Referee comments 3

Review of "Ice Nucleating Particle Concentrations over the Eurasian-Arctic seas" by Li et al., submitted to ACPD (egusphere-2025-2798)

Li et al. present valuable findings on INP measurements in the Eurasian sector of the Arctic Ocean during late summer 2021. These are paired with collocated aerosol size and composition data, supported by reanalysis and air mass trajectory analysis from shipborne observations. The inclusion of measurements from this sector is particularly notable, given the region's proximity to Russia and the general scarcity of INP and aerosol data from this area. This region is especially important as it serves as a key site for sea ice formation after the sea ice minimum in September. The case study highlighted in the paper is especially intriguing, with a well-supported connection between air mass history, wind speed, and aerosol composition suggesting potential fluvial-marine sources. I believe this manuscript merits publication following consideration of the comments outlined below.

We thank Referee 3 for the nice summary and positive feedback on our manuscript egusphere-2025-2798. In response to the questions and suggestions, please find our answers and revisions listed below. **Referee comments are reproduced in bold** and author responses in normal font; *extracts from the original manuscript are presented in red italic* and *extracts from the revised manuscript in blue italic*.

General comments:

My primary concern with the analysis is the lack of discussion regarding the removal of ship exhaust contamination from the online aerosol and HINC measurements. Ship stack emissions are a well-known source of interference in aerosol datasets and must be carefully filtered out, even when the vessel is in motion, since recirculated air can still impact measurements taken fore of the stacks. While previous studies have shown that ship emissions do not significantly affect offline, immersion-mode INP concentrations, the same cannot be assumed for online measurements. I strongly recommend that the authors apply an established method, such as the one developed by Beck et al. (2022), to identify and exclude periods potentially influenced by ship exhaust. Implementing such quality control steps may also improve correlations with the offline INP data.

We agree with the reviewer and appreciate the suggestion. In our study, we did take active measures to minimize its influence. For the PM_{10} filter samples (LVS on the 6th deck), sampling was automatically halted whenever the wind direction was from the ship's funnel to avoid contamination. For the impinger and HINC measurements (on the 2nd deck), we used CPC data to identify time periods as being affected by exhaust plumes based on sharp transient spikes in total particle concentration, which were filtered out and excluded from INP analysis. These measures substantially reduce the risk of exhaust contamination in the reported data, although we acknowledge that low-level or short-lived influences may not be fully eliminated. A corresponding clarification has been added to Section 2.2.1 in the revised manuscript (see lines 91-96): *In addition, to minimize contamination from ship exhaust, specific procedures were followed for the two sampling locations. On the 6th deck, the PM_{10} filter sampling (LVS) was automatically paused whenever wind direction sensors indicated air flow from the ship's funnel. For impinger and HINC measurements on the 2nd deck, spikes in total particle number concentration measured by a CPC were used to identify exhaust plumes; these periods were flagged and removed from the dataset. These measures substantially reduce the influence of exhaust emissions on the reported INP data, although minor residual contamination cannot be fully excluded.*

Specific comments:

Line 16: "...which is a decrease in cloud albedo upon glaciation…" While this precise statement is true, generally a decrease in cloud cover would lead to less surface warming on average, since MPCs contribute to surface warming most of the year except for a short period in the middle of summer (Intrieri et al., 2002). Thus, while cloud albedo decreases due to glaciation, cloud thinning reduces the stronger downwelling

longwave effects from MPCs. May want to consider reframing this statement in light of the first sentence of the paragraph.

We agree that the full radiative response of MPCs also involves potential thinning and an increase in outgoing longwave. We have revised the sentence to reflect this aspect while maintaining the highlight on the dominant shortwave effects relevant to our study (see lines 14-19 in the revised manuscript): *The phase partitioning of hydrometeors in Arctic low-level MPCs affects the Arctic's radiation budget (Korolev et al., 2017; Serreze and Barry, 2011) through cloud phase feedbacks associated with glaciation. This phase transition reduces cloud albedo, enhancing shortwave absorption at the surface during summer and contributing to Arctic warming (Tan and Storelvmo, 2019). In the wintertime, glaciation may also lead to cloud thinning and an increase in outgoing longwave radiation (Intrieri et al., 2002), the dominant radiative impact during the melt season remains the decrease in cloud albedo.*

Line 43: The authors could consider citing Creamean et al. (2022) and Wex et al. (2019) to support the statement regarding the seasonal cycle, particularly for elevated INP concentrations during summer months.

