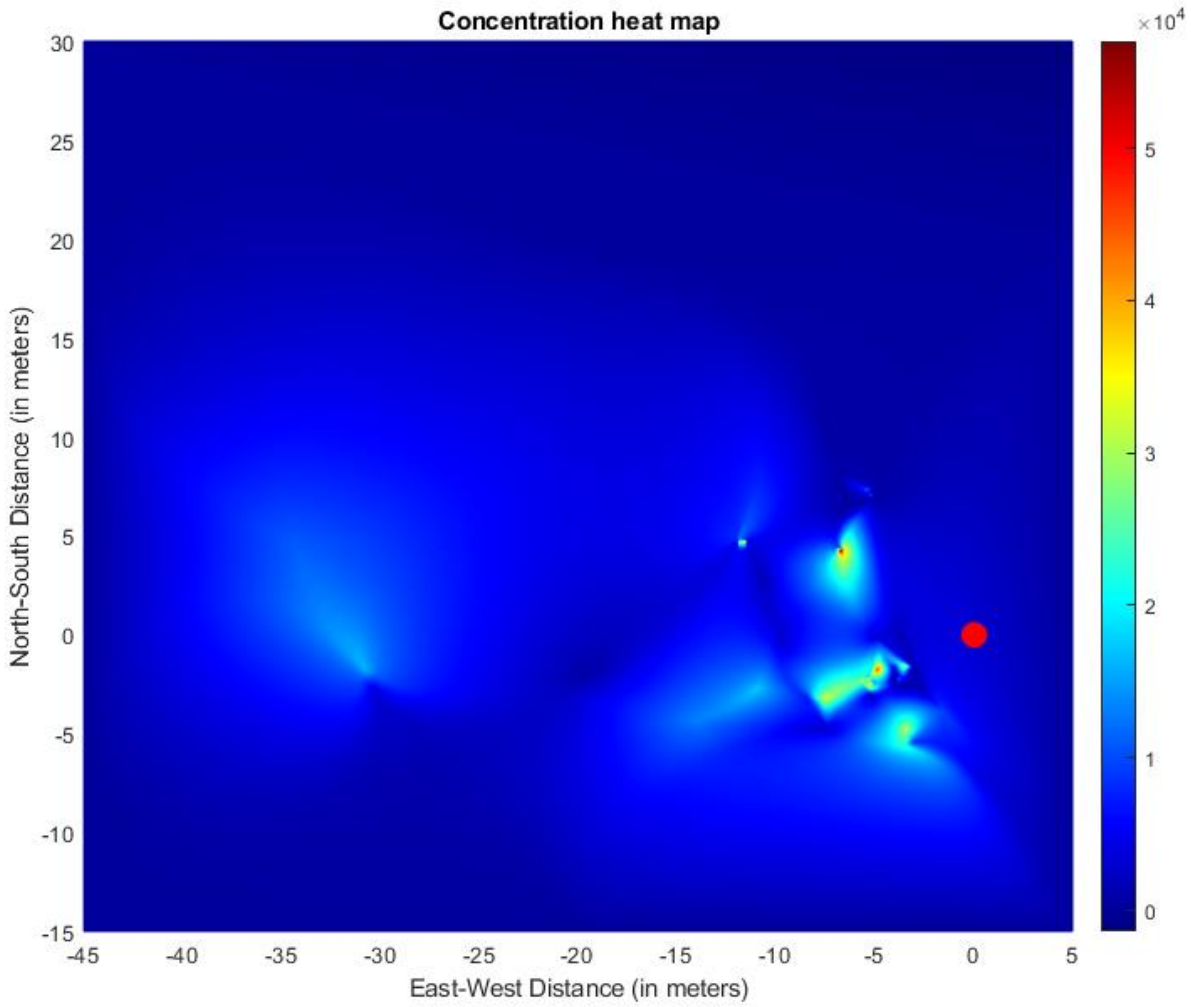
18
Ammonia
NH3 (ppm)
19
NO2
NO2 (ppm)
21
Methane
1e7
CH4 (ppm)
24
Time (s)

Set 2 2-D Path


Distance
(in meters)
140
120
100
80
60
40
20
0
-20
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
Distance (in meters)
N
W
E
S
Wind Direction

