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

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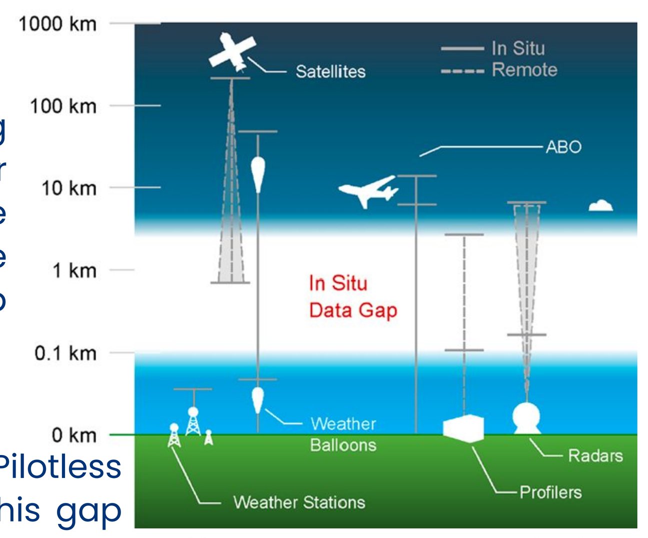
1. Introduction

VOC Sampling

Volatile Organic Compounds (VOCs) are a group of carbon-based chemicals from a wide range of sources, both natural and anthropogenic. These compounds contribute significantly to atmospheric chemistry, affect air quality (e.g., ozone and smog) and human health.



[1] Figure adapted from Pinto et al., (2021)

Traditional Methods

Traditional methods of VOC sampling include fixed stations on the ground or attached to towers, balloons, or large aircraft. Each of these methods provide valuable insights, but leave a large gap for planetary boundary layer data.

Solution

The WASPP (Whole Air Sampling Pilotless Platform) [2] drone system addresses this gap by taking air samples in situ. The samples are then analyzed by the state of the art TOGA-TOF (Trace Organic Gas Analyzer - Time of Flight) [3] gas spectrometry system. In this project, we improved its capabilities by integrating a real-time communication system and low cost sensors reading to the WASPP system.

