Anonymous Referee #2

This study introduces a new methodology for detecting INP, which combines several information sources: the INP concentration profiles derived by lidar measurements; their comparison with UAVs measurements, and use of INP parameterizations for different freezing mechanisms. Necessary thermodynamic parameters are obtained from an atmospheric model.

The proposed approach contributes to better understanding of the complex process of cold cloud formation - one of the emerging issues attracting substantial attention of the scientific community. The article's subject is clearly presented with conclusions of high scientific relevance. It is well structured and provides detailed evidence on the IN subject published in the community. However, in order to more improve the quality of the paper, I invite the authors to consider the following recommendations, comments and questions prior to the publication of the article:

[REPLY] We thank very much referee #2 for his/her careful reading, comments and suggestions, which we address in the following. With his/her suggestions, we believe that the new version of the manuscript is significantly improved, and our findings are promoted in a better way. The author's answers along with the changes in the manuscript are listed below.

> Remark: The figure numbers and the page numbers in the referee comments are corresponding to the original manuscript. If not stated otherwise, figure and page numbers in the authors' answers are referring to the revised, marked-up manuscript version (showing the changes made) which can be found attached to this answer.

<u>General comments:</u>

Section 4 Results and discussion is the most important part of the paper which describes in details the evaluated results of the study. Figure 4 is excellent way to introduce a reader, in general, on considered processes (aerosol, clouds) over the selected observation period. After presenting evaluation of n250 and nINP retrievals (4.1 and 4.2 sub-sessions), Figure 10 is summarizing the major results of the proposed methodology. However, I find it not sufficient to promote the full value of the study. Namely, the figure shows INPs for only two instances of the 2-day selected period. From the figure, it is not possible to have evidence on the INP time evolution over the period, and also to conclude how INP correlates to cloud observations. I therefore ask the authors to generate a time-height INP graph (of a similar format as the one in Figure 4). For this additional result, PollyXT data should be adjusted to the time/height output of the WRF thermodynamic parameters. Consider also to compare the evaluated results with some satellite relevant cloud-related data such as e.g. ice water path, in order to show if the proposed method indicates the occurrence of cold clouds.

[REPLY] We thank the reviewer for this very constructive comment. We worked on these suggestions. We generated a new time height INP graph from the CALIPSO track (Figure 13) and we used the A-train observations during the event of 21-April-2016 in order to present the clouds observed above the scene and to evaluate the proposed methodology in the presence of ice clouds (new Figure 5, Figure 12 and Figure 14).

New version:

Page 10, line 30 – page 11, line 20: Section 3.4 “Space-borne cloud observations” describes the relevant space-borne data used to indicate the occurrence and ice number concentration of clouds.

Page 12, line 34 – page 13, line 6: “Figure 5 provides an overview of the aerosol and clouds above the area, with the MODIS true color image (upper panel) and the combined DARDAR and CALIPSO L2 feature mask (lower panel). Dust is observed above the broader region in altitudes up to 6 km and ice clouds are formed inside the dust layer South of Cyprus in altitudes greater than 4 km (T < 0◦C). The ice clouds are detected/characterized at 1 km horizontal resolution (DARDAR-MASK product) while the dust plume is detected at 20 and 80 km horizontal resolution (CALIPSO L2 product).”

Page 20, line 22 – Page 21, line 13: Presents the satellite relevant cloud-related estimations of ice number concentrations inside the clouds and the INP concentrations in their vicinity.

<u>There are few minor issues to be also considered:</u>

I suggest the following more concise article title: Retrieval of ice nucleating particle concentrations from lidar observations and comparison with UAVs measurements

[REPLY] We thank the reviewer for the suggestion. We change the title in: “Retrieval of ice nucleating particle concentrations from lidar observations and comparison with UAV in-situ measurements”.

Please provide more details on the WRF model data used to complement the observations: reference; resolution; source of the data; are the model temperature and humidity both used in the calculations?

