ALTO-CO_2:
Low-Cost Drone-Based Atmospheric Carbon Dioxide Monitoring Across Urban, Suburban, and Rural Areas in Southern Arizona

INTRODUCTION

Why CO_2 Monitoring Matters
- Rising CO_2 drives climate change and worsens air quality.
- Most monitoring relies on fixed ground sensors.
- These stations can miss how CO_2 changes with height and across locations.

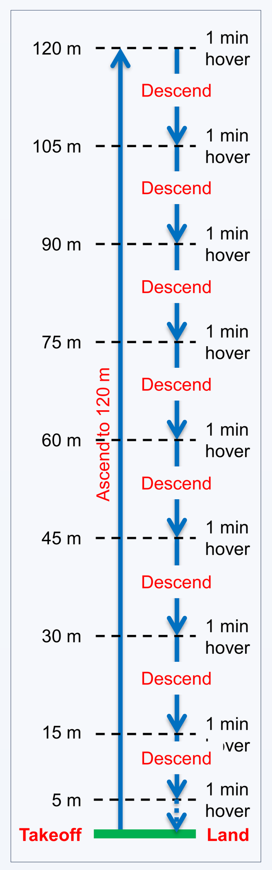

Figure 1: **Vertical flight profile.** Drone recorded CO_2 at 15 m intervals from 120 m down to ground. *Graphic created by Finalist using PowerPoint, 2025.*

What ALTO-CO_2 Does
- Low-cost drone equipped with lightweight CO_2 sensor.
- Flies vertical profiles (*Figure 1*) in urban, suburban, and rural sites.
- Records real-time CO_2 levels at multiple altitudes.

Core Findings
- *Rural* sites showed unexpectedly high CO_2 near the ground.
- *Urban* sites displayed more even mixing across altitudes.
- *Suburban* data fell between these two patterns.

Why It Matters
- Provides affordable, portable air-quality data.
- Adds valuable data for scientists, schools, and communities.
- Helps urban planning and public health efforts better track CO_2.
- Engages students and communities with affordable air-quality science.

OBJECTIVES

1. **Develop** a low-cost drone system to measure CO_2 at multiple altitudes.
2. **Generate** vertical CO_2 profiles from ground level to 120 m.
3. **Compare** CO_2 patterns and variations in altitude across urban, suburban, and rural environments.
4. **Assess** the potential of drones as an affordable, scalable monitoring tool.
5. **Hypothesis & Predictions**
- *Hypothesis*: Urban sites have the highest CO_2, rural the lowest.
- *Prediction*: Urban > Suburban > Rural in CO_2 concentrations.

MATERIALS & METHODS

Materials
- **Drone**: DJI Mini 2 (<250 g)
- **Sensor**: MH-Z19B CO_2 sensor
- **Microcontroller**: Raspberry Pi Pico
- **Power**: 9V battery + voltage regulator
- **Software**: Python, Thonny IDE, pandas/matplotlib for analysis
- **Mounting**: Lightweight rig with ties and fishing line

Methods
- **Calibration**: Self-calibrating CO_2 sensor.
- **Flight profile**: Vertical flights in urban, suburban, and rural sites.
- **Altitude steps**: Data recorded every 15 m, from 120 m down to ground.
- **Custom Code** written for the Pico that controlled measurements and stored data, and for analyzing data after flight.
- **Variables**: Independent = altitude, environment; Dependent = CO_2 concentration (ppm); Controlled = flight profile, intervals; Uncontrolled = wind, traffic, terrain

