Referee comments

Black colour is used for Referee statements

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Frequent new particle formation events in the Indo-Gangetic Plain occur under reduced condensation sink but are obscured by air mass heterogeneity

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Status: open (until 27 Jul 2026)

Comment types: AC – author | RC – referee | CC – community | EC – editor | CEC – chief editor

Referee: 1

RC1: 'Comment on egusphere-2026-2212', Anonymous Referee #1, 22 Jun 2026 reply

General assessment

Srivastav present PNSD measurements across almost a year in the IGP, focusing on the occurrence of NPF events. These are valuable data. India has some of the worst air quality on the planet, and the question of whether secondary formation contributes meaningfully to particle number there is not answered. In China it turned out to matter a great deal, and a well-characterised sub–10 nm dataset from a suburban IGP site is highly valuable. In this context, I think this dataset is worth publishing.

My main concern is one of framing. As it stands, the manuscript reads as though it's working quite hard to present a clean, finished story, and in doing so it skirts around some real limitations in the dataset (data coverage, SMPS availability, pollution contamination of the growth). My view is that being upfront about those limitations would make this a stronger paper, not a weaker one. I'd encourage the authors to lean into that rather than away from it.

The points below are split into a few major issues that I think need resolving before publication, then specific comments, then a general note on the writing.

Response:

We thank the referee for this exceptionally careful, balanced and constructive assessment. We agree that the earlier manuscript did not clearly articulate the limitation of measurements. We have therefore revised the manuscript to clearly represent the concurrent NAIS-SMPS data used for condensation sink and formation-rate calculations. This change is central to the revised manuscript framing. We have responded below in detail to each comment.

Major issues

Major comment 1: SMPS data availability

This is my biggest concern. Late in the paper (Sect. 3.2.2) it emerges that SMPS data overlapping with the NAIS were available for only ~11 NPF days, of which 3 were usable.

This is also clear if the reader is savvy as it is mentioned in sect. 2.3 ("Data for the above 40 nm diameter range from SMPS were available for only a few days (mention in table T1)", and viewing T1 only shows three events, but this is far from clear!

The condensation sink, the coagulation sink, and the formation rates all require the full size distribution out to the accumulation mode and in a polluted environment CS and CoagS are dominated by the >40 nm particles that only the SMPS sees. So I would strongly encourage the authors to state, explicitly and early:

- For how many days, and which days, is the SMPS actually available?
- Is the event-day vs non-event CS comparison (the 0.024 vs 0.046 /s result that the title and abstract are built on) computed over the full record, or only over those few SMPS days?

If the CS conclusion rests on three days, then I'm afraid the central claim of the paper isn't currently supported and needs to be either properly substantiated or removed. If the SMPS coverage is a bit thin, one honest option is to reframe this as a NAIS-led paper, present CS/CoagS/J only for the days where they're defensible (clearly flagged as such), and be explicit that "total particles" actually means "sub 40 nm particles" everywhere the SMPS is absent. None of that is fatal to the paper but the current presentation implies a completeness the data may not have.

Response:

We agree that this information could have been stated more explicitly and early in the manuscript. A data-availability calendar was included as Fig. S1 in the supplementary material, but now we have made it clearer in the manuscript as well. In the revised manuscript, Sect. 2.3 now gives the analysis-specific data coverage before the derived NPF parameters are discussed.

The NAIS-based classification is based on 108 valid NAIS days. However, SMPS measurements were available for a limited part of the campaign, mainly during August-November 2023. Therefore, the concurrent NAIS-SMPS classified days were much more limited: 26 days in total (event + nonevent).

Among these 26 concurrent days, 11 days were classified as NAIS event days and 15 as NAIS non-event days. Of the 11 concurrent NAIS-event days, two days (6 September and 16 October 2023) were flagged as ambiguous/disagreement cases because the SMPS-size distribution did not support a clean event-day interpretation; these two days were therefore not included in the strict event/non-event CS comparison.

Category	n days	Dates
Concurrent NAIS-SMPS days	26	17, 18, 19 August; 6, 7, 9, 10 September; 3, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 27, 28, 29, 30, 31 October; and 1 November 2023
NAIS event days with available SMPS data	11	17 and 18 August; 6 September; and 3, 6, 7, 8, 9, 15, 16, and 17 October 2023
NAIS non-event days with SMPS	15	19 August; 7, 9, and 10 September; 5, 10, 12, 13, 14, 27, 28, 29, 30, and 31 October; and 1 November 2023

Disagreement days (NAIS event days but SMPS non-event days)	2	6 September and 16 October 2023

We now state clearly that the event-day versus non-event-day CS comparison is not calculated from the full 108-day NAIS classification record. CS requires larger particle-size distribution and was therefore calculated only for concurrent NAIS-SMPS size distribution (~2.5-570 nm). As clear from the summary table above, 9 event days and 15 non-event days were used for CS calculation, with daily CS summarised over 06:00-12:00 LT. Therefore, the CS results are presented as limited concurrent data analysis, not as a seasonal or campaign-wide average.

Determining particle formation rate J is not limited only by availability of SMPS data, but also by limited availability of reliable particle growth rate (GR). Growth rate (GR) is calculated from NAIS data by manual inspection for each day and results successfully retrieved 17 days are presented in the supplement Fig. S6. The fitting curves are also presented in Fig. S7 for readers' assessment.

Formation rates were calculated only for a smaller subset of data for which all terms including dN/dt, CS, and the growth-out-of-range term, could be determined reliably. This led to three event case-study days (common days from NAIS-SMPS and GR calculation). We do not intend to present these J values as seasonal or regional averages.

