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Atmospheric Measurement Techniques Discussions
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# *Interactive comment on* "A new method to infer the size, number density, and charge of mesospheric dust from its in situ collection by the DUSTY probe" *by* Ove Havnes et al.

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Reply to ref. # 1.

General comment 1. Comparison Lidar/Photometer and DUSTY measurements. We certainly agree with the referee that the quality of the results obtained with the method introduced in the manuscript depends critically on the quality of the model used in the analysis. We further agree, as we pointed out in the discussion section, that the treatment of charging has to be significantly improved in future work on the development of a more refined "final" model. We mentioned several effects that we intend to consider and, as the referee pointed out, we will have to study the effect of a distribution of dust sizes and the effect of several populations of dust. As the referee also pointed out, the difference in dust density resulting from the DUSTY and Lidar data requires more detailed consideration. We present our current, initial model to demonstrate the potential for an analysis of DUSTY measurements to provide information about the dust size complementary to that obtained through the analysis of Lidar/Photometer measurements and to initiate an effort to explore a new method. Given that the model represents a first step, it is not sophisticated enough to allow a full explanation of the difference between the dust sizes and densities obtained with different methods. Such an explanation will have to wait until a much more developed model including a more complete and complex description of charging has been implemented and the factors mentioned by the referee can be addressed. We will, however, in the present manuscript discuss this in more depth and argue that the difference in dust density given by DUSTY and Lidar may be severely affected by the charging model if it, for example, overestimates the average dust charge. If the average dust charge is reduced in more complete charging treatments, a larger number of dust particles are needed to explain the dust charge density (which is independent of the model for the secondary charging effect) measured by DUSTY. Also, while we in the present manuscript use one single dust size in the analysis, the introduction of a dust size distribution will most likely lead to an overestimate of the average dust size.

General comment 2. Dust versus ice particles/aerosols. One reason why we have used the label dust for all solid particles (NLC particles or ice particles and meteoric smoke particles) which are found in the NLC region), is simply that several of the authors have also been working in the field of “Dusty Plasmas” in which the word “dust” is generally used for a variety of types of solid particles. Historically, important work (e. g. Spitzer, 1941, ApJ, 93, 369) on the charging of solid particles in natural environments has concerned dust particles and we feel that it is natural to relate charging and other processes in the upper mesosphere to similar ones occurring in interstellar clouds, planetary rings, and manufacturing environments. The second reason is that if we use the word dust, which appears 188 times, instead of NLC particles or ice particles, we may save text corresponding to some 15 lines. We hope that it is sufficient that we early on explain that when we use the word dust in the NLC clouds, we are referring to NLC particles and ice particles. If the referee insists, we will use NLC particles or ice particles as suggested.

Replies to the Specific comments: 1. Referred to: Lübken, F.-J., Berger, U., & Baumgarten, G. (2018). On the anthropogenic impact on long-term evolution of noctilucent clouds. Geophysical Research Letters, 45, 6681–6689. https://doi.org/10.1029/2018GL077719 2. Referred to: Carrillo-Sánchez, J. D., D. NesvornÃ¡, P. PokornÃ¡, D. Janches, and J. M. C. Plane (2016), Sources of cosmic dust in the Earth's atmosphere, Geophys. Res. Lett., 43, 11,979–11,986, doi:10.1002/2016GL071697. 3. Referred to: Hervig, M. E., Brooke, J. S. A., Feng, W., Bardeen, C. G., & Plane, J. M. C. (2017). Constraints on meteoric smoke composition and meteoric influx using SOFIE observations with models. Journal of Geophysical Research: Atmospheres, 122, 13,495–13,505. https://doi.org/ 10.1002/2017JD027657 4. : . . . collision . . .Detector) find the mass distribution of the 5. insert : such 6. New text line 91: is shown in Fig.1, is equipped with three grids G0, G1 and G2. Grid G1 prevent . . . 7. We prefer to keep this as is. 8. New text: . . .the cloud (at 81.36 and 86.85 km) are to be 9. cloud system, changed to “noctilucent cloud”. 10. reduction of dust sizes . . .. (changed to) reduction of icy dust sizes 11. line 178 change text: The text was intended to communicate the point that the secondary production of charges during impacts of very fast particles tends to be proportional to the particle mass. However, it is probably sufficient to just quote the results from experiments with impacts of smaller and slower ice particles were the charge production is proportional to the cross section of the particle. This means that we may delete the sentence starting in line 178 and ending in line 180. 12. We are of the opinion that the definition of the impact angle in line 188-189 should be sufficient but it is probably a good idea to give the examples suggested by the referee. We would then insert a sentence in line 189. . . . impacting particle. The impact angle Ïť will be equal to zero for impacts at the top of the wire and equal to 90 degrees for a glancing impact at the extreme side of the wire. 13. Hervig