RESULTS

Vertical CO_2 Profiles: Urban, Suburban, Rural

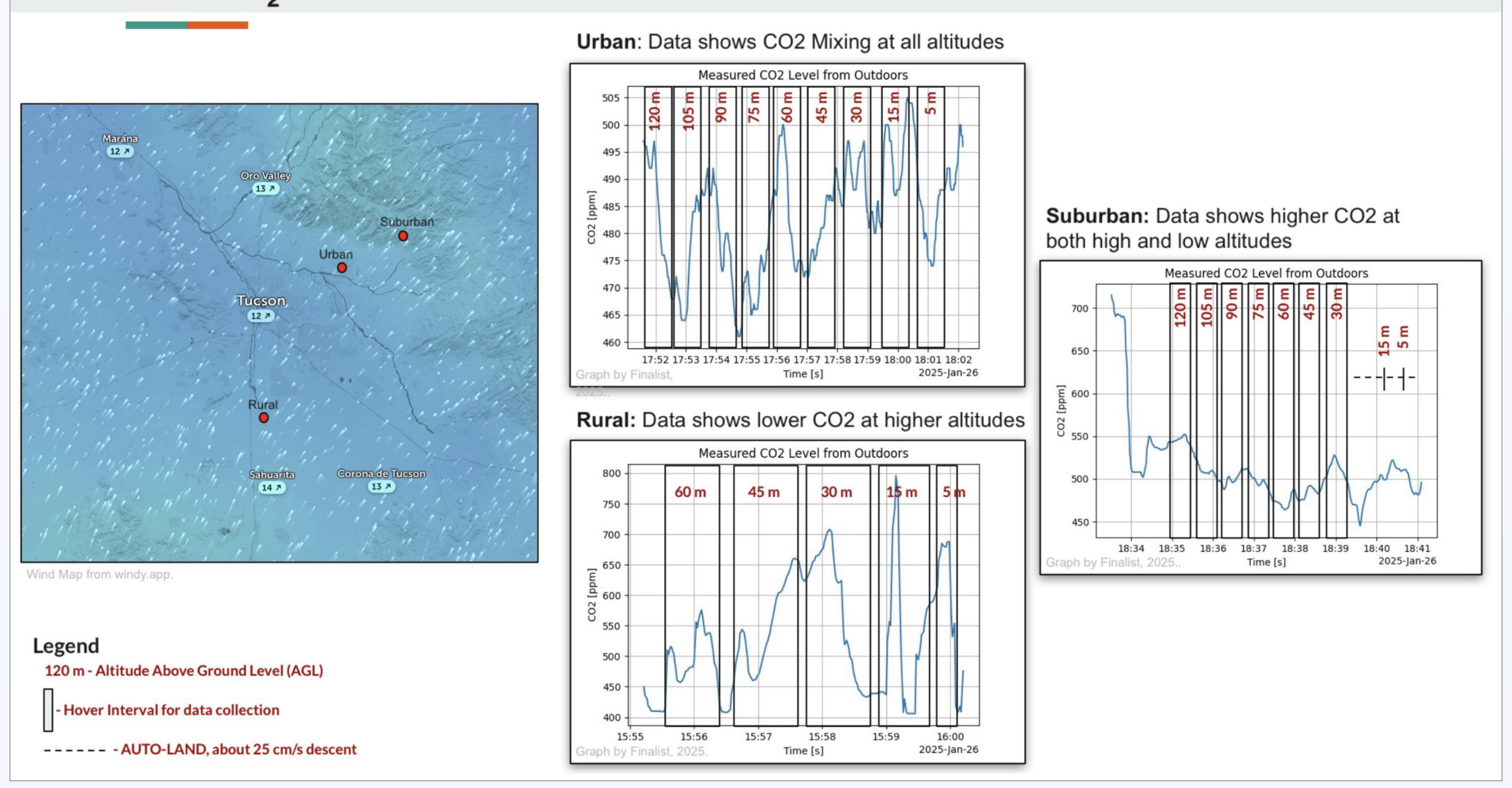

Figure 2 created by Finalist using (Left Image) windy.app & PowerPoint, 2025; and (3 Graphs) matplotlib 3.10.0 & PowerPoint, 2025.

Figure 2
Vertical CO_2 profiles across urban, suburban, and rural sites. *Profiles showed distinct patterns across environments (Jan 5, 2025).*

- **Urban**: Even CO_2 mixing across altitudes, likely from wind dispersion.
- **Suburban**: Higher CO_2 at low + high altitudes; dip near 60 m from circulation swirls.
- **Rural**: Highest CO_2 near ground, decreasing with altitude; linked to local vegetation and agriculture.
- **Conditions**: Windy (12–19 mph) impacted vertical mixing and drone stability.

Figure 3
Average CO_2 by altitude across Environments. *Rural sites showed the greatest variability; suburban sites the lowest overall (Jan 6, 2025).*

- **Rural**: Highest averages from ground to 60 m. Largest variation, peak 796 ppm near ground, lowest 406 ppm higher up (see *Figure 2*).
- **Urban**: Stable values across altitudes, confirming strong mixing. Lower overall concentration than rural or suburban.
- **Suburban**: Mid-level dip between 30 m and 75 m; higher levels overall than urban
- **Key Trend**: Rural profiles showed the strongest altitude-dependent differences.

