Development of a Low-Cost Sensor Array for Real-Time Agricultural Ammonia Monitoring

M. Rosiers[1,2], S.P. Liégeois[1], N. Antoine[1], C. Falzone[1], M. Justin[1], M.B. Jalloh[1], M. Van Damme[2], L. Clarisse[2], P. Coheur[2] & A.C. Romain[1]

[1]Sensing of Atmospheres and Monitoring (SAM) Laboratory - UR SPHERES, Université de Liège, Arlon Campus Environnement

[2]ULB-BLU Space Research Center - UR SQUARES, Université libre de Bruxelles

Introduction

- Ammonia (**NH_3**) is a major agricultural pollutant
- **Negative impact** on human health & climate
- **Monitoring is challenging!**
  - ➢ EU: Increased demand for NH_3 emission data
  - ➢ Conventional methods are essential
  - ➢ However, coarse resolution, expensive, …
- **Need: affordable, high-resolution monitoring solution**
  - ➢ **Development of NH_3 sensor array** (e-nose)
- **E-nose principle**: recognition of **'agricultural gas fingerprint'**
  - ➢ **Prediction of atmospheric NH_3**
  - ➢ High spatial & temporal resolution, affordable, scalable, …

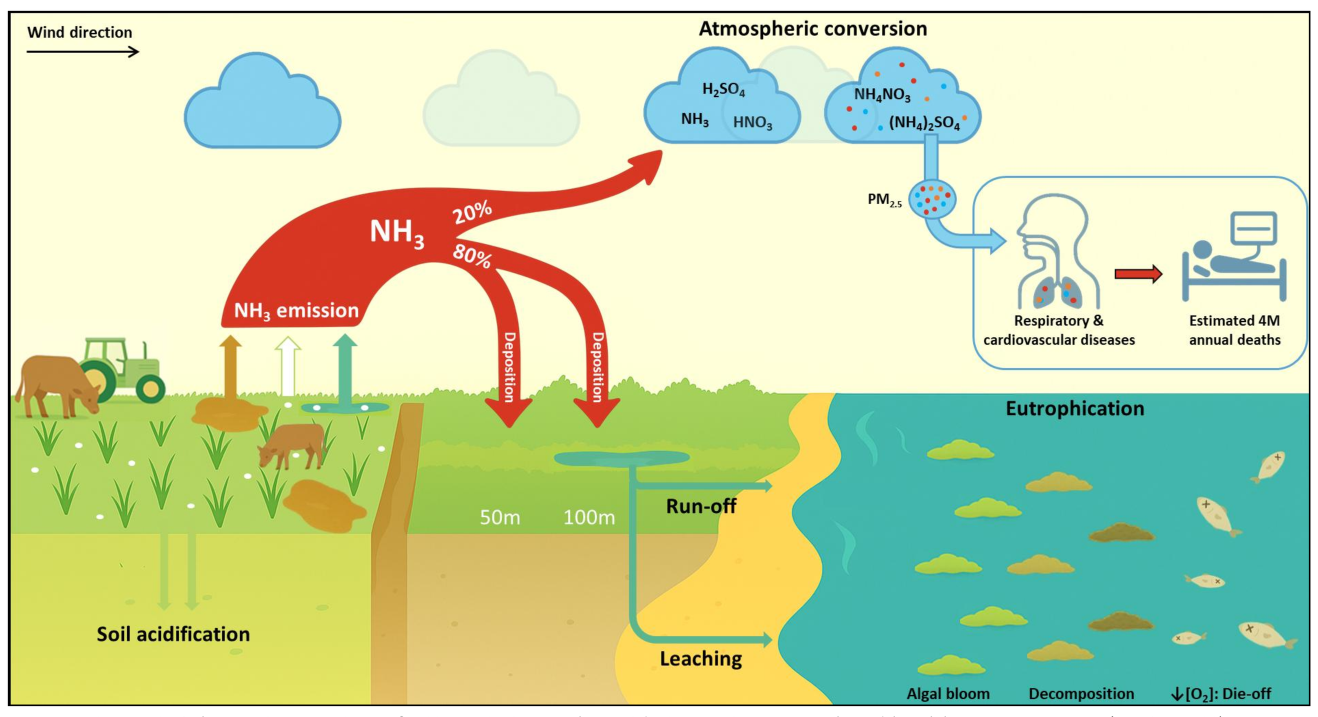

Figure 1: Schematic overview of NH_3 emissions, alongside its environmental and health consequences (Rosiers, AI).