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et al 2012 find filling factors (of MSP in NLC icy dust particles) from 3% and down, as the referee points out. From DUSTY measurements we find that –probably- the max filling factor can possibly be larger than this. We will change the text to include this. 14. See general comment 2. 15. This comment by the referee must be an important part of a "final" discussion and mapping of the effects of dust size distributions. We are aiming at calculating the effect of different dust density distributions and possibly two (or more) populations of dust particles in a future paper with a more complete dust charging model. However, in accordance with the recommendations by the referee we find it appropriate to include a short discussion of the effect of a dust size distribution on the final average dust size from DUSTY. We will discuss the effect of two limiting cases: 1) The secondary charge production is negligible – which indicates small dust particles. 2) The secondary charge production is dominant – which indicates large dust particles In the first case, if the electron density is large, the average dust charge on one dust particle is roughly proportional to its radius. In such cases DUSTY will, by the method used in the present paper where all dust particles at one height are taken to have the same radius, indicate a larger average dust size than the real one. However, effects like the photo-detachment which increase with decreasing dust size, will counteract this especially for sizes less than several nanometer. In the second case this overestimate of DUSTY for the shift of the average dust radius will be larger since a dust particle by impact produces a secondary charge proportional to the square of the dust radius (see Eq. 6). The detailed effect of a dust size distributions, possibly also of two or more populations of dust, on the final outcome of DUSTY dust sizes will require an upgraded dust charging model. 16. Insert: dust number density ND. 17. total number density 18. It cannot be excluded that there are multiple solutions but we feel quite certain that this is not the case. If it were, we believe that the numerical iteration process would show signs of this. 19. now reads: …. a new total dust number density … 20. We would prefer to not use "NLC layer" since this is a structure with several NLC layers. NLC cloud system seems like an acceptable compromise. 21. replace structure with layer. We cannot say if this is icy particles or MSP (meteoric smoke particles). 22. We will insert in Fig.3 panels a), b), c) so we can directly refer to 3b. 23. We will change red to black. 24. We will change, see 22. Also, we are here close to the noise level and our discussion is not very solid. It is mainly meant as suggestions as to what may have been observed. We will expand the discussion on this. 25. Insert words to make it clear that this concerns mainly the icy dust particles. 26. We will change to cm-3. 27. We will quote typical uncertainties for the model which we use. The uncertainties are mainly caused by uncertainties in the secondary charge production. The real uncertainties require a more complete charging model. 28. It could be useful but we decided not to include this. 29. In the analysis of the MISU photometer observations a monodisperse size distribution. 30 was adopted. 31. We will add that we find it somewhat surprising that the lidar backscatter models for pure ice particles and ice particles with 5% FeO (by volume) is so small. 33. See # 15. Our analysis most likely overestimate the average dust particle size – see #15. An improved charging model is essential to arrive at the best information on dust size distributions. 34. We will here also add a sentence that the true difference between the results by Lidar and DUSTY most likely is smaller than what is indicated by our model assuming mono-disperse dust size distribution. 35. The main purpose of this is to show the very large difference between the Lidar and the DUSTY sampling volumes. 36. Yes, and the changes which may result in a more complete charging model (smaller dust, higher dust density), should most likely bring the two results closer together. We will insert a sentence on this. 37. This is just a part of the discussion in order to understand consequences of possible changes of parameters. 38. ok 39.Possibly but not necessarily MSP. 40. Most often ice particles but could also be comparatively large MSP (larger than ca 2 nm).