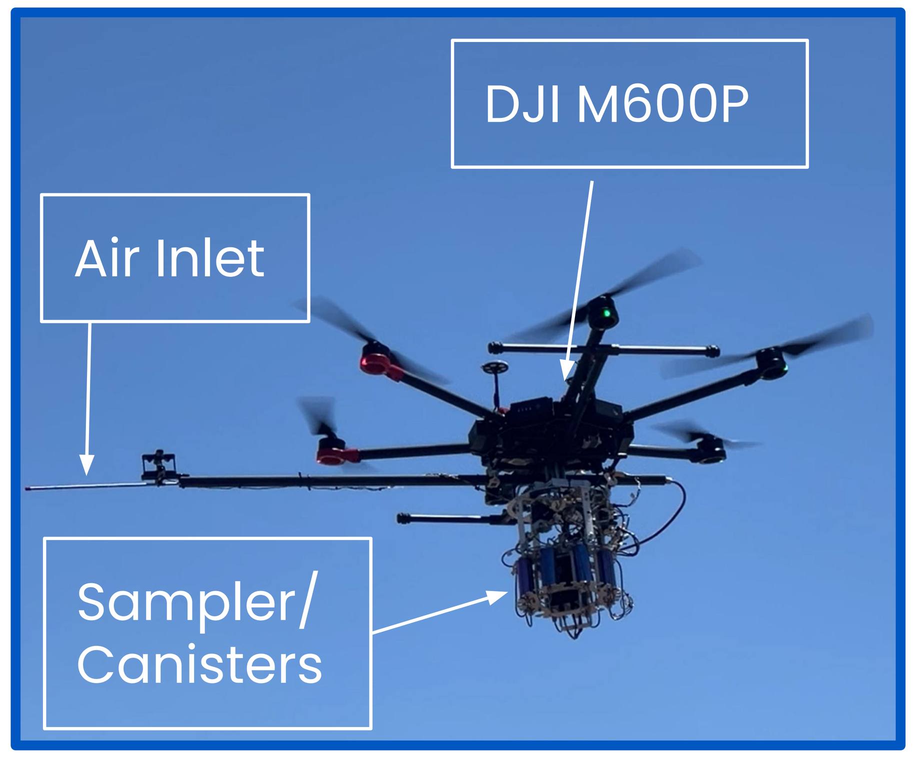
2. WASPP

Whole Air Sampling Pilotless Platform

Ground stations cannot measure how VOC concentrations change with altitude, while crewed aircraft are costly and difficult to deploy for small, targeted studies. WASPP bridges this gap by carrying an automated whole-air sampling system on a DJI Matrice 600 Pro (M600P).

What WASPP Enables

- Samples at selected altitudes, locations, and atmospheric conditions
- Captures **vertical VOC profiles** within the planetary boundary layer
- Reaches areas that are difficult or unsafe for ground crews
- Collects up to 15 separate whole-air samples per flight
- Preserves samples for detailed laboratory analysis by **TOGA-TOF**

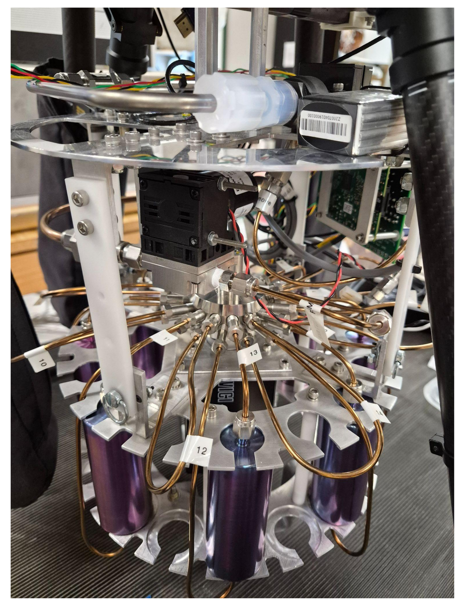


3. VOC Analysis Ecosystem

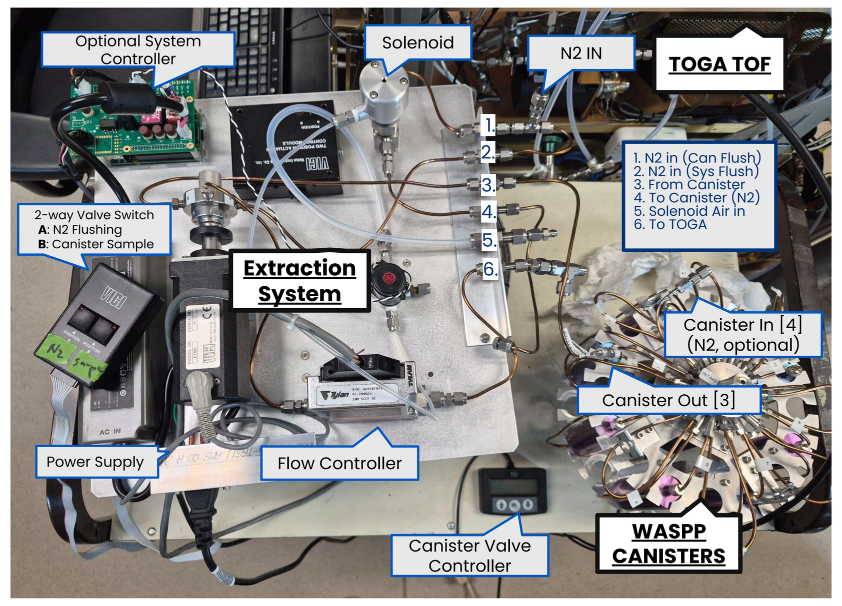
Extraction and Analysis Process

Whole-air samples collected in WASPP canisters are processed through a controlled extraction system that transfers captured volatile organic compounds to the TOGA-TOF instrument for analysis. Valve control, regulated gas flow, and canister flushing help standardize each extraction, while time-of-flight mass spectrometry enables rapid identification and quantification of a broad range of VOCs. This workflow connects airborne sampling with laboratory chemical analysis to characterize atmospheric composition and evaluate sample consistency.

