Lab for Measurement Technology

UNIVERSITÄT DES SAARLANDES

ASIC Air Sensors International Conference
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Session 4C: Indoor Sensing for Air Quality and Ventilation Applications

Low-cost high-performance VOC sensor systems: comparison with analytical measurements and long-term stability

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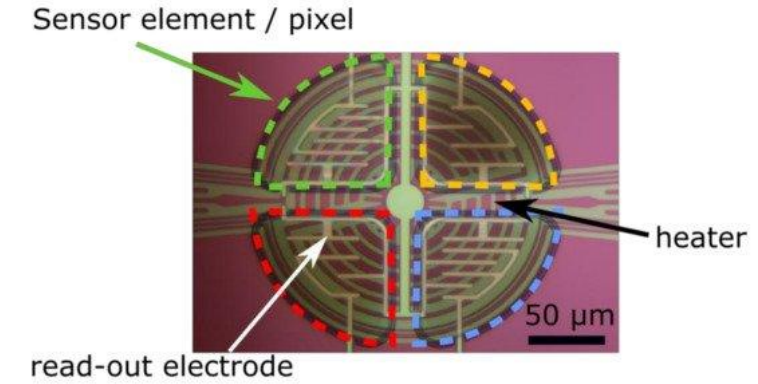
Introduction

Potential and limits of MOS gas sensor systems for IAQ monitoring using:

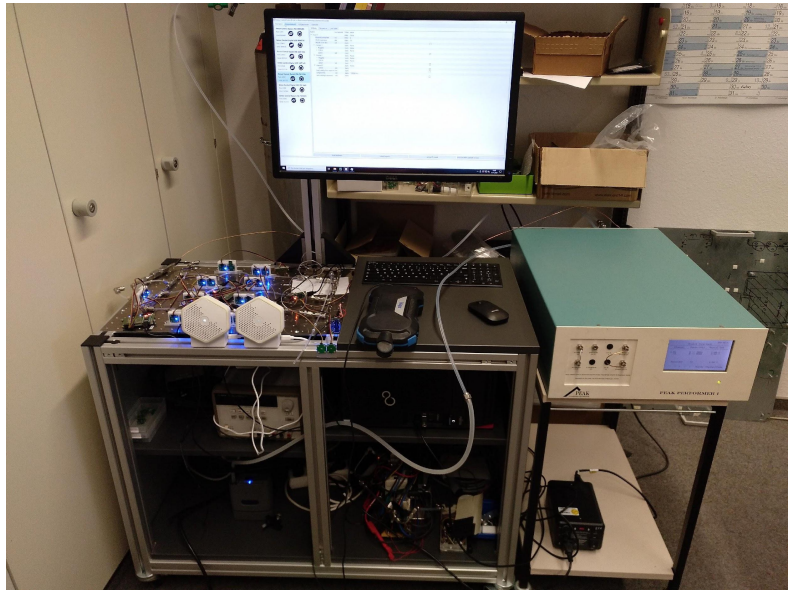
- Temperature cycled operation (TCO)
- Lab calibration with complex randomized gas mixtures
- Data-based models trained with advanced machine learning

Study with several sensors in a typical office environment over a period of more than one year with:

- Reference measurements with analytical systems
- Release tests with VOCs
  - included in the lab calibration
  - additional VOCs



Sensirion SGP30: Rüffer D, Hoehne F, Bühler J. New Digital Metal-Oxide (MOx) Sensor Platform. *Sensors*. 2018; 18(4):1052.



