Responses to the Reviewer #1

RC1: Review on Effect of planetary boundary layer evolution on new particle formation events over Cyprus

General comments:
The paper investigates effect of planetary boundary layer evolution on new particle formation events over Cyprus using the measurements at two measurement sites at different altitude. It also used ceilometer and water vapor passive trace to indicate the boundary layer evolution. The study is in general well written and provide a meaningful contribution to the knowledge of the boundary layer driven NPF events.

Response:
The authors are thankful to the reviewer for their valuable comments and suggestions and appreciate the time and effort the reviewer dedicated. All responses from the authors are remarked in blue. Changes in the revised manuscript text are depicted in red.

Two aspects are my main concern.
Firstly, it still not very clear, at least not so quantitatively, assets the boundary layer mixing process on NPF events. I suggest the author to calculate the time lag for each concurrent events and compare it with time needed for boundary layer increasing from AMX site (532 m) to TRO site (1819 m). It would be better to quality this effect.

Response:
Thank you! We calculated the time required for the PBL height to reach the TRO altitude relative to the NPF event start-time at AMX ($dT_{PBLevolution}$) and the time lag between peak number concentrations of negative polarity particles >2.5 nm ($dT_{PeakConc., N>2.5\ nm, particles(-)}$) for observed concurrent NPF events. Out of 69 concurrent event days, Ceilometer estimated PBL height data was screened out for 24 days (as explained in section 2.3), leaving 45 data points (Figure 5b in the revised manuscript). The average time lags based on particles and PBL height are 1.57 hours (~94 minutes) and 1.73 hours (~104 minutes), respectively.

We have revised Figure 5 and the relevant discussion in the revised manuscript as follows:
The peak in size-segregated ion and particle number concentrations exhibited a time lag of 1-2 hours for concurrent NPF events at both sites (Fig. 4). Further, the size-segregated ion and particle number concentrations were higher at AMX than at TRO. To substantiate our hypothesis, we first obtained NPF event start-times at both sites. The histogram of NPF event start-times indicates that NPF events at the TRO site were consistently detected with a time lag of 1-2 hours compared to AMX (Fig. 5a). We further calculated the time required for the PBL height to reach the TRO altitude relative to the NPF event start-time at AMX ($dT_{PBLevolution}$) and the time lag between peak number concentrations of negative polarity particles >2.5 nm ($dT_{PeakConc., N>2.5\ nm, particles(-)}$) for observed concurrent NPF events. Out of 69 concurrent event days, PBL height data was screened out for 24 days (as explained in section 2.3), leaving 45 data points. The average time lags based on particles and PBL measurements are 1.57 hours (~94 minutes) and 1.73 hours (~104 minutes), respectively (Fig. 5b). The mode diameter of negative polarity particles was also larger at TRO than at AMX. At 7:00 UTC, the negative polarity ion (particle) mode diameters at AMX and TRO were about 13.6 nm (7.8 nm) and 15.5 nm (15.7 nm), respectively (Figs. 5c, 5d). Considering the time lag of 2 hours between these

sites, the negative polarity particle growth rate is estimated to be ~3.9 nm hr^{-1}. During the concurrent NPF event days, the calculated size-segregated growth rates varied from 0.1 to 3.64 nm hr^{-1} (3-7 nm) and 0.18 to 6.08 nm hr^{-1} (7-25 nm) with a mean and standard deviation of 1.53±0.98 nm hr^{-1} and 2.35±1.16 nm hr^{-1}, respectively, at AMX while they varied from 0.12 to 2.91 nm hr^{-1} (3-7 nm) and 0.4 to 8.7 nm hr^{-1} (7 – 25 nm) with a mean and standard deviation of 1.49±0.71 nm hr^{-1} and 3.68±2.22 nm hr^{-1}, respectively, at TRO. The growth rates of smaller particles (3-7 nm) were similar while the growth rates of larger particles (7-25 nm) were higher at TRO indicating that the particles grew rapidly during upward airmass transport from AMX to TRO due to PBL evolution (see section 3.3, Fig. 7), possibly by valley winds or vertical mixing, on concurrent event days. The lower number concentrations of nucleation mode particles at TRO than at AMX (Fig. 4) can facilitate more availability of vapour for rapid growth at TRO. Therefore, we next examine PBL evolution and its influence on the TRO mountain site.

