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WASPP-Com: Integrating Real-Time Sensors and Wireless Control onto NCAR Air Quality Drone Sampling System

Nathan Bartley[1], Agbeli Ameko[2], Behrooz Roozitalab[3], Alan Hills[3], Rebecca Hornbrook[3], Eric Apel[3]

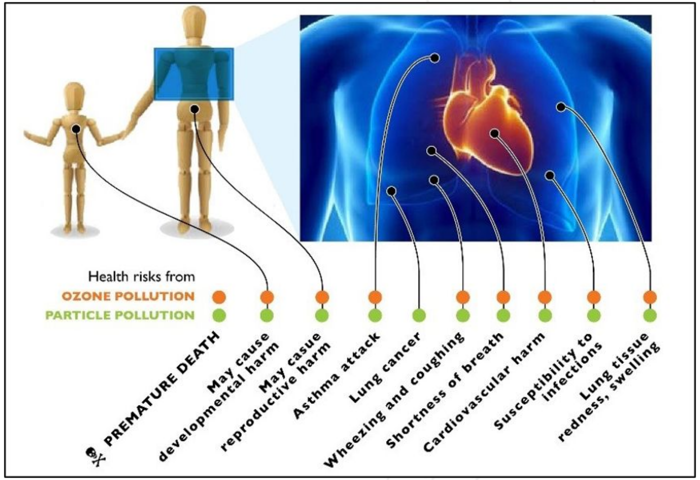
[1]SIParCS 2026 | Texas Tech ECE Graduate Student, [2]CISL, [3]ACOM

Air quality, particularly here on the Front Range is a major issue

The Front Range faces persistent air-quality challenges from **ground-level ozone** and **fine particulate matter**.

- **Health impacts:** Exposure can worsen respiratory and cardiovascular disease and is associated with adverse reproductive outcomes.
- **Vulnerable populations:** Children, older adults, and people with asthma or other pre-existing conditions face the greatest risk during high-pollution events.
- **Ozone concern:** Ozone levels often rise on hot, sunny days. Although invisible, ozone can damage the lungs and worsen chronic respiratory conditions.

Understanding these air-quality problems requires identifying the gases that drive ozone formation.



Picture: American Lung Association

VOCs: Ozone Precursors

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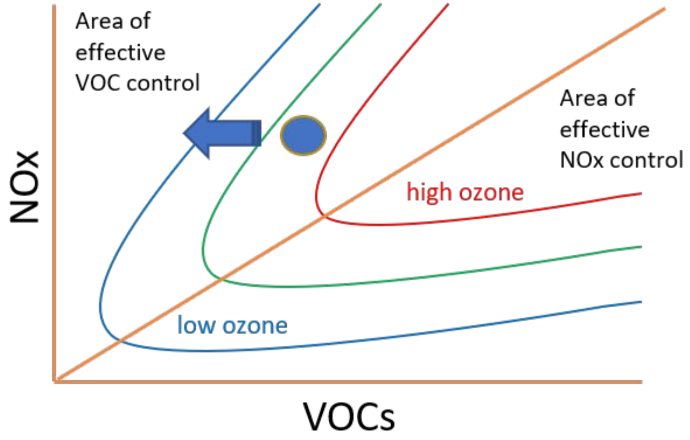
Volatile Organic Compounds

VOCs are a group of carbon-based chemicals from a wide range of sources, both natural and anthropogenic. These compounds severely degrade air quality by forming ozone and smog when combined with NO_X. Understanding VOC concentrations and sources facilitates diagnosis and mitigation of air quality issues