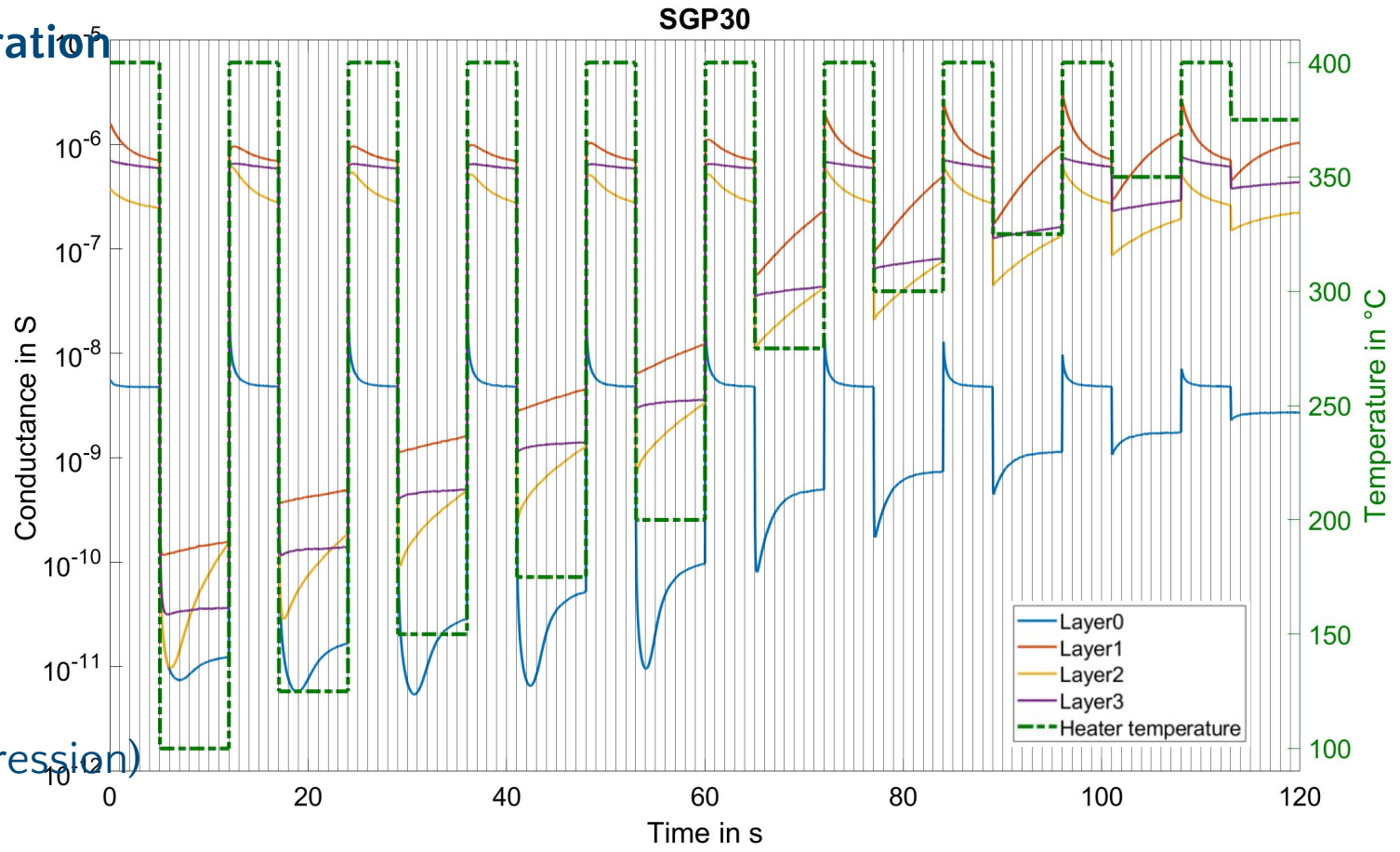
TCO & Data Evaluation

MOS sensors in temperature cycled operation

- Gases from environment react on the surface of a metal oxide
- Reactions are temperature- and material-dependent
  - lead to a change in resistance

Data evaluation

- Divide temperature cycle in 1 second ranges
- Machine learning methods: FESR (**F**eature **E**xtraction, **S**election and **R**egression)

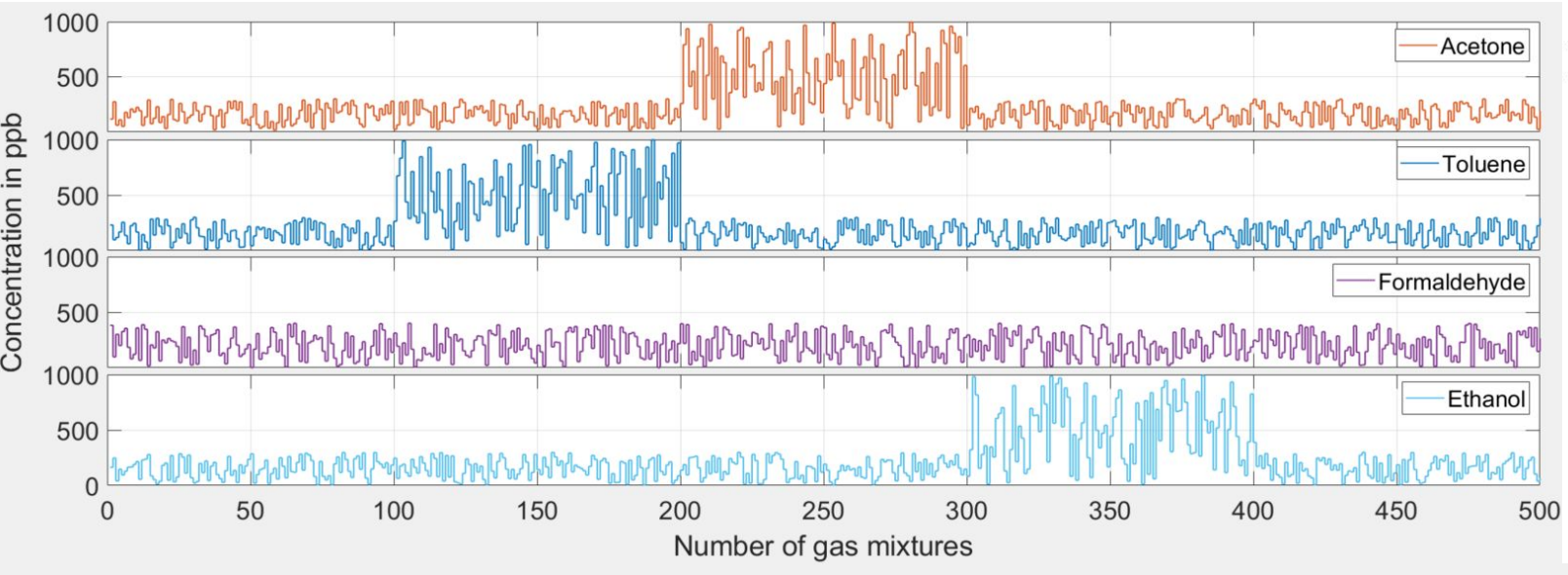


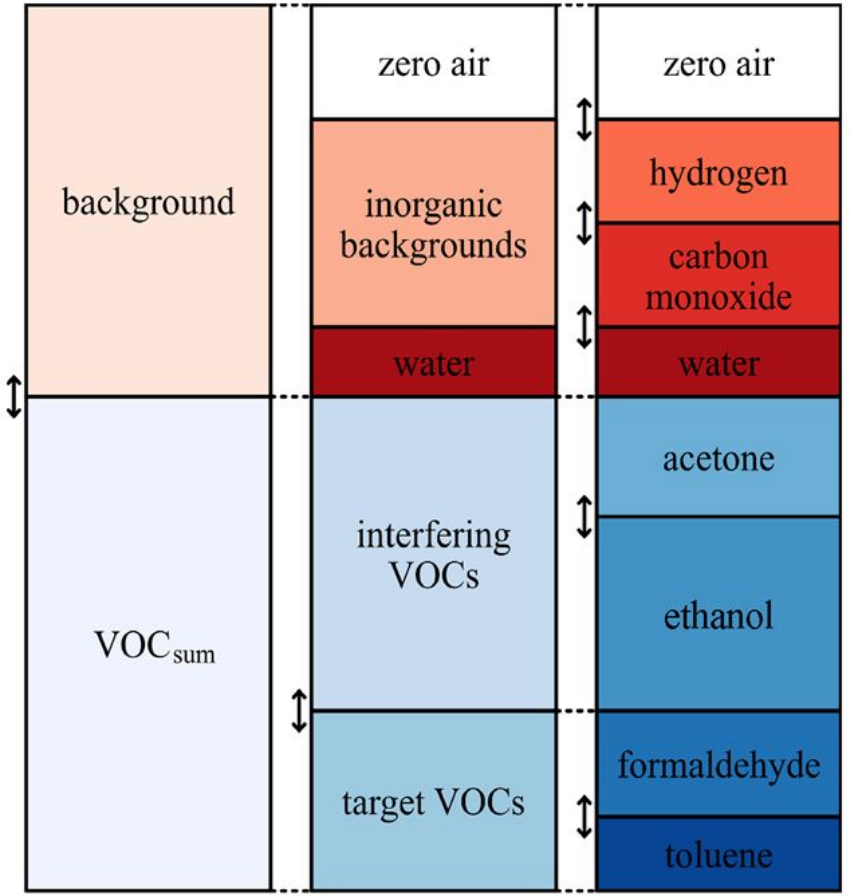
Raw Data → Feature Extraction Mean & Slope → Feature Selection RFE-LSR → Quantification PLS regression

