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# *Interactive comment on* "The research on small-scale structures of ice particle density and electron density in the mesopause region" *by* Ruihuan Tian et al.

**Ruihuan Tian et al.**

tianrh_hit@qq.com

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Dear Reviewer, Thank you for your insightful comments concerning our manuscript entitled "The research on small-scale structures of ice particle density and electron density in the mesopause region". Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied these comments carefully and have made corrections which we hope make our paper more acceptable. The responds to the comments are as following. Once again, special thanks to you for good comments and hope that the correction will meet with approval.



Responses to Reviewer

This manuscript describes development of a model and associated calculations for ultimately determining the ice particle and electron density in the mesopause region. The electron density structures are particularly important for producing Polar Mesospheric Summer Echoes PMSEs and one ultimate goal of this work is to contribute to an understanding of the PMSE source region. The model utilizes a growth model for the ice particles (collision and adsorption of water vapor and condensation nuclei), and a velocity model (dependent on the ice particle mass and dependent on gravity and neutral drag forces) to ultimately determine the ice particle density with altitude. A charging model (OML with CEC) and quasi-neutrality is then used to determine the electron density knowing the ice particle density. Results of using this model are used to show a reduction in electron density in the source region. These reductions produce radar scatter associated with PMSE.

The manuscript is relatively well organized and well laid out. There are some issues with English grammar and style that clearly should be addressed (there is not an unreasonably large number of these English issues, however).

Response

Thank you very much for pointing it out. We have gone over the text and some English usage and grammar mistakes have been revised to make it easier to understand. However, there are some serious issues that preclude publication in Annales Geophysicae AG at this time. A key issue is that the authors have not made a persuasive case of the contribution to the field of this work. They have presented a model and some calculations but not effective tie these to observations to lend credibility to the model results. Also they have not articulated a well-defined, focused issue in the field they want to address. There has been past work in this field with previous models. There is no substantive discussion on how their model is an improvement over past models and what unresolved issues they have been able to solve that past models have not.

Response

Thank you very much for your valuable and thoughtful comments. It is believed that small scale electron density fluctuations can cause PMSE phenomenon (Rapp and Lübken 2004). And previous works (LieâĂŘSvendsen, et al. 2003;Rapp and Lübken 2003) have shown that ice particle irregularities on meter scale can create electron density fluctuations on the similar scale due to plasma attachment by particles and plasma diffusion. In their models, the ice particle density profile is given directly, with an embedded small scale Gaussian structure. However, the formation mechanism of these small-scale particle density structures has not been fully understood. In view of this, the aim of our study is trying to explain the formation of these ice particle irregularities through the growth and movement model. The analysis of relevant previous work and the purpose of this paper have been added in the introduction. Meanwhile, to make our model results more accurate and credible, we have modified the plasma model according to the detailed comments below, which includes dynamic continuity equations for ice particles with various charges and ions, momentum equation for ions and electrons, and quasi-neutral condition. The results of the revised model are in agreement with previous work by Lie-Svenson et al. (LieâĂŘSvendsen, et al. 2003), e.g., for particles with radii of 11 nm or less, electron density is anti-correlated to charged ice particle density and ion density, which is in line with most rocket observations. We have modified the charging model in the second section, and have added a comparison with previous work in the third section.

Therefore, the paper is not suitable for publication in AG in its current form. There must be major revisions and the authors must address these key issues. Further details of some of the critical weaknesses are as follows:

1. The last sentence (line 23-25) of the Abstract is indicative of the major problem. This sentence is vague. Why is this work important? The rest of the abstract has not made a case for this. In fact, the last sentence is very well known to be the case from other work! No novelty of this work is stated.



Response

Thank you very much for pointing it out. We are sorry for our unclearly description on the innovation and significance of this manuscript.

The main value of this paper is to propose a possible mechanism for the formation of small scale ice particle density irregularities in PMSE region based on particle growth and movement model, while the structure of ice particle density is always assumed to be some specific profiles in previous work(Chen and Scales 2005;LieâĂŘSvendsen, et al. 2003;Mahmoudian and Scales 2013;Rapp and Lübken 2003;Scales and Ganguli 2004). A statement of the purpose and significance of this article has been added to the abstract section.

