AIR POLLUTION CONFERENCE BRAZIL
CMAS SOUTH AMERICA
COMMUNITY MODELING AND ANALYSIS SYSTEM

NEGATIVE READINGS IN CONTINUOUS PARTICULATE MATTER MONITORING: MEASUREMENT UNCERTAINTY ASSESSMENT AND DATA VALIDATION THRESHOLD DEFINITION

Kevin da Silva Coelho[1]*, Larissa Lucas Barros[2]*, Igor de Morais Gomes[3]*, Adrielle Luiza Vieira de Melo[4]*, Andler Magno Vieira de Melo[5]*, Karinnie Nascimento de Almeida[6]* and Huiner Reis Araujo[7]*
[1]*kevin.coelho@aires.com.br*
[2]*larissa.barros@aires.com.br*
[3]*igor.gomes@aires.com.br*
[4]*adrielle.melo@aires.com.br*
[5]*andler.melo@aires.com.br*
[6]*karinnie.nascimento@aires.com.br*
[7]*huiner.araujo@aires.com.br*
**Aires Serviços Ambientais*

Abstract: Continuous particulate matter (PM) analyzers routinely report negative hourly concentrations. Although physically impossible as absolute values, such records are metrologically expected near zero, and their handling determines whether reported means are biased or whether genuine instrumental failures survive validation. This study applies and adapts the framework of Jiang et al. (2023), grounded in the GUM, to nine PM series ($PM_{2.5}$, PM_{10} and TSP; 140,270 valid hourly records) measured by BAM 1020, TEOM 1405, TEOM 1405-D and Thermo 5028i analyzers. Expanded uncertainties (k = 2) were estimated for each instrument, and six candidate thresholds (−2.5 to −20.0 µg m^{-3}) were applied to quantify data loss and annual means assessed against CONAMA Resolution No. 506/2024. Expanded uncertainties ranged from ±2.41 to ±3.70 µg m^{-3}, negative readings accounted for 0.15–2.99% of the records, and annual means proved almost insensitive to the threshold (maximum deviation 4.4%), whereas data loss was highly sensitive. A unified threshold of −3.0 µg m^{-3} is recommended: it is anchored to the expanded uncertainty of the instrument set, keeps data loss below 1% in seven of the nine series, and avoids the more permissive −10.0 µg m^{-3} adopted in some jurisdictions, which would retain records of clearly anomalous magnitude.

Keywords: particulate matter, negative readings, measurement uncertainty, GUM, data validation

INTRODUCTION

Continuous monitoring of particulate matter (PM) underpins air quality management and public health protection. The inhalable fractions PM_{10} and $PM_{2.5}$ are consistently associated with cardiorespiratory morbidity and premature mortality (WHO, 2021; Pope III and Dockery, 2006). In Brazil, CONAMA Resolution No. 506/2024 defines the national compliance standards and retains total suspended particles (TSP) as an auxiliary parameter, still relevant in industrial and licensing contexts.

Automatic PM analyzers — beta attenuation monitors (BAM), tapered element oscillating microbalances (TEOM) and hybrid systems — routinely record negative hourly concentrations. These readings arise from the combination of instrumental noise, measurement uncertainty near zero, very clean air, loss of semi-volatile species and operational variations in flow rate, temperature and pressure (Jiang et al., 2023; Thermo Scientific, 2016). Their treatment is not standardized: truncating them to zero introduces a positive bias in reported means, whereas accepting them uncritically may allow records associated with real instrumental failures to survive data validation. International practice ranges from −10.0 µg m^{-3} in the US EPA/AQS validation system to −4.99 µg m^{-3} in dissemination platforms such as AirNow (Jiang et al., 2023), and Brazilian networks lack an explicit, metrologically justified criterion.