Lab Calibration: Randomized Gas Mixtures

Randomized gas mixtures for simulating IAQ

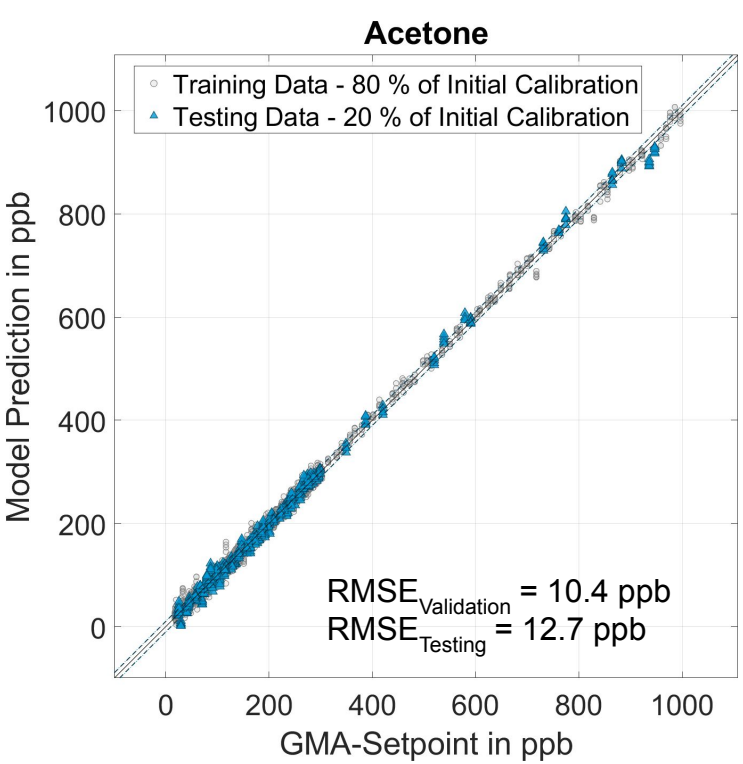
- Gas mixtures consists of:
  - 4 VOCs, one dominant representative per VOC substance group
  - **VOC_{sum}** as an additional target from the sum of the 4 VOCs
  - 2 interfering gases **Hydrogen** (400–2000 ppb), **Carbon monoxide** (150–2000 ppb) & **humidity** (20–70%)