2. The authors mention another well-known work in this field (Lie-Svenson et al. 2003). How is this work an advance over the past work? This should at least be clearly shown since Lie-Svenson is often used as a benchmark work. Also, the work of Lie-Svenson shows the importance of using ion mass (through the ion continuity equation) on the electron and ion structures in the PMSE source region. The work has been validated through experimental observations. Some of these effects have been described by the work of A. Mahmoudian, On the signature of positively charged dust particles on plasma irregularities in the mesosphere, J. Atmos. Sol. Terr. Phys., 2013 which is based on earlier work by Chen and Scales, JGR 2005. Therefore, this implies the authors work is not consistent with observations since it does not contain ion inertia (it just assumes the Boltzmann approximation)? No direct substantive comparison with data has been shown in this work to lend any validity.

Response

Thank you very much for your instructive suggestions.

Lie-Svenson et al. studied the plasma response to initially given small-scale ice particle perturbations in the mesopause region. The formation process of these small-scale structures of ice particle density is still not fully understood. The aim of our study is trying to explain the formation of these small-scale ice particle density structures based on the growth and movement model of particles. The analysis of relevant previous work and the purpose of this paper have been added in the introduction section. After studying the previous work and observations carefully, we find that the assumption of ion immobility in our previous manuscript version was not accurate. So we modify the plasma model in the revised manuscript according to Lie-Svenson et al.'s theory (LieâĂŘSvendsen, et al. 2003). The revised plasma model considers production, loss and transport of ions and electrons, and dynamic particle charging. Some more detailed description on the modified plasma model has been made in the model section 2. According to the revised model, for particles with radii of 11 nm or less, electron density is anti-correlated to ion and charged ice particle density near the boundary of condensation region. It is in agreement with previous work by Lie-Svenson et al. (LieâĂŘSvendsen, et al. 2003) and most rocket observations(Rapp and Lübken 2004). Detailed results analysis and comparison with previous work have been added in the results and discussion section 3.

3. What inaccuracies are introduced into the model due to the fact that an equilibrium charge is considered (equation 22). Lie-Svenson et al and other work consider a dynamically time varying particle charge. This would appear to be particularly important since the ice particle mass/radius is changing.

Response

Thank you very much for pointing it out.

According to research of LieâĂŘSvendsen et al. (LieâĂŘSvendsen, et al. 2003), the assumption of chemical equilibrium would overestimate the electron depletion and seriously underestimate the ion enhancement, i.e., the equilibrium charge is indeed not a valid approximation in studying plasma response to small-scale ice particle irregularities. In view of this, we have modified the plasma model with dynamic particle charging



considered.

In our study, it is assumed that condensation nuclei enter the condensation region with a fixed flux. They grow by absorbing water vapor and move under the action of gravity and neutral drag force. Note that, the charge to mass ratio of ice particles is very low, the electric field force on the particles can be ignored compared to the other two forces, so the dynamic particle charge does not affect the formation of the final particle density profile. Ice particle density will form stable small-scale structures after several hours. The particles keep entering and leaving the condensation region, but as long as the external environment does not change, the distribution of particle density and radius remains unchanged. Then the influence of these stable small-scale structures on electron and ion density is studied by the modified charging model just like LieâĂŘSvendsen et al. did in their work (LieâĂŘSvendsen, et al. 2003).

The more detailed description of the modified plasma model has been added in the model section 2.

4. In the model section 2, there appears to be too much detail when the primary equation for the ice particle velocity model is equation 8 (perhaps equation 1 should be stated for completeness). The rest of the approximations may be useful but they can be much more succinctly summarized to shorten this section and eliminate all the equations. The final simplified collision equations may also be useful.

Response

Thank you very much for your instructive suggestions. We have summarized the approximate conditions into words to make the article more concise.

5. In general, one could strongly argue that the plasma (and charging) is much less well modeled in the model equations in section 2 than previous models (ie. Lie-Svenson et al., Chen and Scales). Therefore, it is highly questionable if the current work is an advance since there is no comparison using these past modeling approaches. This,

again, goes back to the key issue with the manuscript.

Response

Thank you very much for pointing it out. We are sorry for using a very rough plasma model in our original text. The plasma model has been modified, which considers production, loss and transport of ions and electrons, and dynamic particle charging. We have made some more detailed description on the modified plasma model in the model section 2.