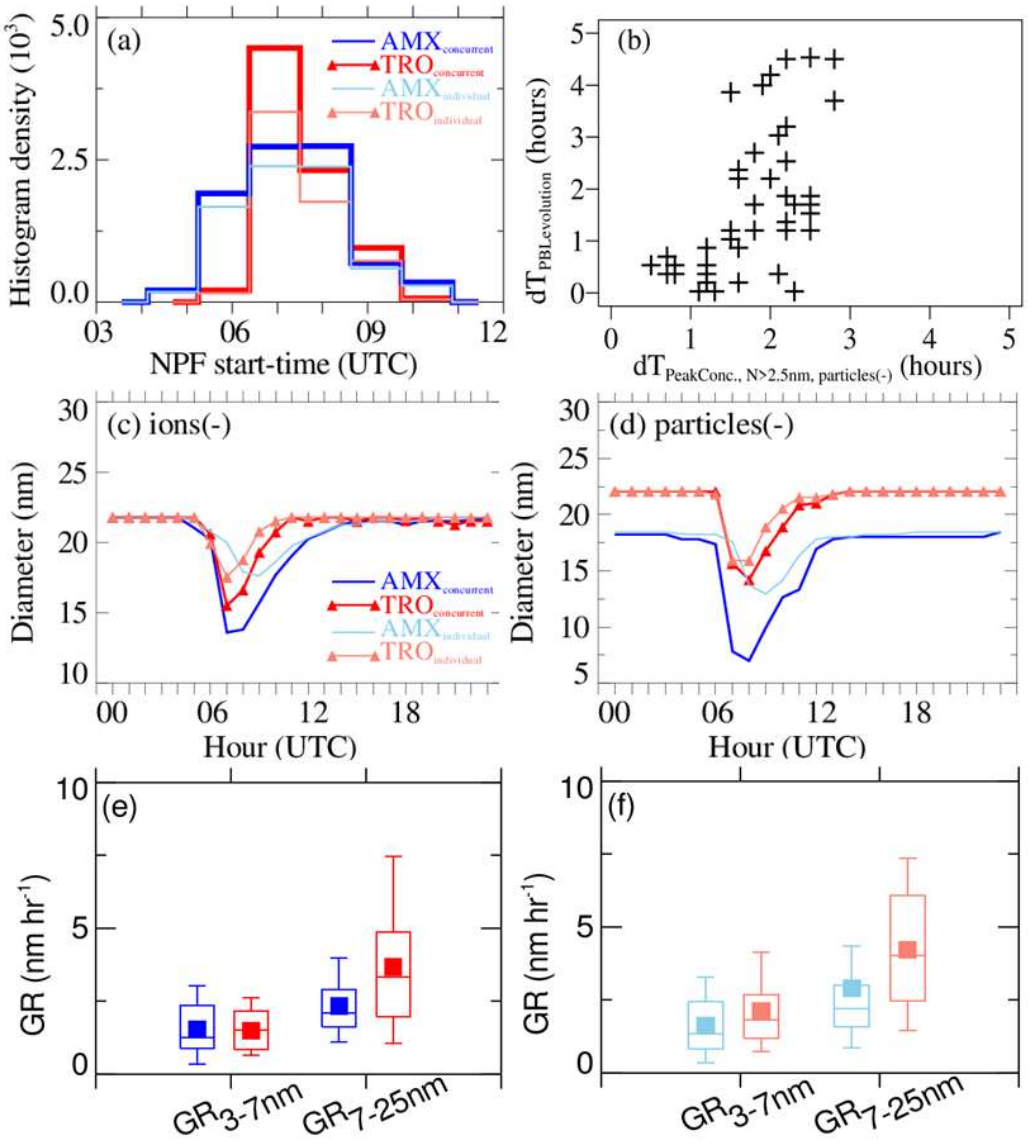

Figure 5. (a) Histogram density of NPF events start-time for the observed concurrent NPF events at AMX (dark blue) and TRO (dark red). The light blue and light red coloured lines indicate NPF events observed individually at AMX and TRO, respectively. (b) scatter plot of

the time lag between peak number concentrations of negative polarity particles >2.5 nm ($dT_{PeakConc., N>2.5 nm, particles(-)}$) and the time needed for PBL to reach TRO altitude relative to the NPF start-time at AMX ($dT_{PBLevolution}$). Median diurnal variation of negative polarity (c) ion and (d) particle mode diameter. The box-whisker plot of size-segregated particle growth rates for negative polarity for the observed (e) concurrent NPF events and (b) individual NPF events. The filled square indicates the mean, the horizontal line indicates the median, the bottom and top of the box indicate the 25th and 75th percentiles, and the bottom and top of the whisker indicate the 10th and 90th percentiles.

Secondly, there are lots of previous work was mentioned in discussion part, I suggest the author to move some of them into introduction part.

Response:

In the discussion section, we primarily compare our findings with previous studies and highlight gaps in understanding the vertical extent of NPF occurrence within the PBL. As suggested, we have moved the relevant text to the introduction section.