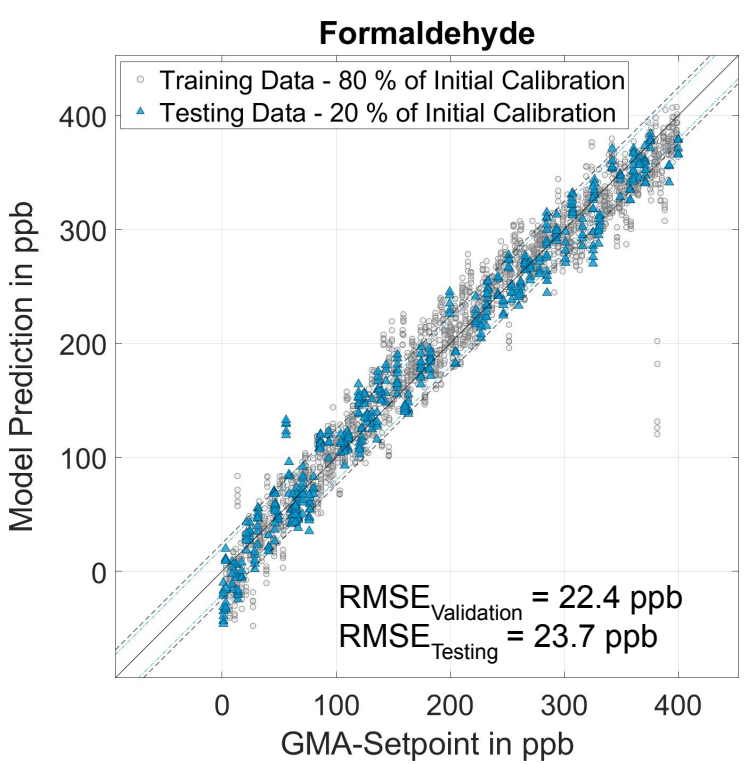


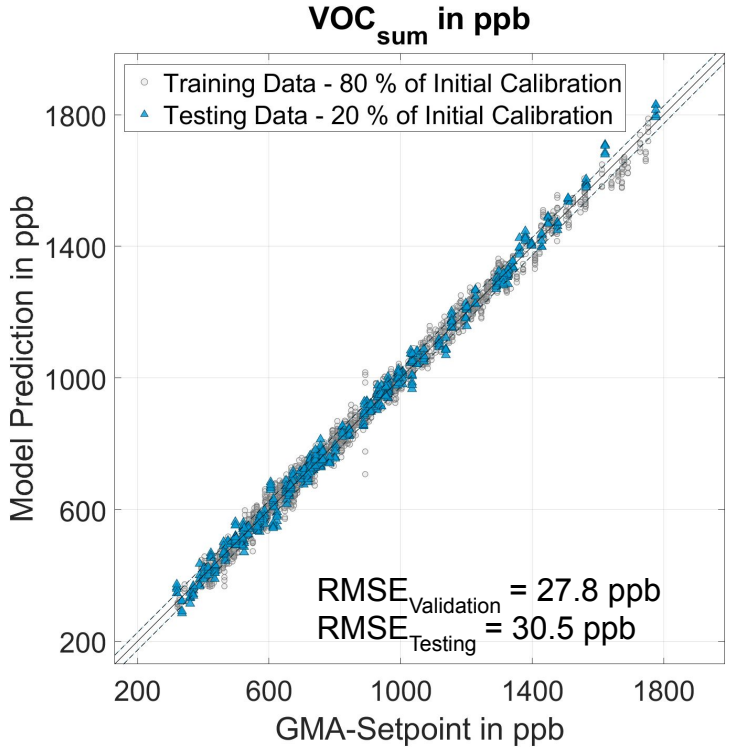


T. Baur et al. Random gas mixtures for efficient gas sensor calibration. *Journal of Sensors and Sensor Systems*, 2020; *9*(2), 411-424.

Lab Calibration: PLSR-Models



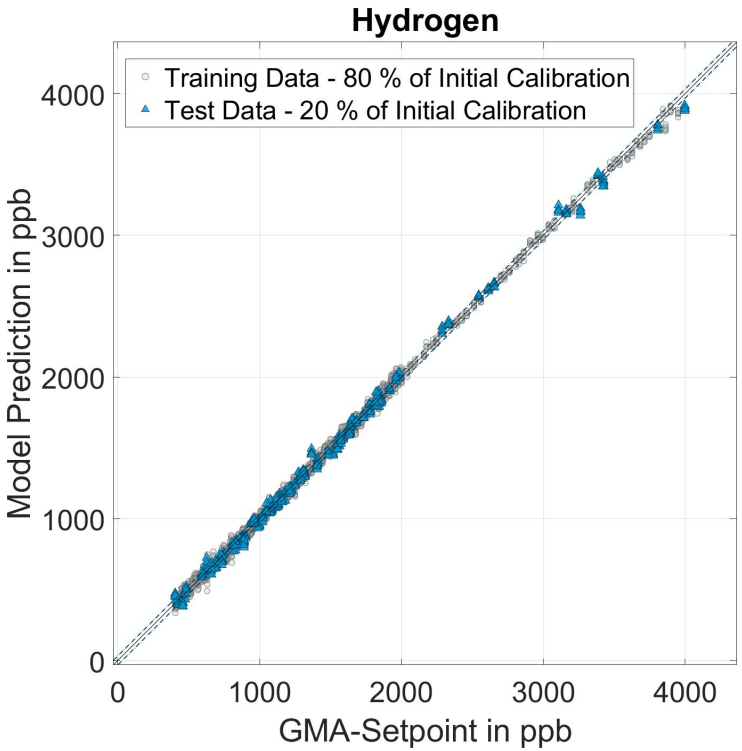




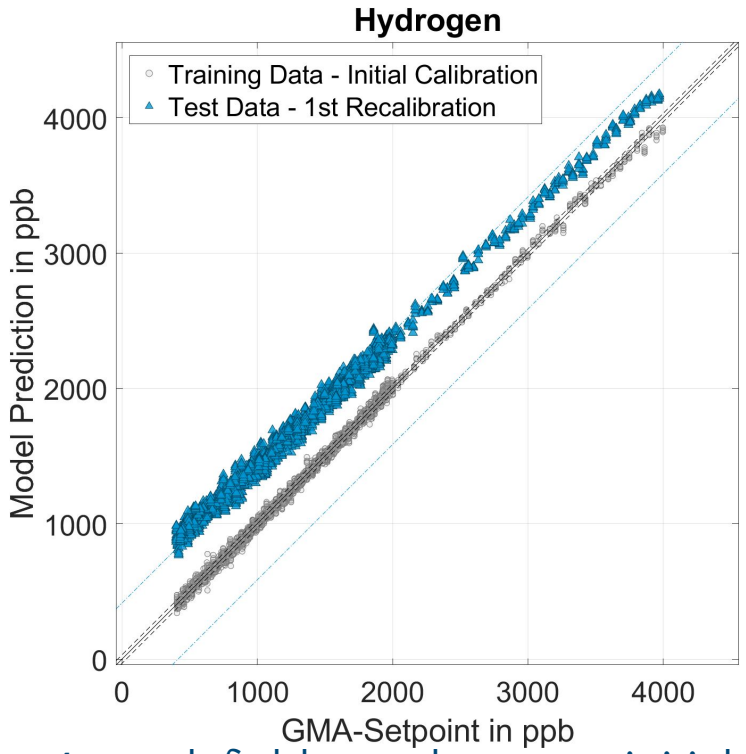
Models for 4 VOCs, 2 interfering gases, humidity and VOC$_{sum}$ derived from a single digital sensor

T. Baur et al. Field Study of Metal Oxide Semiconductor Gas Sensors in Temperature Cycled Operation for Selective VOC Monitoring in Indoor Air. *Atmosphere*. 2021; 12(5):647.