Average CO_2 by Altitude Across Environments

Average CO2 Levels [ppm] by Altitude

Altitude [m]	Rural	Urban	Suburban
120		485	546
105		476	512
90		480	500
75		471	497
60	498	484	473
45	542	482	484
30	575	490	513
15	519	493	503
5	571	483	507

Table by Finalist, 2025

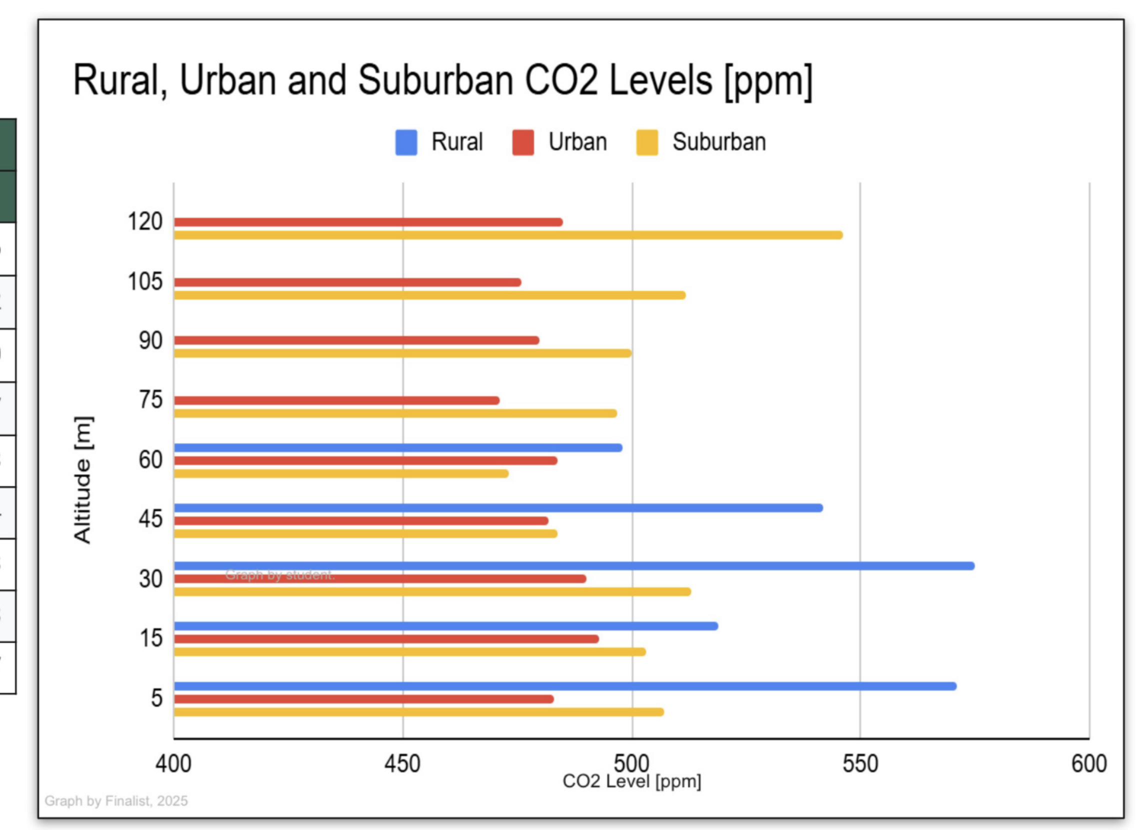

Figure 3 created by Finalist using Excel, 2025.