This work therefore aims to (i) estimate the expanded measurement uncertainty (k = 2) of four PM analyzers operating in Brazilian networks, following GUM principles; (ii) quantify the impact of candidate invalidation thresholds on data loss and on the compliance metrics of CONAMA Resolution No. 506/2024; and (iii) propose a unified, technically defensible threshold for the routine treatment of negative hourly readings of $PM_{2.5}$, PM_{10} and TSP.

METHODS

Datasets. Nine hourly series from four monitoring projects operated in Brazil were analyzed, totaling 140,270 valid hourly records. Four analyzer models are represented: Met One BAM 1020 (beta attenuation; Met One Instruments, 2013), Thermo Scientific TEOM 1405 (TSP) and TEOM 1405-D (dichotomous, PM_{10} and $PM_{2.5}$), both operating without FDMS (Thermo Scientific, 2008), and Thermo Scientific 5028i (beta attenuation with nephelometric correction; Thermo Scientific, 2012).

Measurement uncertainty. Uncertainty was estimated following JCGM 100:2008 (GUM) under a conservative scenario centered on concentrations

close to zero, the critical condition for defining thresholds for negative values. For each instrument the relevant sources — instrument precision, sample flow rate, temperature and pressure correction, size-selective inlet efficiency and, for the 5028i, the nephelometric correction — were converted into standard uncertainties using the divisor of the assumed distribution (1.732 for rectangular, 2.000 for normal), combined in quadrature ($u_c^2 = \Sigma u_i^2$) and expanded as $U = k \cdot u_c$ with $k = 2$ (≈ 95% confidence).

Threshold impact assessment. Six candidate thresholds (−2.5, −3.0, −5.0, −10.0, −15.0 and −20.0 µg m^{-3}) were applied to each hourly series. Records below the threshold were invalidated and, for every scenario, three metrics were computed: (i) the data loss rate, as the percentage of hourly records invalidated; (ii) the arithmetic annual mean, built from daily means with at least 75% valid hours; and (iii) the number of exceedances of the 24-h standards of CONAMA Resolution No. 506/2024. The final criterion balanced the inflection (scree) point of the data-loss curve, the estimated expanded uncertainty and the conservative validation practice of Brazilian environmental agencies.

FINDINGS AND ARGUMENT

Table 1. Monitoring series, instruments and occurrence of negative hourly readings.

Series	Pollutant	Instrument	Negative (%)	U (k=2, µg m^{-3})
1	PM_{10}	BAM 1020	0.164	±2.41
2	PM_{10}	BAM 1020	0.146	±2.41
3	$PM_{2.5}$	BAM 1020	0.427	±2.41
4	$PM_{2.5}$	BAM 1020	0.450	±2.41
5	PM_{10}	TEOM 1405-D	0.918	±3.34
6	$PM_{2.5}$	TEOM 1405-D	1.814	±3.34
7	TSP	TEOM 1405	0.204	±3.70
8	PM_{10}	5028i	0.313	±2.97
9	$PM_{2.5}$	5028i	2.986	±2.97

Expanded uncertainty. The GUM budgets yielded U = ±2.41 µg m^{-3} for the BAM 1020, ±3.34 µg m^{-3} for the TEOM 1405-D, ±3.70 µg m^{-3} for the TEOM 1405 applied to TSP and ±2.97 µg m^{-3} for the 5028i. Instrument precision dominated every budget; beyond it, the TSP inlet efficiency was the second largest term for the TEOM 1405 (u_i = 0.58 µg m^{-3}) and the nephelometric correction for the 5028i (u_i = 0.87 µg m^{-3}). The admissible band around zero is therefore not uniform, and the largest value, ±3.70 µg m^{-3}, sets the scale below which a negative reading cannot be distinguished from noise.

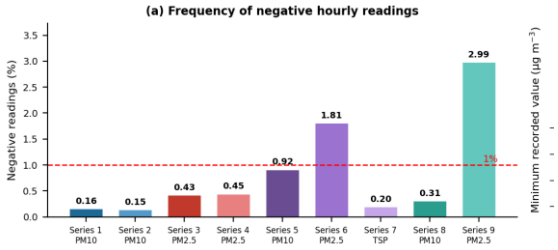


Figure 1. Negative hourly readings by series: frequency, as a percentage of valid records.