We added Creamean et al. (2022) and Wex et al. (2019) referring to the seasonal cycle of INP concentrations in the revised manuscript (see lines 44-45).

Line 47: The authors could replace Hall (2004) with more updated citations on Arctic amplification, such as Yoshimori et al. (2025) and/or Rantanen et al. (2022).

Thanks for providing the updated references and we updated accordingly in our reference list regarding Arctic amplification (see line 50 in the revised manuscript).

Line 48: Define MBA as marine biogenic aerosol.

MBA was defined in the previous paragraph at its first appearance (see line 38 in the revised manuscript).

Figure 1: The ship track is incomplete, as it does not extend to Murmansk at the end. Additionally, it would be helpful to indicate the location of the ship's exhaust stack in panel b, as this is relevant for evaluating potential contamination in the aerosol measurements.

The ship track does not extend to Murmansk due to operational restrictions imposed by the Russian Navy at the beginning of the cruise. During this initial phase, navigation data were classified and cannot be publicly released. Additionally, scientific measurements were not permitted until the ship left the restricted zone, which is why both the track and data coverage begin later.

We modified Fig. 1b to indicate the location of the ship's exhaust funnel as suggested.

Line 86: Out of curiosity, why are samples stored in the fridge overnight prior to analysis?

As part of our standard quality control procedure, the frozen samples are first stored overnight at 4 °C to allow controlled melting at moderate temperature prior to DRINCZ analysis. This approach helps prevent thermal degradation of potentially heat-sensitive IN components, ensuring consistency and reliability in the measurements.

Line 178: It is intriguing that the authors note their results are comparable to those of Hartmann et al. (2021), despite the fact that Hartmann's measurements were taken in early summer (during the onset of sea ice melt and primary productivity) whereas the present study occurs in late summer, following the peak in productivity and during the period of the annual sea ice minimum. It would be interesting for the authors to elaborate on why they consider these datasets comparable, given the seasonal and biogeochemical differences between the two time periods.

While the timing of the two studies differs, we suggest the comparable N_{INP} magnitudes arise from a seasonal succession of source mechanisms. In early summer (Hartmann et al., 2021), the onset of melt drives a significant flux of efficient terrestrial mineral INPs into the marine environment. By late summer, this is replaced by peaking marine biological productivity and maximum exposure of snow-free land, which enhances biogenic and local dust emissions. This transition maintains a consistent N_{INP} baseline throughout the summer despite shifting biogeochemical drivers.

Figure 2: Why are the Welti, Bigg, and Creamean datasets only presented at –15 °C? Additionally, what datasets do the bright purple and orange boxes at –15 °C represent? The visibility of the Welti, and Bigg and Leck data could be improved for clarity. The authors may also consider incorporating more recent INP data from the MOSAiC expedition (Barry et al., 2025), which includes observations in a similar region west of Svalbard, as well as data from Irish et al. (2014), which, although from the Canadian Archipelago, could provide a useful spatial comparison for July and August. Note that Barry et al. (2025) is currently available as a preprint: https://egusphere.copernicus.org/preprints/2025/egusphere-2025-128/.

These datasets are only shown at -15 °C because their published data were reported exclusively (Bigg 1996) or most consistently at this temperature, making it a common comparison point across all studies for a relatively clear demonstration. The bright purple and orange boxes at -15 °C represent Creamean et al. (2019) and Bigg (1996), respectively. We have now clarified this in the figure caption and made clearer temperature-based categories to avoid confusion.