We further added the following text, as suggested by the reviewer to bring out depth and novelty, in the revised manuscript as follows:

Aircraft observations over boreal forests showed that particle concentrations (>1.5 nm) peak near the surface in the morning and mix within the evolving PBL layer during the day (Leino et al., 2019). However, airborne observations are costly and operationally challenging. Our sites offer a unique opportunity to study the vertical extent of NPF events and aerosol populations within the PBL, due to their close proximity, and the mountain background site (TRO) is within the PBL is for about >80% of days during the year. The intense solar radiation, the intricate mixture of both natural and anthropogenic emissions from continental and marine origins, the presence of local breeze systems (mountain, valley, sea, and land) and elevated dust layers further add complexity to the PBL–NPF relationship over the region. The combination of these factors poses a significant challenge in understanding the drivers behind the frequent NPF events observed in Cyprus and, more broadly, across the Eastern Mediterranean.

Specific comments:

- line 220: "We used two approaches to examine the influence of PBL evolution on the occurrence of NPF 219 events at the mountain background site, TRO. AMX is assumed to be in the PBL at all times." You mean you used two method to judge whether the TRO within boundary layer? Also, the sentence is a litter bit confuse as you are talking about TRO and suddenly mention AMX. Please consider to rearrange it.

Response:

Thank you for the comment. We have corrected statements in the revised manuscript as "We used two distinct methods to investigate how often the mountain background site, TRO, is influenced by PBL evolution."

- line 236: Please move this sentence line 238 "under stable conditions", and rephrase this sentence "The PBLH from ERA5 is realistically…"

Response:

Agree. We have adjusted and rephrased sentences to "Zhang et al. (2022) showed that the ceilometer estimated PBLH generally compares well with the bulk Richardson number method under stable conditions. ERA5 also used the bulk Richardson number method to calculate PBLH (Hersbach et al., 2020)."

- line 244: Please keep consistent for “ERA5” but not “ERA-5”.

Response:

We now use ERA5 throughout the manuscript.

- Figure 3: Part of it was hidden.

Response:

We have re-arranged the panels as below, as was also pointed out by the other reviewer;

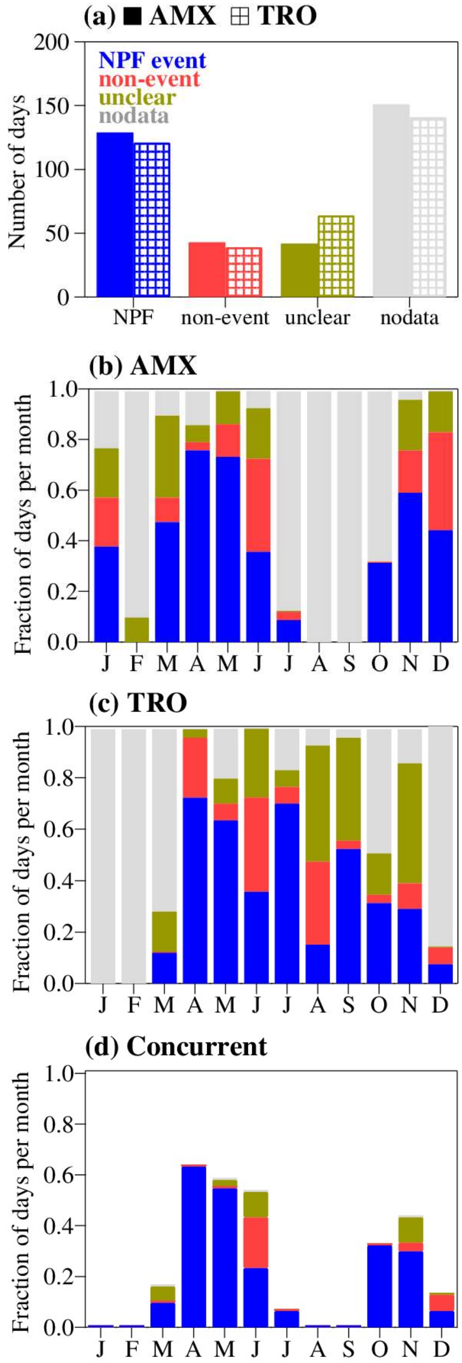

Figure 3. (a) Number of days of different event types at both AMX and TRO sites, (b) occurrence frequency (in fraction of days per month calculated as the number of event days divided by the total number of calendar days in the month) of different event types at AMX,

(c) same as (b) but for TRO, and (d) same as (b) but for concurrent days of NPF events, non-events and unclear days at both AMX and TRO sites, excludes individual different events types and nodata

- line 344: “sustained wind speed” → confusing

Response:

The wind speed is generally lower during both NPF events and non-events (2-6 m/s). We have revised the sentences to “The low relative humidity (Fig. S3d), higher ozone concentrations (Fig. S3e), and lower wind speed (Fig. S3f) further indicate environmentally favourable conditions to promote particle formation and growth.”

line 346-348: Please be careful that sun photometer measurement the total columns of aerosol from ground to top of atmosphere. The integration path of AMX is longer than TRO. In addition, the contribution of AOD was dominated within boundary layer. It’s obvious that AMX larger than TRO, so I did not get useful information here.

