# Mobile measurement of carbon dioxide and methane emissions in Cyprus

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## Motivations

Greenhouse Gas (GHG) emissions in the Eastern Mediterranean and the Middle East (EMME) region are continuously increasing to reach nowadays levels that are comparable to the total emissions of the EU-28. However, very little is known on the sources contributing to these emissions (profile/fingerprint) as well as their spatial and temporal variability. Leveraging recent technological developments on Unmanned Aerial Vehicles (UAVs) and miniaturized sensors, we propose here to combine several mobile platforms (car, UAV) to investigate carbon dioxide ($CO_2$) and methane ($CH_4$) concentrations over Cyprus to better assess regional and local GHG fluxes. We present here preliminary results obtained from high-precision (Picarro G2401) on-road mapping of $CO_2$/CO/$CH_4$ over the island of Cyprus together with our first UAV-$CO_2$ (HPP3.2, SenseAir AB) atmospheric profiling. Ultimately, this set-up will be further used to investigate GHG emissions over selected countries of the EMME region.

## 2 Methodology

### The measurement system

The schematic is shown as Fig.1. It consists of two $CO_2$ sensors (SaA and SaB, a micro-pump, a dryer, a 0.2 µm filter and a SHT75 sensor. The dryer is filled with magnesium perchlorate and with cotton on both sides. During flight developments, Picarro (G2401-m) used as a reference instrument was put next to $CO_2$ sensors.

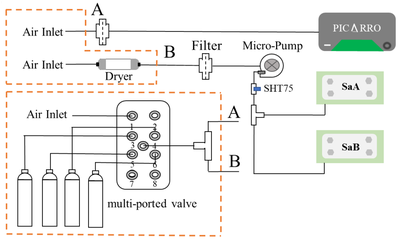



Fig.2.1 The schematic of the system for lab tests and field development (A and B represent air flows to Picarro and $CO_2$ sensors respectively).

### 2.1 SenseAir lab tests

Table 2.1 The overview of SenseAir lab tests

| Performance Tests | Purposes |
|---|---|
| 2.1.1 Calibration | Confirm the presicion and stability |
| 2.1.2 Allan Deviation | Confirm the noise |
| 2.1.3 T/P Tests | Correct from T/P changes |
| 2.1.4 Humidity Tests | Correct from RH changes |
| 2.1.5 Simulated Flights | Assess the measurement error from T/P |

#### 2.1.1 Calibration

Four high pressure calibration cylinders with well-known amounts of $CO_2$ (380.096ppm, 400.336ppm, 419.782ppm and 459.773ppm ) were applied to calculate response curves. Each standard gas ran for 30 min, and to ensure complete flushing of the cell of the analyzers only the last 10 min of data were used. The cylinder with 459.773ppm $CO_2$ was cosidered as the ambient air for precision calculation (Fig.2.1.1).

#### 2.1.2 Allan deviation

Allan deviation was implied to characterize noise and drift of SaA and SaB.

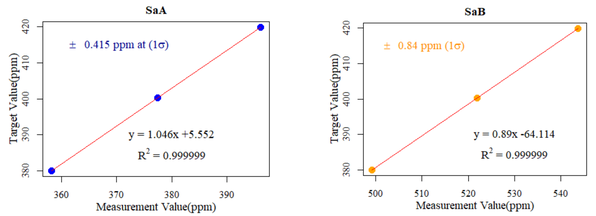
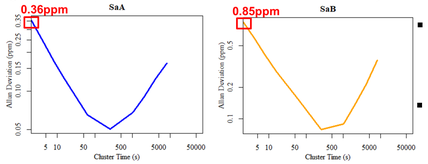



Fig.2.1.1 The precision of SaA and SaB is respectively ±0.415ppm and ±0.84ppm at 1σ.




- $CO_2$ precision improves to ±0.05ppm and ±0.08 ppm in around 250s for SaA and SaB respectively.
- The precision is respectively ±0.36ppm and ±0.85ppm at 1σ 1 Hz.

Fig.2.1.2 Allan deviation of unfiltered $CO_2$ dry air mole fraction versus cluster time (s).

#### 2.1.3 T/P and simulation flight tests

The tests were performed in an environmental chamber.

- T tests: range from 0 ℃ to 45 ℃ and every 9 ℃ was a step, pressure kept at 950 mbar.
- P tests: range from 600 mbar to 1000 mbar and every 100 mbar was a step, temperature kept at 25 ℃.
- Simulation tests for SaB: T changed from 15 ℃ to 35 ℃ and every 5 ℃ was a step, corresponding to 600 mbar, 700 mbar, 800 mbar, 900mbar and 1000 mbar.

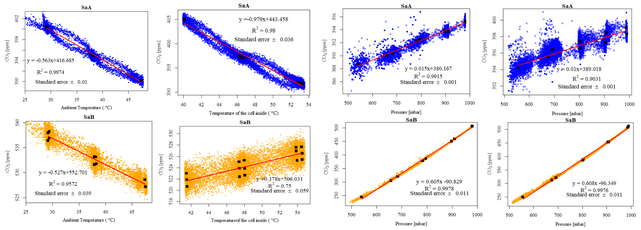



Fig.2.1.3.1 Temperature (on the left) & Pressure (on the right) equations from T/P lab tests.