In Sect. 2.2.1, p. 5, lines 156-160, we have revised the wording to explicitly define "total particles" and "ions" as two separate NAIS measurement channels: total particles refers to the NAIS particle-mode measurement (2.5–42 nm), and ions refers separately to the NAIS ion-mode measurement of naturally charged particles (0.8–42 nm). This removes the earlier ambiguity and makes clear that the text does not imply accumulation-mode (SMPS-range) particles are included in "total particles" when SMPS data are absent.

Finally, we clarify that the conclusion that NPF events occur under reduced CS conditions is supported by our own concurrent NAIS-SMPS observations, specifically the 24-day strict CS-comparison subset (9 event + 15 non-event days, after excluding the 2 disagreement days) and does not rest only on the three formation-rate case-study days. Specifically, Fig. 9 presents the event/non-event CS comparison from the usable concurrent NAIS-SMPS subset, showing lower CS on event days during the nucleation/growth window. Fig. 11 then provides a detailed 5-10 October case study in which the 7 October NPF event occurs during a period of reduced CS relative to the surrounding non-event days. Formation rate calculations are still restricted to three case-study events for which all required terms could be determined reliably. Thus, our interpretation is that reduced CS is an important condition for NPF occurrence at CAS-AO, while meteorology and air-mass variability further modulate whether the event signature remains clean or becomes obscured. This interpretation is consistent with not only this work but as well supported by previous work from Delhi and other Indian urban environments showing that NPF occurrence and particle survival are regulated by the balance between pre-existing aerosol loading, condensation/coagulation sinks, vapour production, and meteorology (Ali et al., 2025; Gani et al., 2019; Jose et al., 2021; Kanawade et al., 2022; Sebastian et al., 2022), as well as with the broader polluted-megacity framework linking NPF survival to competition between growth and scavenging by pre-existing particles (Kulmala et al., 2017; Lee et al., 2019).

Text revised/added in the manuscript: [Sect. 2.2.1, p. 5, line 158-162]

Unless stated separately, "total particles" refers to the NAIS particle-mode measurement (i.e., the number size distribution of all particles regardless of natural charge state, following unipolar charging), reported over the 2.5–42 nm range used in this study; "ions" refers separately to the NAIS ion-mode measurement of naturally charged particles over 0.8–42 nm. The two channels are reported separately throughout this study unless explicitly stated as combined.

Text revised/added in the manuscript: [Sect. 2.3, p. 6, line 203-209]

Data coverage for the different instruments and derived quantities is summarised in Fig. S1. Although the overall measurement period extended from May to December 2023, the number of valid days available for individual analyses differed because of instrument interruptions, missing data periods, precipitation-affected ion measurements, and gaps during the daytime growth window used for event classification. The NAIS-based NPF classification was performed using 108 valid NAIS days. SMPS measurements usable for the concurrent NAIS-SMPS analysis were available for a limited subset of the campaign (26 days), mainly during August-November 2023.

Text revised/added in the manuscript: [Sect. 2.3, p. 9, line 309-318]

For the event/non-event CS comparison, daily CS values were summarised as the median CS during 06:00-12:00 LT. This morning window was selected to represent the pre-onset, onset, and early-growth period of NPF while avoiding later afternoon boundary-layer accumulation and local emission effects. Condensation sinks were calculated only for days with concurrent NAIS and SMPS data (9 event days and 15 non-event days), because particles outside the NAIS size range contribute substantially to these sinks. For CS calculations, NAIS particle data were used up to 20 nm and SMPS data above 20 nm, producing a merged PNSD of approximately 2.5-570 nm for concurrent-instrument days.

Major comment 2: Data coverage is never made clear.

Similar to my above point, the measurements run May through December, yet Sect. 3.2.1 implies only 108 data days. While this is a lot of missing time, our instruments are indeed temperamental, so this is quite normal. However, the reader is left guessing where the gaps are and which instruments were running when. I would encourage the authors to open the results with a full time-series / data-availability plot showing NAIS and SMPS coverage across the whole period, alongside the MET data, and anything else appropriate. This single figure would resolve a lot of the ambiguity and would let readers judge the seasonal claims for themselves.

Response:

We have now updated section 2.3 to mention the data availability. We cite and discuss Fig. S1 (in previous manuscript version as Fig. S6) in the main text and use it to show the availability of NAIS, SMPS, and meteorological measurements across the May-December 2023 period. We also state why days were excluded: missing NAIS records, instrument interruptions, precipitation-affected ion measurements, and gaps during the daytime classification/growth window.

Major comment 3: Clarity regarding GRs

Median GRs of ~15 nm/h in the 3–7 nm range (rising to ~19–27 nm/h at larger sizes) are at the very top of anything reported anywhere. If real, that's a very important result with real consequences, as the particle number scales with J, but both the mass of the growing mode and the survival probability are extremely sensitive to GR, so growth this fast could be a major local source of both number and mass.

But the authors themselves acknowledge that pollution plumes intermittently mimic and inflate growth signatures, so I'd want much more reassurance that these GRs aren't contaminated. It would be great if the authors could both state clearly which classification scheme (Dal Maso or Dada) is used to select the events that feed the GR calculation, how many events that is, and why.

Given the contamination risk, please show some peak fits and some diameter-versus-time plots so the reader can judge whether the growing mode is being cleanly separated from pollution.

Following from the high GRs, I would encourage you to discuss the potential contribution of these events to particle mass, not just number (see Kulmala et al., 2022, https://doi.org/10.1039/D1EA00096A). Estimating mass from the PNSD would be straightforward for such events where SMPS data exist.