Data gap

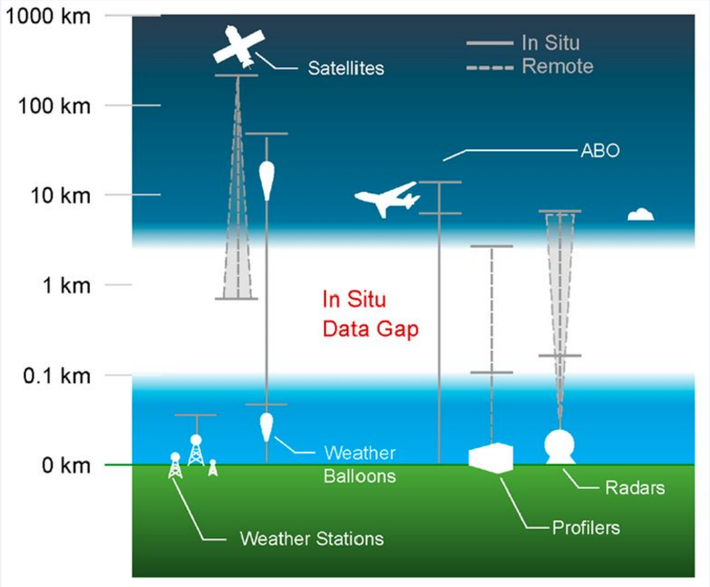
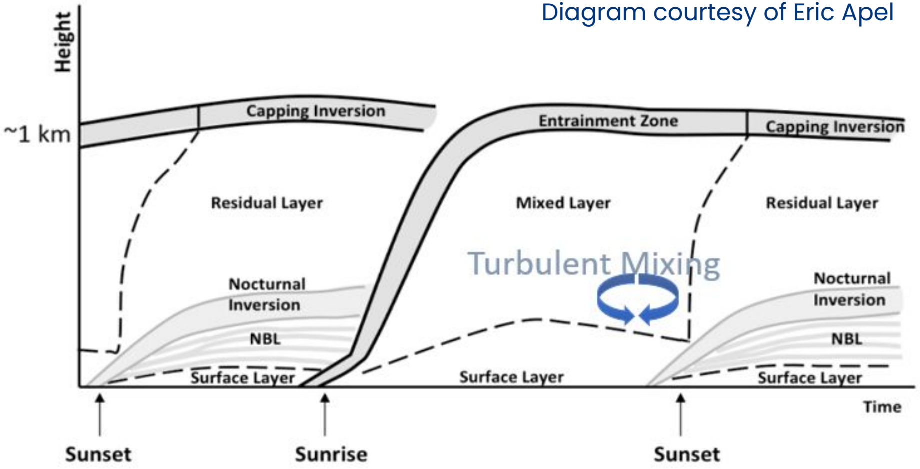


Diagram from Pinto, et. al.[1]

VOC Sampling

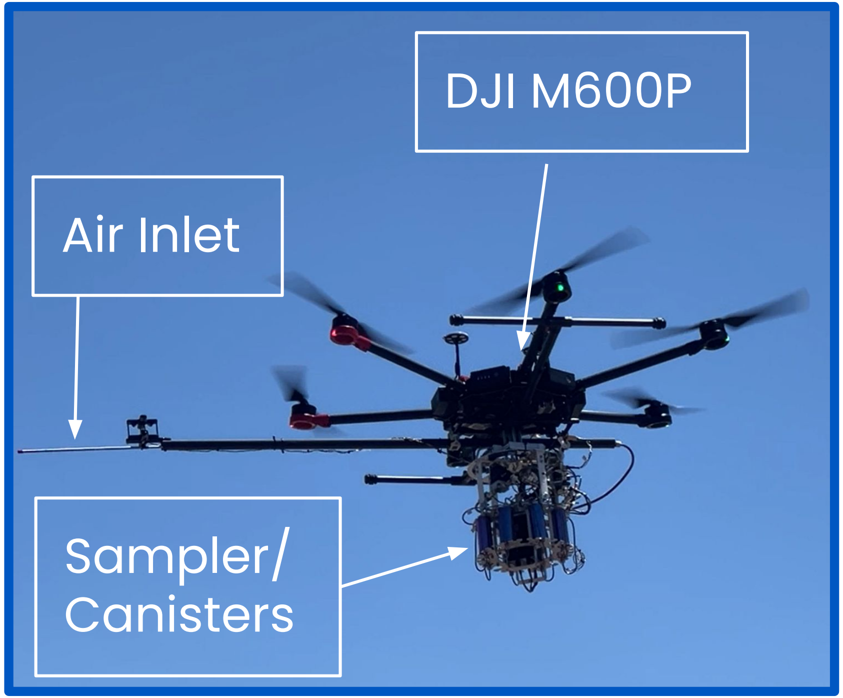
Traditional methods for in situ air sampling like balloons, towers, and aircraft fail to fully capture VOC behavior in the planetary boundary layer. Implementing UAS can help fill the the data gap

Diagram courtesy of Eric Apel



[1] Pinto, J. O., and Coauthors, 2021: The Status and Future of Small Uncrewed Aircraft Systems (UAS) in Operational Meteorology. *Bull. Amer. Meteor. Soc.*, **102**, E2121–E2136, https://doi.org/10.1175/BAMS-D-20-0138.1.