Lab Calibration: Drift Compensation

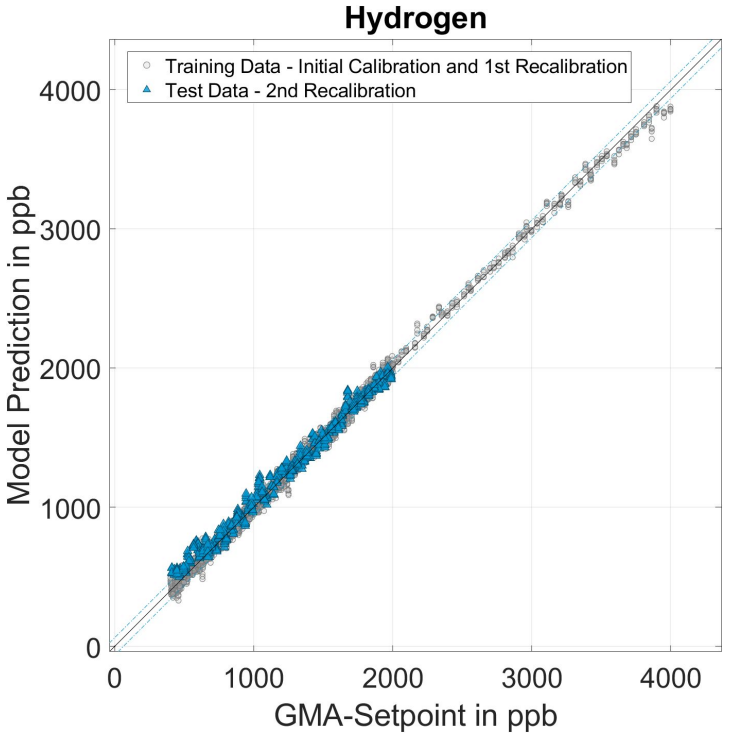


Initial Calibration



4-week field tests between initial calibration and 1st Recalibration

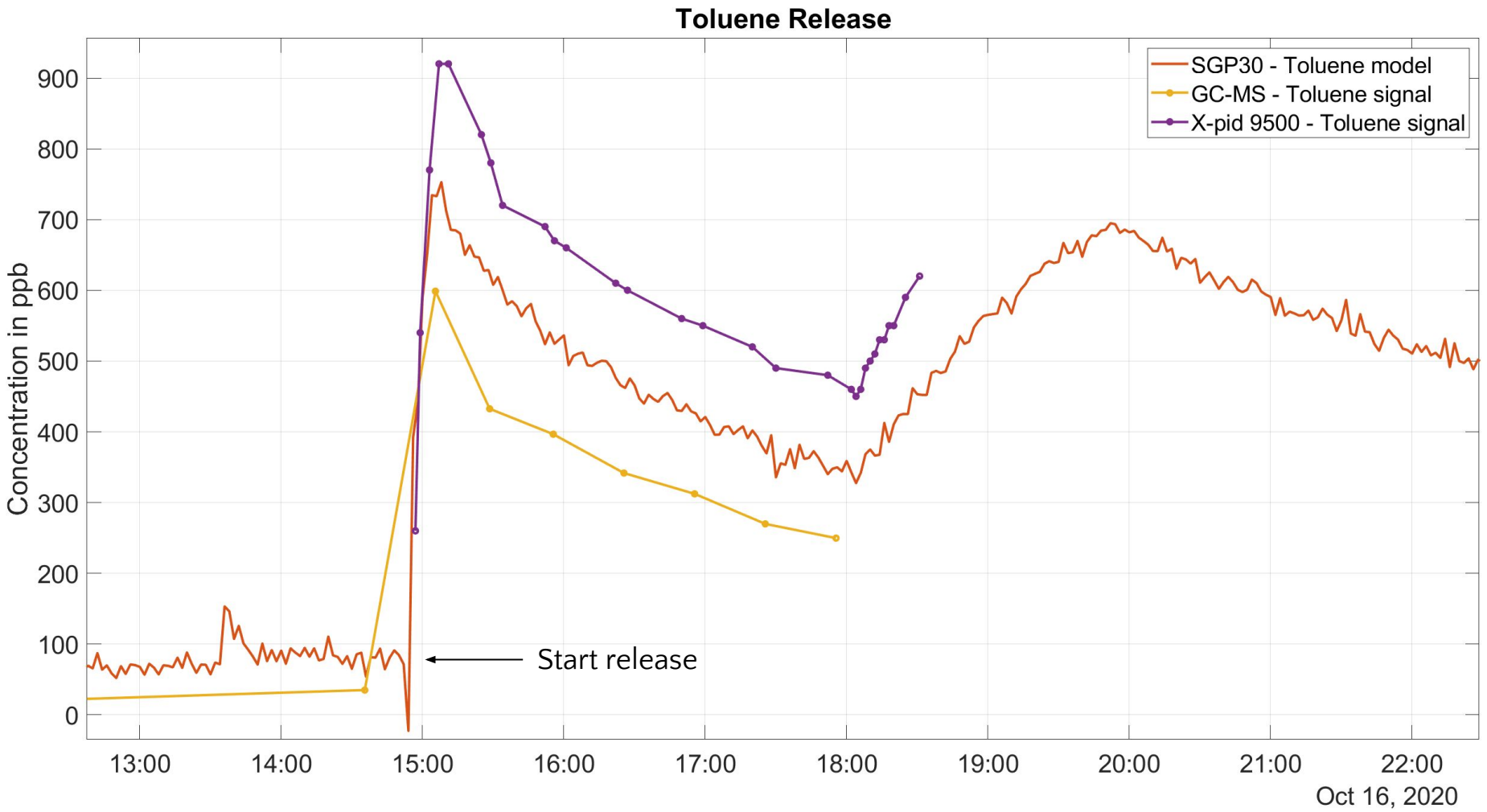
 Drift



Drift compensation through additional training data from 1st Recalibration

C. Schultealbert et al. Measuring Hydrogen in Indoor Air with a Selective Metal Oxide Semiconductor Sensor. *Atmosphere*, 2021; *12*(3), 366.

Release Test: Toluene



Two release tests, each with

0.164 ml Toluene (fast/slow)