Response:

The revised manuscript states that candidate GR days were selected from the Dal Maso et al. (2005) Class I and Class II event days because GR estimation requires a visually traceable diameter-time growth mode. We agree that pollution plumes and local emission signals can mimic or distort apparent growth signatures in this environment, and this is why each candidate event was screened manually before GR values were retained. Pollution/plume-affected periods were identified from short-lived, abrupt concentration enhancements across larger particle sizes, looking closely to diameter concentration plot temporal evolution without a coherent diameter-time growth pattern from the nucleation mode, and where possible were checked against changes in wind direction/speed and discontinuities in the PNSD. The influence of these factors in a polluted regime is one of the highlights of this paper. Each candidate event day was examined individually. The nominal 3–7 nm and 7–20 nm intervals were used as initial search ranges, but the full nominal interval was not imposed when part of the range was affected by noise, weak mode separation, plume-like variability, or discontinuous concentration enhancements. Instead, we tested different contiguous sub-ranges and fitting windows within each nominal interval and retained only the portion where the fitted feature followed a coherent NPF growth mode. This procedure yielded 17 NAIS event days suitable for at least one GR estimate.

The revised GR statistics are now reported together with successful-fit counts. For the nominal 3-7 nm range, the appearance-time method gives 6 successful fits with a median GR of 10.6 nm h^{-1} and IQR of 7.9-15.9 nm h^{-1}, while the Gaussian/mode-peak method gives 5 successful fits with a median GR of 14.7 nm h^{-1} and IQR of 10.2-18.0 nm h^{-1}. For the nominal 7-20 nm range, the appearance-time method gives 12 successful fits with a median GR of 16.8 nm h-1 and IQR of 13.9-26.6 nm h^{-1}, while the Gaussian/mode-peak method gives 15 successful fits with a median GR of 19.0 nm h^{-1} and IQR of 16.4-20.4 nm h^{-1}.

To address the reviewer's concern about contamination, we had already discussed the difficulty of GR estimation in polluted environments in Sect. 3.2.2, including the influence of overlapping pollution-related modes, wind shifts, precipitation, instrumental noise, and the limitations of both visual and automated classification approaches under such conditions.

To further strengthen this discussion, and make the assessment more transparent, we have added event-wise fitting diagnostics to the Supplement. Fig. S7 shows, for each of the 17 GR event days, the particle size distribution together with the fitted mode-peak and appearance-time points used for the GR calculations. These diagnostics allow the reader to evaluate whether the fitted feature represents a continuous growing particle mode or may be affected by plume-like variability.

Finally, following the reviewer's suggestion, we have added a qualitative discussion of the potential contribution of these fast-growth events to particle mass, not only particle number. We now state that, if sustained, such high GRs could increase particle survival probability and may contribute to particle volume and mass as the growing mode reaches larger diameters. However, because quantitative mass estimates require reliable larger-size PNSD information and concurrent SMPS overlapped with reliable GR calculation was limited, we do not present mass contribution. Instead, we identify this as an important implication that requires longer concurrent NAIS–SMPS measurements and supporting precursor-gas observations. (As pointed out by reviewers themselves)

Text revised/added in the manuscript: [Sect. 3.2.2, p. 18, line 548-553]

For the nominal 3-7 nm range, the appearance-time method yielded 6 successful fits with a median GR of 10.6 nm h^{-1} and IQR of 7.9-15.9 nm h^{-1}, while the Gaussian/mode-peak method yielded 5 successful fits with a median GR of 14.7 nm h^{-1} and IQR of 10.2-18.0 nm h^{-1}.

Text revised/added in the manuscript: [Sect. 3.2.2, p. 18, line 554-562]

The growth rate values should be interpreted as fitted values within the nominal 3-7 nm and 7-20 nm ranges rather than unconditional full-window averages. In several cases, only a contiguous sub-range could be fitted because parts of the nominal interval were affected by weak mode separation, plume-like variability, or missing data. The contiguous sub-ranges were chosen by visual inspection so that the change in appearance or maximum-concentration times across NAIS channels followed the investigated growing mode without being heavily affected by these variabilities. Most commonly, the fitted feature was affected either by the mode appearing or disappearing abruptly across a wide diameter range while otherwise growing steadily, or by high-concentration plumes during the event, which made the maximum concentration of the growing mode and its occurrence time impossible to determine reliably from channel-wise fitting.

Text revised/added in the manuscript: [Sect. 4, p. 28, line 812-817]

Despite these limitations, the results demonstrate frequent NPF occurrence and rapid growth in the IGP during periods with favourable conditions. The high growth rates may increase particle survival probability and can contribute to particle volume and mass if growing modes reach larger diameters; however, robust quantification of the NPF contribution to particle mass or CCN requires longer concurrent NAIS-SMPS measurements and supporting precursor-gas observations, together with a rigorous assessment of whether the observed growth rates remain representative over the time needed for particles to reach CCN-relevant sizes.

Major comment 4: Condensation sink equation

Condensation sinks equation (line 257).

Please double-check this. The standard formulation is CS = 2πD .... The manuscript has 4πD, which is a factor-of-two error when Dp is a diameter.

