Dear Editor and referees,

We are pleased to have been given the opportunity to again revise our manuscript entitled, *"Characteristics of layered occurrence ratio of polar mesosphere summer echoes observed by EISCAT VHF 224 MHz Radar".* We thank you and referees and 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 'yellow 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.

A point-by-point response to the Editor

Reply to Editor's comments:

Reply to comment: before to reply this comment, first the authors would like to thank your careful works and valuable comments. The comments and suggestions are very useful for our manuscript. We have addressed these comments and suggestions, and made (tracked) changes in the manuscript.

Minor Comments:

(a): Pg. 1, Throughout the manuscript: earth -> Earth.

reply: It is done. In "Revised Manuscript" we have replaced earth by Earth.

(b): Pg 2, line 14: ... (1) these echoes are summer phenomena.

reply: It is done. In "Revised Manuscript" the correction is at page 2, line 16.

(c): Pg 3, lines 5-6: Please, verify the citations

reply: It is a typo. In "Revised Manuscript" the correction is at line page3, line 7.

(d): Pg 3, lines 9-11: This statement is confused, please, re-write it.

reply: It is done. In "Revised Manuscript" the re-written statement is at page3, line 10-14.

(e): Pg 4, lines 3-4: The authors have mentioned 6 modes of the radar operation. However, they describe only two of them. Maybe they could explain shortly the difference among all operation modes.

reply: Thanks for suggestion. We have expanded Table 2 to give the parameters of 6 modes of the EISCAT VHF 224MHz radar.

(f): Table 3: Please, put the units into the brackets, i.e., (min) instead of /min

reply: It is done. In "Revised Manuscript" the correction is at Table 3.

(g): Pg 7. lines 9-11. Please, give a meaning for the Spearman rank coefficient, in this case.

reply: It is done. In "Revised Manuscript" the correction is at Pg8, lines 7.

(h): Pg. 16. line10. "But, we still can not. . .."

reply: It is done. In "Revised Manuscript" the correction is at Pg17, lines 27.

Major Comment:

(a) The authors must clarify their contribution with this study. They are using an almost solar cycle of data to study PMSE occurrence and the data is really valuable to understanding some unsolved points on this topic.

reply: By analyzing the EISCAT VHF radar data, we found that mono and double layer OR is higher than the tri-layer OR. In addition, a seasonal variation of the OR between these three layers is noticed. Furthermore, we have proposed a new method to estimate the characteristics of the layered PMSE OR. Results obtained from this new method is used to understand the solar cycle dependency and geomagnetic variation dependency of the layered PMSE OR. The relationship between layered PMSE OR and $F_{10.7}$ and between layered PMSE OR and K values also be analyzed. We used the $F_{10.7}$ and K values corresponding to the occurrence of PMSE with threshold of $N_e > 2.6\times10^{11}m^{-3}$. So that, the correlation of PMSE with solar and geomagnetic activities is not expected to affect by discontinuous PMSE. The study of relations between PMSE and solar activities and between PMSE and geomagnetic activities are significative.

(b) Page 8. Line 7. As the author has only o solar cycle, it is not prudent to say that the layered OR has a period of 7-8 year. More data are necessary to conclude about the periodicity that seems to follow the solar activity.

reply: Thanks for suggestion. Fig.2 shows that the gap between two peaks of PMSE OR is about 7 or 8 years. It is true that we cannot explain that the layered OR has a period of 7-8 year. It is necessary to need more data to conclude about the periodicity that seems to follow the solar activity. We have removed the description form manuscript.

(c) Figures 3 and 4. Why do the authors fit a polynomial curve to the PMSE OR? Is not a sinusoidal curve more appropriated?

reply: As described in the paper, Fig. 3 illustrates the mean seasonal variation of the mono- (blue bars) double- (yellow bars) and tri-layer (red bars) PMSE OR and quartic polynomial fitting (black dot-curve) and sine fitting (red dot-dash curve) for the monolayer PMSE OR during 2004-2015. The fitting equation of quartic polynomial fitting is $f(x)=1.448\times10^{-6}x^4-9.715\times10^{-4}x^3+0.2182x^2-17.82x+332.7$ and the fitting degree R=0.5316. The fitting equation of sine fitting is $f(x)=23.67\text{-}11.5\bullet\cos(0.04509\omega)+24.79\bullet sin(0.04509\omega)$ and the fitting degree R=0.5287. According to the fitting results, a quartic polynomial fitting with a relatively high degree of fit is used.

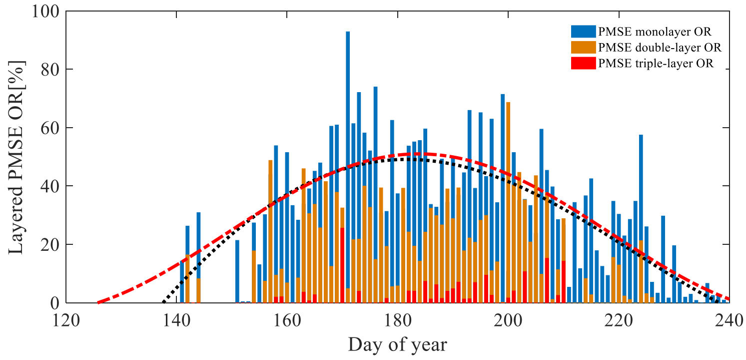
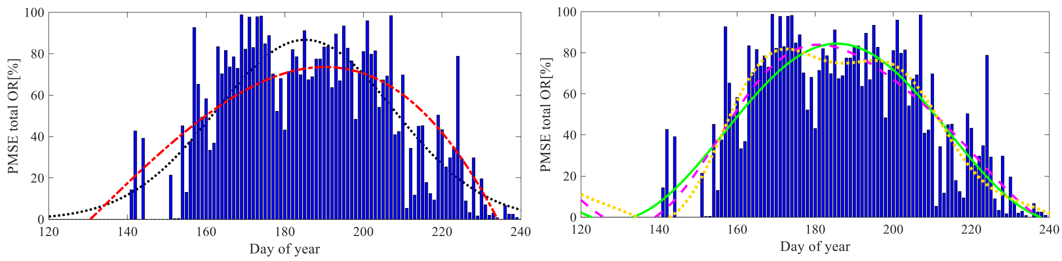


Fig. 3 Mean seasonal variation of the PMSE mono-(in blue), double-(in yellow), triple-layer (in red) occurrence ratio at Tromsø using observations from 2004 to 2015.

