# Rapid gas measurements in volcanic plumes with UAVs: online and offline measurements of various trace gases with light UAVs

Location:

Hall **X2**, poster board X2.139

**Monday**, 24 April 2023, **10:45 – 12:30**


Niklas Karbach[1], Lisa Höhler[1], Bastien Geil[1], Jonas Blumenroth[2], Heiko Bozem[2], Christian von Glahn[2], Peter Hoor[2], Nicole Bobrowski[3,4], and Thorsten Hoffmann[1]

[1]Department of Chemistry, Johannes Gutenberg-University, Mainz, Germany;
[2]Institute for Atmospheric Physics, Johannes Gutenberg-University, Mainz, Germany;
[3]Heidelberg University, Heidelberg, Germany;
[4]Istituto Nazionale di Geofisica e Vulcanologia (INGV), Osservatorio Etneo, Catania, Italy

✉: nkarbach@students.uni-mainz.de
✉: t.hoffmann@uni-mainz.de

# Electrochemical gas sensors

Airborne gas measurements in volcanic plume are challenging. Not only for the pilot, who constantly needs to adjust the position of the drone to compensate for changes in plume geometry caused by changes in wind direction and speed, but also for the instrumentation which is exposed to quickly changing conditions (in plume vs. out of plume). Those rapidly changing environmental conditions make it extremely hard to perform accurate and repeatable airborne measurements of the low concentration analytes in volcanic plume.

In the volcanic community it is well known, that electrochemical sensors are prone to strong cross interferences (temperature, pressure, relative humidity and other gases) and have a slow response time on the order of 10´s of seconds. Those characteristics seem to impede the use of those sensors in the above-described challenging conditions. However, as electrochemical sensors are comparatively small and low-cost, it is still highly desirable to use this type of sensor. Especially on light UAVs.

Experiments were designed and conducted to characterize the response of electrochemical $H_2$ sensors to changes in temperature, pressure and relative humidity. Models were then designed to account for those changes and calculate a corrected $H_2$ concentration. The design can be used for all types of electrochemical gas sensors.

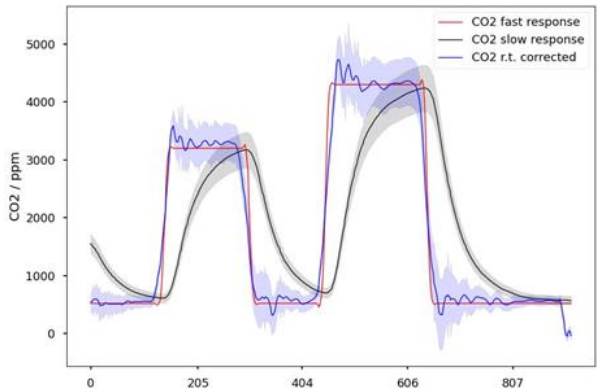



Figure 3: Visualization of the response time of a slow responding CO2 sensor during a calibration (black). In red the theoretical CO2 concentration is shown. The blue line shows the response time corrected concentration.

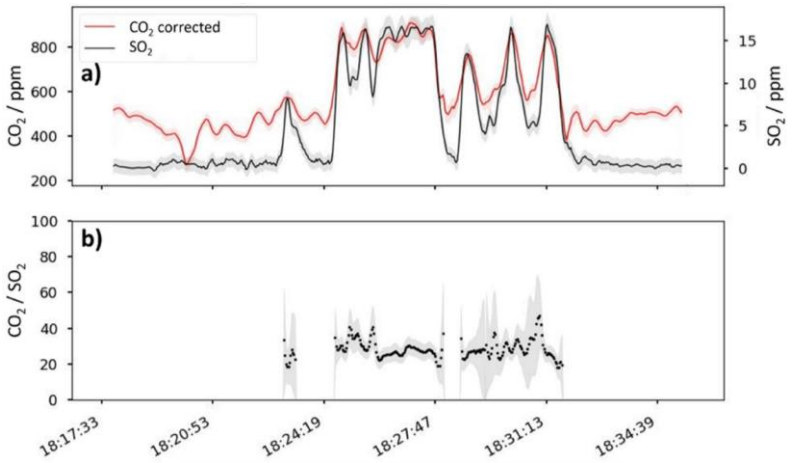



Figure 1: measured $CO_2$ and $SO_2$ concentrations during a campaign at Vulcano Island, Italy in 2022. One can see the quickly changing concentrations during the measurement flight. Some peaks are only a few 10 seconds wide, showing the necessity of a fast responding (or response time corrected) sensor.