Response:

We thank the referee for pointing this out. We rechecked the condensation sink equation and agree that, when Dp denotes particle diameter, the correct form is $CS = 2\pi D \sum \beta(Dp) Dp\ N(Dp)$. We have corrected the equation in Sect. 2.3 and recalculated all CS values using the diameter-based formulation following Pirjola et al. (1999) and Ezhova et al. (2018) (Ezhova et al., 2018; Pirjola et al., 1999). The correction reduces the reported CS values by a factor of two. Accordingly, for the concurrent NAIS-SMPS comparison using the 06:00-12:00 LT window, the corrected event-day median CS is 0.0095 s^{-1} (IQR: 0.0074-0.0147 s^{-1}; n = 9), compared with 0.0292 s^{-1} (IQR: 0.0171-0.0413 s^{-1}; n = 15) for non-event days.

This reduces the absolute CS values by a factor of two while preserving the relative event/non-event contrast. Because this correction applies uniformly to all CS values, the relative difference between events and non-event days and the statistical separation remain unchanged, but the absolute values and the discussion of their magnitude have been updated throughout the manuscript. We have updated the equation, CS values, figure discussion, and manuscript text accordingly.

Text revised/added in the manuscript: [Sect. 2.3, p. 9, line 303-308]

The condensation sink (CS) was calculated from the aerosol particle number size distribution following the diameter-based formulation described by (Ezhova et al., 2018; Pirjola et al., 1999): $CS = 2\pi D \sum \beta(Dp) Dp N(Dp)$.

Updated: Fig 9 and Fig 11 & Table 1

Text revised/added in the manuscript: [Sect. 3.3, p. 24-25, line 747-750]

On 7 October, the daily median CS was 0.0158 s^{-1} (IQR: 0.0078-0.0199 s^{-1}), and during 06:00-12:00 LT it was 0.0093 s^{-1} (IQR 0.0056-0.0185 s^{-1}). Thus, the event occurred during a low-CS morning period relative to surrounding polluted conditions.

Specific comments

We thank the reviewer for these detailed comments. We have revised the Abstract, Introduction, Instrumentation, and figure captions/text to improve clarity, remove overstatements, and make the terminology and size ranges more precise.

Abstract

L13: "in **the** sub–10 nm size range".

L14: "microphysical evolution" what does microphysical mean here specifically? Either define it or use a plainer phrase.

The frequency of NPF is a headline finding, so give the summer and winter frequencies in the abstract rather than just "frequent in summer, less common in winter". Likewise, since the sub–10 nm gap is a central motivation, state the diameter ranges you actually measured when you say "using ion and particle measurements".

Response:

The Abstract now uses “the sub–10 nm size range” and replaces “microphysical evolution” with the clearer phrase “occurrence and growth”. We have also specified the measured size ranges: NAIS ion measurements covered approximately 0.8–42 nm and NAIS particle measurements covered approximately 2.5–42 nm, with SMPS measurements available for the larger particle-size range during the limited overlap period. The seasonal NPF frequencies are now reported explicitly using valid NAIS classification days, with events occurring on 30 of 35 valid days in May–June (86 %) and on 20 of 73 valid days during the winter/post-monsoon period (28 %). The Abstract also now includes the corrected event/non-event condensation-sink contrast for the 06:00–12:00 LT analysis window.

Text revised/added in the manuscript: [Abstract, p. 1, line 10]

In highly polluted regions such as the Indo-Gangetic Plain (IGP), where precursor concentrations and condensation sinks are among the highest globally, NPF remains poorly constrained due to limited observations of particles and ions in the sub–10 nm size range.

Here, we investigated the occurrence and growth of NPF at a suburban IGP site (CAS-AO, Sonipat, Haryana), during May-December 2023 using ion (0.8–42 nm) and particle (2.5–42 nm) measurements together with meteorological data. NPF events were frequent during summer, occurring on 30 of 35 valid days in May-June (86 %), and were much less frequent during the winter/post-monsoon period, with 20 out of 73 valid days (28 %). The weak seasonal variability of ion concentrations relative to nucleation-mode particles suggests that particle survival and growth were strongly modulated by condensation sink, meteorology, and air-mass heterogeneity. The median daily condensation sink during 06:00–12:00 LT was lower on event days than on non-event days (0.0095 vs 0.0292 s^{-1}). Particle growth rates increased with size, from 14.7 nm h^{-1} in the 3–7 nm range to 19.0 nm h^{-1} in the 7–20 nm range, indicating size-dependent growth.

Introduction

L40: a single percentage range can't apply to both total particle number and CCN concentrations as they're different quantities. Please separate them.

We have separated the statement on particle number from the statement on CCN contribution and revised the wording to avoid implying that the same percentage range applies equally to both quantities. The revised text states that NPF can contribute substantially to particle number and, where particles grow sufficiently, to CCN, but that these contributions vary among sites, seasons, and background aerosol conditions.

Text revised/added in the manuscript: [Sect. 1, p. 2, line 47–50]

NPF followed by growth can contribute substantially to atmospheric particle number concentrations, while its contribution to cloud condensation nuclei (CCN) depends on whether newly formed particles grow to CCN-relevant sizes.

L43: "At the nanoscale level" is ambiguous; be specific about the size regime you mean.

Revised. We now refer explicitly to "sub–10 nm particles and ions" or to the relevant particle diameter range instead of using the phrase "nanoscale level".

Text revised/added in the manuscript: [Sect. 1, p. 2, line 45–46]

Charged sub–10 nm particles and ions influence atmospheric electrical properties and can provide early information on cluster formation and growth.

L62: I think you mean the "dynamics of particles in the 3–10 nm range", rather than "clusters below 3–10 nm".

Corrected. We now refer to "particles in the 3–10 nm range", which is the intended meaning.

