

Dear Reviewer,

We are pleased to have been given the opportunity to revise our manuscript entitled “Characteristics of layered occurrence ratio of polar mesosphere summer echoes observed by EISCAT VHF 224 MHz Radar”. We appreciate the effort of all of you to review our paper and providing us very insightful and constructive comments. Herein we explain how we revised the paper based on reviewer comments and recommendations.

We uploaded the following files,

[1] **Point-by-Point reply manuscript:** in this file replies to comments are given.

[2] **Revised Manuscript:** this is the clean and ‘revised version’ of the paper. In this file all the changes made in previously submitted manuscript is ‘highlighted’ with ‘blue color’.

[3] **Track changes manuscript:** In this file, there are two kinds of writing:

(a) The ‘underline’ writing represents the corrected and newly added words and sentences.

(b) The ‘~~strikethrough~~’ writing represents the deleted words and sentences.

We again appreciate the careful review and constructive suggestions of all of you. Below is our reply to comments.

Reply to Reviewer comments:

Reply to comment: before to reply this comment, first the authors would like to thanks the reviewer for guidance. The reply to this comment is given stepwise here, because we want to show the mistake and also its correction.

Specific comments:

(a): At page #1, lines 1-2: the sentence: “The ionosphere is an important part of the near the earth space environment and the mesosphere is the coldest region in the earth’s atmosphere at local summer time.” Regardless the season the mesosphere is the coldest region of the Earth’s atmosphere, not only during the summer. I suggest rewrite the sentence to make this clearer.

reply: Thanks to your suggestion. We have revised this as “The ionosphere is an important part of near the Earth space environment and the mesosphere is the coldest region in the Earth’s atmosphere”. In revised manuscript it can be found at page#1, lines29.

(b): Section 3.1-Calculation method: The authors should explain better the reason to use the threshold of 2.6×10^{11} electrons/m³ to detect the PMSE.

reply: Thanks to your suggestion. We added a better explanation in the revised manuscript.

Volume reflectivity is defined as “backscattering cross section per unit volume” (Hocking, 1985). Noted that: $\eta = \sigma_0 \times N_e$, where η is the volume reflectivity, $\sigma_0 = 5 \times 10^{-29} m^2$ is the effective scattering cross section, and N_e is the electron density (raw electron density can represent equivalent electron density for the case of PMSE) measured by the EISCAT radars. The selection of PMSE threshold is still an open question. Different threshold has been used for detecting PMSE echoes by VHF radar. For example, see the Table 1 given below. We used the PMSE threshold given by Hocking and Röttger (1997). The reason for using $N_e = 2.6 \times 10^{11} m^{-3}$ as threshold is that it corresponds to the threshold ($\eta = 1.3 \times 10^{-17} m^{-1}$) used for PMSE. Therefore, in this study the PMSE were considered to be present only if the electron density satisfies the threshold ($N_e > 2.6 \times 10^{11} m^{-3}$).

Table1: PMSE studied with calibrated radars at 224MHz. This table is referenced from Li (2011). (see Appendix A)

Frequency (Bragg scale) MHz (m)	Location	Reference	Reflectivity
224(0.67)	Tromsø (69° N)	Hoppe et al. (1988)	1.5×10^{-16}
		Röttger and LaHoz (1990)	2.3×10^{-17}
		Hocking and Röttger (1997)	$1.3 \times 10^{-17} - 1.3 \times 10^{-15}$
		Belova et al. (2007)	1.5×10^{-14}
		Rapp et al. (2008)	5.0×10^{-14}

(c): At page #6, lines 11-13: In that sentence the authors mention a condition $t \geq 1$ min. It is not clear where this condition came from. They should make this clearer.

reply: Thanks to your suggestion. For calculating the PMSE OR, we have selected only those events for which the PMSE threshold ($N_e > 2.6 \times 10^{11} m^{-3}$) is satisfied, for time ($t \geq 1$ min) in the altitude range of 80–90 km. Of course, you can also define the time $t \geq$ any time interval.