Whole Air Sampling Pilotless Platform (WASPP)



WASPP system during a demo flight

WASPP Advantages

- **Fills sampling gaps:** Collects boundary-layer VOC data not easily accessible by ground stations and crewed aircraft.
- **Measures in 3D:** Capable of sampling vertical and horizontal concentrations.
- **Lower cost & risk:** Accesses difficult or unsafe areas cheaper than traditional flights.
- **Targeted sampling:** Captures air directly near pollution sources, plumes, and inversions.
- **Lab-quality analysis:** Preserves whole-air samples for detailed VOC analysis via TOGA.

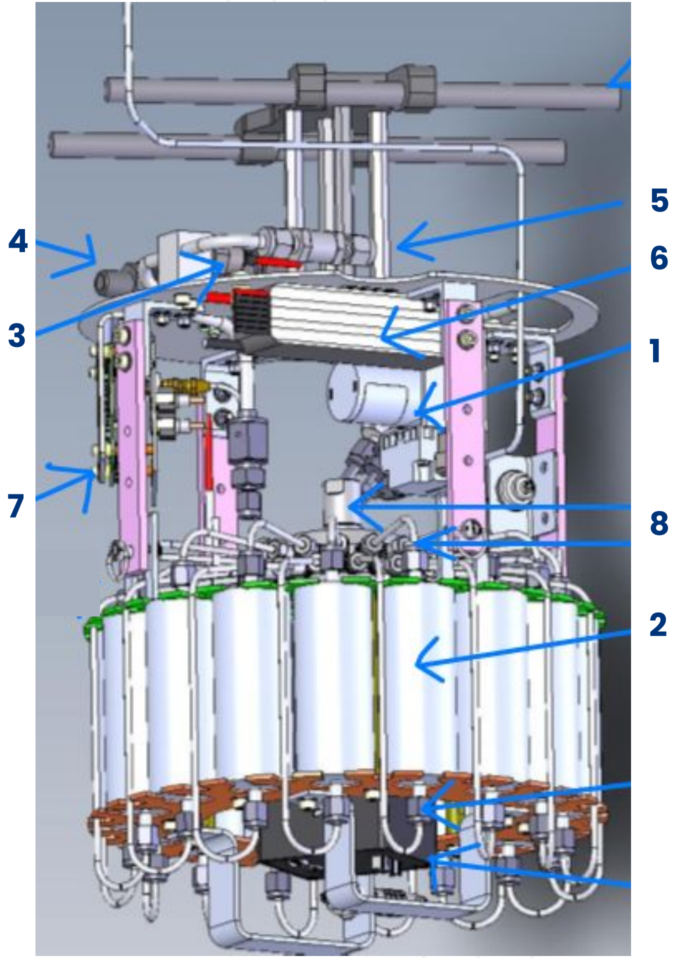
[1] Asher, E.; Hills, A. J.; Hornbrook, R. S.; Shertz, S.; Gabbard, S.; Stephens, B. B.; Helmig, D.; Apel, E. C. Unpiloted Aircraft System Instrument for the Rapid Collection of Whole Air Samples and Measurements for Environmental Monitoring and Air Quality Studies. Environ. Sci. Technol. 2021, 55, 5657– 5667, DOI: 10.1021/acs.est.0c07213