Text revised/added in the manuscript: [Sect. 1, p. 2, line 64-67]

However, current knowledge of these processes in the IGP remains limited because previous studies have largely relied on the Scanning Mobility Particle Sizer (SMPS) and similar instruments optimised for larger particle diameter (typically above 10 nm), which often miss the dynamics of particles and ions in the 3–10 nm size range (Kanawade et al., 2022).

L64: if the seasonal contrast isn't yet understood, how is it being asserted as significant? Reword.

Revised. We have removed the wording that implied the seasonal contrast was already established as significant. The sentence now states more neutrally that longer observations are needed to evaluate seasonal variability in the IGP.

Text revised/added in the manuscript: [Sect. 1, p. 2, line 67-68]

Furthermore, many existing observations are conducted over short time durations, making it difficult to fully understand the seasonal variability of NPF and sub–10 nm particle dynamics in the IGP.

L66 onwards: NPF gets formally introduced here, after its impacts have already been discussed. The intro would flow better if NPF were defined earlier. This passage also carries a lot of unnecessary detail, e.g. "NPF emerges as a pivotal process where gas-phase molecules converge to initiate the formation of solid or liquid particles" can go.

We have reorganized the Introduction so that NPF is defined earlier, before discussing its impacts. We also removed wordy and repetitive phrases, including the sentence beginning "NPF emerges as a pivotal process…".

Text revised/added in the manuscript: [Sect. 1, p. 2, line 42]

New particle formation (NPF) is the atmospheric process by which low-volatility vapours form molecular clusters that can grow into detectable aerosol particles.

L70: "As these nascent particles grow into the Aitken mode, their number concentration often increases further." This isn't a property of NPF, the number in a growing population generally falls (coagulation, dilution). What increases is the observed concentration in a fixed size band as the mode passes through it. That's an observational effect, and the sentence should be reframed accordingly.

We have revised this sentence to clarify that the apparent increase in concentration in a fixed size interval occurs as the growing mode passes through that interval. We no longer imply that the total number in a growing particle population necessarily increases.

Text revised/added in the manuscript: [Sect. 1, p. 2, line 50]

During an NPF event, the observed concentration in a fixed nucleation-mode size interval can increase as the growing mode passes through that interval...

Nucleation mechanisms paragraph: I'd point the authors to Kulmala et al., 2023 (https://doi.org/10.1038/s41561-023-01305-0), which is the current reference for how to frame this. Given that you're observing NPF at 30 degrees Celsius I doubt you're seeing pure SA-NH3, but I'd bet you're got a tonne of much stronger bases.

"In the overall aerosol loading, NPF contribution… makes a significant part of that": this is overstated as a general claim. It's true at some sites and not others; please qualify.

We updated the nucleation-mechanism framing to reflect current understanding and added Kulmala et al. (2023). The revised text no longer implies that pure sulfuric-acid–ammonia nucleation must dominate under warm, polluted IGP conditions. Instead, we note that stronger bases and organic vapours may also be important, while mechanism identification remains limited by the absence of precursor-gas measurements.

Text revised/added in the manuscript: Revised manuscript: [Introduction, p. 2, line 47; p. 2, line 50; p. 3, line 3; p. 3, line 77].

"NPF contribution makes a significant part" overstated is addressed by the qualified wording: "can contribute substantially..."

and:

"Both contributions vary strongly among sites, seasons, and background aerosol conditions."
The nucleation-mechanism framing is addressed by:

"More recent studies show that the atmospheric mechanism is often more complex...
and
"In warm and polluted environments such as the IGP..."

Instrumentation (2.2.1, 2.2.2)

Inconsistent treatment of the two instruments: detailed uncertainties are given for the SMPS but not the NAIS. Please balance this (there are some estimates available for NAIS uncertainty, but not as many as for SMPS).

Several things are missing: did the NAIS and SMPS agree in their overlapping size range, and if not, what correction was applied? How was the SMPS inversion performed, and which version of AIM was used? Was retrospect used to invert the NAIS data?

L160: "Multiple instruments are clubbed together" please use more formal phrasing.

L186: pedantic, but the correct quantity is the particle number size distribution (PNSD); please use this throughout.

Response:

We have revised Sect. 2.2.1 and 2.2.2 to describe the NAIS and SMPS processing more explicitly and consistently.

For the NAIS, we now state that the spectra were inverted by the NAIS/Airel instrument software using the instrument-specific inverter v14.1-hrnd-elm25-chv. The exported spectra were then post-processed and inlet-loss correction based on the Gormley–Kennedy tube-loss formulation, and ion-mode correction following Wagner et al. (2016) were done. We have not used Retrospect.

We have added a more balanced description of NAIS uncertainty. The revised text notes that NAIS uncertainty is size- and mode-dependent, and that intercomparison studies (Gagné et al., 2011; Wagner et al., 2016) show that air-ion spectrometer concentrations can vary between instruments and operating conditions. Wagner et al. (2016) further reported uncorrected ion-mode concentration biases of −15 to −30 % below 5 nm and up to +8 % at diameters of 19.6 nm and larger, while the corrected ion concentration uncertainty can be reduced to below 10 %. We also state that particle-mode measurements near the lower size limit are affected by corona-generated charger ions; therefore, sub–2.5 nm NAIS total-particle data were excluded from quantitative particle analysis. For the SMPS, we now state that raw scans were inverted using TSI Aerosol Instrument Manager software, AIM version 11.03.00.

We have also added a statement on the NAIS–SMPS overlap treatment. During concurrent operation, the instruments were compared over their overlapping size range of approximately 12–42 nm. The instruments captured similar temporal variability, but absolute concentrations differed; therefore, day-specific multiplicative scale factors were derived from the median concentration ratio in the overlapping size range and applied before constructing continuous NAIS–SMPS PNSDs for sink calculations. The NAIS-based event classification was not affected by this scaling.

