

FunSNM Workshop on Enhancing Sensor Network Metrology for Atmospheric Monitoring

Technical workshop report, 28 November 2025

The FunSNM workshop “Enhancing Sensor Network Metrology for Atmospheric Monitoring” was organised to present and critically discuss recent methodological developments, software tools, and applied case studies addressing metrological traceability, uncertainty evaluation, calibration, data quality, and aggregation methods in distributed sensor networks, with a strong focus on air-quality and atmospheric monitoring applications.

The workshop brought together experts from national metrology institutes, European research infrastructures, and academia, reflecting the interdisciplinary nature of sensor network metrology at the intersection of measurement science, statistics, software engineering, and environmental monitoring.

The workshop was opened by Shahin Tabandeh (VTT MIKES), who introduced the Fundamental Principles of Sensor Network Metrology (FunSNM) project, its motivation, and its role within the European Partnership on Metrology. The introduction highlighted the need to move beyond sensor-centric calibration approaches toward network-level, uncertainty-aware methodologies, capable of supporting regulatory and scientific use of sensor network data.

Atmospheric monitoring and regulatory context

The keynote presentation was delivered by Tuukka Petäjä (University of Helsinki / ACTRIS), who provided an overview of recent advancements in atmospheric and air-quality monitoring. His talk placed sensor networks within the broader ACTRIS research infrastructure and addressed upcoming challenges related to the new EU Air Quality Directive, including the implementation of monitoring supersites, harmonised calibration procedures, and quality-assured data flows. The presentation emphasised the increasing demand for high spatial and temporal resolution data and the corresponding metrological challenges.

European Metrology Network perspectives

Three presentations introduced the activities of relevant European Metrology Networks (EMNs):

Francesca Pennechi (INRIM) presented the European Metrology Network for Mathematics and Statistics (EMN MathMet), highlighting the role of advanced statistical methods in uncertainty evaluation, modelling, and data analysis for complex measurement systems.

Céline Pascale (METAS) presented the European Metrology Network for Climate and Ocean Observation (EMN COO), with a focus on traceability, uncertainty, and quality assurance for climate-relevant measurements, including the increasing role of sensor networks.

Nathalie Guigues (LNE) presented the European Metrology Network for Pollution Monitoring (EMN PolMo), outlining ongoing activities related to air-quality measurements, sensor technologies, training, and stakeholder engagement.

Together, these contributions demonstrated strong alignment between FunSNM objectives and EMN priorities, particularly regarding low-cost sensors, network-level non-conventional calibration, and regulatory support.

Correlation and uncertainty in sensor networks

Gertjan Kok (VSL) presented a methodological contribution titled “Accounting for Correlations in Sensor Network Measurements”. The talk addressed the impact of spatially and temporally correlated errors on uncertainty evaluation in sensor networks. Using Gaussian process modelling and real air-quality datasets, the presentation demonstrated that neglecting correlations can lead to significant underestimation of uncertainty in aggregated and interpolated results compared to the case in which all errors are assumed independent. On the other hand, assuming that all sensors are fully correlated and taking a single sensor uncertainty as representative for the uncertainty of, e.g., an average of many sensor readings can lead to an unnecessary conservative uncertainty.

Due to the growing interest in exploring the possibility of using gas and PM sensors for regulatory purposes related to the EU’s revised air quality directive 2024/2881, it becomes essential to carefully define the measurand and assess its uncertainty for measurement results derived from air quality sensor networks.