Response:

We understand that the integration path of AMX is longer than that of TRO. The idea is to compare the seasonal diurnal patterns in AOD rather than their magnitudes. As observed, the diurnal patterns in AOD during spring, summer, and autumn closely resemble one another (which indicates that TRO is indeed influenced by the PBL evolution), whereas in winter they do not align well (PBL weakly influences TRO). Since we have large asynchronous gaps in the NAIS data, we wanted to utilize these continuous measurements to provide an overall picture of aerosol loading at these sites. We have revised the discussion as “Seasonally averaged diurnal patterns of columnar aerosols (AOD) during spring, summer and autumn closely resemble one another (probably indicating that TRO is influenced by the PBL evolution) with higher aerosol loading at AMX compared to TRO (Fig. S4a), whereas they do not align well in winter (TRO is weakly influenced by the PBL evolution).”

- line 348-351: Large AE at TRO site means smaller particles there. Most large particle would be concentrated at low altitude due to gravity effect but not NPF effect. How did you remove the effect of gravity effect?

Response:

It is challenging to disentangle the contributions of primary emissions and secondary formation to total particle concentrations in areas with notable local emissions (e.g., traffic, and residential sources). However, the presence of high concentrations of small particles (large AE) at remote mountain locations, where such local emissions are minimal or absent, suggests that airborne secondary production may dominate. It is not possible to track particles in the atmosphere, and therefore impossible to remove the effect of gravity in observations. We modified the statement as “Additionally, the higher Ångström exponent at TRO (Fig. S4b), particularly in winter when the TRO mostly lies in the free troposphere (see section 3.3), suggests that these small particles are likely from local primary emissions (traffic, residential, etc.) or airborne secondary production or both. ”

- line 353-364: It would be better if you can calculate time different of two vertical lines (peak concentrations) and compare with time needed for boundary layer increasing from AMX site (532 m) to TRO site (1819 m).

Response:

Please refer to the response to comment #1 or Figure 5b in the revised manuscript.

- line 375-377: "In contrast, the peak concentrations occurred at the same time of day for individual NPF events at each site, implying a uniform influence of local-to-regional atmospheric conditions on the particle formation process". I don't understand this phrase. Please clarify and correct it.

Response:

For the reader, we explain individual NPF events in the revised manuscript as "We present analysis on concurrent and individual (i.e. an event happening only at one site while the other site did not show an event) NPF events.".

From Fig. S7, the air mass history appears to be distinct during individual NPF events at both sites. Individual NPF events at AMX are associated with air masses within the PBL, while at TRO it is linked to free-tropospheric air masses or PBL air masses that are reaching up to the TRO from the south side. These individual NPF events at both sites are not exclusively investigated here and are out of the scope of this study. We have delected the statement "implying a uniform influence of local-to-regional …" we actually do not know based on two-point observations.

- line 404-411: This section should move to introduction section. In addition, meteorological parameters like wind and temperature affect boundary layer evolution not PBL evolution affects meteorological parameters.

Response:

Section 3.3 substantiates our findings based on NPF characteristics and variations in particle number concentrations, mode diameter, and thereby the hypothesis. We would like to retain it here.

- line 448: "grey-coloured thin lines" → "grey thin line"

Response:

We have corrected it.

Responses to the Reviewer #2

RC2: Review of the Manuscript "Influence of Planetary Boundary Layer Dynamics on New Particle Formation in Cyprus" by Neha Deot.

This manuscript investigates the role of planetary boundary layer (PBL) dynamics in shaping new particle formation (NPF) processes in Cyprus, providing valuable regional data that could fill an existing gap in the literature. While the study highlights an important atmospheric phenomenon, there are several areas where the work could benefit from greater depth and clarity.

Response:

The authors are thankful to the reviewer for their valuable comments and suggestions and appreciate the time and effort the reviewer dedicated. All responses from the authors are remarked in blue. Changes in the revised manuscript text are depicted in red.

Major Comments.

Depth and Novelty of the current Research

The research focuses on a critical aspect of atmospheric science, but the novelty of the study is not articulated strongly enough. A few points to consider:

- How does this study advance the understanding of PBL-NPF interactions compared to prior research in regions like Finland, France, or South China etc.?

Response:

We have revised both the introduction and discussion sections partly to highlight current understanding and knowledge gaps.