Base System Components

1. **Air Pump:** Draws external air from the inlet into the canisters.
2. **100 mL Canisters:** Cleanly hold air samples for testing
3. **Pressure Sensors:** Ambient and system pressure sensors. Indicates canister pressure levels
4. **Flow Meter:** indicates if canister has reached target pressure
5. **Check Valve:** Lets air flow once canister pressure has reached desired PSI
6. **22V LiPo Battery:** Powers computer and components, separate from drone pwr
7. **Computer:** Raspberry Pi 2 with PCB attachment that controls the system
8. **Valco Valve:** Cleanly alters flow path between pressurized canisters

Limitations:

- **Fully autonomous:** Samples triggered by altitude
- **No operator control:** Limited use cases
- **Sampling Hard Coded:** Altering sampling altitudes required changing the code



WAS Sampling

Sampling Sequence

1: During flight, controller receives signal to begin sampling sequence.
2: Sensors log baseline data (pressure, GPS, system status, wind speed, and more).
3: Pump flushes the next empty canister, then fills it with a new air sample, with the valve turning to the next empty slot after.
4: Process repeats for up to 8 separate air samples during a single flight.
5: Back on the ground, the air samples are analyzed using TOGA

Valve Flow Path

16-port Valco valve routing air samples to individual canisters.

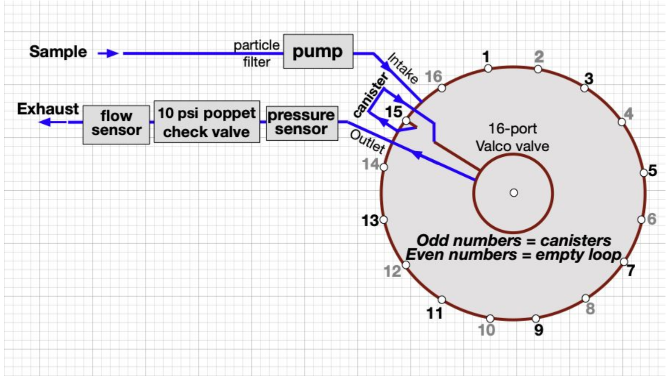
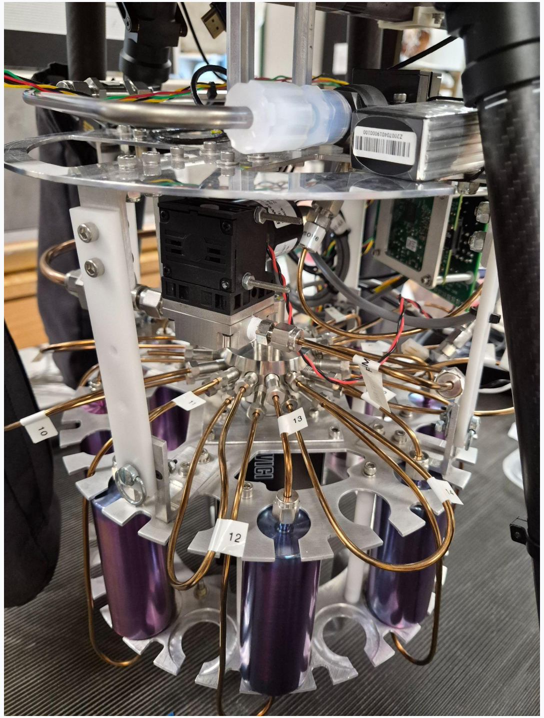


Diagram Courtesy of Daun Jeong

System Hardware



Limitations of the Original WASPP System

Fully Autonomous Sampling

- Sampling followed a pre-programmed sequence
- Limited ability to adjust timing or altitude during real flight conditions
- This limits applications to only vertical sampling at set altitudes

Limited Operator Control

- Pilot could not manually trigger or delay sampling from the ground
- Pilot only controls drone platform, not sampler
- Difficult to respond to changing plume location, wind, or field conditions.