Set 2



Wind Direction

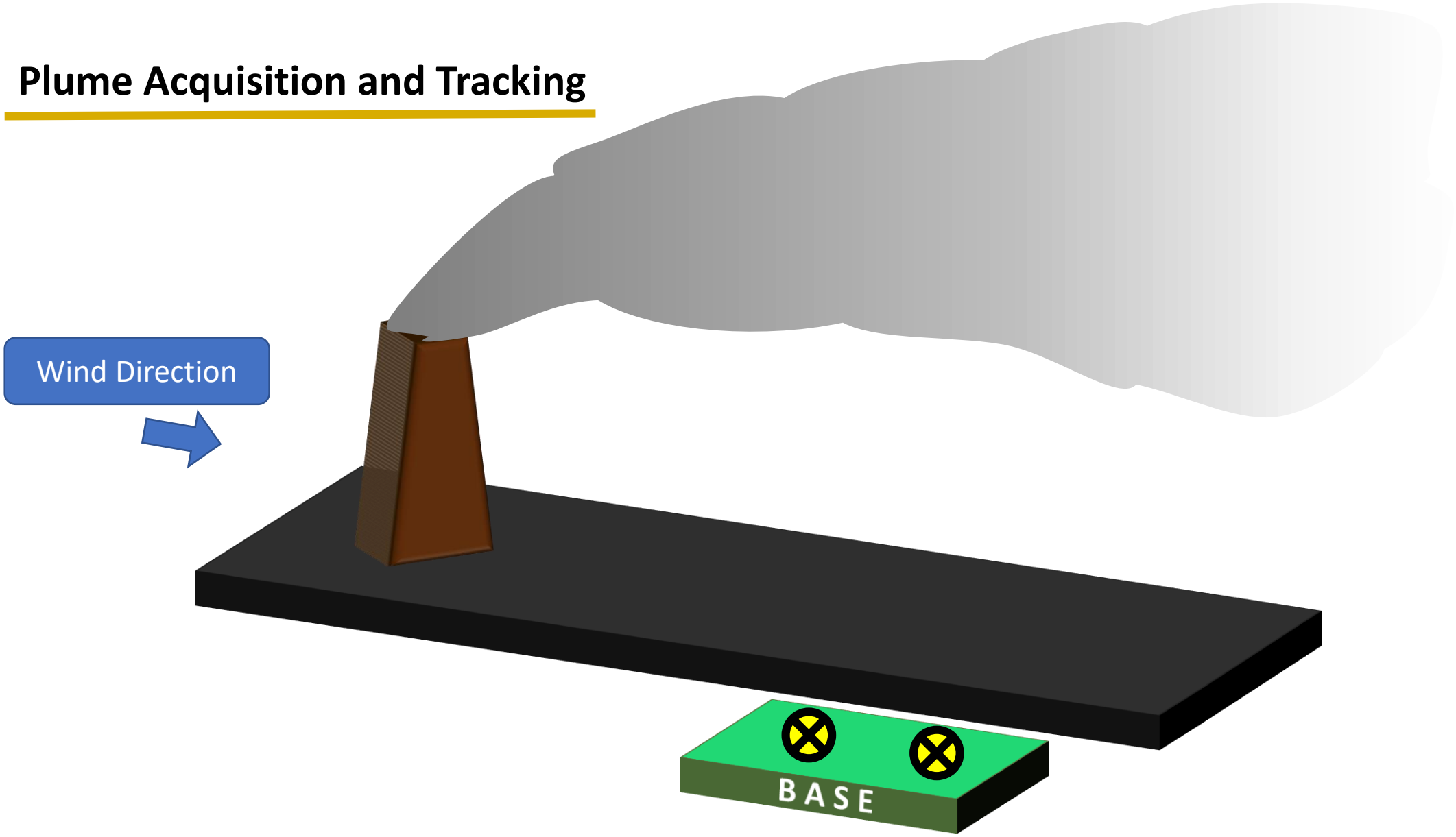
Conclusions/Limitations

- We flew our low-cost air quality package on a UAV and were able to detect plumes (visible and invisible).
- Our measurements are consistent with progressive stages (flaming and smoldering) of the fire.
- The series of experiments can be used to measure different chemicals in various plumes with the installation of an appropriate sensor package.
- Constraining Factors:
  - Lack of opportunities to conduct experiments
  - Flight Regulations