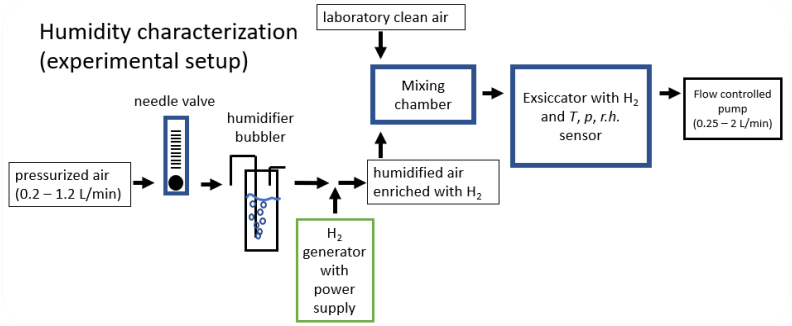



Figure 2: Experimental setup used for the humidity experiments. The humidity could be set by changing the ratio of humidified to laboratory clean air. The concentration of $H_2$ could be set by adjusting the total volume flow of the flow controlled pump.

# Electrochemical gas sensors

As expected, the experiments confirmed the strong cross sensitivities of electrochemical gas sensors. It could be shown, that especially temperature and relative humidity had an enormous impact on the measured concentration in low analyte concentration environments. Three experimental series were conducted to determine the influence of temperature, pressure and relative humidity.

Pressure influence:

It could be seen, that the $H_2$ sensor did show a pressure dependent behavior. Upon decreasing the pressure in a sealed measurement chamber by partially sucking fractions of the gas mixture out of the chamber, the signal of the sensor did drop. Repressurizing the chamber with H2 free air did not alter the measured signal. Therefore, it can be concluded, that the sensor measures the $H_2$ partial pressure and not the mixing ratio of $H_2$ in air. However, the output is not exactly as predicted by theoretical calculations and a smaller than expected correlation can be seen.

Temperature influence:

In temperature experiments, it was shown, that the sensor output did show a positive correlation with temperature. This was expected, as not only the reaction kinetics show a positive temperature dependance, but also the diffusion increases with temperature. Both effects affect the total reaction rate, which corresponds to the measured sensor signal.

Relative humidity influence:

Relative humidity has a strong negative correlation with the measured sensor signal. It could be shown, that for a $H_2$ concentration of ~250 ppm (calibrated at 40% r.h.), the measured concentration at 75 % r.h. of the sensor is only 31 ppm. Which represents an error of 88 %. The reaction product of the oxidation of $H_2$ is water, which might be one of the reasons, why the sensor shows such an enormous cross correlation.

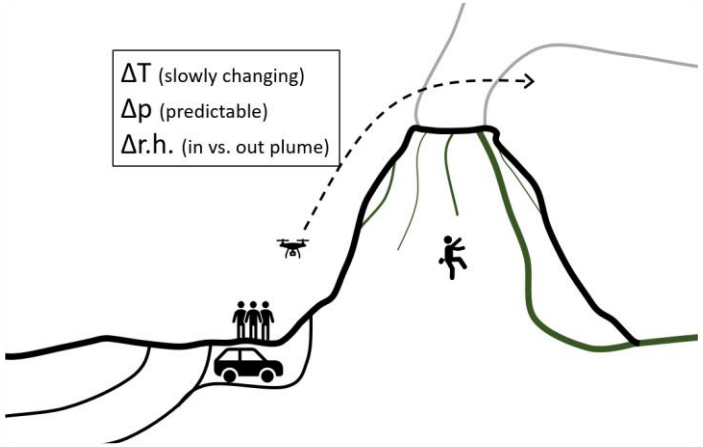



Figure 4: Sketch of a typical measurement routine. The scientists drive to an adequate landing spot in proximity to the volcano. The sensor system is then attached to the drone and the drone is flown to the sampling site.

Figure 5: Pictures taken with little-RAVEN´s onboard camera during a measurement flight. On the pictures, the strong heterogeneity of the plume can be seen, which helps understanding the necessity of fast responding sensors and a correction for the influence of temperature, pressure and especially humidity.

# Electrochemical gas sensors

The results of the experiments are shown in their corresponding graph on this slide. For the influence of humidity and temperature, the fit equation that is provided, can be used to correct the measured concentration. On the y-axis, the deviation factor (measured concentration divided by the true concentration) is shown against the relative humidity / temperature. This represents the correction factor that can be used on the measured data to yield the corrected data.

It could be shown, that the application of those correction algorithms significantly improves the quality of the data as can be seen most drastically by correcting the influence of humidity.