Briefly, there are limited studies delineating the vertical extent of NPF within the PBL on a diurnal scale. Aircraft observations over boreal forests showed that particle concentrations (>1.5 nm) peak near the surface in the morning and mix within the evolving PBL layer during the day (Leino et al., 2019). However, airborne observations are costly and operationally challenging. Our sites offer a unique opportunity to study the vertical extent of NPF events and aerosol populations within the PBL, due to their close proximity, and also the mountain background site (TRO) is within the PBL for about >80% of days during the year. High-altitude free tropospheric locations offer pristine environments and are often considered ideal for studying pre-industrial processes. However, this study (and previous studies from elsewhere) highlights the importance of understanding the specific conditions of a given site. Additionally, local factors such as geographical features and local breeze system together with regional airmass history can significantly impact mountain/high-latitude locations as evident in this and previous studies. Thus, we need local-to-regional scale understanding for a specific location to interpret field observations.

Boulon et al. (2011) in Central France observed that NPF events occurred more frequently at a mountain site (the Puy de Dôme station, 1465 m a.m.s.l.) compared to a nearby rural site at a lower altitude (the Opme station, 660 m a.m.s.l., roughly 12 km southeast of the Puy de Dôme). We are also in similar settings, with TRO (mountain site) about 20 km southwest of the AMX (lower altitude site) and a substantial altitude change (1287 m) within a short horizontal distance. The follow-up study from France (Farah et al., 2018) found that the Puy de Dôme station remained within the PBL about 50% of the time in winter and up to 97% in summer, analogous to our findings. However, the NPF event frequency and characteristics between sites in these two locations (Cyrpus and France) are not the same. This indicates that PBL-NPF interactions may not also be the same in distinct environments (France, Cyprus, South China, etc.).

In future studies, we could carry out simultaneous measurements of sub-3 nm particles (PSM & NAIS), aerosol population (SMPS, PM sampler), aerosol precursor species (APi-TOF), and relevant meteorological parameters to more comprehensively elucidate these processes together with PBL dynamics. These observations will also be crucial to investigate the long-range transported dust impact on NPF, which is yet to be explored.

Lastly, the Eastern Mediterranean and Middle East region has been recognized as a global climate change hotspot. It also serves as a convergence zone for air masses originating from three distinct continents (Europe, Asia, and North Africa), including marine, anthropogenic, and desert dust sources. Moreover, there are a limited number of studies investigating NPF over the EMME region and the complexities involved. Our study provides new insights into the PBL-NPF relationship over this region.

We have added the following text to the revised manuscript.
1. Introduction – "Aircraft observations over boreal forests showed that particle concentrations (>1.5 nm) peak near the surface in the morning and mix within the evolving PBL layer during the day (Leino et al., 2019). However, airborne observations are costly and operationally challenging. Our sites offer a unique opportunity to study the vertical extent of NPF events and aerosol populations within the PBL, due to their close proximity, and the mountain background site (TRO) is within the PBL for about >80% of days during the year. The intense solar radiation, the intricate mixture of both natural and anthropogenic emissions from continental and marine origins, the presence of local breeze systems (mountain, valley, sea, and land) and elevated dust layers further add complexity to the PBL–NPF relationship over the region. The combination of these factors poses a significant challenge in understanding the drivers behind the frequent NPF events observed in Cyprus and, more broadly, across the Eastern Mediterranean."

2.1 Measurement sites – "The Eastern Mediterranean and Middle East region has been recognized as a global climate change hotspot, which serves as a convergence zone for air masses originating from three distinct continents (Europe, Asia, and North Africa), including marine, anthropogenic, and desert dust sources."

4. Discussion – "Airborne observations of sub-3 nm particles over boreal forests showed that the total particle number concentrations (>1.5 nm) are the highest near the ground in the morning, and the aerosol population is well mixed within evolving PBL later in the day (Leino et al., 2019). "

4. Discussion – "Nonetheless, only about 50% of NPF events occurred concurrently at both sites when air masses originated from the northwest to northeast corridors (with AMX located north-northeast of TRO). Figure S7 illustrates the monthly-averaged, two-day backward air mass trajectories as a function of altitude for NPF events at AMX and TRO. Despite the proximity of these sites (~20 km), NPF events often occur in distinct air masses (Fig. S7). At TRO, the remaining events were linked to free-tropospheric air masses or the PBL under similar conditions, with air masses arriving from the southwest to the southeast corridor. Air

mass history together with the intense solar radiation, the intricate mixture of both natural and anthropogenic emissions from continental and marine origins, the presence of local breeze systems (mountain, valley, sea, and land) and elevated dust layers over the region poses a significant challenge in understanding the drivers behind the frequent NPF events observed in Cyprus and, therefore adds complexity to the PBL–NPF relationship."

- What unique atmospheric conditions or challenges in the Eastern Mediterranean make this work distinct? For instance, could the region's combination of desert dust, marine air masses, and urban pollution add complexity to the PBL-NPF relationship?