A City Exhales: Upwind vs Downwind CO_2 Profiles of Tucson

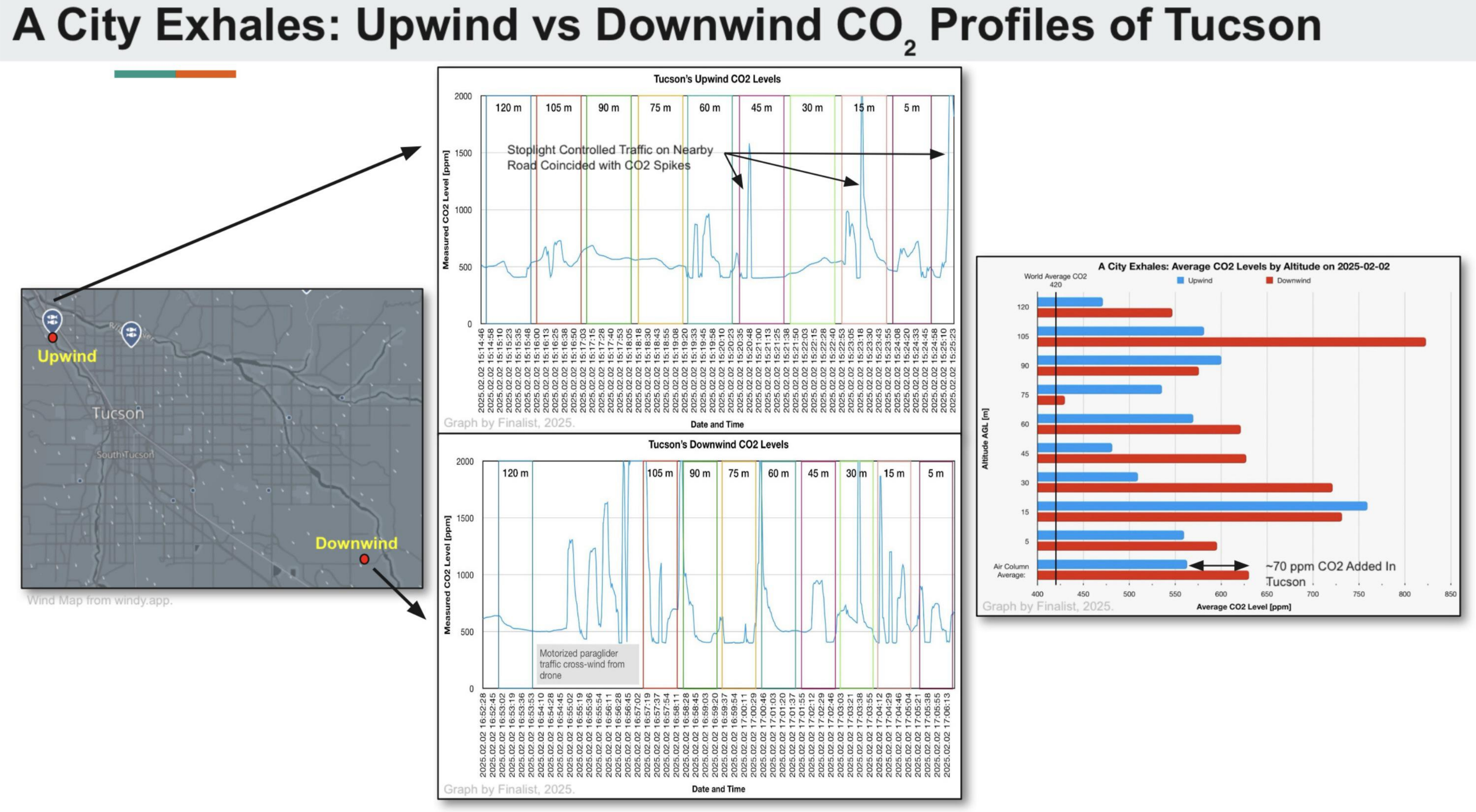

Figure 4 created by Finalist using (left image) windy.app & PowerPoint, 2025; (center two graphs) matplotlib 3.10.0 & PowerPoint, 2025; and (right graph) Excel & PowerPoint, 2025.

Figure 4
Upwind vs downwind CO_2 profiles of Tucson. *City emissions measurably increased CO_2 downwind (Feb 2, 2025)*

- **Upwind**: Lower baseline CO_2 entering Tucson.
- **Downwind**: ~70 ppm higher on average; occasional spikes >2000 ppm.
- **Spikes**: Attributed to traffic and road emissions.
- **Impact**: Tucson measurably added CO_2 to surrounding air.

CONCLUSIONS

- **Hypothesis not fully supported**: rural sites had the highest ground-level CO_2, not urban.
- **Prediction partly correct:** suburban sites showed higher averages than urban but with unexpected mid-altitude dips.
- **Vertical drone profiles** revealed patterns that fixed ground sensors miss.
- **Low-cost drones and sensors** proved to be an affordable, portable air-quality monitoring tool.

Key Takeaways
- **CO_2 is complex:** Local context (human activity, vegetation, weather) drives patterns.
- **Why it matters:** Vertical monitoring gives insights for climate research, air-quality policy, and public health.
- **Technology impact:** Drones make advanced monitoring accessible and scalable.

LIMITATIONS

- **Wind and weather** conditions affected flight stability and CO_2 readings.
- Flights were limited to **single** days, all conducted on Sundays.
- Battery capacity limited hovers to 1 minute each.
- Drone **safety features** (auto-land, altitude limits) shortened two of the flights.

FUTURE DIRECTIONS

- **Monitor additional pollutants** (CO, NO_2, SO_2, CH_4).
- Apply **machine learning** to predict pollution patterns.
- **Study seasonal and weather-related effects** on CO_2.
- Expand **geographic scope**.
- **Share results** to inform urban planning, public health, and climate research.
- **Engage communities** with data to guide strategies for reducing carbon footprints.
- **Impact**: Next steps combine multi-pollutant sensing and ML prediction to make monitoring smarter and broader for science, policy, and communities.

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