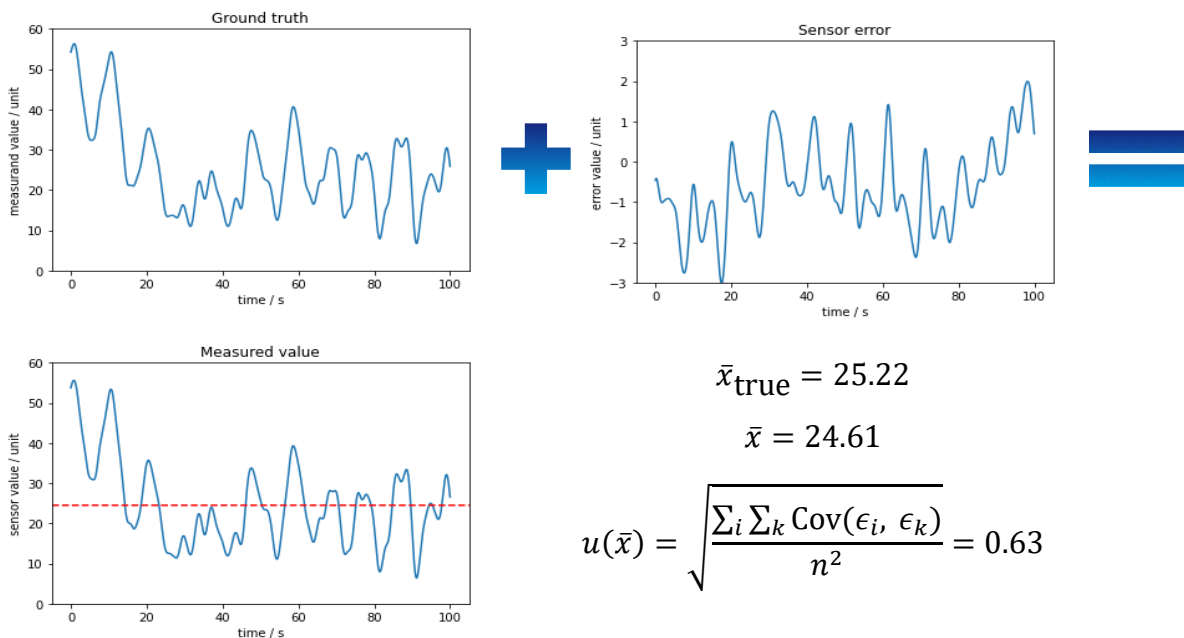


Figure 1: The measured value is the sum of the (true) value of the measurand and the sensor error. Both have their own variations and correlations. For uncertainty evaluation it is essential to take the relevant correlations into account, i.e., the correlations in the sensor errors.

Data quality characteristics for sensor networks

Mads Johansen (FORCE Technology) presented “Data Quality Characteristics for Improved Metrology in Sensor Networks”, focusing on the systematic treatment of data quality dimensions such as completeness, consistency, timeliness, and accuracy. The presentation linked ISO-based data quality concepts with metrological requirements and highlighted the importance of structured metadata for reliable sensor network operation and automated data processing.

Infrastructure requirements for distributed sensor networks

Martin Koval (CMI) addressed infrastructure requirements for metrological distributed sensor networks, discussing practical challenges related to data handling, scalability, communication, and long-term operation. The talk highlighted that metrological robustness must be supported not only by calibration concepts, but also by reliable technical infrastructure.

Software and semantics in sensor network metrology

Anupam Prasad Vedurmudi (PTB) presented “The Role of Software and Semantics in Sensor Network Metrology”, focusing on agent-based systems, automated uncertainty propagation, and semantic representations of sensors, calibration, and data quality. The presentation highlighted the role of machine-interpretable metrological information, including Digital Calibration Certificates (DCCs), as a foundation for scalable and explainable sensor network analysis.

Transferring metrological traceability to sensor networks

Maitane Iturrate-Garcia (METAS) presented “Transferring Metrological Traceability to Sensor Networks”, reviewing calibration strategies for air-quality sensor networks and identifying gaps in current practice. The talk emphasised that classical laboratory calibration is often impractical for large networks and discussed in-situ calibration, co-calibration, portable references, and statistical techniques as viable alternatives, stressing the importance of fit-for-purpose solutions.

Global calibration models for low-cost sensor networks

Miloš Davidović (Vinča Institute of Nuclear Sciences / University of Belgrade) presented “Global Calibration Models for Low-Cost Sensor Networks”, addressing the scalability and cost challenges of frequent recalibration. Using large-scale case studies from Italy and Serbia, the presentation demonstrated that multi-unit global calibration can reduce variability and maintain acceptable performance across large low-cost sensor deployments.

Aggregation of reference, fixed, and mobile sensors

Sébastien Petit (LNE / Airparif) presented a real-world case study titled “Aggregation of Reference Sensors and Fixed and Mobile Low-Cost Sensors”, focusing on air-quality mapping in the Paris region. The presentation demonstrated statistically rigorous aggregation methods that account for correlation, temporal averaging, and uncertainty propagation, enabling the production of high-resolution pollution maps with quantified uncertainty.

AI-based soft sensors for atmospheric monitoring

Hasan Sarwar (University of Helsinki / INAR) presented “ML-Based Soft Sensors for Ozone Estimation”, describing the development and evaluation of machine-learning models using data from multiple reference stations. The presentation highlighted both the potential and limitations of AI-based soft

sensors, particularly regarding cross-site generalisation, representativeness of training data, and uncertainty awareness.

In-situ calibration and system-level approaches

Henrik Söderblom (VTT MIKES), presented “A Laplace-Domain Tool for In-Situ Calibration and Malfunction Detection”. The talk introduced a system-level calibration approach applied to a city-scale sensor network in Helsinki, using Laplace-domain modelling and Monte Carlo uncertainty propagation to address drift detection and over-determined calibration problems under transient conditions.

The workshop demonstrated that sensor network metrology is progressing toward integrated, automated, and system-level methodologies. Key technical challenges identified across presentations include correlated uncertainties, scalable calibration and traceability transfer, uncertainty propagation in AI-based methods, and machine-interpretable information in sensor network metrology. The FunSNM project continues to address these challenges through coordinated methodological development, software tools, and applied demonstrations, contributing to the establishment of robust metrological foundations for sensor networks.