Frequency and magnitude are decoupled. Negative readings ranged from 0.15% (Series 2, PM_{10}) to 2.99% (Series 9, $PM_{2.5}$) of valid records (Figure 1). The BAM 1020 series were the most stable (0.15-0.45%), consistent with their lowest expanded uncertainty, and $PM_{2.5}$ exceeded PM_{10} for every instrument — expected, since $PM_{2.5}$ concentrations are lower and more exposed to near-zero noise. Frequency alone, however, is a poor diagnostic: Series 7 (TSP) combines one of the lowest frequencies (0.20%) with the most extreme minimum of the set (−176.9 µg m^{-3}), and Series 5 and 6, measured at the same site, reach about −150 µg m^{-3} — nearly fifty times the largest expanded uncertainty. Such magnitudes point to instrumental failure or sampling instability, precisely what an uncertainty-anchored threshold must isolate.

Table 2. Data loss rate (%) by series and candidate threshold (µg m^{-3}).

Series	−2.5	−3.0	−5.0	−10.0	−15.0	−20.0
1	0.158	0.132	0.058	0.021	0.000	0.000
2	0.136	0.136	0.088	0.049	0.000	0.000
3	0.363	0.281	0.000	0.000	0.000	0.000
4	0.171	0.123	0.041	0.007	0.000	0.000
5	0.675	0.644	0.493	0.280	0.208	0.151
6	1.599	1.402	0.862	0.327	0.187	0.135
7	0.156	0.156	0.151	0.119	0.109	0.083
8	0.186	0.177	0.110	0.025	0.000	0.000
9	2.577	2.248	1.225	0.296	0.110	0.042

Data loss is the sensitive metric; the annual mean is not. Loss falls steeply between −2.5 and −5.0 µg m^{-3} in the most sensitive series and then flattens (Figure 2, Table 2): Series 9 goes from 2.577% to 2.248% at −3.0, 1.225% at −5.0 and 0.296% at −10.0 µg m^{-3}, and Series 6 from 1.599% to 1.402%, 0.862% and 0.327%. Series 1, 2 and 8 remain below 0.2% at any threshold. At −3.0 µg m^{-3}, seven of the nine series lose less than 1% of their records; only Series 6 and Series 9 — both $PM_{2.5}$ — exceed that reference, and in both cases the loss reflects a genuine concentration of negative readings just beyond the uncertainty band rather than an over-restrictive criterion.

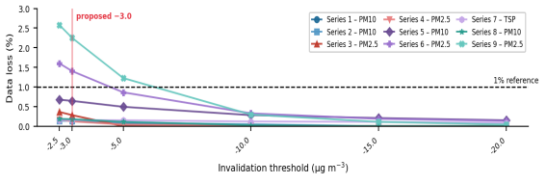


Figure 2. Data loss rate as a function of the invalidation threshold.

Annual means behaved very differently (Figure 3): taking the −20.0 µg m^{-3} scenario as reference, the deviation stays below 0.6% in seven series, and the largest values — 2.5% for Series 6 and 4.4% for Series 9 — occur at the most restrictive threshold and correspond to less than 0.4 µg m^{-3} in absolute terms. Every series remained below the annual standards of CONAMA Resolution No. 506/2024 under all thresholds tested, and the number of 24-h exceedances was unchanged. The threshold therefore does not alter the regulatory conclusion here; it must be decided on metrological grounds and on preserving temporal representativeness.

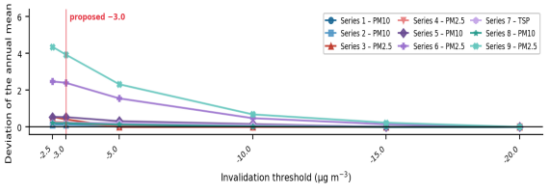


Figure 3. Sensitivity of the annual mean to the invalidation threshold, expressed as the deviation relative to the −20.0 µg m^{-3} scenario.