Fig. 4(a) (b) shows the mean seasonal variation of PMSE total OR (blue bars) and curve-fitting for total PMSE OR during 2004-2015. We used a variety of curve fitting methods. In Fig. 4(a) the fitting equation of gaussian fitting (black dot-curve) is $f(x) = 86.75 \bullet \exp(-((x-185.2)/32.02)^2)$ and the fitting degree R=0.7579. The fitting equation of cubic polynomial fitting (red dot-dash curve) is $f(x) = \text{-}1.693 \times 10^{-4} x^3 + 0.06584 x^2 \text{-} 6.671 x + 125.5$ and the fitting degree R=0.6912. In Fig. 4(b) The fitting equation of 1/ π harmonic function (green solid curve) is $f(x) = 41.36\text{-}32.72 \bullet \cos(0.05462\omega)\text{-}28.05 \bullet sin(0.05462\omega)$ and the fitting degree R=0.7714. The fitting equation of 2/π harmonic function (pink dash curve) is $f(x) = 42.37\text{-}23.39 \bullet cos(0.0562\omega)\text{-}35.91 \bullet sin(0.0562\omega) + 5.37 \bullet cos(0.0562\omega)\text{-}0.3935 \bullet sin(0.0562\omega)$ and the fitting degree R=0.7816. The fitting equation of 3/π harmonic function (yellow dot curve) is $f(x) = 43.4\text{-}8.496 \bullet cos(0.05832\omega)\text{-}42.14 \bullet sin(0.05832\omega) + 5.826 \bullet cos(0.05832\omega) + 2.218 \bullet sin(0.05832\omega) \text{-}5024 \bullet cos(0.05832\omega)\text{-}4.666 \bullet sin(0.05832\omega)$ and the fitting degree R=0.7896. According to the fitting degree and the editor's suggestions. We choose the 3/π harmonic function fitting. The method is higher goodness of fit and has its applicability.



(a) (b)

Fig. 4(a) (b) Mean seasonal variation of the PMSE total occurrence ratio.

(d) Further explanation on Subsection 4.1 and Figures 5, 6 and 7 are necessary. The main point released by the authors was not clear to me, i.e., that there is not direct relation between the PMSE OR and solar activity. The same comment above can be extended to Figure 8. on Subsection 4.1.

reply: Thanks for your suggestion. We main study layered PMSE OR in the paper. The legends on the figure4,5,6 is the average of PMSE occurrence rate in three time periods separated by the black dashed line. It is well known that 2006 is solar minimum and 2012 is solar maximum, the legends on the figure4,5,6 shown the PMSE mono- and double-layer average OR is not consistent with solar activity. So, we say that there has no correlation between PMSE mono- and double-layer OR and solar activity. To prove the conclusion, we calculate the correlation coefficient between PMSE layered OR and solar activity and between PMSE layered OR and geomagnetic activity in next section. Then the conclusion is convinced. We have made improvements to make Fig5-8 easier to understand in revised manuscript.

(e) Another concern is regarding to the usage of the threshold to determine the PMSE OR. The authors have not explained why they are using those assumptions. The main conclusion of them are based on these analysis, then it must be clear.

reply: Thanks for your suggestion. In order to obtain the correlation between mono, double and triple layer PMSE OR, we defined 5 electron density thresholds. Of course, you can define other threshold values. Smirnova et al. (2010) found that the choice of the threshold does not influence the shape of the variation curves for PMSE OR. Zeller and Bremer (2009) indicated that different threshold values are for the investigations of the influence of geomagnetic activity on PMSE, however, of less importance. Because, we will calculate the correlation coefficients between layered PMSE OR and $F_{10.7}$ and between layered PMSE OR and K index. The aim of choosing 5 different thresholds is to increase the number of samples for correlation coefficient calculations. We give a more detailed explanation in revised manuscript at page13, line 6-16 for this problem.

Reference

Smirnova, M., Belova, E., Kirkwood, S., and Mitchell, N.: Polar mesosphere summer echoes with ESRAD, Kiruna, Sweden: Variations and trends over 1997–2008, Journal of Atmospheric and Solar-Terrestrial Physics, 72, 435-447, doi:10.1016/j.jastp.2009.12.014, 2010.

Zeller O. and Bremer J., The influence of geomagnetic activity on mesospheric summer echoes in middle and polar latitudes, Annales Geophysicae, 27(2): 831-8372, DOI: 10.5194/angeo-27-831-2009, 2009.

A point-by-point response to the Referee#1

Reply to Reviewer#1's comments:

Reply to comment: before to reply this comment, first the authors would like to thank 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/m^3 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 $N_e=2.6\times10^{11}$ m^{-3} as threshold is that it corresponds to the threshold ($\eta=1.3\times10^{-17}$ m^{-1}) used for PMSE. Therefore, in this study the PMSE were considered to be present only if the electron density satisfies the threshold ($N_e > 2.6\times10^{11}$ 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)	1.3×10^{-17}-1.3×10^{-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 ≥ 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 ≥ 1 min) in the altitude range of 80－90 km. Of course, you can also define the time t ≥ 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 >2.6×10^{11} 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×$10^{11}m^{-3}$ (N_e >2.6×$10^{11}m^{-3}$). Once a vertical profile of the electron density has two peaks and these two peaks are higher than the threshold (N_e >2.6×$10^{11}m^{-3}$), 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×$10^{11}m^{-3}$, N_e >1.5×$10^{11}m^{-3}$, N_e >2.6×$10^{11}m^{-3}$, N_e>3×$10^{11}m^{-3}$ and N_e>3.5×$10^{11}m^{-3}$ 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×$10^{11}m^{-3}$, and the PMSE case occurred 8 times under threshold conditions of N_e>3.5×$10^{11}m^{-3}$. 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, line1.
(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.