Initial Sensor Selection – Based on Literature

Name	Manufacturer	Type	Target gases	Detection range NH_3 (ppm)	Detection range other analytes (ppm)
TGS2602	FIGARO	MOX	NH_3 & VOCs	0-30	-
MQ-137	Winsen Elec.	MOX	NH_3	5-500	-
MQ-135	Winsen Elec.	MOX	VOCs & NH_3	10-1000	-
GGS4330 T	Umwelt	MOX	NH_3	0-100	-
NH_3-SM30-20	ELT SENSOR	EC	NH_3	0-20	-
NH_3-SM30-100	ELT SENSOR	EC	NH_3	0-100	-
MQ-3	Winsen Elec.	MOX	VOCs	-	VOCs: 0-500
TGS2620	FIGARO	MOX	VOCs & CH_4	-	VOCs: 0–5000
TGS2610	FIGARO	MOX	VOCs & CH_4	-	VOCs: 0–5000;
TGS813	FIGARO	MOX	VOCs & CH_4	-	-

Table 1: an overview of the broad selection of low-cost MOX and EC sensors for this study. All characteristics are taken directly from official manufacturer datasheets.

Sensor Selection

Methodology

- Sensor array needs to capture complex agricultural gas mixture
- **In-lab sensor performance assessment** (NH_3, EtOH & CH_4)
  - ➢ Based on single analyte & controlled gas mixtures (incl. RH & T)
- Cycle-based exposure - [analyte] between 0.1-2.5 ppm ≈ in-situ
  - ➢ Reference: humidified synthetic air (20/80 O_2/N_2 – RH = 55%)
- **Feature Extraction:** Median value of Steady-State sensor signal
- **Data Preprocessing:** Data Cleaning & Scaling (Column-wise)
- **Sensor Selection:** Sensor Characteristics (LOD, Sensitivity, etc.) & PCA

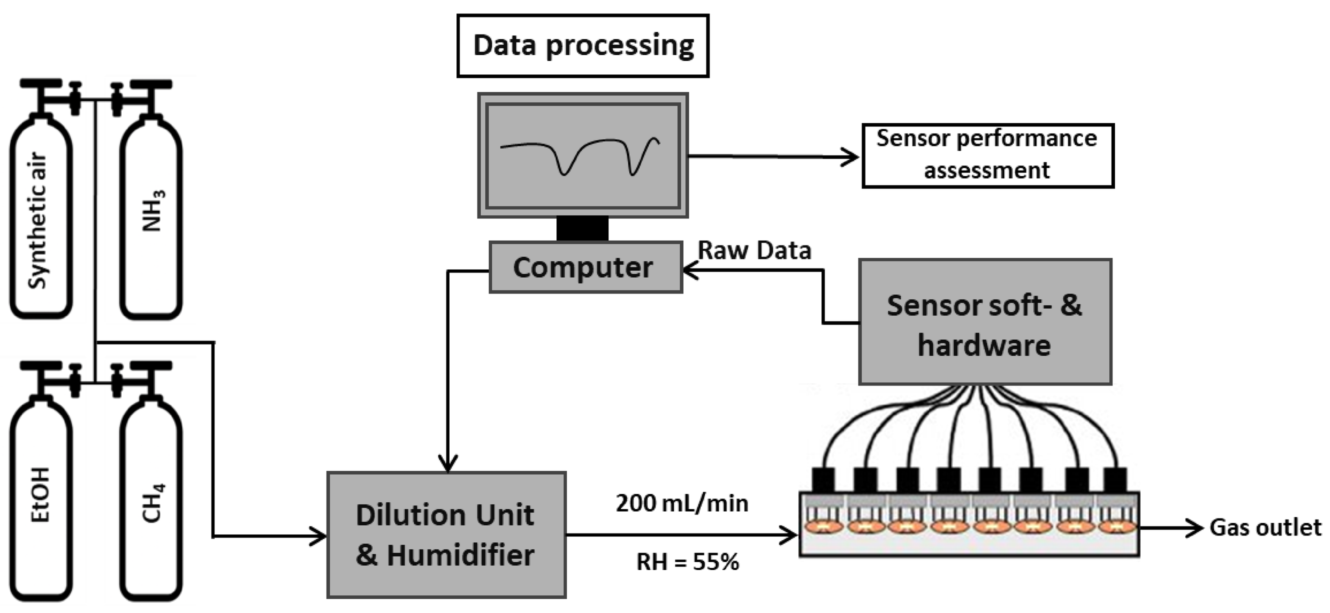

Figure 2: Schematic overview of the experimental design, used to assess sensor specific characteristics.