Reply to refere #2 Many of the comments by Referee #2 are similar to those from referee #1 and we also refer to the answers to #1. 1. We have in the writing process had several iterations on the abstract and felt that this was in good shape. Since the referee to some degree disagrees on this, we will make another iteration where we also consider the comments by the referee. 2. We will change to .... understood ... 3. The secondary charge production by impacts of dust particles (ice and metal particles) on to metal surfaces has been demonstrated in many laboratory experiments. We refer to some of these works in the manuscript ca (178 to 212). The laboratory works by Tomsic (2001) demonstrate that initially, as the impacts starts, the majority of particles carried away by impacting dust particles or their collision fragments are negatively charged. After a few minutes this changes and the net charge carried away becomes positive. We may still add some text on the secondary charging effect. 4. That is correct. 5. In the present paper the analysis is based on a situation where the payload coning is small (zero). The incoming dust particles will impact on the grid wires with impact angles from 90 deg (glancing impact at the edge of a wire) to 0 deg (impact at the “top” of the wire). In Havnes and Næsheim (2007) we consider situations where the coning angle is large and conclude that to explain the observed current variations caused by payload spin and coning. 6. We may replace $\sigma$p with Cp 7. Secondary charges are produced by glancing impacts on the grid wires. This means that only part of the wire takes part in producing secondary charges. Earlier modelling (Havnes and Næsheim 2007) find that only impacts on around 28% of the projected grid area (on to e.g. the bottom plate) lead to secondary production. 8. We refer to the answer to referee #1 - General comment #1 and comment #15. We will list the simplifying assumptions which have been made. 9. It is correct that the electron density is taken from Faraday measurements which has a height resolution of around a km. The DUSTY measurements have a height resolution of ca 10 cm. The DUSTY results will identify very narrow structures but it is correct that to achieve the best possible structure profiles, the electron density measurements should have a similar height resolution as for the electrons. Improved electron densities should soon be available to be used in our planned future work including an improved charging model. 10. The lidars will certainly not be able to identify narrow structures. This is clear from the lidar resolution in height and time which we point out (lines 408 to 415). We did plan to verify our results in the MAXIDUSTY campaign by flying a dust mass spectrometer MASS (references on lines 83 and 84) on MXD-1. The comparison between MASS and DUSTY-results would indicate if our results where correct. However, since MASS has a height resolution of

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close to a km the comparisons could only be done for average values. However, the MASS instrument on the MXD-1 payload did not work properly. 11. We will look into making some revisions.

Reply to Ref # 3. 1. See references on line 441-4. 2. This follows from the fact that the surface potential on all single isolated dust particles (when the dust density is much lower than the electron density) will be the same for given plasma conditions. Since the surface potential is proportional to the dust charge, and inversely proportional to the dust radius then the dust charge will be proportional to the dust size. This requires that the dominant charging effect is collisions between ions and electrons in the plasma, and dust particles. 3. There is a constraint in the model itself in the sense that if we change the plasma conditions then the dust charges change also. Fig.7 shows the dust charge density. The dust particles have a tendency to absorb electrons most effectively (unless photoelectric and photo-detachment effects are effective) since they move so much faster than the ions. So, a lot of dust leads to fewer electrons. They are all closely bound together since dust so “easily” absorbs electrons and (normally) less easily absorbs the ions. 4. Best fit of smoothed 3rd degree curves to observations below and above the layer. The raw data are the initial raw data smoothed by a sliding mean method to remove noise. Some of the slow general background variations can come from payload charging. The rapid variations are due to payload rotation. 5. See #4. 6. See #4 7. The ion density will be equal to the sum of the electron density and dust charge density (Eq. 10). 8. That small scale structures are present is supported also by DUSTY (and also by radar measurements – which are not included here). 9. In this context the reference value for rd is not changed. We could have chosen another reference dust size but that is not necessary since we can change the secondary efficiency by just changing $\eta$S,ref. 10. We will mention that an effective photoelectric effect will reduce the average dust charges (in extreme cases maybe make it positive) and, together with the photo-detachment effect, lead to an increase of computed dust density, and a decrease of dust radius. See the other referee reports 11. We will consider these comments.

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