The improvement of this study over previous work is to present a possible formation mechanism of small-scale ice particle structures. The analysis of relevant previous work and the research purpose of this paper have been added in the introduction section.

6. The model results in Section 3 show some promising trends but these must be more closely compared to observational data. Also, there appear to be no direct linkages to a specific observation the authors are trying to understand. The authors should strive to do more than demonstrate their model does what is expected from the basic physics. Only general comparisons are made to observations, which is not enough for a novel contribution.

Response

Thank you very much for your instructive suggestions.

The main purpose of this paper is to present a possible explanation on the formation of the small-scale ice particle irregularities in PMSE region. Through the growth model, we obtain ice particle density structure at meter scale near the boundary of condensation region, which is consistent with the assumed ice particle density structure scale in the theoretical calculations of previous work (LieâĂŘSvendsen, et al. 2003;Rapp and Lübken 2003), and is consistent with observations by the sounding rocket flight ECT02 in July 1994 (Rapp and Lübken 2004). Based on the modified plasma model,



for particles with radii of 11 nm or less, electron density is anti-correlated to density of ions and charged ice particles, which are in agreement with rocket observations by the sounding rocket flight SCT-06 in August 1993 (LieâĂŘSvendsen, et al. 2003) and the sounding rocket flight ECT02 in July 1994 (Rapp and Lübken 2004), respectively.

Detailed results analysis and comparison with previous work have been added in the results and discussion section 3.

7. Again, the authors should strive to see if their model is consistent with observations. For example, the average number of charges is less than one (see line 264) with values of 0.2 and 0.3. Does this indicate that the charging model (using a simple equilibrium charge) is insufficient? Doesn't the particle growth impact what charging model is used. Does the fact that the average charge is less than 1.0 indicate there are positive, negative, and uncharged particles? This has been observed/postulated during experiments? The current simple OLM equilibrium charging model does not take the fact of dynamic particle growth into consideration and may likely be inadequate for what the authors are trying to do (with such small initial particle sizes). This has not been commented on at all. For such low particle charges would a stochastic model (e.g. Mahmoudian) be better.

Response

Thank you very much for your valuable and instructive comments.

The particle radius in this study is less than 11 nm, and an ice particle carries two negative elementary charges at most. The quantized stochastic charging model (Robertson and Sternovsky 2008) is more appropriate to determine the particle charge. Therefore, we modify the plasma model and use the quantized stochastic charging model to calculate the capture rates of electrons and ions by ice particles. The results show that for particles with a radius about 5 nm, the proportion of particles carrying one negative charge is about 97%. For particles with radii ranging from 7 nm to 11 nm, the proportion of particles carrying one negative charge ranges from 97.5% to 85.1%, and that value for particles carrying two negative charges is in 0.53% - 13.6%, which is consistent with observations by Havnes et al. (Havnes, et al. 1996) and numerical results by Rapp and Lübken (Rapp and Lübken 2001).

As we have said before in the response to comment 3, the dynamic particle charging process does not affect the formation of the final particle density profile, i.e., the particle charging process is negligible when calculating the particle density structure based on the particle growth and motion model. After the stable particle density profile is obtained, the corresponding electron and ion density are calculated according to the modified charging model. In this case, ice particle density structure and radius keep stable, which means that the influence of dust growth and motion on charging process is negligible. More detailed results analysis and comparison with previous work have been added in the results and discussion section 3 and detailed description on the modified plasma model have been made in the model section 2.

8. Figure 3 and 4 appear to show the electron density structures. These appear to be on the space scale of 10 meters or less. How do these results compare with other models, e.g. Lie-Svenson et al. Also why are these results an advance over these past modeling results?

Response

Thank you very much for pointing it out.

The small-scale electron density structures are the consequences of ice particle density irregularities. The main improvement of this paper is to propose a possible formation mechanism of the ice particle density irregularities based on particle growth and movement model, while previous work directly sets the particle density structure to a specific form. The scale and position of the ice particle density irregularities are affected by particle radius distribution function, neutral wind speed, and water vapor density etc. For example, the particle density profiles for different radius distribution functions are shown in Fig. 1.