We also replaced the informal phrase “multiple instruments are clubbed together” with “the station integrates sensors connected to a digital logger” in Sect. 2.2.3 and revised the terminology throughout the manuscript to use “particle number size distribution (PNSD)” where appropriate.

Text revised/added in the manuscript: [Sect. 2.2, p. 4, line 138 (NAIS inversion); p. 5, line 179 (SMPS inversion); p. 6, line 182-187 (NAIS–SMPS overlap comparison)]

“The NAIS spectra were inverted by the NAIS/Airel instrument software using the instrument-specific inverter v14.1-hrnd-elm25-chv.”

“The raw SMPS scans were inverted using TSI Aerosol Instrument Manager software (AIM version 11.03.00).”

“During concurrent operation, the NAIS and SMPS were compared in their overlapping size range of approximately 12–42 nm... day-specific multiplicative scale factors were derived from the median concentration ratio in the overlapping size range and applied before merging.”

Figure 2

The colour scales are mismatched: particles span ~2 orders of magnitude while ions span ~5. As drawn, this makes it look as though there are NPF events with no corresponding ions, which I don't think is your intended message. Please harmonise the scaling (or at least pull down that upper range for the ions a bit!)

Response:

The larger scale range for the ion number size distribution was chosen because ions show a different order of variability across size ranges. We agree, however, that this could give the unintended impression that particle NPF signatures occurred without corresponding ion variability. We have revised Fig. 2 by narrowing the ion colour scale from 10^0–10^5 cm^{-3} to 10^1–10^4 cm^{-3}. This still allows the ion panels to show the main ion-concentration variability but avoids compressing the NPF-relevant variability in the 10^2–10^3 cm^{-3} range. We retain separate colour scales for particles and ions because their absolute concentrations differ, but the revised scaling is now more balanced between the panels.

Updated: Fig 2.

Panel (a) doesn't directly show particle number concentrations, and if there's no SMPS support then this isn't "total particles" but sub 40 nm particles. Label accordingly. This applies to all discussion.

We have also revised the panel label as NAIS-negative channel total-particle and the caption to particle mode PNSD (ions + neutral particle) to clarify that it is PNSD over the NAIS size range, not the full atmospheric particle number concentration.

Figure 3 and associated text

The choice of size windows is a bit odd. 3–5 nm and then 7–12 nm. Why not 3–7 nm, especially given that's the window used for the growth-rate analysis? Please make the size windows consistent across analyses, or justify why they differ.

Response:

Fig. 3 is intended to summarize monthly day–night variability in selected NAIS size ranges that are relevant to NPF interpretation. For this bulk statistical figure, in Fig. 3, we retained the 3–5 nm and 7–12 nm particle ranges. The narrower 3–5 nm range is used to represent the earliest particle-mode signal while reducing the influence of larger local or combustion-related particles and other non-NPF variability that can affect broader size ranges that may influence particles above about 5 nm. In contrast, the growth-rate analysis uses wider ranges such as 3–7 nm and 7–20 nm for two reasons. First, the 3–7 nm range is commonly used in the NPF literature for GR estimation, which allows comparison of our high GR values with previous global studies. Second, the GR analysis was not a bulk monthly statistic; each candidate event was inspected manually, and only the time–diameter region showing a coherent growing mode was retained. This manual screening reduces the likelihood that traffic or plume-related signals dominate the fitted GR. Thus, the different size windows reflect different analysis objectives: Fig. 3 presents broad monthly day–night variability over all valid days, whereas the GR analysis uses literature-comparable size ranges applied only to manually screened event periods. The intermediate 5–7 nm interval is excluded from the bulk monthly statistics because it represents a transitional size range where freshly nucleated particles and residual local or combustion influence can overlap, making it the least reliable segment for a clean day-night contrast at monthly resolution.

Although it was mentioned in some places as

7–12 nm: in the Dada classification method, where the original 7–25 nm range was restricted because >12 nm was influenced by background aerosol, noise, and local/regional sources.

3–5 nm: in the Aliaga/ranking method, where we mentioned that it is lowest reliable NAIS particle range and helps avoid lower-limit artefacts and larger traffic/combustion influence.

3–7 nm and 7–20 nm: in the GR method, where we state that these are nominal GR fitting windows and were manually screened event by event.

We agree that this information was scattered across the manuscript and have therefore added the following lines in Sect. 3.1:

Text revised/added in the manuscript: [Sect. 3.1, p. 10-11, line 364-390].

Within the retained 3–12 nm range identified in Fig. 2, Fig. 3 presents two narrower sub-windows, 3–5 nm and 7–12 nm. The 3–5 nm window isolates particles closest to the NAIS lower detection limit, capturing the earliest stage of a growing mode while limiting the contribution of larger, locally influenced particles, including traffic emissions, that increasingly populate the distribution above about 5 nm in this urban-influenced setting. The 7–12 nm window remains conservatively below the approximately 12 nm threshold beyond which background Aitken-mode aerosol dominates the signal, as established in Fig. 2.

Figure 4 / classification

Internal inconsistency to fix: the Discussion (around L723) quotes GRs of "~9.7–11.4 nm/h (3–7 nm)" and "~12.9–15.6 nm/h (7–20 nm)", which don't match the medians reported in the Results and abstract (10.6 / 14.7 and 16.8 / 19.0 nm/h). The numbers need to be reconciled.