Hocking, W. K., Measurement of turbulent energy dissipation rates in the middle atmosphere by radar techniques: A review, Radio Sci., 20, 1403–1422, doi:10.1029/RS020i006p01403, 1985.

Hocking, W. K., and J. Röttger, Studies of polar mesosphere summer echoes over EISCAT using calibrated signal strengths and statistical parameters, Radio Sci., 32, 1425–1444, doi:10.1029/97RS00716, 1997.

Qiang, L., Multi-frequency radar observations of polar mesosphere summer echoes: Statistical properties and microphysical results, INAUGURAL- DISSERTATION, 2011.

Hoppe, U.P., C. Hall, and J. R¨ottger, First observations of summer polar mesospheric backscatter with a 224 MHz radar, Geophys. Res. Lett., 15, 28–31, doi:10.1029/GL015i001p00028, 1988.

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.

A point-by-point response to the Referee#2

Reply to Referee#2's comments:

Reply to comment: before to reply this comment, first the authors would like to thank your careful works and valuable comments. The comments and suggestions are very useful for our manuscript. We have addressed these comments and suggestions, and made (tracked) changes in the manuscript.

Specific Comments:

(1): Section 4.1, the authors introduced a new method for characterize the PMSE OR, they claimed that the new method will avoid the data discontinuity problem? But there is no detailed explanation or justification about how this will compensate the data discontinuity issue? .... Page12, In this section, the day when the first occurrence of PMSE in 2004 (regardless of duration) was recorded as1 and the day with the later occurrence of PMSE increased by sequence. . ., from these lines what I understood is that they have taken number of occurrence days rather than hours (used in the earlier studies), if it is so, what is the role of altitude and how the OR percentage calculated? Instead of hours if you're taking the number of occurrences by day earlier method (based on time) also may give the same result! Justify it.

reply: The day when the first occurrence of PMSE in 2004 (regardless of duration) was recorded as 1, and the day with the later occurrence of PMSE increased by sequence. A contiguous array was obtained, then take $F_{10.7}$ and the median of the K index during a day values corresponding to the occurrence of PMSE, which is also a continuous array. Next, we discuss the correlation between layered PMSE OR and $F_{10.7}$ and between layered PMSE OR and K values. Since the occurrence of PMSE is not continuous during the day, sometimes the occurrence is very short (a few minutes). It is very difficult to discuss the relationship between PMSE OR, solar and geomagnetic activity Without this method. We used the $F_{10.7}$ and geomagnetic K index where PMSE occurrence, there is a corresponding relationship between PMSE and $F_{10.7}$ and between PMSE and K index. If so, they are correlativity. In the long term, their relationship is convincing.

The second method for calculating PMSE OR: First of all, a computing threshold of electron density is defined. We have specified a certain altitude range and the observation time of the radar is known, which constitutes a rectangular area. Calculate the number of electron density $N_e > 2.6\times10^{11}$ m^{-3} and the total number of electron density in this area, the ratio of them is PMSE OR. That is, PMSE OR=the number of electron density $N_e > 2.6\times10^{11}$ m^{-3} / the number of total electron density.

The first method for calculating PMSE OR: The applied procedure is based on individual horizontal profiles. When $N_e > 2.6\times10^{11}$ m^{-3}, the time is taken as the starting time of the PMSE occurrence time; When $N_e \leq 2.6\times10^{11}$ m^{-3} with horizontal stacking time sections, the time is the end time of PMSE. Layered PMSE OR= the sustained time of layered PMSE / the total observation time of radar. PMSE OR is different by the two calculation methods and the multi-layer PMSE OR calculated by the second method is higher than the first method. But there is no right or wrong between the two methods, the definition of calculation method is different.
Identified on multi-layer PMSE: There is alternations between electron density > 2.6×10^{11}m^{-3}

and < $2.6\times10^{11}m^{-3}$ at vertical altitude. We identify that there are multiple layered PMSE. The specific distinguish of double layer or triple layers of PMSE, it depends on the number of PMSE layer were increased with the increase of times of the electron density >$2.6\times10^{11}m^{-3}$ replace the electron density <$2.6\times10^{11}m^{-3}$ at the exact same time. We first determine whether the echo is a mono-layer PMSE or double-layer PMSE and then calculate the PMSE OR.

(2): Figure 2 clearly shows a solar cycle variation, e.g., maximum during solar maxima years and minimum during solar minimum years. But the authors claimed that as a sinusoidal wave! This may mislead the readers. From my understanding if we follow the existing method the influence of solar radiation on PMSE is positive (Bremer et al., 2006). Clarify it.

reply: Thanks for suggestion. It may be some misunderstood. The sinusoidal wave that we are talking about is not the relationship between the solar activity and layered PMSE, but the trend of mono- double- and triple-layer PMSE OR, which has obvious wave peak and wave valley. If it can be confirmed that layered PMSE OR is closely linearly related to solar activity, then the trends of PMSE OR should be periodical, so we did the following correlation analysis. Smirnova et al. (2010) shows the correlation of the year-by-year variations of PMSE occurrence rate and length of season with solar activity, represented by the solar 10.7 cm radio flux, is negative but not significant. This is consistent with our results, but contrary to the result of Bremer et al., (2006). Therefore, it is still a scientific project worth exploring.