Data Treatment

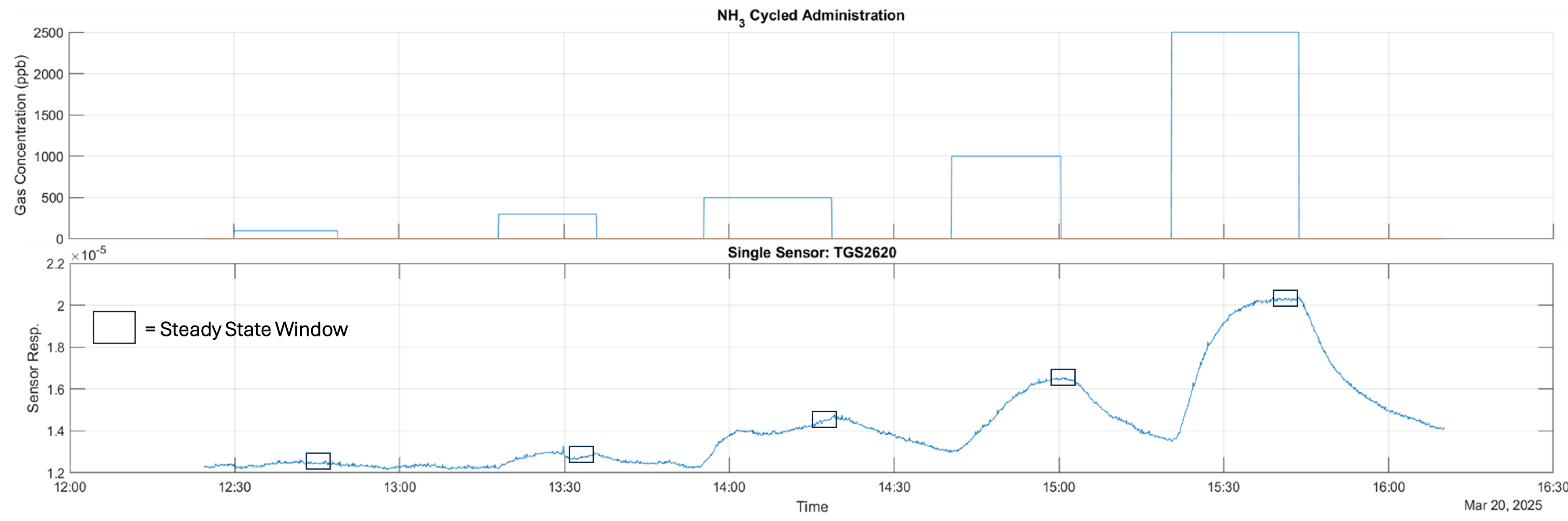

Figure 3: Experiments were conducted from January until May 2025, resulting in a total of 72 included datapoints, separated along 2 PCAs,as shown below