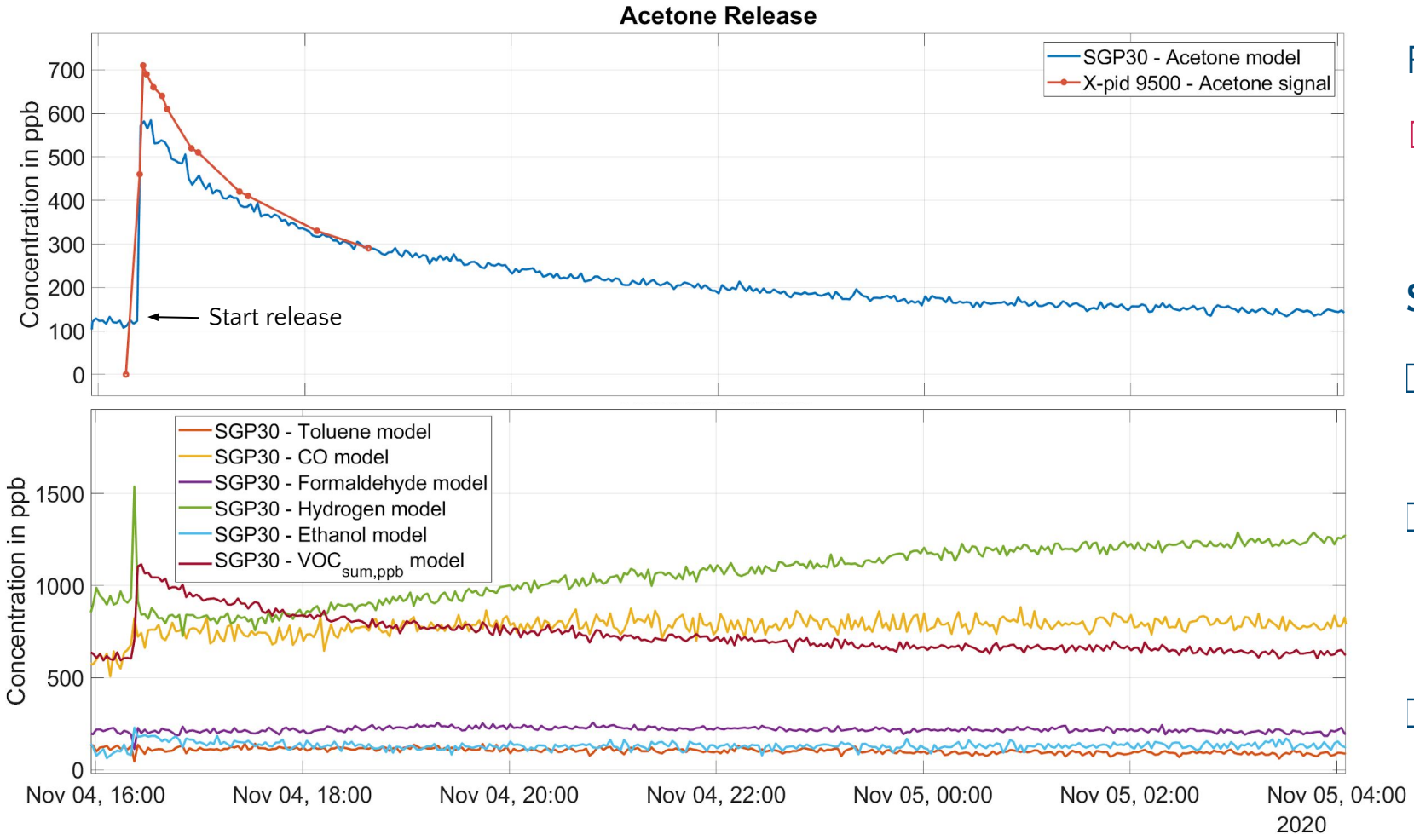
 600 ppb (theoretically)

Selective prediction

- SGP30 Toluene model
  - Signal increase: **670 ppb**
- Analytical measurements
  - GC-MS (Tenax): **563 ppb**
  - GC-PID: **950 ppb** (Dräger X-pid 9500)

T. Baur et al. Field Study of Metal Oxide Semiconductor Gas Sensors in Temperature Cycled Operation for Selective VOC Monitoring in Indoor Air. *Atmosphere*. 2021; 12(5):647.

Release Test: Acetone



Release test with 0.114 ml Acetone

- **600 ppb (theoretically)**

Selective prediction:

- SGP30 Acetone model
  - Signal increase: **460 ppb**
- Analytical measurements
  - X-pid 9500: **710 ppb**
- SGP30 VOC_{sum} model
  - Signal increase: **600 ppb**

T. Baur et al. Field Study of Metal Oxide Semiconductor Gas Sensors in Temperature Cycled Operation for Selective VOC Monitoring in Indoor Air. *Atmosphere*. 2021; 12(5):647.