(3): Section 2, There is no a single reference about the EISCAT radar and its data quality! It will be useful if you can include some information about GUISDAP with references. Of course, the radar experiment details are given in table2, however please include the vertical resolution of the data and give brief information about based on which criteria the multiple layers are identified and what is the average occurrence altitude of each layer (i.e., mono, double and tri layer)?

reply: The EISCAT VHF (224 MHz) radars are collocated at Tromsø, Norway (69.61N, 19.21E). It is powerful tool for studying the lower ionosphere. Detailed descriptions of the radar can be found in Baron (1986). These measurements by EISCAT radar are very well suited for investigating the characteristics of PMSE. (for previous work, see e.g. Li et al., 2010 and references therein). In our case, the analysis was done using the well documented 'GUISDAP' software package and taking into account measurements with the local ionosonde (see Lehtinen and Huuskonen, 1996 and www.eiscat.se for details) The data acquisition channels of the radar start at 59.7 km and up to 139.5 km with a range resolution of 300 m (i.e., height resolution owing to the radar beam vertically pointing for all the observations) the altitude resolution is include in table1.

Identified on multi-layer PMSE: The applied procedure for the detection of multiple PMSE layers is based on individual vertical profiles with a high temporal resolution. The layer ranges are identified by an electron density threshold of $2.6\times10^{11}m^{-3}$ ($N_e>2.6\times10^{11}m^{-3}$). Once a vertical profile of the electron density has two peaks and these two peaks are higher than the threshold ($N_e>2.6\times10^{11}m^{-3}$), we select it as a double layer. For a detailed instruction on multiple structures see e.g. (Hoffmann, P. 2005 and Ge et al. 2016).

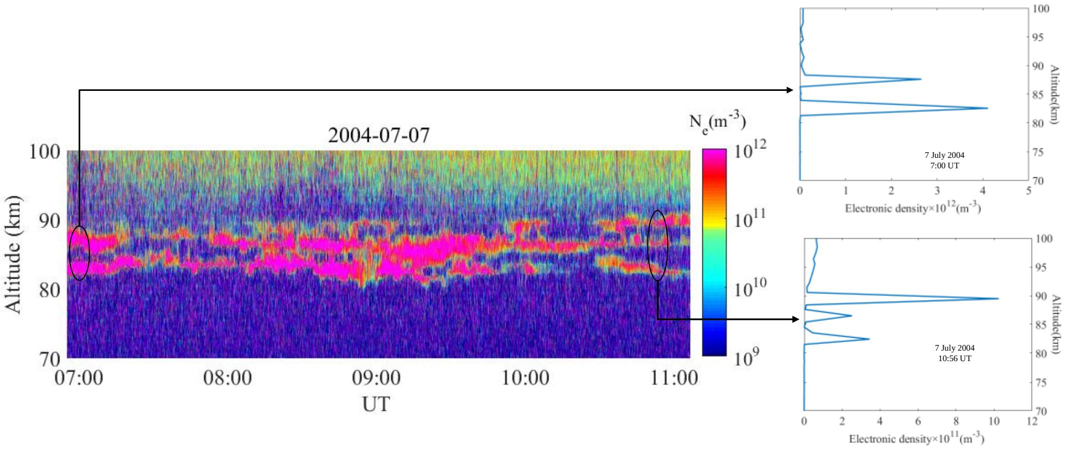


Fig.1 left panel: The layered phonmenon of PMSE. Upper right panel: double-layer PMSE phenomenon. Lower right panel: three-layer PMSE phenomenon.

The average occurrence altitude of each layer:Fig.2 shows a mean height of 84.8 km for single PMSE layers, whereas in the case of multiple PMSE layers, the lower layer occurs at a mean height of ~83.4 km. For the second layer in the case of multiple PMSE layer structures shows a maximum at about 86.3 km.

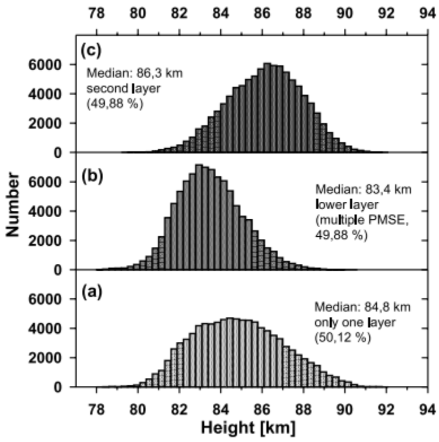


Fig. 2. Histogram of the preferred centroid heights of PMSE, based on observations during June and July for seven years (1996-1997, 1999-2003): (a) for single layer PMSE, (b) for the lower layer in the case of multiple PMSE layer structures, and (c) for the second layer in the case of multiple PMSE layer structures (Hoffmann, 2005).

(4): To find the characteristic of PMSE occurrence ratio (OR), a computing method and threshold must be defined. First of all, . . ., the threshold of electron density (Ne>2.6×10^{11} m^{-3}) was calculated (Hocking and Röttger ,1997). Not clear, modify the sentence. During the PMSE time the electron density will be bite-out (Kelly 2010) so one can expect decrement in the electron density. Here what the authors meant to say? They have taken only above this limit (Ne>2.6×10^{11} m^{-3}) or below?

reply: Thanks for suggestion. We have modified the sentence in revised manuscript. Rapp and Lübken (2004) showed that the characteristics of PMSE observations are consistent with the assumption of volume scatter from electron number density irregularities and can not be due to specular reflections from single steep gradients as they appear for example at the edges of the electron bite-outs (see also Hocking and Röttger, 1997, for a discussion of the feasibility of specular reflection to explain PMSE).

(5): It may look good if you change the title as, "Characteristics of layered polar mesospheric summer echoes occurrence ratio observed by EISCAT VHF 224 MHz radar" and discuss about the multiple layered PMSE occurrence and its possible generation mechanism in the introduction part? And brief about why the study of characterization of multiple PMSE OR is important?

reply: Thanks for suggestion and we delightedly accept it. We have changed the title as, "Characteristics of layered polar mesospheric summer echoes occurrence ratio observed by EISCAT VHF 224 MHz radar".