SaA: $C_{cor}=C_{obs}+0.5635\times(Ta-Ta_0)+0.979\times(Tc-Tc_0)-0.0125\times(P-P_0)$

SaB: $C_{cor}=C_{obs}+0.527\times(Ta-Ta_0)-0.378\times(Tc-Tc_0)-0.6065\times(P-P_0)$

Where $T_c$ represents the cell temperature and $T_a$ represents ambient temperature.

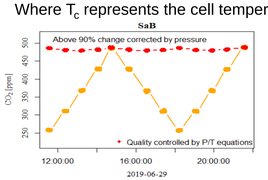



Fig.2.1.3.2 The simulation flight test of SaB.

- SaB is more sensitive to pressure changes.
- Simulation tests of SaB show above 90% change corrected by pressure.
- The linearity of SaA shows better for T equations and the linearity of SaB shows better for P equations.

### 2.2 Field development and observation

#### 2.2.1 Manned aircraft

$CO_2$ sensors were put next to Picarro (G2401-m) on the aircraft (Beechcraft Baron 58).

Fig.2.2.1 The setup and platform.

#### 2.2.2 Unmanned aerial vehicle (UAV)

The set up is shown in Fig.2.2.2. A small fixed-wing UAV with a wingspan of 1.83m and customized avionics and payload developed by the Unmanned Systems Research Laboratory of the Cyprus Institute was applied for flights A series of circular flight paths were implied over a highly agricultural area.

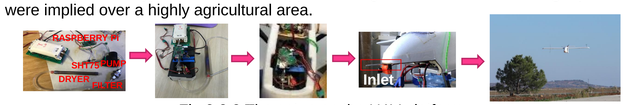



Fig.2.2.2 The setup on the UAV platform.

#### 2.2.3 Ground-car-based observations

The set up is shown in Fig.2.2.3. The observation is based on a Picarro (G2401) set-up that measures simultaneously atmospheric carbon dioxide ($CO_2$) and methane ($CH_4$) to characterize GHG hotspots in Cyprus.

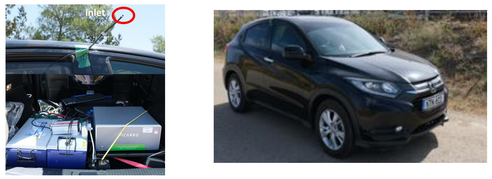



Fig.2.2.3 The setup in the car.

## 3 Results

### 3.1 Field development and observation

Water vapor was controlled through a dryer at a average of 0.0024% for two hours. Fig.3.1.1 is the result of the manned aircraft test.

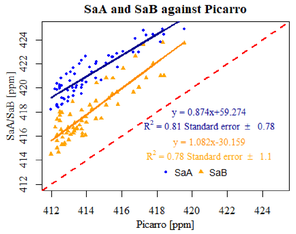



Fig.3.1.1 SaA and SaB values against Picarro G2401 values during the manned aircraft flight (on April 8, 2019).

- The pressure was under 800 mbar.
- The precision of SaA and SaB was respectively ±1.4ppm (1σ) and ±1.7ppm (1σ) at 1 Hz, ±0.78ppm (1σ) and ±1.1ppm (1σ) at 1 min during flights.

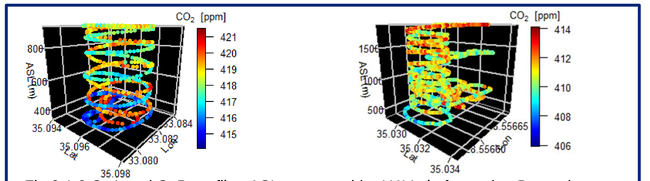



Fig.3.1.2 SaA and SaB profiles ASL measured by UAV platforms (on December 17, 2019 and January 21, 2020).

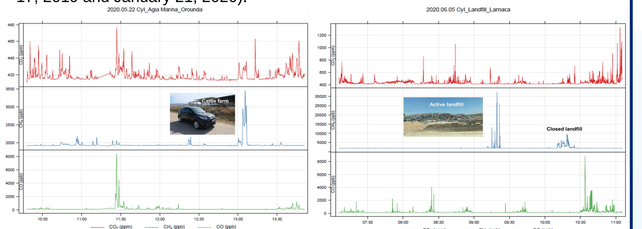



Fig.3.1.3 Ground-car-based observations (on May 22 and June 5, 2020).


Fig.3.1.4 Ground-car-based observations of $CH_4$ in Cyprus (hotspots are marked).

- SHT75 sensor has been replaced by another T/RH sensor with faster response time.
- Five car-based observations have been done to make general survey to locate hotspots of GHGs from west to east in Cyprus.
- An anemometer is being installed to the car to aid location of unidentified plumes.

## 4 Recommendations

- Every single SenseAir sensor behaves differently, and characterization is necessary.
- The flow rate for SenseAir sensors should be above 500 ml/min.
- A dryer is necessary for the UAV-$CO_2$ sensor system, as SenseAir RH tests were non-repeatable.
- UAV-$CO_2$ sensor system is adequate for horizontal measurements to investigate ground-based emissions.

## 5 Future work

- $CO_2$ sensor system is being integrated onto a multicopter for horizontal mapping.
- More ground-based mobile observations will be performed to investigate local emission hotspots through different seasons.

## References

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