WASPP Canisters



Extraction System



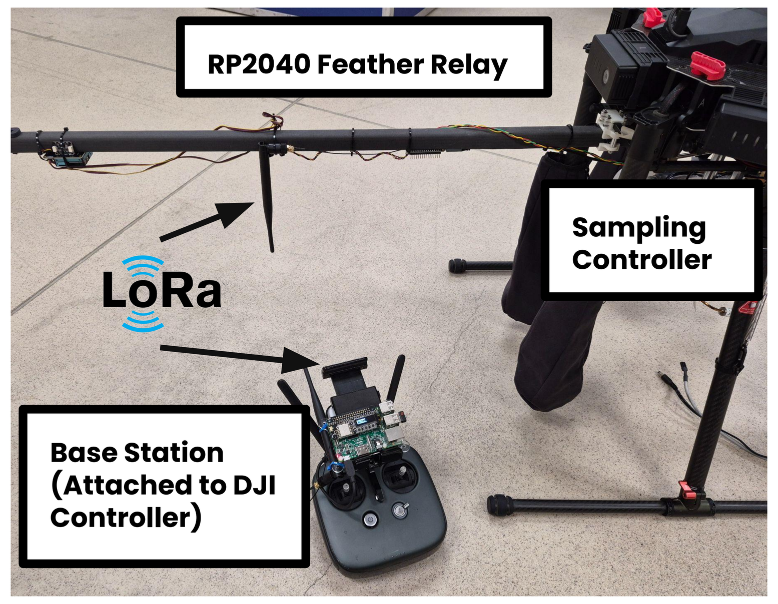
TOGA-TOF

4. Sensor and Wireless Upgrades

LoRa Network Setup

To improve sampling accuracy and operator awareness, we upgraded WASPP with a bidirectional 915 MHz LoRa (long range) radio communication link between a Raspberry Pi 3 base station and an added onboard RP2040 Feather relay.

- Sends commands for sample collection, status requests, and live sensor streaming
- Relays commands from the Feather to the Raspberry Pi 2 sampling controller over USB serial
- Returns valve position, pump state, flow rate, pressures, battery voltage, GPS data, and sampling progress
- Integrates BME680 and $PM_{2.5}$ (and potentially other sensors) for real-time environmental telemetry