Response:

We have corrected this internal inconsistency. The values quoted in the Discussion were from an earlier version of the GR analysis. We have now reconciled the Discussion with the Results and Abstract.

The revised Discussion now reports the final GR statistics as follows: for the nominal 3–7 nm range, the appearance-time method gives a median GR of 10.6 nm h^{-1}, while the Gaussian/mode-peak method gives 14.7 nm h^{-1}. For the nominal 7–20 nm range, the corresponding median GRs are 16.8 and 19.0 nm h^{-1}. The earlier values of ~9.7–11.4 nm h^{-1} and ~12.9–15.6 nm h^{-1} have been removed.

Text revised/added in the manuscript: [Sect. 3.3, p. 26-27, line 773-777]

Importantly, the growth rates in this study exhibit a clear size dependence. The event-wise dataset gives median values of 10.6 and 14.7 nm h^{-1} in the nominal 3-7 nm range using the appearance-time and Gaussian/mode-peak methods, respectively, and 16.8 and 19.0 nm h^{-1} in the nominal 7-20 nm range. These values are comparable to the range of 5.7-30 nm h^{-1} reported for Delhi in previous studies under highly polluted conditions (Aliaga et al., 2023; Mönkkönen et al., 2004; Sarangi et al., 2015).

Figure 6

Needs tidying (de-squishing) before publication; it's hard to read at present.

Response:

We have revised Fig. 6 to improve readability.

Updated: Fig 6.

Since the visual classification is acknowledged to be subjective, it might be worth plotting the mean Class I and Class II events as heatmaps, so readers can see what an average event of each class actually looks like.

It is already there in Fig S5 (updated Supplementary section). These are now cited when discussing classification subjectivity.

Figure 9

I'd strongly recommend estimating particle mass from the PNSD and adding it to this figure (not obligatory!).

Response:

We considered this suggestion carefully, but we have not added a quantitative particle-mass panel to Fig. 9. Although mass estimation is useful, a defensible seasonal/event-composite mass estimate requires reliable larger-size PNSD coverage, and the concurrent NAIS-SMPS record is too limited for that purpose. Adding such a panel would imply a level of representativeness that the present data do not support. We therefore added a qualitative discussion of possible particle volume/mass implications and identify longer concurrent NAIS-SMPS measurements as the correct path for quantifying this in future work.

Text revised/added in the manuscript: [Conclusion, p. 28, line 813-817]

The high growth rates may increase particle survival probability and can contribute to particle volume and mass if growing modes reach larger diameters; however, robust quantification of the NPF contribution to particle mass or CCN requires longer concurrent NAIS-SMPS measurements and supporting precursor-gas observations, together with a rigorous assessment of whether the observed growth rates remain representative over the time needed for particles to reach CCN-relevant sizes.

Section 3.2 / organisation

L579: we've suddenly returned to a discussion of Dal Maso here, well after it was introduced. The manuscript's organisation needs work overall. The classification discussion is scattered, and a tighter structure would help the reader a lot as you could describe the methods, state which one is best, and move forwards with it.

Response:

The main comparison of the Dal Maso, Dada, and Aliaga-based classifications is kept in Sect. 3.2.1, where the classification results are presented and the subsequent use of the Dal Maso classification is stated. The paragraph referred to by the referee in Sect. 3.2.2 was not intended to reintroduce the classification results, but to discuss why classification and GR estimation are difficult in a polluted environment. It is framed explicitly as a limitation/uncertainty discussion, focusing on pollution plumes, overlapping modes, meteorological perturbations, and the resulting difficulty in extracting reliable growth rates.

Figure 10

There looks to be a time offset between the two instruments. The SMPS appears to lag the NAIS by roughly an hour. Please check the timestamps and synchronisation.

The SMPS also looks as though it may be under-reading particle concentrations on these days; worth verifying (the NAIS is known to over-read, so maybe that's the more appropriate statement).

Response: We re-examined the SMPS and NAIS timestamps for the days shown in Fig. 10. A systematic offset of approximately 30 minutes was identified during data processing and has been corrected; the figure has been regenerated with synchronised timestamps. Regarding the possible under-/over-reading, we did not attempt to attribute the absolute-concentration offset to a specific instrument; instead, as described in Sect. 2.2.2, we apply a day-specific multiplicative scale factor derived from the median concentration ratio in the NAIS-SMPS overlapping size range (~12-42 nm) before constructing the merged PNSD used in Fig. 10. This scaling reconciles absolute concentrations empirically, regardless of which instrument is the source of the discrepancy.

Updated: Fig 10.

Figures 11 and 12

- These really should be combined into a single figure with a shared, aligned time axis. As it stands they're on separate pages, so it's impossible to read straight down from the aerosol/sink panels to the meteorology.

  We have combined Fig 11 and 12.

  Updated: Fig 11-12.

  I don't think the J values are valid without the supporting SMPS data: without the full distribution the CoagS is too small and J is therefore underestimated. This ties back to Major Issue 1. Or are these only the days where the SMPS was available?

  For what subset of days is the condensation sink actually calculated? If it's only these three days, then the paper's central CS conclusion rests on three points and needs to be reconsidered.

  The quantity names aren't in the header row, and inconsistent font sizes are used. Please clean this up.

We agree that formation-rate calculations require the larger-particle part of the PNSD because the coagulation sink would otherwise be underestimated. The J values reported in Table 1 are therefore calculated only for the subset of event days for which concurrent NAIS and SMPS measurements were available and for which all required terms could be determined reliably, including dN/dt, GR, CoagS, and the growth-out-of-range term.