[REPLY] We thank the reviewer for this comment. We added the necessary information on the modeled fields used in the end of section 3.2. The paragraph added is the following:

New version: page 9, line 17: “In the final step, the n_{INP} profiles are estimated using the ice nuclei parameterizations presented in Section 2 (Eq. (1)-(7)). For these calculations we are using collocated modeled profiles of the pressure, temperature and humidity fields. Specifically, for the PollyXT-based nINP calculations we use hourly outputs from the Weather Research and Forecasting atmospheric model (WRF; Skamarock et al. (2008)) which is operational at the National Observatory of Athens at a mesoscale resolution of 12 x 12 km and 31 vertical levels (Solomos et al., 2015, 2018). Initial and boundary conditions for the atmospheric fields and the 30 sea surface temperature are taken from the National Center for Environmental Prediction (NCEP) global reanalysis at 1◦x1◦ resolution. For the CALIPSO-bases nINP calculations we use the track-collocated meteorological profiles from the MERRA-2 model (Modern-Era Retrospective analysis for Research and Applications, Version 2) which are included in the CALIPSO V4 product (Kar et al., 2018).”

P9 L22-23: ’Figure 4 provides an overview of the times and heights of the PollyXT and CALIPSO lidar measurements, along with the UAV measurements, between 20 and 22 April 2016’. What are the arguments that this particular period of observations is selected for detailed analysis but not some other similar ones during the April campaign?

[REPLY] Thank you very much for this comment, indeed this information was missing. We added this information in the manuscript in:

New version: page 12 line 24: “The pure dust event on 20 to 21 April 2016 is considered the golden case of our dataset, as it has been observed simultaneously with the PollyXT lidar, the UAVs and the A-Train satellites. Additionally, it is the only pure-dust event of our dataset where we have simultaneously good lidar observations and in-situ INP measurements.”

What is the acronym OPC?

[REPLY] OPC is “Optical Particle Counter”. We made the first letters in each word capital in the manuscript.

New version: page 10, line 15: “Cruiser was additionally equipped with an Optical Particle Counter (OPC, Met One Instruments, Model 212 Profiler).”

P10 L21: It should be useful to also show the volume depolarization ratio image.

[REPLY] We updated Figure 4. The new figure has three images: the backscatter coefficient at 1064 nm, the volume depolarization ratio at 532 nm and the feature mask of the scene.

Figure 4: Please include date markers on the x-axe (together with corresponding times)

[REPLY] We included the date also in the markers.

Figure 1 (left) Why D15-dust is shown for T>-18C which is out of the validity range of this parameterization? Similar done for U17. Are the dashed lines extrapolations of D15 and U17? Please comment in the text.

[REPLY] Indeed the dashed lines are extrapolations of the parameterizations in the immersion-freezing range. This information is mentioned in the manuscript, but it is now additionally mentioned in the text of Figure 1.

New version: Figure 1 legend: “In the immersion mode (right) panel, the parameterizations are extrapolated over the immersion-freezing temperature range (dashed lines)”.

Specify what are continental aerosols Figure 3: Include please a reference for the selected bimodal distribution, if any

[REPLY] We consider this sentence as an accidental merge of two separate commends: “**Specify what are continental aerosols”** and **“Figure 3: Include please a reference for the selected bimodal distribution, if any”**.

For the first one: “**Specify what are continental aerosols”**

[REPLY] We specify what is considered as continental aerosols in the following sentence:

New version: page 5, line 24: “As the majority of the samples used for D10 were non-desert continental aerosols, this INP parameterization has been considered to be suitable for addressing the immersion and condensation freezing activity of **mixtures of anthropogenic haze, biomass burning smoke, biological particles, soil and road dust** (Mamouri and Ansmann, 2016). **From here on these mixtures are addressed as continental aerosols.”**

For the second one: **“Figure 3: Include please a reference for the selected bimodal distribution, if any”**

[REPLY] Considering the choice of the bimodal size distribution (instead of e.g. a size distribution with more modes), we refer here to the work of Remer and Kaufinan (1998), stating that physical processes in the atmosphere most frequently result in a bimodal structure of the aerosol size distribution. The specific bimodal size distribution is calculated as the best fit of the in situ measurements.

References:

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