Response:

The Eastern Mediterranean region serves as a convergence zone for air masses originating from three distinct continents (Europe, Asia, and North Africa), including marine, anthropogenic, and natural dust sources. The intense solar radiation, the intricate mixture of both natural and anthropogenic emissions from continental and marine origins, and the presence of local breeze systems (mountain, valley, sea, and land) concurrently add complexity to the PBL–NPF relationship. Moreover, elevated dust layers over the region can also influence PBL dynamics by altering the near-surface temperature gradient. The combination of these factors poses a significant challenge in understanding the drivers behind the frequent NPF events observed in Cyprus and, more broadly, across the Eastern Mediterranean. We have added relevant details and discussion in the revised manuscript as indicated in the response to the previous comment.

Interpretation of Results

The data presented is intriguing, but several aspects warrant deeper analysis and more comprehensive discussion, for example:

1. The study observes concurrent NPF events between the two sites only ~50% of the time. Why might this be the case? Could localized meteorological conditions, chemical heterogeneity, or even differences in precursor availability explain these findings?

Response:

About 50% of the NPF events occurred concurrently at both sites when air masses originated primarily from the northwest to northeast corridors (with AMX being to the north-northeast of TRO). Figure S7 shows the monthly-averaged, two-day air mass backward trajectories as a function of altitude for the observed individual NPF events at AMX and TRO. Despite the proximity of these sites (approximately 20 km), NPF events can occur within distinct air masses at these locations. At TRO, the remaining NPF events appear to have occurred in free-tropospheric air masses and/or within the PBL when air masses arrived from the southwest to the southeast corridor. It is our understanding that the history of air masses plays a critical role in differentiating these sites, in addition to other factors such as the intense solar radiation, the intricate mixture of both natural and anthropogenic emissions from continental and marine origins, the presence of local breeze systems (mountain, valley, sea, and land) and elevated dust layers.

We have added the following discussion in the revised manuscript.

"Nonetheless, only about 50% of NPF events occurred concurrently at both sites when air masses originated from the northwest to northeast corridors (with AMX located north-northeast of TRO). Figure S7 illustrates the monthly-averaged, two-day backward air mass trajectories as a function of altitude for NPF events at AMX and TRO. Despite the proximity of these sites (~20 km), NPF events often occur in distinct air masses (Fig. S7). At TRO, the remaining events were linked to free-tropospheric air masses or the PBL under similar conditions, with air masses arriving from the southwest to the southeast corridor. Air mass history together with the intense solar radiation, the intricate mixture of both natural and anthropogenic emissions from continental and marine origins, the presence of local breeze systems (mountain, valley, sea, and land) and elevated dust layers over the region poses a significant challenge in understanding the drivers behind the frequent NPF events observed in Cyprus and, therefore adds complexity to the PBL–NPF relationship.”

2. The 1–2 hour lag in particle detection attributed to vertical mixing and up-valley winds is plausible but needs stronger support. Would a modeling exercise or sensitivity analysis help validate this mechanism?

Response:

As suggested by the first reviewer, we calculated the time required for the PBL height to reach the TRO altitude relative to the NPF event start-time at AMX ($dT_{PBLevolution}$) and the time lag between peak number concentrations of negative polarity particles >2.5 nm ($dT_{PeakConc., N>2.5\,nm, particles(-)}$) for observed concurrent NPF events. The average time lags based on particles and PBL height are 1.57 hours (~94 minutes) and 1.73 hours (~104 minutes), respectively. This finding together with air mass history substantiates our hypothesis.

Indeed, a modeling exercise using a three-dimensional WRF-Chem model would be ideal, particularly with high-resolution wind fields, given the close proximity of the sites (20 km). We will pursue this in future studies, incorporating additional simultaneous measurements at both sites, such as aerosol precursors.

3. Why are particle growth rates not compared systematically between sites to explore environmental or chemical factors impacting aerosol growth?

Response:

Thank you for the comment. We have calculated size-segregated particle growth rates based on NAIS particle data. We have added panels (e) and (f) in Figure 5 and the following discussion to the revised manuscript.

During the concurrent NPF event days, the calculated size-segregated growth rates varied from 0.1 to 3.64 nm hr^{-1} (3-7 nm) and 0.18 to 6.08 nm hr^{-1} (7-25 nm) with a mean and standard deviation of 1.53±0.98 nm hr^{-1} and 2.35±1.16 nm hr^{-1} respectively, at AMX while they varied from 0.12 to 2.91 nm hr^{-1} (3-7 nm) and 0.4 to 8.7 nm hr^{-1} (7 – 25 nm) with a mean and standard deviation of 1.49±0.71 nm hr^{-1} and 3.68±2.22 nm hr^{-1}, respectively, at TRO. The growth rates of smaller particles (3-7 nm) were similar while the growth rates of larger particles (7-25 nm) were higher at TRO indicating that the particles grew rapidly during upward airmass transport from AMX to TRO due to PBL evolution (see section 3.3, Fig. 7), possibly by valley winds or vertical mixing, on concurrent event days. The lower number concentrations of nucleation mode particles at TRO than at AMX (Fig. 4) can facilitate more availability of vapour for rapid growth at TRO.