"discuss about the multiple layered PMSE occurrence and its possible generation mechanism in the introduction part": We have added the description as "One remarkable feature of all PMSE is the fact that the radar echoes often occur in the form of two or more distinct layers that can persist for periods of up to several hours. Until now, the layering mechanism leading to these multiple structures is only poorly understood in spite of some previous attempts involving gravity waves, the general thermal structure, and Kelvin-Helmholtz-instabilities (Röttger, 1994; Klostermeyer, 1997; Hill et al., 1999, Hoffmann et al., 2005)" in revised manuscript.

"why the study of characterization of multiple PMSE OR is important": PMSE have been intensively studied for more than 30 years. However, the cause of PMSE is still far from clear. We must study the characterization of multiple PMSE OR since we realized that there exist layered PMSE. The characterization of multiple PMSE OR might shed light on the generation of PMSE. It can further optimize the systematic PMSE studies at frequencies higher than the 'standard' 50 MHz and also to obtain further insight into the mechanism of these echoes. It also can promote the faster development of electromagnetic environment exploration research.

(6): Page1 line 15, solar cycle, can be used. . ., modify the sentence.

reply: Thanks for suggestion. It is done. In "Revised Manuscript" the correction is at Page1 line 16.

(7): Page1 line 18, PMSE layered. . ., use only one term either Layer PMSE or PMSE layered throughout the manuscript, my suggestion is use Layered PMSE.

reply: It is done. We have made corrections in "Revised Manuscript".

(8): Page1 line 20, it can be obtained. . ., write as, it is obtained. . .,

reply: It is done. In "Revised Manuscript" the correction is at Page1 line 21.

(9): Page2 line 1, write as, possible indicator of global climate change.
reply: It is done. In "Revised Manuscript" the correction is at Page2 line 2.
(10) Page2 line 5, 2003 is not recent year, change the sentence.
reply: It is done. In "Revised Manuscript" the correction is at Page2 line 6.
(11) Page2 line 7, even though this theory has been presented incompletely. . ., why? Please give a brief about the incompleteness.
reply: The widely excepted theory of PMSE formation by Rapp and Lübken (2004) has been presented incompletely - negatively charged ice particles reduce the mobility of free electrons an allow electron irregularities at the Bragg scale to persist. Latteck, R. and Bremer, J., (2013) shows that PMSE are caused by inhomogeneities in the electron density of the radar Bragg scale within the plasma of the cold summer mesopause region in the presence of negatively charged ice particles. However, in order to avoid misunderstanding, we deleted this content.
(12) Page2 line 23, Yi et al., 2011 citation is irrelevant for this context, they discuss only about the density variation not PMSE. According to Smirnova et al., (2010) F $_{10.7}$ is negative but not significant, please mention it.
reply: Thanks for your suggestion. The citation of Yi et al., 2011 is deleted from revised manuscript.
About Smirnova et al., 2010 citation: We have mentioned it according to review's suggestion at page 2, lines25-26.
(13) Page3 line 5, spacing are missing
reply: Thanks for your suggestion. In "Revised Manuscript" the correction is at Page3 line 7.
(14): Page3 line 11, The correlation of PMSE. . ., research of 224MHz radar. Sentence not clear.
reply: Thanks for suggestion. It is done. In "Revised Manuscript" the sentence was described as" The correlation of the ionization level with PMSE at 224 MHz is as significant as that the correlation of the ionization level with PMSE at 53.5 MHz, then previous studies provide the research basis and ideas for the PMSE study detected by 224MHz radar".
(15): Page3 line 19, The PMSE OR calculation. . . solve the defects that of measurements. . .How? What is the demerit of the existing method and how the new method is useful?
reply: We are sorry that we didn't make it clear enough. We did not solve the discontinuity problem of PMSE data measured by radar, but the correlation of PMSE OR with $F_{10.7}$ and K index without discontinuous PMSE OR's influence. The data analysis in respect of the influence of solar and geomagnetic activity is not meaningful as EISCAT VHF radar does not provide continuous PMSE observations. But we design the day when the first occurrence of PMSE in 2004 (regardless of duration) was recorded as 1, and the day with the later occurrence of PMSE increased by sequence. It gives a continuous PMSE, $F_{10.7}$ and K index data set. We use the $F_{10.7}$ and geomagnetic K index values corresponding to the occurrence of PMSE. Then the correlations between layered PMSE OR and $F_{10.7}$ and between layered PMSE OR and K index will be study.
(16): Antenna beam width in the table and the text is differs? Write the correct value.
reply: Thanks for suggestion. In the beginning, we referred to the paper of Palmer et al. (1996), the text "a cylindrical 120m×46m antenna, with beam-widths of 1.8° north-south and 0.6° east-west" see Palmer et al. (1996) at page308, section (2. THE DATASET). Then we referred to the paper of Belova et al. (2013). The table1 is updated from Rapp and Lübken (2004) (see Table

1). After we found that their descriptions were inconsistent. We refer to many literatures and found that most of antenna beam width is the value described in Table 1. We have modified the antenna beam width value in the revised manuscript.

2. THE DATASET

The EISCAT VHF radar experiments

The EISCAT VHF 224 MHz radar (Folkestad *et al*., 1983) is located near Tromsø at 69.6°N, 19.2°E. It uses a cylindrical 120 m × 46 m antenna, with beam-widths of 1.8° north–south and 0.6° east–west. The beam was pointed vertically for all the experiments, and the height resolution was either 0.3 km or 1.05 km. The integration time depended on the experiment and analysis, but was typically 1 min. The peak transmitter power was generally about 1 MW.

Fig.2 Antenna beam width in the text

Table 1. Parameters of the radars.