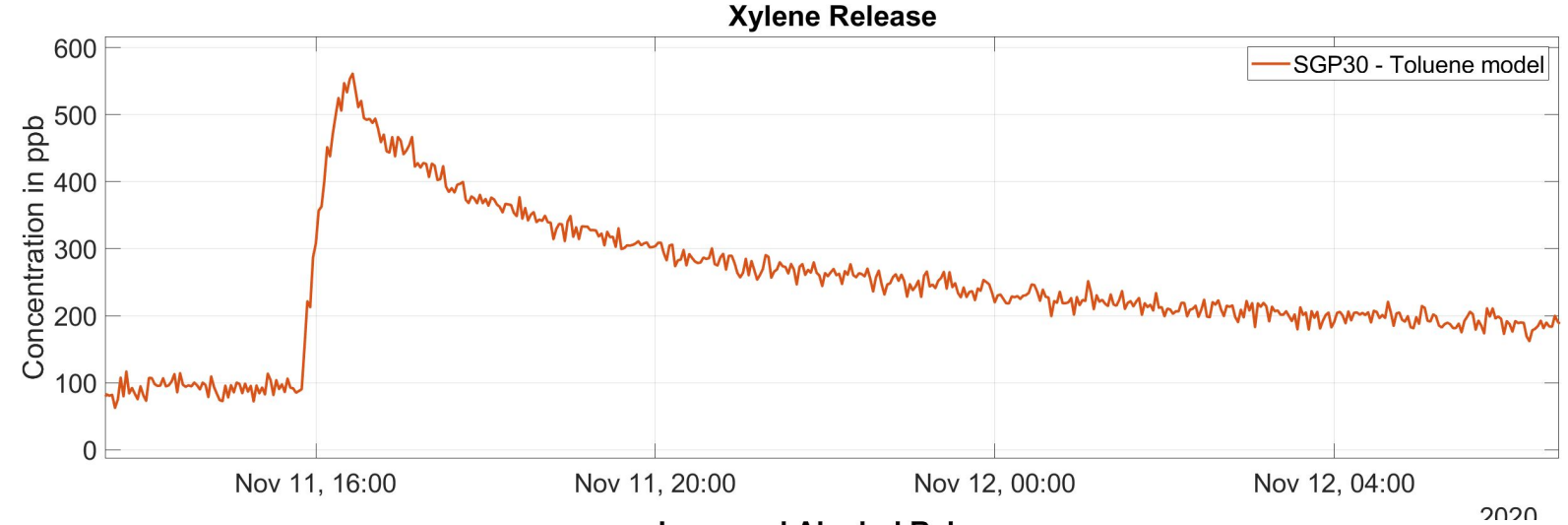
VOC Substance Groups Theory

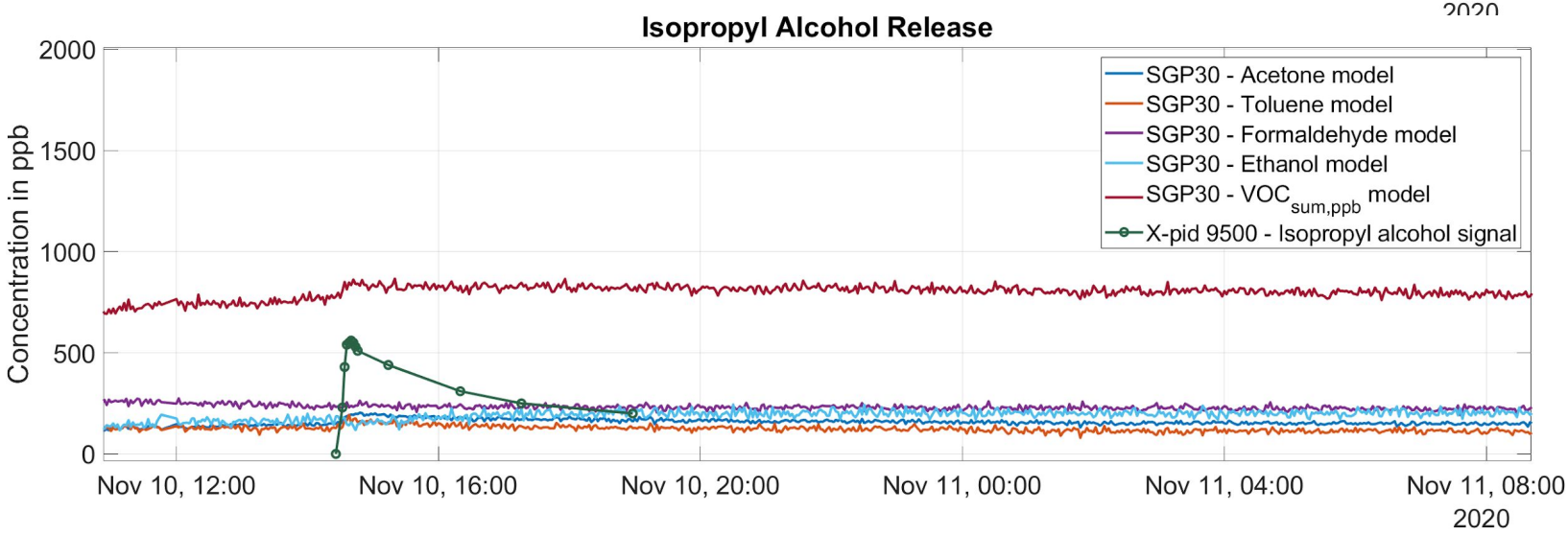
Aromatics

- Toluene (calibration)
- Xylene (release test)
- **Model reacts as a substance group-based signal**

Alcohols

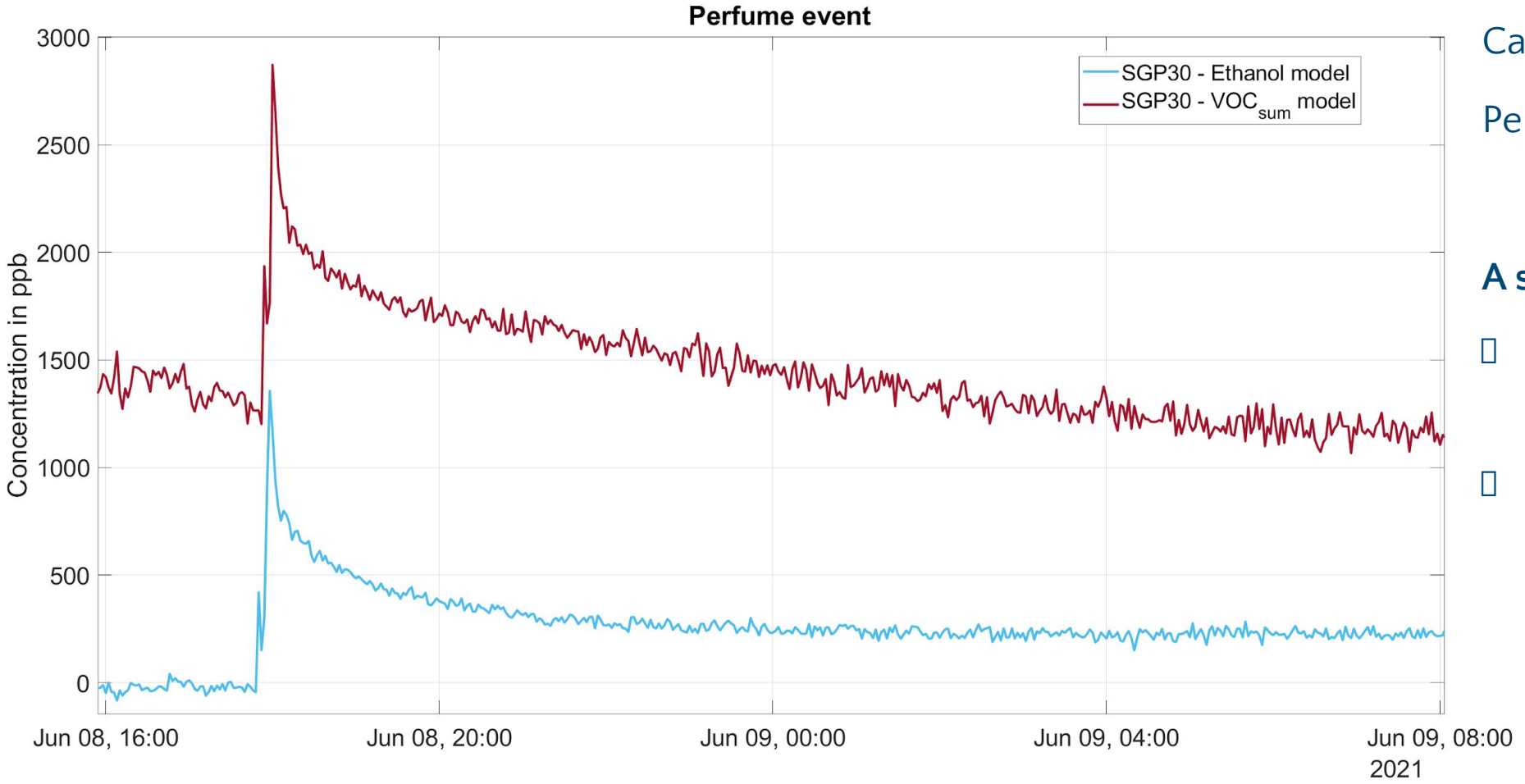
- Ethanol (calibration)
- Isopropyl Alcohol (release test)
- **Ethanol does not react to Isopropyl Alcohol release**