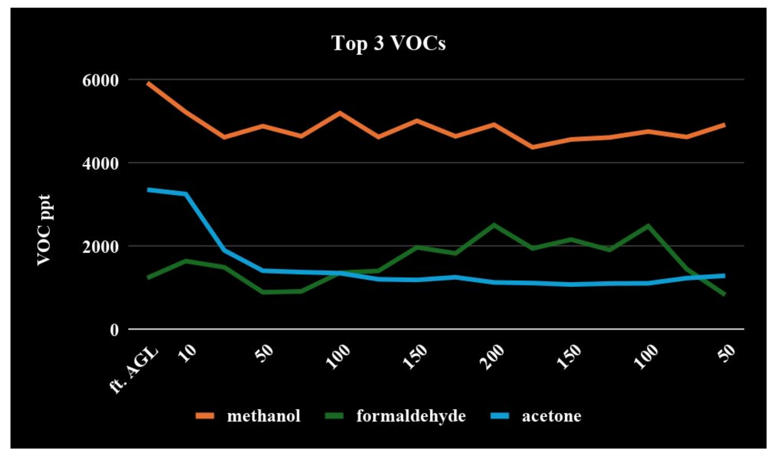
LoRa Packet Design

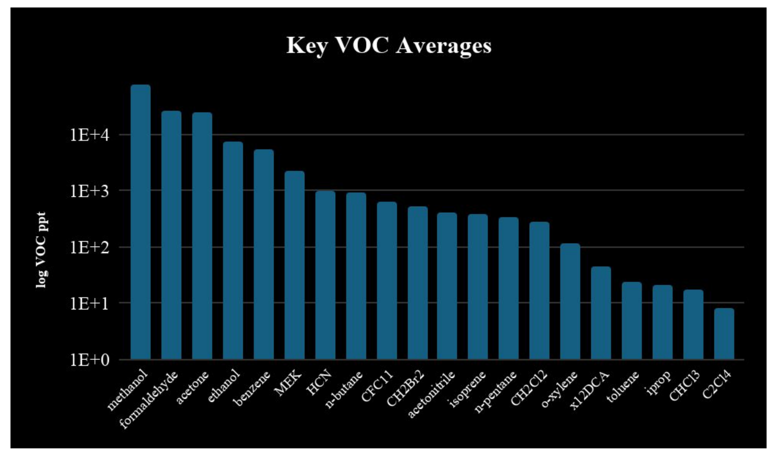
- **CMD**: Sends operator commands for sampling, status requests, and sensor streaming.
- **ACK**: Confirms command receipt and reports success or failure.
- **SENSOR**: contains sensor data from the BME680 (pressure, humidity, gas, temperature) and $PM_{2.5}$.
- **STATUS**: Returns Drone Pi status, including GPS, pump, valve, pressure, flow, power, and wind speed.

5. Results

Field Measurements: During a collaboration between ACOM, EOL, and the Colorado State University, we were able to add a WASPP flight test and collect real VOC data at the Christman Airfield in Fort Collins. In order to manage battery life, we sampled from ground level, to 200 feet above ground level (AGL), then back down in increments of 50 feet.

Full test flight at Christman Airfield with CSU Drone Center Director Christopher Robertson (left) and Eric Apel from ACOM (right) with WASPP sampling at ~50 ft AGL





Species Concentrations: Preliminary results identified nearly 80 species, many of which are toxic. More analysis is needed to determine their behavior and interactions in the environment. Methanol had the highest concentration.

- **Ozone Precursors:** Formaldehyde is a major VOC oxidation product that is important to understand the ozone formation and air quality management.
- **Boundary Layer Mixing:** Daytime convection creates a well-mixed boundary layer, making clear concentration gradients difficult to detect (e.g., acetone).
- **VOC Source Attribution:** For example, CH_2Cl_2 is an anthropogenic emissions tracer, isoprene is a biogenic emissions tracer, and acetonitrile is a biomass burning emissions tracer.
- **Future Sampling:** Sampling during more stable atmospheric conditions and across a wider altitude range may reveal clearer species-specific gradients.

6. Conclusion and Future Work

The addition of wireless control and monitoring opens up a world of possibilities, allowing for measurements outside a simple pre-programmed vertical profile. UAS are still under appreciated for remote sensing applications in Earth and atmospheric sciences and have more potential to advance these fields.

Applications

- Wildfire smoke analysis
- Contaminant Source Identification
- Study tropospheric gradients

Future Work

- Wireless component housing
- Low cost sensor calibration
- Upgrade flight platform
- UAS-equipped low cost sensor data integration with Mesonet weather stations and GDEX

[1] Sampling Altitude Graphic: Pinto et al., (2021): The Status and Future of Small Uncrewed Aircraft Systems (UAS) in Operational Meteorology. *Bull. Amer. Meteor. Soc.*, https://doi.org/10.1175/BAMS-D-20-0138.1.
[2] WASPP: Asher et al., (2021): Unpiloted Aircraft System Instrument for the Rapid Collection of Whole Air Samples and Measurements for Environmental Monitoring and Air Quality Studies. Environ. Sci. Technol., https://doi.org/10.1021/acs.est.0c07213
[3] TOGA-TOF: Jeong et al. (2026): Trace Organic Gas Analyzer Time-of-Flight mass spectrometer (TOGA-TOF) system for airborne observations of formaldehyde, Atmos. Meas. Tech., https://doi.org/10.5194/amt-19-2985-2026.
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