(d): The description of the method of calculation at page #6, lines 15-20, which takes as an example of the monolayer PMSE occurrence, seems to be a little confused. The description is clearer when the authors described the occurrence ratio of the double and tri-layer PMSE. I suggest to rewrite the description of the monolayer PMSE occurrence. From Table 3 one can see that the author defined the OR of the PMSE as the percentage ratio between the duration of the mono, double and triple layer PMSE and the total time of observations. The description mentioned

above should be as clear as the information coming from the Table 3.

reply: Thanks for suggestion. We have revised the abovementioned description as “The calculation method is based on individual horizontal profiles. When the electron density satisfy the PMSE threshold $N_e > 2.6 \times 10^{11} \text{ m}^{-3}$, then that time was taken as the starting time of the PMSE occurrence and the time when the electron density fails to satisfy the threshold was taken as the end time of PMSE occurrence. The time of PMSE duration is the time difference between the end and the starting time of the PMSE occurrence. Taking the calculation method of PMSE monolayer occurrence ratio as an example: We defined the ratio between the sustained time of monolayer PMSE and the total observation time as the PMSE monolayer OR.” The applied procedure for the detection of multiple PMSE layers is based on individual vertical profiles with a high temporal resolution (Hoffmann, P. 2004). The layer ranges are identified by an electron density threshold of $2.6 \times 10^{11} \text{ m}^{-3}$ ($N_e > 2.6 \times 10^{11} \text{ m}^{-3}$). Once a vertical profile of the electron density has two peaks and these two peaks are higher than the threshold ($N_e > 2.6 \times 10^{11} \text{ m}^{-3}$), we select it as a double layer. The PMSE double-layer OR is the ratio between the sustained time of PMSE double layer and the total observation time. The tri-layer OR is also calculated in this way.” In revised manuscript this can be found at page#6, lines 14-15 and page#7, line1.

(e): In section 4, the authors propose a method to make PMSE OR continuous. They considered as day 1 the first PMSE occurrence in 2004, day 2 as second PMSE occurrence and so on. I get the idea. By doing that, one would get a continuous date set. However, in the time domain there are gaps due to days without PMSE. Despite of allowing direct comparison with the solar and geomagnetic activities, I would not say that the PMSE data set has become continuous. Still regarding the method, I suggest adding axis at top showing the time in years in the Figures 5 to 8. This will make easier to follow the time in years.

reply: Thanks for suggestion. We used $F_{10.7}$ values and geomagnetic K index values corresponding to the occurrence of PMSE. That is, when PMSE events occurred on the day, we took the $F_{10.7}$ and K index values for this day. If there is no PMSE, we will not take the values of $F_{10.7}$ and K index. Because we analyze the variations of PMSE mono-, double- and triple-layer OR with threshold conditions of $N_e > 1 \times 10^{11} \text{ m}^{-3}$, $N_e > 1.5 \times 10^{11} \text{ m}^{-3}$, $N_e > 2.6 \times 10^{11} \text{ m}^{-3}$, $N_e > 3 \times 10^{11} \text{ m}^{-3}$ and $N_e > 3.5 \times 10^{11} \text{ m}^{-3}$ during 2004-2015, the number of PMSE events in the same year is different with different threshold conditions. It is possible to happen: such as in 2004, the PMSE case occurred 10 times under the threshold conditions of $N_e > 1 \times 10^{11} \text{ m}^{-3}$, and the PMSE case occurred 8 times under threshold conditions of $N_e > 3.5 \times 10^{11} \text{ m}^{-3}$. Therefore, we can't add axis at top showing the time in years in the existing Figures 5 to 7. However, we redrew Figures 5 to 7 and adding axis at top showing the time in years. In this way, the relationship between Figure 5-6 and

Figure 8 becomes clear. In revised manuscript this can be found at page#12 and 15, Figs.5,6,7,8.

(f): Despite of positive correlations between PMSE occurrence and solar flux and K index, the authors should point out that the coefficients indicate correlations from moderate to weak.

reply: Thanks for suggestion. According to the Referee's advice, we have revised them and it can be found at page#17, lines 6-7 and 10.

(g): One important point that the authors have not addressed is the correlation between the duration of the PMSE and the solar and geomagnetic activities.

reply: Thank you for valuable comments. Because PMSE echoes are intermittent. The duration of PMSE is very short, some are only a few minutes. $F_{10.7}$ value is the average data of the day, the K index value is the average data of 3 hours, so the correlation between the duration of the PMSE and the solar and geomagnetic activities are still not discussed. But we will continue to do our best to solve this problem.