Caption of figure 1: Figure 1 The ice particle density distribution near the (a) upper boundary and (b) lower boundary of the condensation layer for different radius distribution functions. In (a) the center of the radius distribution function R00 = 1.08. In (b) R00 = 0.8. The solid blue line: $\Delta$ = 0.01 and A = 56.4; the red dotted line: $\Delta$ = 0.03 and A = 18.8.

Summary: This manuscript is not suitable for publication in AG at this time. If the authors consider a revision (which should be major) the key points the authors should consider are:

1. Making stronger case for why this work is superior to past models (i.e. Lie-Svenson). Certainly the author's model is inferior in terms of the model of the ionospheric plasma (no ion inertia) and charging (no dynamical variation) model. A possible advantage is the ice particle growth model but this would appear to be problematic as well without properly doing the charging model correctly. If the novelty in the ice particle growth does not counterbalance the weakness in plasma and charging models, then there is no real contribution or advance in the modeling.

Response

Thank you very much for your instructive suggestions.

The main improvement of this paper is to propose a possible mechanism for the formation of small-scale ice particle density irregularities based on particle growth and movement model, while the particle density structure in previous work was always assumed as some specific forms.

After consulting previous work and observations, we find that the assumption of ion immobility in our original manuscript is not accurate and the equilibrium charge is not a valid approximation for studying plasma response to small-scale ice particle irregularities. So we modified the plasma model used in this paper by considering the production, loss and transport of ions and electrons, and dynamic particle charging processes.

2. There is no substantive comparison with observational data or a focus of an important unresolved scientific issue addressed. This was not clearly articulated and again is a substantial weakness in the paper. It should be addressed in a summary/discussion section and also noted in the Abstract.

Response

Thank you very much for pointing it out. We are sorry for not comparing the results with the observations.

The modified model shows that, for particles with radii of 11 nm or less, the electron density is anti-correlated to ion and charged ice particle density, which is in line with rocket observations by the sounding rocket flight SCT-06 in August 1993 (LieâĂŘSvendsen, et al. 2003) and the sounding rocket flight ECT02 in July 1994 (Rapp and Lübken 2004), respectively. We have added more detailed results analysis and comparison with previous work in the results and discussion section 3.

The main purpose of this paper is to present a possible explanation of the origin of the small-scale ice particle irregularities in PMSE region. Previous works (LieâĂŘSvendsen, et al. 2003;Rapp and Lübken 2003) have shown that ice particle density irregularities on meter scale can create electron density fluctuations on the similar scale, which can cause PMSE phenomenon. In their models, however, the ice particle density profile is given initially, such as small scale Gaussian structure. The aim of our study is trying to present a possible explanation on the formation of these ice particle irregularities through the growth and movement model. The analysis of relevant previous work and the research purpose of this paper have been added in the introduction to make the paper more coherent. Also, a statement of the purpose and value of this article has been added to the abstract section.

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Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-10/angeo-2019-10-AC1-supplement.pdf

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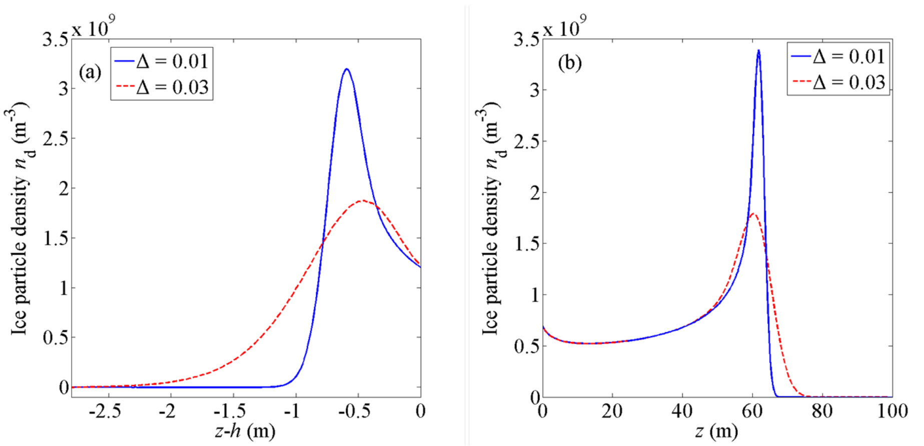


**Fig. 1.** Figure 1 The ice particle density distribution near the (a) upper boundary and (b) lower boundary of the condensation layer for different radius distribution functions.