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From software-assisted predictions to hardware-driven observations: advancing independent air quality sensor measurements

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Low-cost air quality sensors are rapidly expanding observational capacity worldwide, particularly in regions with limited regulatory monitoring. However, increasing reliance on complex and often opaque data processing algorithms has blurred the boundary between “true” measurements and model-derived products, complicating data interpretation, comparability, and fitness-for-purpose assessments. Current performance standards largely focus on accuracy metrics, while providing limited guidance on transparency, traceability, and the nature of the underlying data-generating process (DGP).

Here, we present a conceptual and operational framework to classify sensor-derived data products based on their DGP and degree of measurement independence. Building on metrological principles and recent discussions on sensor processing levels, we introduce a formal definition of Independent Sensor Measurements (ISM), supported by five minimum criteria addressing signal dominance, admissible corrections, contemporaneity, signal provenance, and model independence from local data infrastructure. The framework distinguishes independent measurements from non-independent measurements and predictive products, and maps these categories onto an extended processing-level classification scheme.

The proposed classification enables users, manufacturers, and standardization bodies to more transparently communicate what a sensor product actually represents, supporting more appropriate data use, comparability across sites, and informed technology selection.

This work provides the foundation for integrating transparency and traceability into future sensor standards, incentivizing hardware-driven improvements, and strengthening the credibility of sensor deployments in regulatory, research, and community applications, particularly in low- and middle-income regions.

References:

Diez, S. *et al.* A framework for advancing independent air quality sensor measurements via transparent data generating process classification. *npj Clim Atmos Sci* 8, 285 (2025). <https://doi.org/10.1038/s41612-025-01161-2>