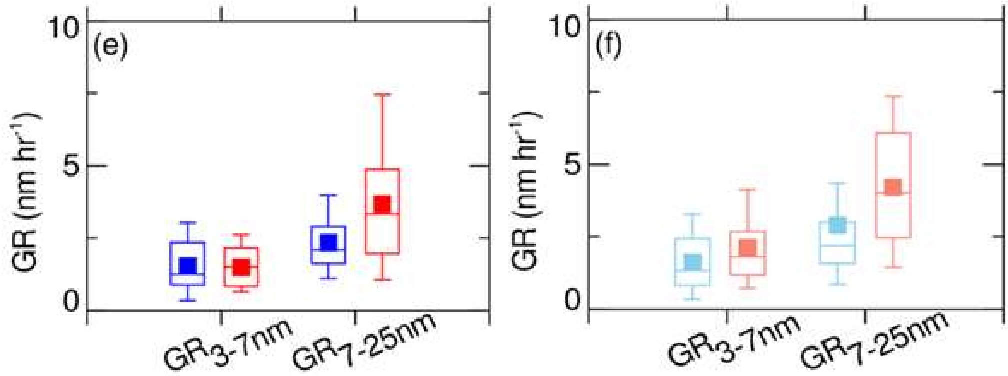

Figure 5(e,f). The box-whisker plot of size-segregated particle growth rates for negative polarity for the observed (e) concurrent NPF events and (f) individual NPF events. The filled square indicates the mean, the horizontal line indicates the median, the bottom and top of the box indicate the 25th and 75th percentiles, and the bottom and top of the whisker indicate the 10th and 90th percentiles

The authors could probably expand the discussion to include alternative mechanisms for site-to-site discrepancies, support transport and mixing hypotheses with additional data or quantitative modeling and maybe Include particle growth rate comparisons to add depth to the environmental impact analysis.

Response:

We have calculated size-segregated particle growth rate analysis which further substantiates our hypothesis. The physio-chemical and dynamical/meteorological factors driving the frequent occurrence of NPF events at these sites are planned to be pursued in future by incorporating additional simultaneous measurements at both sites, such as aerosol precursors. The field measurements aided with box or regional model simulations to interpret field measurements would be ideal, but not always possible.

Uncertainties and Limitations

The AMX site is assumed to always reflect PBL conditions, but is this assumption realistic? How might deviations affect the study's conclusions? Missing data from instruments like the NAIS is mentioned but not explored. How significant are these gaps in terms of bias or statistical robustness? If this is possible, please, add a subsection explicitly addressing uncertainties, including the potential impact of AMX site assumptions and data gaps. Also, use confidence intervals, error bars, or sensitivity analyses to quantify the reliability of key findings.

Response:

The statement, "AMX is assumed to be in the PBL at all times," was incorrectly stated, and therefore, it has been removed. The PBL is the lowest part of the atmosphere directly influenced by interactions with the Earth's surface and experiences strong diurnality due to heating, cooling, and turbulence caused by solar radiation and other surface processes. The areas immediately above the surface are always part of the PBL. The question here is how often TRO (the mountain site) was within the PBL relative to AMX, as the PBL's height can vary significantly between the two sites due to differences in altitude, local meteorology, and diurnal variations.

We have stated involved uncertainties or gaps in the presented analysis in relevant sections; Section 2.2.1: “Note that NAIS data is available for approximately 60% and 63% of the days at AMX and TRO, respectively (Fig. S1), which is statistically robust for this analysis.”

Section 2.2.3: “We have used quality-assured and quality-controlled data using standard procedures and instrument data quality flags”

Section 2.3: “we apply a robust data filtering technique to remove under or over-estimated PBLH data values in conjunction with ERA5 PBLH data. ……. After applying these constraints, we retained 5688 hourly data points from a total of 7248 valid hourly data points, thereby ensuring that only the most reliable data were included in the PBLH analysis”

To account for data with extremely high or low values or skewed distributions, we have used the median (Figs. 4, 5, and 6), which provides a more representative value.

Broader Implications

The study briefly mentions the relevance of NPF to climate models but does not expand on how these findings contribute to global or regional policy and scientific efforts. For example, how do the results improve our understanding of aerosol-cloud-climate interactions in climate change hotspots like the Eastern Mediterranean?