Radar	ESRAD	EISCAT VHF
Geographic coordinates	67.87° N 21.10° E	69.59° N 19.23° E
Operating frequency	52 MHz	224 MHz
Transmitter peak power	72 kW	1.5 MW
Antenna 3-dB beam width	6°	1.7° NS × 1.2°EW
Antenna effective area	3740 m^2	5690 m^2

Fig.3 Antenna beam width in the Table1

(17): Page5 line 6, write as, till now. . .,

reply: It is done. In "Revised Manuscript" we have rewrote it.

(18) Section 3.1 modify the subtitle as, Layered PMSE OR calculation method.

reply: It is done. In "Revised Manuscript" the correction is at Page5 line 16.

(19) Page6line 15, . . ., algorithm based on grid partitioning. It will be useful for the readers if you provide little bit detail about this algorithm.

reply: Thanks for your suggestion. We have provided detail about this algorithm in revised manuscript section 5.1.

(20) In table 3 column 2, is that total observation time for whole year or only the summer time (May-August)? If it is whole year, better to show only from the operation hours of summer months and see is there any difference in the statistics or not? Put the % in row1 and column 6-9.

reply: Thanks for your suggestion. Column 2 shows the total observation time only for the summer time (May-August). The % is corrected in revised manuscript.

(21) Page8 line 28, write as, explain the occurrence mechanism of PMSE.

reply: Thanks for your suggestion. It is done. In "Revised Manuscript" the correction is at Page9 line 16.

(22): Page10 line 7, write as, not understood well.

reply: Thanks for suggestion. It is done. In "Revised Manuscript" the correction is at Page11 line 2.

(23): Section 4.1, subtitle change as, A new method for layered PMSE OR calculation.

reply: It is done. In "Revised Manuscript" the correction is at Page11.

(24): Page10 line 24, when the PMSE is known to be present. How you decide the PMSE is present or not? Explain it here.

reply: It is done. In "Revised Manuscript" we have added the interpretation as " if electron density satisfies the threshold $N_e > 2.6\times10^{11}\text{m}^{-3}$, we identify layered PMSE exist at this moment"

(25): Page10 line 24, The ratio between the. . .calculated respectively. Why the ratio is calculated and what is its significance? Brief it.

reply: Thanks for suggestion. Layered PMSE OR= the numbers of layered PMSE electron densities values greater than the threshold/ the numbers of total electron density during 80-90 km. If we want obtain the layered PMSE OR, we must calculate the ratio. Furthermore, the relations between PMSE and solar activity and between PMSE and geomagnetic activity are analyzed. PMSE are a suitable tool to permanently monitor the thermal and dynamical structure of the mesopause region allowing insights into important atmospheric key parameters like neutral temperatures, winds, gravity wave parameters, turbulence, solar cycle effects, and long terms changes（Rapp and Lübken,2004).

(26) Page12 line 9, We get their variation trends to be largely consistent. . ., rates are reliable. Sentence is not clear. Above the Hocking et al., threshold level the variation is not consistent! Check it.

reply: Thanks for suggestion. We calculated the Pearson linear correlation coefficients between monolayer PMSE OR with threshold $N_e > 1\times10^{11}m^{-3}$ and $N_e > 1.5\times10^{11}m^{-3}$, and between monolayer PMSE OR with threshold $N_e > 1\times10^{11}m^{-3}$ and $N_e > 2.6\times10^{11}m^{-3}$, and between monolayer PMSE OR with threshold $N_e > 1\times10^{11}m^{-3}$ and $N_e > 3\times10^{11}m^{-3}$, and between monolayer PMSE OR with threshold $N_e > 1\times10^{11}m^{-3}$ and $N_e > 3.5\times10^{11}m^{-3}$. The correlation coefficients are 0.911,0.7949,0.8230 and 0.7795, respectively. Therefore, the variation trends of layered PMSE OR with different threshold are largely consistent. Smirnova et al. (2010) found that the choice of the threshold does not influence the shape of the variation curves for PMSE OR. Zeller and Bremer (2009) indicated that different threshold values are for the investigations of the influence of geomagnetic activity on PMSE, however, of less importance. They both think that the variation trends of PMSE OR with different threshold are consistent.

(27) Solar cycle 23, the minimum condition was extended from 2006-2009.

reply: Thanks for suggestion. It is done. In "Revised Manuscript" the correction is at Page13 line 19.

(28) Page12 line 15, In other words, no correlation. . ., However, the earlier method shows very clear positive variation with the solar cycle (see figure 2)? Justify it.

reply: Thanks for your suggestion. Fig. 2 shows that the mono- double- and triple-layer OR agrees with the total PMSE OR. In addition, we found that the layered PMSE layered OR from 2008 to 2010 is relatively low and the solar activity was relative 'quiet' in these years. However, due to the discontinuity of PMSE, we did not discuss the correlation between layered PMSE OR and solar activity.

(29) Page15 line 5, P value less than 0.5,

reply: The P value is used to decide whether to reject or accept the null hypothesis (a general statement that there is no relationship between the two measured phenomena). The P value less than the significance level (α=0.05) for any correlation coefficients can reject the null hypothesis, and the correlation coefficients are considered statistically significant with 95% confidence level.