The suggested references are valuable contributions to Arctic INP research and provide important regional perspectives. We now added comparison data from Barry et al. (2025) in our updated Fig. 2 and corresponding comparison text in the revised manuscript (see lines 205-214): *In addition, our summertime N_{INP} spectra over the Eurasian-Arctic Seas are largely consistent with recent year-long observations from the Central Arctic (Barry et al., 2025; represented by orange crosses in Fig 2). Barry et al., (2025) reports that biological INPs dominate the Arctic spectrum year-round, with a significant seasonal peak in early summer (June-July) reaching concentrations up to 1.4 L^{-1} at -15 °C. While our late-summer observations (August-September) generally fall within the range of these Central Arctic measurements, they do not capture the extreme peaks observed earlier in the melt season. This discrepancy likely reflects the temporal shift in marine productivity and terrestrial runoff, which peaks prior to our late-summer campaign. Nevertheless, the overall consistency in N_{INP} magnitudes and temperature-dependent trends across these two geographically distinct sectors suggests that the Eurasian Arctic Seas share a similar INP regime with the Central Arctic Ocean, characterized by regional emissions from the marginal ice zone and snow-free land surfaces.*

Line 232: Why did the authors choose 2-day back trajectories rather than longer ones that might capture long-range transport? Also, was the boundary layer height obtained from ERA5?

The use of 2-day back trajectories focuses on identifying local to regional influences on INP concentrations, particularly in the Arctic boundary layer, as trajectories were initialized near sea level and removed if they exceeded the boundary layer height. This approach was chosen to directly link near-surface measurements with recent surface interactions. We agree that this approach may not fully capture potential long-range transport events, such as those associated with aged mineral dust or recirculated aerosols that have residence times exceeding two days. Also, the boundary layer height was indeed obtained from ERA5.

To address this limitation, we have extended our back trajectory analysis to 7 days (see Fig. E3 for all measurements at -34 °C and -15 °C; and Fig. E4 for selected high and low N_{INP} cases at -20 °C, respectively, in the Appendix) and complement our discussion in Section 3.5 (see lines 335-338 in the revised manuscript): *"This finding is corroborated by extended 7-day back trajectories (see Fig. E3 in the Appendix). Notably, elevated N_{INP} observed near Novaya Zemlya at both -34 °C and -15 °C coincide with air masses characterized by prolonged residence over the western Siberian coast - a hotspot acting as a potent source for both mineral dust and biological particles as discussed previously."* and section 3.6 (see line 368 in the revised manuscript): *"…from the west Siberian coast, suggesting INP influence from both local source and long-range transport."*

For boundary layer height, it was used to filter backward trajectories obtained from ERA5 hourly output, consistent with the meteorological fields used to compute the trajectories.

Lines 241-243: These statements are supported by Nieto-Caballero et al. (2025) and Weiber et al. (2025). The authors could consider including these citations.

Thanks for providing the updated references, and we updated accordingly in our reference list regarding thawing permafrost as a source of INPs (see lines 324-325 in the revised manuscript).

Line 272: The authors may wish to highlight that, despite the substantial presence of melt ponds covering up to 20–30% of the sea ice surface (Webster et al., 2015), the peak of primary productivity has already passed (e.g., Ardyna et al., 2020). Consequently, local biological sources of warm-temperature INPs are likely to be minimal during this period.
We thank the reviewer for this insightful point. While Webster et al. (2015) and Ardyna et al. (2020) focus on different Arctic sectors, we agree that the general phenological transition from peak productivity to a late-summer minimum likely applies to our study area, perhaps with a spatiotemporal shift. Even with substantial melt pond coverage, the biological matter available for aerosolization is expected to diminish following the main bloom. As a result, we acknowledge that this seasonal biogeochemical constraint likely contributes to the relatively low abundance of warm-temperature INPs observed during the campaign. We now acknowledge this in the revised manuscript (line 371-373) "*During the late summer, there is a substantial presence of melt ponds up to 20 - 30% of the sea ice surface (Webster et al., 2015), the peak primary productivity has already passed (Ardyna et al., 2020), leading to low local sources of INP coming from the ice-covered region.*"

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