Feature Extraction

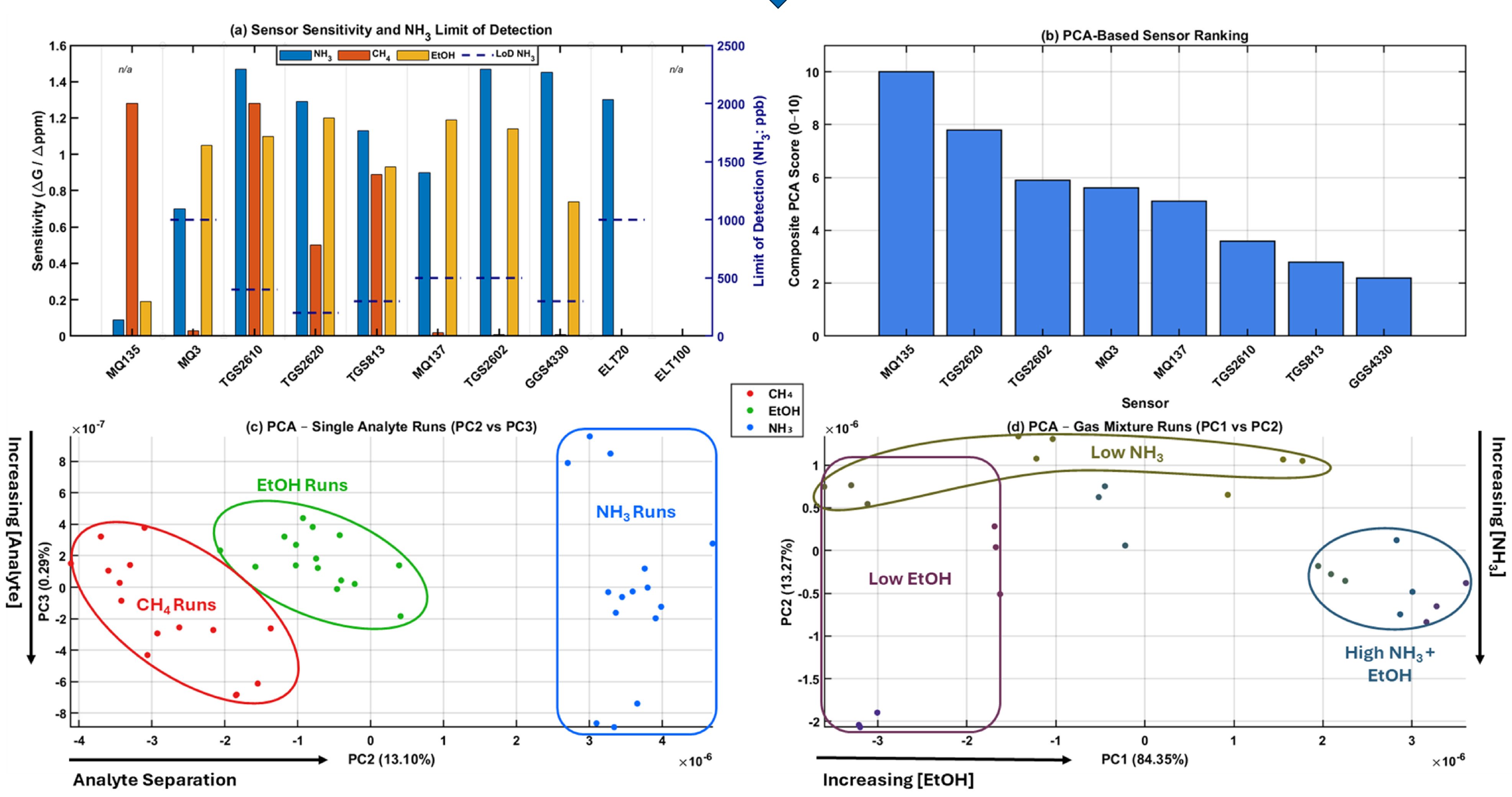

Figure 4: Sensor characteristics of the selected low-cost MOX and EC sensors. (a) Bar chart showing sensor sensitivities to NH_3, CH_4, and EtOH (ΔG/Δppm), with overlaid NH_3 LoD (ppb).(b) PCA-based ranking of sensors by composite score derived from loadings.(c) PCA biplot (PC2 vs PC3) of single-analyte experiments, with clusters for NH_3 (blue), CH_4 (red), and EtOH (green) runs distinctly separated.(d) PCA biplot (PC1 vs PC2) of gas mixture experiments, where score locations correspond to RGB-blended concentrations and clusters indicate regions with low NH_3, low EtOH, or high NH_3+EtOH.

Conclusion

- Based on Biplots of PCAs:
  - ➢ **MQ135 (CH_4), TGS2620, TGS2602 & MQ3 (EtOH)**
- Strong separation of single analyte gases
- Identification of EtOH & NH_3 gradients in complex gas mixtures
- **No EC? ➔** High LOD – good performance at > 1 ppm