(30): Use the same terminology throughout the manuscript, "either dual layer or double layer, and tri or triple or multi-layer".

reply: Thanks for suggestion. It is done. We have revised it in revised manuscript

(31): Page15 line 21, Interestingly, we found that. . ., a negative correlation with $F_{10.7}$. . ., However, the negative correlation is less than 0.5 and similar kind of result already reported by Smirnova et al. (2010). Why the authors want to highlight this point though the K value also shows similar kind of positive correlation with layer PMSE OR?

reply: Smirnova et al. (2010) used the ESRAD 52 MHz MST radar to study diurnal, day-to-day and year-to-year variations of PMSE. We used the EISCAT 224MHz radar to calculated layered PMSE OR and study the correlation between layered PMSE OR, $F_{10.7}$ and K index. Research on the layered PMSE OR has been studied very rarely in previous literature, not to mention the study of the correlation between layered PMSE OR and solar activity and between layered PMSE OR and geomagnetic activity. Although, many previous literatures also shown that there is positive correlation between PMSE and geomagnetic activity. The correlation between layered PMSE OR and K index was rarely studied. In contrast with our results, the investigations at Andenes during 1994–2008 found that the correlation between PMSE and solar activity (the solar Lyman a radiation) is positive, as is correlation between PMSE and geomagnetic indices (Bremer et al., 2009). Therefore, there is necessary to continue studying the characteristic of layered PMSE and actively promote the development of scientific research on the physical mechanism of PMSE occurrence.

(32): Page16 line 4, It indicates. . ., how it can indicate?

reply: Layered PMSE OR is positively correlated with the K index and the coefficients indicate correlations is moderately correlated. The correlation coefficient between PMSE mono- and $F_{10.7}$, double-layer OR and $F_{10.7}$ both are very low, indicating that their correlation is weak or even not relevant. what's more, the PMSE tri-layer OR has a negative correlation with $F_{10.7}$, Although the correlation was lower than what we have supposed. It indicates that those are not close linear relationship between PMSE and solar activities and between PMSE and geomagnetic activities. There are other influencing factors for the formation and development of PMSE. Smirnova et al. (2010) shown that the end of the PMSE season is associated with enhancement of the equatorward meridional winds and zonal wind shear.

(33): Page16 line 8, the positive correlation between. . ., enhanced magnetic activity caused precipitating particles increase in the mesosphere. Earlier the authors claimed that they removed the precipitation events!

reply: Thanks for your suggestion. We made the mistake. We mean that the data which is misplaced by precipitating particles were eliminated, not the increased electron density caused by precipitating particles. we check a lot of literature. Then, we found that this phenomenon is interpreted as a trace of a meteor. Their occurrence time is very short but electronic density is very large in that moment. We have revised it in the revised manuscript.

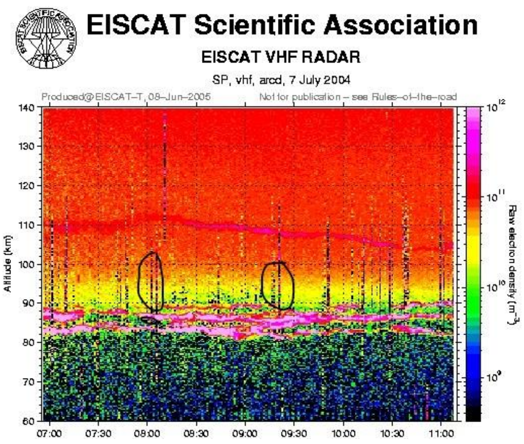


Fig.4 PMSE obsevered by EISCAT. The black curve circle indicates the abnormal echo not PMSE.

(34) Page16 line 8, write as, but still we. . .

reply: It is done. In "Revised Manuscript" the correction is at Page17 line 27.

(35) Page16 line 22, write as, reference or earlier report.

reply: It is done. In "Revised Manuscript" the correction is at Page18 line 11.

(36) Page16 line 23, write as, it is maximum in mid-July. . .,

reply: It is done. In "Revised Manuscript" the correction is at Page18 line 12.

(37) Page16 line 27, under different electron density threshold conditions are largely consistent. I feel above Ne>$2.6\times10^{11}m^{-3}$ this threshold the consistency is not significant (see fig., 9).

reply: Thanks for your suggestion. The variation trends of PMSE mono- double- and tri-layer OR under different electron density threshold conditions are identified by Fig. 5,6,7. Fig.9 shows the correlation coefficients between PMSE OR and $F_{10.7}$ and between PMSE OR and K index with simultaneous occurrence. the strengths of the correlation between layered PMSE OR (with threshold conditions of $N_e > 1\times10^{11}m^{-3}$, $N_e > 1.5\times10^{11}m^{-3}$, $N_e > 2.6\times10^{11}m^{-3}$, $N_e > 3\times10^{11}m^{-3}$ and $N_e > 3.5\times10^{11}m^{-3}$, respectively) and $F_{10.7}$ corresponding to the occurrence of PMSE and between layered PMSE OR and K index corresponding to the occurrence of PMSE are not coincident.

(38) Page16 line 27, write as, it is found that. . .,

reply: It is done. In "Revised Manuscript" the correction is at Page18 line 16.

References

Baron, M.: EISCAT progress 1983–1985. Journal of Atmospheric and Terrestrial Physics, 48, 767–772.,1986, doi: 10.1016/0021-9169(86)90050-4, 1986.

Belova, E., Kirkwood S., Sergienko T.: EISCAT and ESRAD radars observations of polar mesosphere winter echoes during solar proton events on 11–12 November 2004. Annales Geophysicae, 31(7):1177-1190, doi:10.5194/angeo-31-1177-2013, 2013.

Bremer, J., Hoffmann, P., Höffner, J., Latteck, R., Singer, W., Zecha, M., and Zeller, O.: Long-term changes of mesospheric summer echoes at polar and middle latitudes, Journal of Atmospheric and Solar-Terrestrial Physics, 68, 1940-1951, doi:org/10.1016/j.jastp.2006.02.012, 2006.

Bremer, J., Hoffmann, P., Latteck, R., Singer, W., Zecha, M.: Long-term changes of (polar) mesosphere summer echoes. Journal of Atmospheric and Solar-Terrestrial Physics. 71, 1571–1576, doi: 10.1016/j.jastp.2009.03.010, 2009.

Hill, R. J., D. E. Gibson-Wilde, J. A. Werne and D. C. Fritts: Turbulence-induced fluctuations in ionization and application to PMSE, Earth Planets Space, 51, 499–513, doi: 10.1186/BF03353211, 1999.