## Influence of relative humidity on $H_2$ sensor

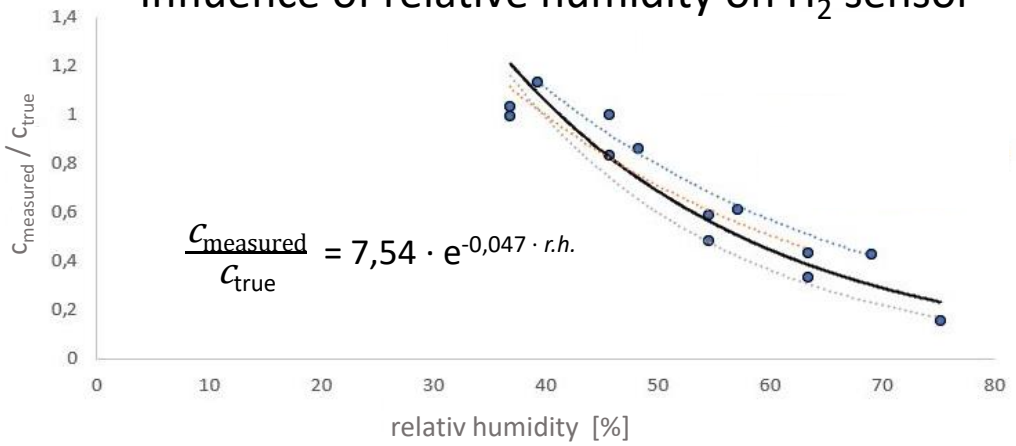



Figure 6: Influence of relative humidity on the measured sensor signal of an Alphasense $H_2$ sensor. The strong negative correlation with relative humidity can be seen. Of all measured influences, relative humidity had the strongest impact on the measured signal. This is likely due to water being the reaction product of the reaction.

## Influence of temperature on $H_2$ sensor

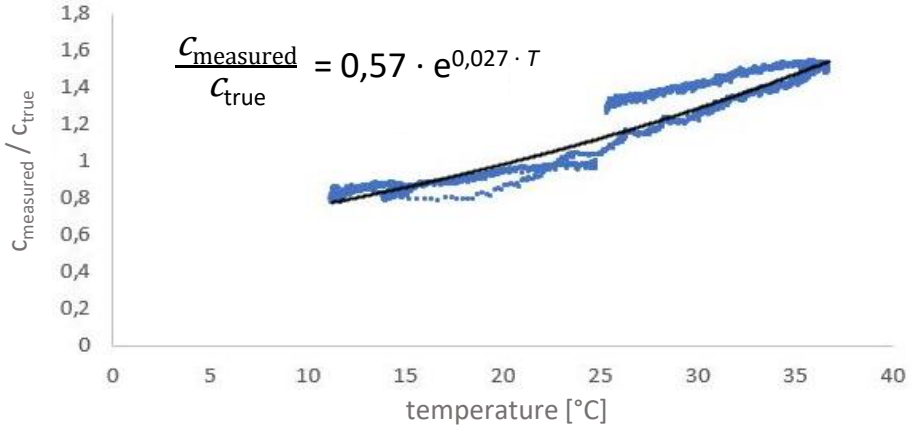



Figure 8: Influence of temperature changes on the measured sensor signal of an Alphasense $H_2$ sensor. With increasing temperature, the measured signal increases and vice versa.

## Influence of pressure on $H_2$ sensor

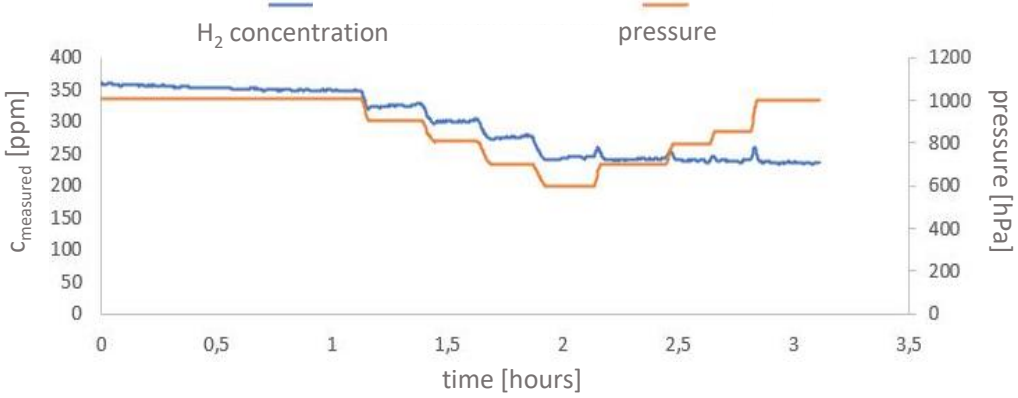



Figure 7: Measured sensor signal (Alphasense $H_2$ sensor) and pressure in a sealed measurement chamber plotted over time. At ~ 2,2 h, the chamber was repressurized with $H_2$ free air. It can be seen, that the sensor does not react to the mixing ratio of $H_2$, but rather to the partial pressure of $H_2$.