T. Baur et al. Field Study of Metal Oxide Semiconductor Gas Sensors in Temperature Cycled Operation for Selective VOC Monitoring in Indoor Air. *Atmosphere*. 2021; 12(5):647.

Long-Term Stability



Calibration: October 2020

Perfume event: June 2021

A spray of parfum

- Ethanol model increase:
  1380 ppb
- VOC_{sum} model increase:
  1540 ppb

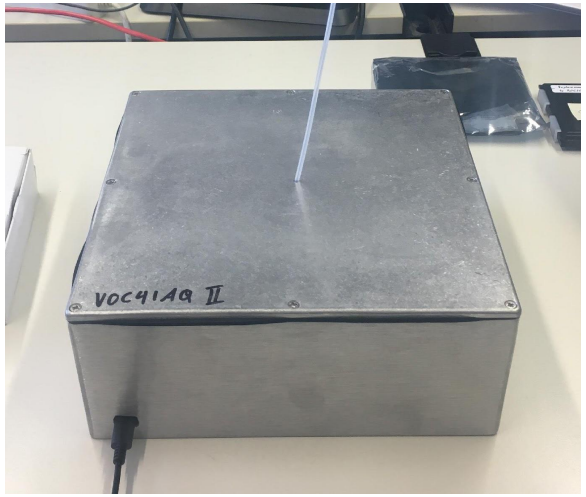
Outlook

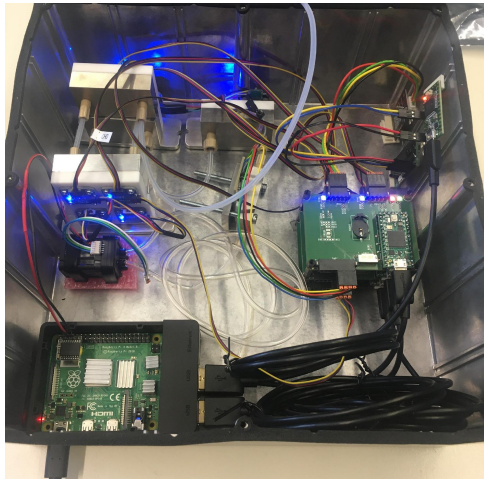
Research project “VOC4IAQ”

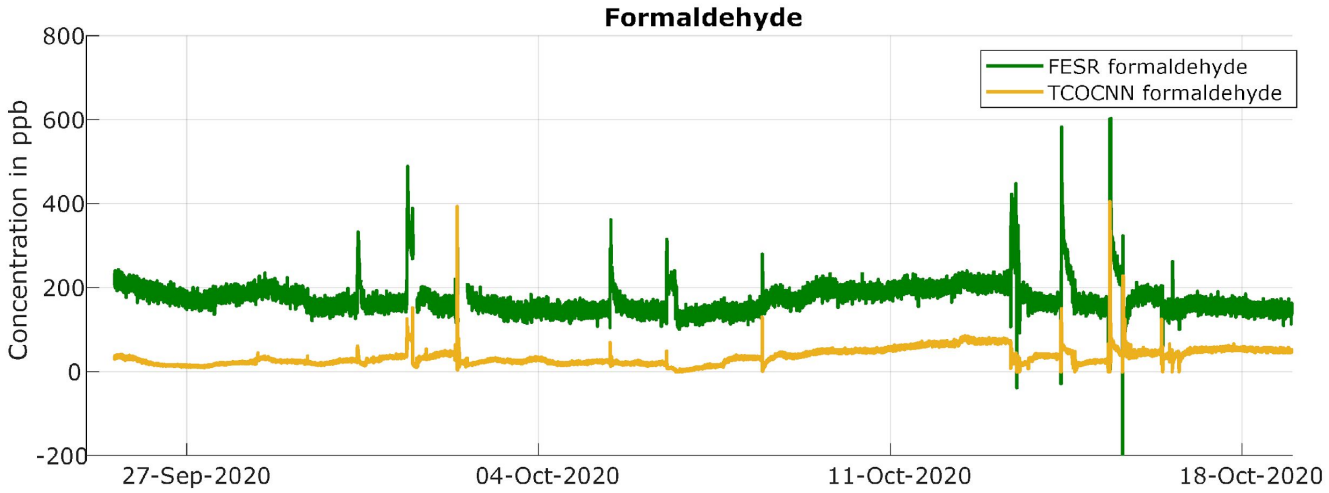
- More extensive lab measurements
  - 11 VOCs + H_2 + CO + humidity
- More realistic field experiments
  - Presence of people
  - Release of hygiene & cleaning products
  - Cooking events

Deep Learning

- TCOCNN 10-layer deep convolutional neu network
  - comparable results as with FESR
  - smaller noise in the field tests







Y. Robin et al. High-Performance VOC Quantification for IAQ Monitoring Using Advanced Sensor Systems and Deep Learning. Atmosphere, 2021; 12(11), 1487.

Backup: VOC_{sum} over Time