Future Work

Model Development

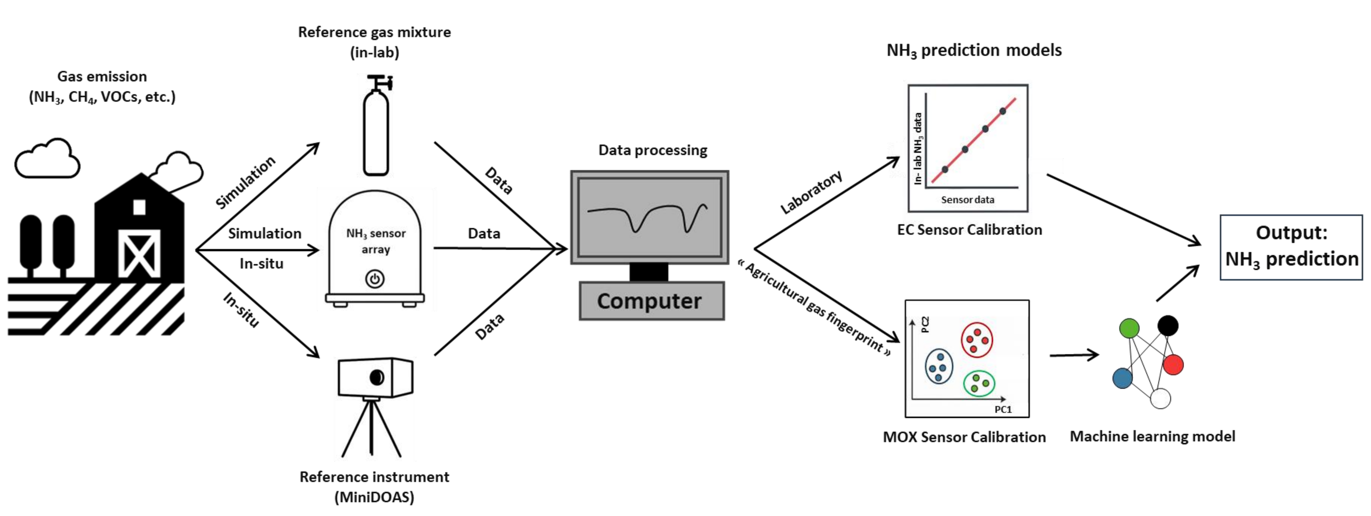

Figure 5: Schematic overview of the different calibration techniques applied during this project.

- **Dual-model NH_3 prediction:**
  - ➢ **[NH_3] < 1-2 ppm:** MOX*-based - MiniDOAS Prediction Model
  - ➢ **[NH_3] > in-situ calibration range:** EC**-based – Laboratory Model
- **Increased NH_3 prediction range** (sub-ppm to 50 ppm)

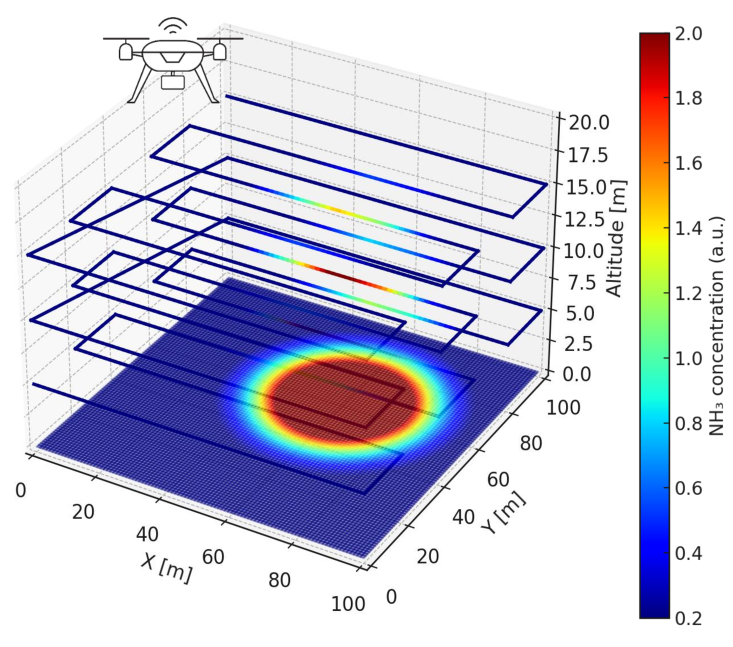

Figure 6: NH_3 plume intensity along drone paths; red = high, blue = low.

* MOX = Metal-Oxide sensor
** EC = Electrochemical sensor

Measurement Perspectives

- Manufacture and deploy 10-20 instruments
- Use mother-daughter calibration network
- Field measurement campaigns in Europe (BE & FR)
- **Drone**-based measurement campaigns
  - ➢ **Unprecedented 3D NH_3 measurements**
- Increase knowledge on small-scale NH_3 variation
  - ➢ Enhance legislation on NH_3 emissions
- Compare with satellite & airplane IR measurements

International Meeting on Chemical Sensors (IMCS) 2025 – June 22-26, 2025 – Freiburg, Germany

This research is part of the Space4ReLaunch project, which is supported by the SPW Economie Emploi Recherche of the Walloon Region, under the grant agreement nr 2210181.