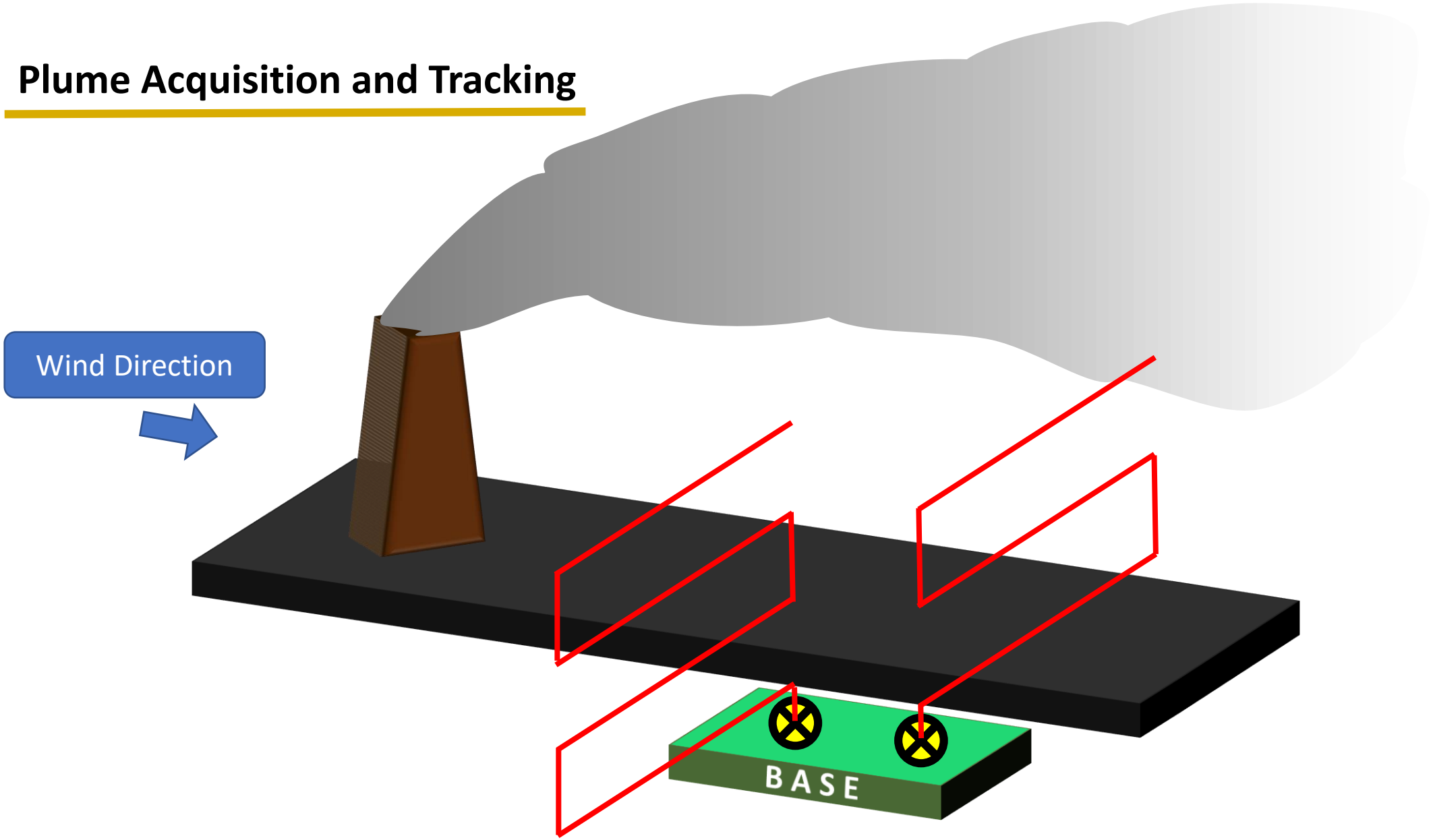
Work in Progress/Future

- Data collection tests in different sites
- Create a plume distribution map
- Plume model creation combining machine learning and first principles
- Implementing plume tracking in 3-D

Plume Acquisition and Tracking



Plume Acquisition and Tracking



Plume Acquisition and Tracking