We also clarify that the event/non-event condensation-sink comparison does not rest on only these three formation-rate case-study days. Formation rates are restricted to three events, but the CS comparison is calculated from the usable concurrent NAIS–SMPS subset, consisting of 9 event days and 15 non-event days. For this comparison, the daily median CS was calculated during 06:00–12:00 LT using the merged NAIS–SMPS PNSD.

The missing quantity names in the table header were caused by a formatting issue during document-to-PDF conversion. We have corrected the table formatting, restored the header row, and made the font size consistent throughout the table.

A general note on the writing

The writing needs a careful check throughout. A few things crop up repeatedly singular/plural slips ("these cluster" should be "these clusters"),

subject–verb disagreement ("ion concentrations does not show", "are play a more important role"),

missing articles ("in sub–10 nm size range", "from NAIS negative channel"),

There's also some wordiness that could be trimmed hard, e.g. "facilitating the observation of changes in resultant particle populations".

Also in the references there appear to be two separate Aalto et al. (2001) entries; please de-duplicate and check the reference list generally.

Response: We proofread the manuscript and corrected grammar, singular/plural agreement, missing articles, repeated wording, harmonised spelling, and checked duplicate references including Aalto et al. (2001), and reference-list duplication. Examples include 'these clusters', 'the remaining 58 non-event days', and replacing 'clubbed together' with formal AWS wording.

Summary of marked-manuscript changes

In addition to the text changes listed, the following figures and Table were revised: Fig. 2 (narrowed ion colour scale for panel balance), Fig. 6 (layout corrected for readability), Fig. 9 and Table 1 (condensation-sink values recalculated following the corrected equation), Fig. 10 (timestamp synchronisation corrected), and Fig. 11 (combined with the former Fig. 12 into a single figure with a shared time axis). In the Supplement, figures have been reordered for a clearer sequence, and two new figures have been added: Fig. S7 (event-wise growth-rate fitting diagnostics for the 17 retained GR event days) and Fig. S8 (bootstrap analysis of the event/non-event condensation-sink contrast).

Closing response

We again thank the referees for their constructive comments. The revised manuscript is now more explicit about measurement coverage, the analysis-specific subsets, and the limitations of interpreting derived quantities under limited concurrent NAIS-SMPS availability. We believe these changes make the manuscript clearer, more transparent, and better aligned with the strength of the observations.

References:

Ali, U., Singh, V., Faisal, M., Kumar, M., and Gani, S.: Exploring the influence of physical and chemical factors on new particle formation in a polluted megacity, Environ. Sci. Atmos., 5, 25–47, https://doi.org/10.1039/d4ea00114a, 2025.

Ezhova, E., Kerminen, V.-M., Lehtinen, K. E. J., and Kulmala, M.: A simple model for the time evolution of the condensation sink in the atmosphere for intermediate Knudsen numbers, Atmos. Chem. Phys., 18, 2431–2442, https://doi.org/10.5194/acp-18-2431-2018, 2018.

Gani, S., Bhandari, S., Seraj, S., Wang, D. S., Patel, K., Soni, P., Arub, Z., Habib, G., Hildebrandt Ruiz, L., and Apte, J. S.: Submicron aerosol composition in the world's most polluted megacity: the Delhi Aerosol Supersite study, Atmos. Chem. Phys., 19, 6843–6859, https://doi.org/10.5194/acp-19-6843-2019, 2019.

Jose, S., Mishra, A. K., Lodhi, N. K., Sharma, S. K., and Singh, S.: Characteristics of Aerosol Size Distributions and New Particle Formation Events at Delhi: An Urban Location in the Indo-Gangetic Plains, Front. Earth Sci., 9, https://doi.org/10.3389/feart.2021.750111, 2021.

Kanawade, V. P., Sebastian, M., Hooda, R. K., and Hyvärinen, A.-P.: Atmospheric new particle formation in India: Current understanding and knowledge gaps, Atmos. Environ., 270, 118894, https://doi.org/10.1016/j.atmosenv.2021.118894, 2022.

Kulmala, M., Kerminen, V.-M., Petäjä, T., Ding, A. J., and Wang, L.: Atmospheric gas-to-particle conversion: why NPF events are observed in megacities?, Faraday Discuss., 200, 271–288, https://doi.org/10.1039/C6FD00257A, 2017.

Lee, S., Gordon, H., Yu, H., Lehtipalo, K., Haley, R., Li, Y., and Zhang, R.: New Particle Formation in the Atmosphere: From Molecular Clusters to Global Climate, J. Geophys. Res. Atmos., 124, 7098–7146, https://doi.org/10.1029/2018jd029356, 2019.

Pirjola, L., Kulmala, M., Wilck, M., Bischo, A., Stratmann, F., and Otto, E.: FORMATION OF SULPHURIC ACID AEROSOLS AND CLOUD CONDENSATION NUCLEI: AN EXPRESSION FOR SIGNIFICANT NUCLEATION AND MODEL COMPARISON, Elsevier Sci., J. Aerosol Sci. Vol. 30, No. 8, p. 1079}1094, 1999, 1998.

Sebastian, M., Kompalli, S. K., Kumar, V. A., Jose, S., Babu, S. S., Pandithurai, G., Singh, S., Hooda, R. K., Soni, V. K., Pierce, J. R., Vakkari, V., Asmi, E., Westervelt, D. M., Hyvärinen, A.-P., and Kanawade, V. P.: Observations of particle number size distributions and new particle formation in six Indian locations, Atmos. Chem. Phys., 22, 4491–4508, https://doi.org/10.5194/acp-22-4491-2022, 2022.