# Little-RAVEN

Little-RAVEN (remote-controlled aircraft for volcanic emission analysis) is a versatile measurement platform to measure $CO_2$ and $SO_2$, as well as temperature, pressure and relative humidity in up to 3 km distance. Additionally, the platform can be equipped with a small absorber (impregnated syringe filter) to selectively enrich certain airborne compounds in the direct environment of the drone. Long range capable telemetry allows to view online measurement data and switching of the micro pump.

The small design of both the drone and the sensor package unlocks many landing sites, that are otherwise inaccessible by larger drones. Even handheld take-off and landing is possible (see picture).
Additionally, the drone is C1 certified resulting in very little regulatory limitations during flight.

Figure 9: Picture of little-RAVEN during a handheld take-off. Under the drone, the adapter plate and the sensor system can be seen.

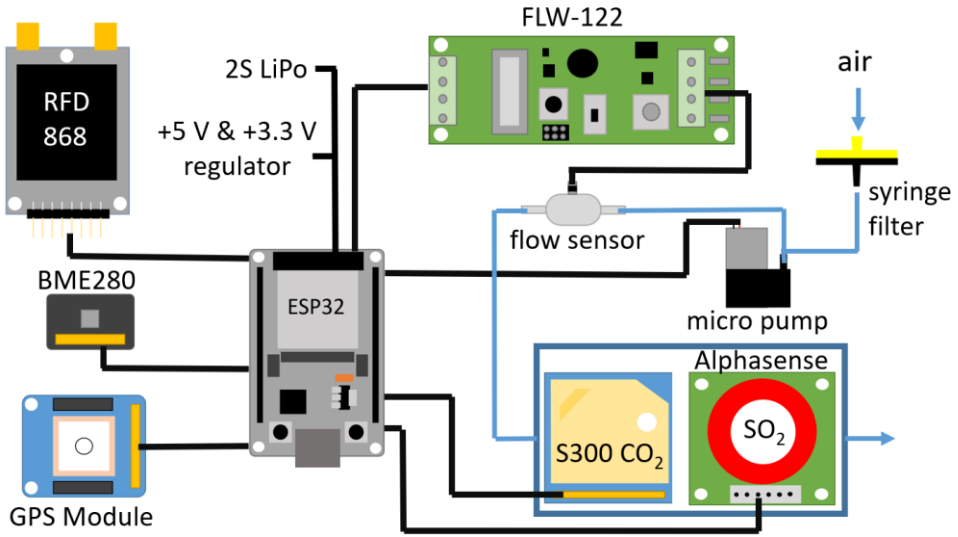



Figure 11: Schematics of the sensor system. The microcontroller (ESP32) reads the various sensors and sends a formatted string to the long range telemetry system (RFD868). The micro pump with the flow sensor (FLW-122) draws ~ 600 mL/min through a reactive halogen specific absorber and over the CO2 and SO2 sensor.

For more information on little- RAVEN:

Figure 10: Adapter-plate that is used to attach the sensor system to the drone. The rails allow for a quick and easy attachment of various systems under the drone.

self designed CAD file

printed on a low cost 3D printer

# Little-RAVEN at Etna

As was already explained on the previous slide, little-RAVEN is extremely versatile, allowing to quickly adjust its mission goals.
On a campaign in 2022 at Etna, little-RAVEN was equipped with impregnated syringe filters to absorb reactive halogen species in oxidation states -1, ±0 and +1. The online measurement data of the $CO_2$ and $SO_2$ sensor was used to locate the plume and switch the sampling pumps for the absorber on, once the drone was inside the plume.

In one experiment, the syringe filters were swapped for a miniaturized alkaline trap to absorb acidic gases in the plume.