Minor Comments:

(a): Page#2, line 2. "Its strongest average echo occurs..." replace by "On average, the strongest echo occurs..."

reply: It is done. In "Revised Manuscript" the correction is at Page#2, line 3.

(b): Page#2, lines 5-6. The sentence "this was recently confirmed by Blix et al. from simultaneous rocket and radar observations (Blix et al., 2003)". I suggest changing it to read as "This was confirmed by Blix et al. (2003) from simultaneous rocket and radar observations."

reply: It is done. In "Revised Manuscript" the correction is at Page#2, lines 5-6.

(c): Page #2, line 8. "...it still provided..." replace by "...it still provides..."

reply: In "Revised Manuscript" the description was removed after think with care.

(d): Page #2, lines 14-15. The sentence "...these echoes are a summer phenomenon, lasting from June to August..." may cause some misunderstanding as in the Southern hemisphere is winter. It's better to say clearly which hemisphere those measurements came from.

reply: It is done. In "Revised Manuscript" the correction is at Page#2, lines 16-17.

(e): Page #3, line 7: "...in the same sites. . ." replace by "...at the same sites. . ."

reply: It is done. In "Revised Manuscript" the correction is at Page#3, lines 9.

(f): Page #3, line 14: "characters" replace by "characteristics"

reply: It is done. In "Revised Manuscript" the correction is at Page#3, line 16.

(g): Page #3, line 25: "...and a cylindrical 120m×46m antenna. . ." replace by "...and has a cylindrical 120m×46m antenna.

reply: It is done. In “Revised Manuscript” the correction is at Page#3, line 28.

(h): Page #3, line 26: “. . . beam-widths of 1.8° north-south and 0.6° east-west was used on it.” I suggest to exclude “was used on it”.

reply: In “Revised Manuscript” the description was rewrote after think with care.

(i): Page #4, lines 1-2: I suggest inserting an end point in the sentence “. . . EISCAT radar.” and then start the next one as “The level of electron density. . .”.

reply: It is done. In “Revised Manuscript” the correction is at Page#5, line 5.

(j): Page #5, line 2: To keep the same pattern replace “3-4 kilometers” by “3-4 km”

reply: It is done. In “Revised Manuscript” the correction is at Page#5, line 17.

(k): Page #6, line 22: "we believe" replace by "we consider"

reply: It is done. In “Revised Manuscript” we have rewrote it, at page#7, line 1-6.

(l): Page #8, line 17: please, inform the order of the polynomial fit.

reply: It is done. In “Revised Manuscript” the correction is at Page#9, line 1.

(m): Page #10, line 7: “lead” replace by “leads”

reply: It is done. In “Revised Manuscript” the correction is at Page#10, line 15.

(n): Page #11, lines 1-2: “...observations shown...” replace by “...observations have shown...”

reply: It is done. In “Revised Manuscript” the correction is at Page#11, line 15.

(o): Page #12, line 8: PMWE replace by PMSE

reply: It is done. In “Revised Manuscript” the correction is at Page#16, line 10.

References:

- Belova, E., P. Dalin, and S. Kirkwood, Polar mesosphere summer echoes: A comparison of simultaneous observations at three wavelengths, *Ann. Geophys.*, 25, 2487–2496, doi: org/10.5194/angeo-25-2487-2007, 2007.
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- Qiang, L., Multi-frequency radar observations of polar mesosphere summer echoes: Statistical properties and microphysical results, INAUGURAL- DISSERTATION, 2011.

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- Rapp, M., I. Strelnikova, R. Latteck, P. Hoffman, U.-P. Hoppe, I. Häggström, and M. Rietveld, Polar mesosphere summer echoes (PMSE) studied at Bragg wavelengths of 2.8 m, 67 cm, and 16 cm, *J. Atmos. Sol. Terr. Phys.*, doi: 10.1016/j.jastp.2007.11.005, 2008.
- Röttger, J., and C. LaHoz, Characteristics of polar mesosphere summer echoes (PMSE) observed with the EISCAT 224 MHz radar and possible explanations of their origin, *J. Atmos. Terr. Phys.*, 52, 893–906, doi:10.1016/0021-9169(90)90023-G, 1990.