Response:

We have revised the broader implications to align with global scientific efforts addressing climate challenges, as follows:

“Despite significant progress in regional and global climate models enhanced with process-based parameterisations derived from controlled laboratory experiments, ambient measurements, and space-borne observations, a comprehensive understanding of the climate system remains elusive. The aerosol-cloud interaction is one of the largest sources of uncertainty in the climate system, primarily due to ambiguity in CCN production, which arises from uncertainties in both primary emissions and airborne secondary production (IPCC, 2023). Furthermore, the uneven geographical distribution and spatial heterogeneity of measurement networks, coupled with asynchronous monitoring and inconsistent data collection methods for various atmospheric variables hinder the ability to constrain model assimilation and validation. Thus, the process-level understanding of atmospheric processes, their interactions and feedback from them, such as the intricate mixture of primary emissions and airborne production of aerosols, is crucial for advancing future climate predictions, particularly the EMME region which has been recognised as a global climate change hotspot with high vulnerability to climate change impacts.”

how do the results improve our understanding of aerosol-cloud-climate interactions in climate change hotspots like the Eastern Mediterranean?

Response:

Please see the response to the above comment.

Are there any size distribution measurements available, such as from an SMPS? Including this data, if available, could significantly strengthen your results and enrich the content of your article.

Response:

Unfortunately, there were no simultaneous measurements of particle size distribution from SMPS or PSM during the study time period. As of starting of 2023, we have continuous SMPS measurements. We will be able to include those observations in future publications.

Minor Comments

- How do these results compare to studies in other regions with distinct PBL dynamics, such as monsoonal areas, polar regions, or highly urbanized environments?

Response:

We have compared our findings with those from other regions, specifically emphasizing the linkages between NPF occurrence and PBL evolution in the discussion section. This study focuses on the effect of PBL evolution on NPF occurrence at a mountain site (TRO) relative to simultaneous measurements from a nearby lower-altitude site (AMX). This study does not delve into the physio-chemical or meteorological/dynamical influence on the NPF phenomena.

There is an extensive body of literature on PBL dynamics and NPF in diverse environments, including monsoonal regions (India, Africa, South America, Australia), polar areas (the Arctic and Antarctica), and urban regions (China, India, the USA, Europe, Mexico, etc.). Due to its breadth, summarizing all these locations is beyond the scope of this study.

To deduce the effect of PBL dynamics on NPF, observations from acoustic remote sensing tools like sodar (Sound Detection and Ranging) and optical instruments such as wind LIDAR (Light Detection and Ranging) are essential for investigating PBL dynamics with high spatial and temporal resolution. Additionally, balloon-borne radiosonde observations are critical for examining thermodynamic parameters that govern energy transfer between the PBL and the atmosphere above it, stability, and convective processes. While model reanalysis products provide valuable insights, they are currently not available at very high spatial resolution (1 km).

- Are there notable agreements or contradictions with global patterns that could deepen the scientific understanding of PBL-NPF processes?

Response:

Our previous study (Baalbaki et al., 2021), which utilized one year of continuous measurements from NAIS (data availability > 98%) at the AMX site, revealed that NPF events occurred on 58% of the days. The frequency ranged from 33% in summer to 86% in spring, with the highest reported frequency after South Africa (86%) (Hirsikko et al., 2012) and Saudi Arabia (73%) (Hakala et al., 2019).

Our study not only highlights the high frequency of NPF at the lower-altitude AMX site but also at a mountain site. We further observed that 50% of NPF events occurred concurrently indicating the influence of PBL evolution on the mountain site (TRO). Our study is in agreement with previous studies showing NPF events occurrence in mountain locations under the influence of air masses from the PBL (Sebastian et al., 2021; Bianchi et al., 2016; Sellegri et al., 2019; Farah et al., 2018), but there are limited studies from the EMME region which has been recognised as a global climate change hotspot with high vulnerability to climate change impacts. Our study also contradicts Boulon et al. (2011) findings showing NPF occurs more frequently at a mountain site (the Puy de Dôme station, 1465 m a.m.s.l.) than at a nearby rural lower-altitude site in Central France.

- Some figure captions need to be fixed. For example, in Figure 5, the caption's references to 'a)', 'b)', and 'c)' do not align with the correct sequence of the figures.

Response:

Thank you. We have corrected them now.

- Figure 3. (c) and (d) should be in the right order. Also, for (c) and (d) the months on the x-axis are not visible.

Response:

We placed (b) and (d) on top of each other to facilitate comparison between the AMX and TRO sites and rearranged the panels into a single column.

- Could key findings, such as size-segregated particle concentrations or particle growth rates, be summarized in supplementary tables to enhance accessibility for readers?

Response:

We have presented both size-segregated particle concentration and growth rates in the main text.

- Line 226. Delete the “----"

Response:

Deleted.

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