Data that was acquired during this campaign is presented in the pico presentation of B. Geil
(Thu, 27 April, 14:02 – 14:04, PICO spot 3b; 10.5194/egusphere-egu23-6677)

# Rapid gas measurements in volcanic plumes with UAVs: online and offline measurements of various trace gases with light UAVs


Niklas Karbach[1], Lisa Höhler[1], Bastien Geil[1], Jonas Blumenroth[2], Heiko Bozem[2], Christian von Glahn[2], Peter Hoor[2], Nicole Bobrowski[3,4], and Thorsten Hoffmann[1]

[1]Department of Chemistry, Johannes Gutenberg-University, Mainz, Germany; [2]Institute for Atmospheric Physics, Johannes Gutenberg-University, Mainz, Germany; [3]Heidelberg University, Heidelberg, Germany; [4]Istituto Nazionale di Geofisica e Vulcanologia (INGV), Osservatorio Etneo, Catania, Italy

✉: nkarbach@students.uni-mainz.de
✉: t.hoffmann@uni-mainz.de

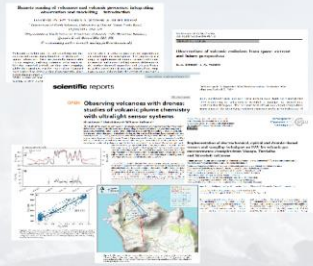

## Introduction and motivation

Interdisciplinary and international research interest:

Plume chemistry can give hints on magmatic processes
Plume chemistry of interest for atmospheric processes and models

High public interest:

Local volcanic hazard prevention (gas emissions & eruptions)
Global influence of volcanoes on weather and climate




→Development of new instrumentation and methods
- →miniaturization and improvement of current techniques (robustness & ease of use)
- →better understanding of electrochemical gas sensors
- →new methods for gas sampling (see presentation by B. Geil)
- →combination of multiple instruments and methods in one system

→simplified monitoring of volcanic activity


## Little-RAVEN

Online $CO_2$ and $SO_2$ & active filter sampling

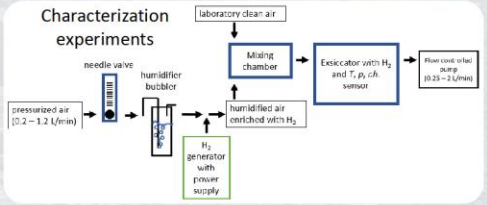
Miniaturized design with commercially available drone:
- →little regulatory limitations during flight (C1 drone)
- →no limitations on landing site (handheld take-off and landing)

Low entry hurdles:
- →regulatory (A1 license)
- →flight experience

## Electrochemical gas sensors

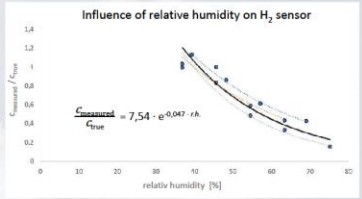
Challenging conditions during flight:
cross interferences
→ analyte gas concentration, r.h., *T*, *p*

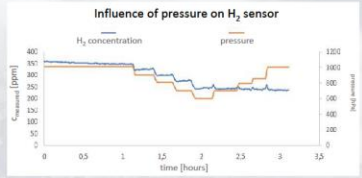
Knowledge of sensor characteristics needed
…to estimate the error
…to get more accurate results

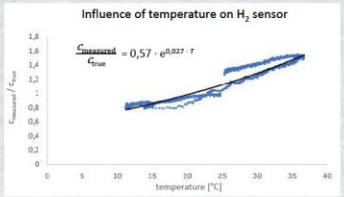



Results:

| | |
|---|---|
| humidity: | → up to 88 % error if not corrected |
| pressure: | → partial pressure (not mixing ratio) |
| temperature: | → smaller influence than r.h. |

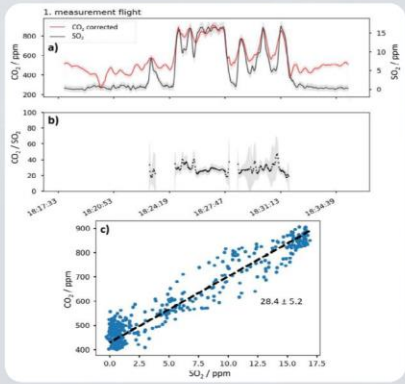



## Summary and outlook

Little-RAVEN [1]
- -extra lightweight & small
  - ->easy to transport
  - ->fast & flexible measurements
- -online results
  - ->allows for active gas sampling




Electrochemical sensors
- -small & lightweight (perfect for drone)
- -BUT: cross sensitivities!!
  - → good knowledge of the sensor improves quality of measured data
  - → experiments designed to evaluate the influence of r.h., T and p

-experimental setup may be used to characterize other types of sensors

→influence of cross interferences is highly dependent on use case (low vs. high analyte concentration)

[1]


FORSCHUNGSINITIATIVE DES LANDES RHEINLAND-PFALZ
TeMaS Terrestrial Magmatic Systems
Sharing is encouraged