Low System Awareness

- No real-time view of pump, valve, pressure, battery, GPS, or sample status
- Problems could go unnoticed until after landing
- No understanding of air quality or chemistry prior to sample

My project was to address these issues by implementing wireless control and live telemetry for the Pilot

Solution: Wireless Communication

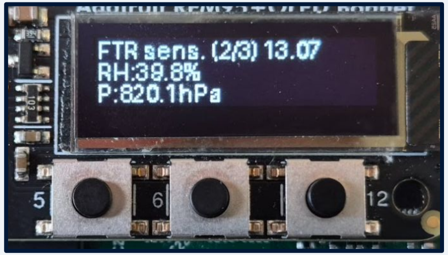
Base Station

Send Commands

A. Take Sample
B. Read Status
C. Sensors

Receive Telemetry

Real-time sensor data stream from WASPP components



LoRa

Wireless Link

WASPP

Wireless Relay

(RP2040 Feather)

- Acts as relay for wireless commands to the Sampling Controller
- Transmits auxiliary sensor data to Base Station for informed sampling

USB

WAS Controller

(RPi 2 with PCB board)

- Handles air sampling process
- Sends status updates and logs key data for post-flight VOC comparison

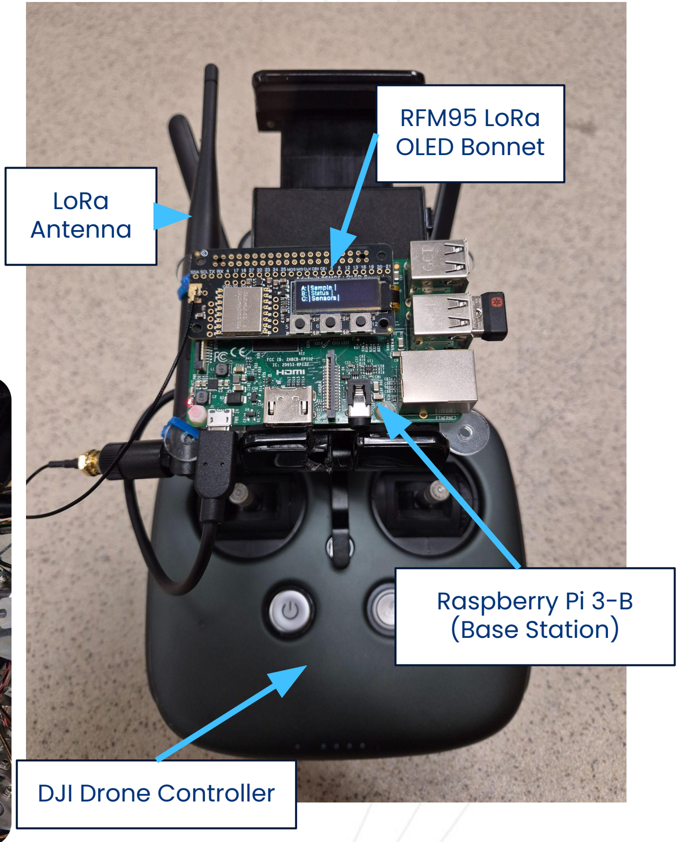
Wireless Hardware

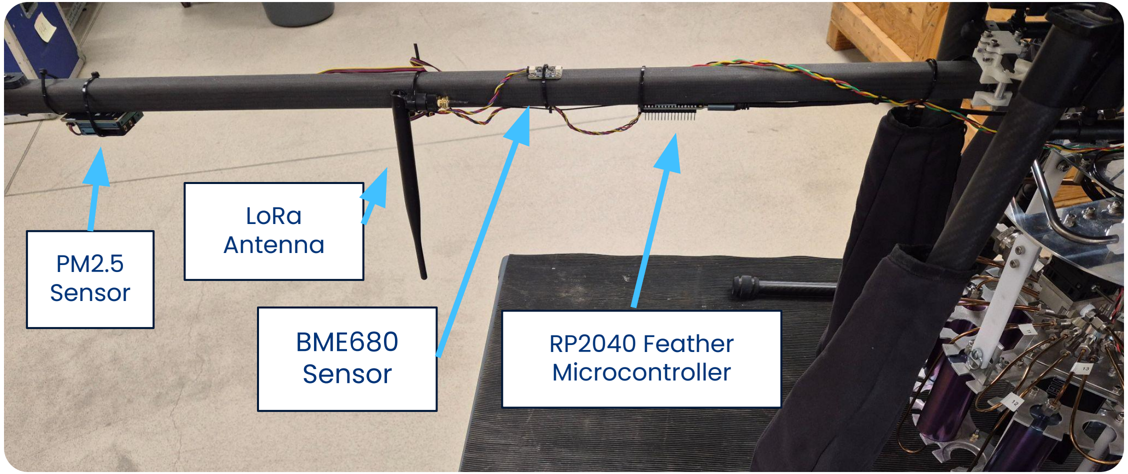
Relay and Sensors

- RP2040 Feather acts as LoRa (long range) radio relay between base station and sampler
- BME680 and PM2.5 additions provide valuable data in real time.