Selecting the criterion. The −10.0 µg m^{-3} threshold recommended by Jiang et al. (2023) for New South Wales minimizes data loss, but it is about 2.7 times the largest expanded uncertainty estimated here and would absorb, as ordinary variability, records far outside instrumental capability. Conversely, −2.5 µg m^{-3} lies below the expanded uncertainty of three of the four instruments and would invalidate readings compatible with their own noise. A threshold of −3.0 µg m^{-3} falls within the estimated uncertainty range (±2.41 to ±3.70 µg m^{-3}) — the same order as instrumental noise — while remaining restrictive enough to flag records of clearly anomalous magnitude, in line with the conservative validation practice of the Brazilian regulatory context.

CONCLUSIONS

Negative hourly readings should not be treated as instrumental failure by default: part of them are compatible with the behavior expected from analyzers operating near the detection limit. The expanded uncertainties obtained here, from ±2.41 to ±3.70 µg m^{-3}, show that the admissible band around zero depends on the measurement principle and on the monitored fraction, being narrowest for the BAM 1020 and widest for the TEOM 1405 applied to TSP.

Across the nine series, data loss was the metric most sensitive to the invalidation criterion, while annual means and exceedance counts were essentially unaffected. A unified threshold of −3.0 µg m^{-3} is recommended for $PM_{2.5}$, PM_{10} and TSP: hourly records below −3.0 µg m^{-3} should be invalidated; records between −3.0 and 0.0 µg m^{-3} should be retained but converted to zero for reporting, reconciling the metrological interpretation with the institutional practice of not publishing negative concentrations; and recurrent or extreme events, such as those in Series 5 to 7, should trigger investigation of instrument logs, maintenance records and meteorological conditions.

The recommendation derives from four analyzer models and a limited range of environmental conditions. Extending it to coastal, high-humidity sites, FDMS-equipped instruments and zero-air test campaigns — the step of the original protocol not reproduced here — would allow empirical verification.

REFERENCES

CONAMA – Conselho Nacional do Meio Ambiente. Resolução nº 506, de 5 de julho de 2024: estabelece padrões nacionais de qualidade do ar e fornece diretrizes para a sua aplicação. Brasília: Ministério do Meio Ambiente, 2024.

JCGM – Joint Committee for Guides in Metrology. Evaluation of Measurement Data: Guide to the Expression of Uncertainty in Measurement. JCGM 100:2008. Sèvres: BIPM, 2008.

Jiang, Ningbo, Matthew Riley, Stephen White, Yvonne Scorgie, and Toan Trieu. "On Thresholds for Controlling Negative Particle (PM2.5) Readings in Air Quality Reporting." Environmental Monitoring and Assessment 195 (2023): 1187. https://doi.org/10.1007/s10661-023-11750-8

Met One Instruments. BAM-1020 Beta Attenuation Mass Monitor Operation Manual. Grants Pass, OR: Met One Instruments, 2013.

Pope III, C. Arden, and Douglas W. Dockery. "Health Effects of Fine Particulate Air Pollution: Lines That Connect." Journal of the Air & Waste Management Association 56 (2006): 709–742.

Thermo Scientific. Model 1405 Dichotomous Ambient Particulate Sampler: Instruction Manual. Franklin, MA: Thermo Fisher Scientific, 2008.

Thermo Scientific. 5028i Particulate Monitor Instruction Manual. Franklin, MA: Thermo Fisher Scientific, 2012.

Thermo Scientific. Mass Calculations for the Various Configurations. Technical Bulletin TS0066, Rev. 07/2016. Franklin, MA, 2016.

WHO – World Health Organization. WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. Geneva: WHO, 2021.