Base Station

- RPi 3 with LoRa OLED Bonnet
- Portable control of the sampling component
- View Live sensor data
- Trigger sampling sequence





Wireless Network and Packet Structure

Base Station
Raspberry Pi 3 with RFM95 LoRa OLED Bonnet

915 MHz LoRa

RP2040 Feather Relay
Onboard wireless relay and environmental sensor interface

Relay through Feather

Drone Pi Sampling Controller
Raspberry Pi 2 controlling pump, valve, and sampling hardware

CMD — Command

Sent from Base Station

`sys, t, sid, to, seq, cmd`

Used for:

- take_sample
- pi_status
- live_start

ACK — Acknowledgment

Confirms command receipt

`sys, t, sid, seq, cmd, ok, msg`

Reports success, failure, or timeout-related information from the drone controller.

SENSOR — Live Data

Generated by RP2040

`temp, hum, press, gas, pm25...`

Streams environmental measurements:

- BME680 gas/met metrics
- PM2.5 particulates
- UV & ambient light

STT — System Status

Drone Pi telemetry

`gps_t, lat, lon, alt, battery, state...`

Critical flight states:

- GPS loc & sat count
- Pump/valve configuration
- Battery, pressure & flow

Network Features

• JSON-formatted packets • Sequence number command-ACK pairing • Bidirectional communication • 100% offline local operation • Live telemetry awareness

Field Measurements

WASPP Flight Test & VOC Data Collection

Strategic Collaboration

Partnered with ACOM, EOL, and Colorado State University at Christman Airfield (Fort Collins) to capture real VOC data.

Vertical Mapping

Sampled atmospheric composition from ground level up to 200 feet Above Ground Level (AGL) for precise vertical profiling. Sampled every 50 ft. during ascent and descent

Proof of Concept Testing

This expedition provided promising results for the new wireless sampling control and live telemetry additions. Sampling controls behaved as expected and sensor data displayed on the base station provided useful real-time data for informed sampling

Video from Lewis Groswald

Extraction and TOGA-TOF Analysis

WASPP Canister
Whole-Air Sample

→

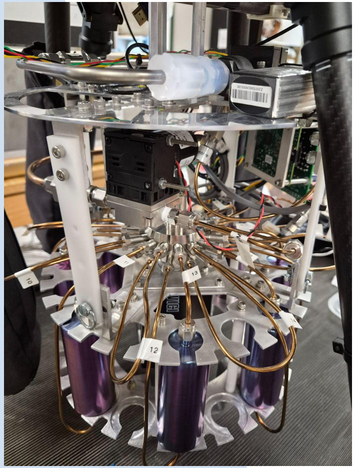
Extraction System
Transfer from Canisters to TOGA-TOF

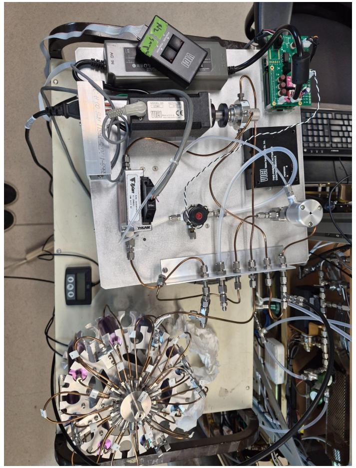
→

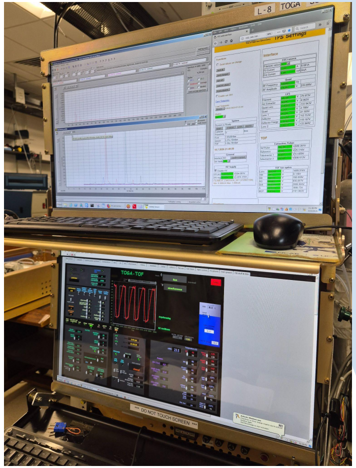
TOGA-TOF
Gas Chromatography Time of Flight detection of compounds

→

VOC Concentrations
Final Data







This process turns airborne samples into VOC compound concentration data for evaluating atmospheric composition and sample consistency.

Preliminary Extraction Results

Broad Chemical Detection

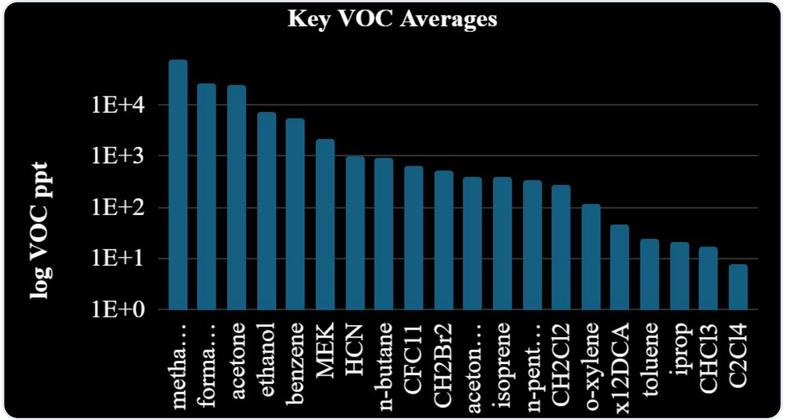
- TOGA-TOF identified **nearly 80 VOC species**
- Included anthropogenic, biogenic, biomass-burning, and oxidation compounds
- Detection alone does not indicate hazardous exposure

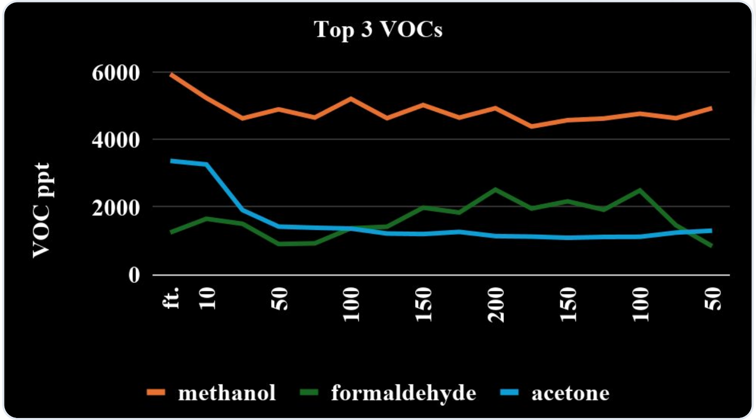
Source & Chemistry Indicators

- **CH_2Cl_2:** anthropogenic emissions
- **Isoprene:** biogenic emissions
- **Acetonitrile:** biomass-burning tracer
- **Formaldehyde:** key ozone formation indicator

Vertical Profile Findings

- Daytime convection created a **well-mixed boundary layer**
- Clear vertical gradients were difficult to detect
- Methanol and acetone were generally higher near the ground





Conclusion

Wireless Command & Telemetry
Wireless command and telemetry were successfully integrated.

Field Testing Success
Real whole-air samples were collected during field testing.

VOC Identification
TOGA-TOF identified a broad range of VOCs.

Atmospheric Mixing
Atmospheric mixing limited the observed vertical gradients.

Future Flights
Future flights should target more stable conditions to resolve vertical gradients.

Future Work

Furthering UAS application in atmospheric research

Wireless Component Housing

Design and fabricate secure housings for sensors and loose wireless components.

Low Cost Sensor Calibration

Use WASPP to calibrate low cost sensors by comparison with ground and tower systems.

Upgrade Flight Platform

Enhance drone capabilities for increased flight time, stability, and payload capacity.

UAS-Equipped Sensor & Mesonet Integration

Adapt sensors for Mesonet weather stations and integrate atmospheric data with GDEX.

Photo from Lewis Groswald

Questions?

Thank you for your time and attention.