Hocking, W. K., Röttger J.: Studies of polar mesosphere summer echoes over EISCAT using calibrated signal strengths and statistical parameters. Radio Science, 32(4):1425-1444, doi: 10.1029/97RS00716 ,1997.

Hoffmann, P.: On the occurrence and formation of multiple layers of polar mesosphere summer echoes. Geophysical Research Letters, 32(5), L05812, doi: 10.1029/2004gl021409, 2005.

Klostermeyer, J.: A height - and time - dependent model of polar mesosphere summer echoes. Journal of Geophysical Research: Atmospheres, 102(D6), doi: 10.1029/96JD03652, 1997.

Latteck, R., and Bremer, J.: Long-term changes of polar mesosphere summer echoes at 69°N, Journal of

Geophysical Research Atmospheres, 118, 10441-10448, doi:10.1002/jgrd.50787, 2013.
Lehtinen, M.S., Huuskonen, A.: General incoherent scatter analysis and GUISDAP, Journal of Atmospheric and Solar-Terrestrial Physics, 58, 435–452, doi:10.1016/0021-9169(95)00047-x, 1996.
Li, Q., Rapp, M., Rottger, J., Latteck, R., Zecha, M., Strelnikova, I., Baumgarten, G., Hervig, M., Hall, C., Tsutsumi, M.: Microphysical parameters of mesospheric ice clouds derived from calibrated observations of polar mesosphere summer echoes at Bragg wavelengths of 2.8 m and 30 cm. Journal of Geophysics Research. 115, D00I13, doi:10.1029/2009JD012271, 2010.
Palmer, J. R., Rishbeth H., Jones G. O. L., et al.: A statistical study of polar mesosphere summer echoes observed by EISCAT. giophyJournal of Atmospheric and Terrestrial Physics, 58(1-4):307-315, doi:10.1016/0021-9169(95)00038-0, 1996.
Rapp, M. and. Lübken F.-J: Polar mesosphere summer echoes (PMSE): Review of observations and current understanding. Atmospheric Chemistry and Physics, 4(11/12), 2601-2633, doi:10.5194/acp-4-2601-2004, 2004.
Röttger, J.: Middle atmosphere and lower thermosphere processes at high latitudes studied with the EISCAT radars. Journal of Atmospheric and Solar-Terrestrial Physics, 56(9):1173-1195, doi: 10.1016/0021-9169(94)90056-6, 1994.
Smirnova, M., Belova, E., Kirkwood, S., and Mitchell, N.: Polar mesosphere summer echoes with ESRAD, Kiruna, Sweden: Variations and trends over 1997–2008, Journal of Atmospheric and Solar-Terrestrial Physics, 72, 435-447, doi:10.1016/j.jastp.2009.12.014, 2010.
S. Ge, H. Li, Y. Chen, M. Wang, L. Meng and T. Xu: Seasonal occurrence of polar mesosphere summer echo variations with different layers. 2016 11th International Symposium on Antennas, Propagation and EM Theory (ISAPE), Guilin, pp. 756-758, doi: 10.1109/ISAPE.2016.7834075, 2016.
Zeller O. and Bremer J., The influence of geomagnetic activity on mesospheric summer echoes in middle and polar latitudes. Annales Geophysicae, 27(2): 831-8372, doi: 10.5194/angeo-27-831-2009, 2009.

A list of all relevant changes made in the manuscript

We have done a lot of small language corrections and rewrote a lot of sentences based on the reviewers and editors' suggestions. Here, we only list the important and large revisions.

1 According to the reviewer#2's suggestion, we have changed the title.

2 According to the reviewer's suggestion, we have changed the structure of the paper. We have added the section of "3 Data analysis".

3 According to the editor's suggestion, we have extended Table 2.

4 According to the reviewer and editor's suggestion, we have rewritten the section"**4.2 Layered PMSE OR calculation method".**

5 According to the editor's suggestion, we have redrawn Figure 3 and 4 and modified the fitting curve.

6 According to the reviewer and editor's suggestion, we have rewritten the section" **5.1 Another method for layered PMSE OR Calculation".**

7 According to the reviewer#1's suggestion, we have redrawn Figure 5, 6 and 7 with axis at top showing the time in years.

8 According to the editor's suggestion, we have given the explanation for why we used 5 different density thresholds to analysis layered PMSE OR.

9 According to the reviewer's suggestion, we have redrawn Figure 8 with axis at top showing the time in years.

10 According to the reviewer#1's suggestion, we have given the correlations from moderate to weak.

11 We have added" Data availability"," Competing interests" and "Authors' contributions".

12 We have added some references.

Characteristics of layered polar mesosphere summer echoes occurrence ratio ~~of polar mesosphere summer echoes~~ observed by EISCAT VHF 224MHz Radar

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Abstract. Polar Mesosphere Summer Echoes (PMSE) are strong radar echoes observed in polar mesopause during local summer. Observations~~Measurements~~ of layered PMSE ~~observed~~ carried out by the European Incoherent Scatter Scientific Association Very high frequency (EISCAT VHF) radar ~~from 2004 to 2015~~during 2004-2015 in the latest solar cycle~~, can be~~is used to study the variations of PMSE occurrence ratio (OR). Different seasonal behavior of PMSE is found by analyzing the seasonal variation of PMSE mono-, double- and tri-layer OR.~~The seasonal variation of PMSE mono-, double- and tri-layer occurrence ratio was analyzed, and there is different seasonal behavior.~~ A method was ~~given~~ used to calculate the PMSE mono-, double- and tri-layer ~~occurrence ratio~~OR under different electron density threshold~~ conditions~~. In addition, a method to analyze the correlation ~~between~~ of layered PMSE ~~layered occurrence ratios~~OR ~~and~~ with solar 10.7 cm flux index ($F_{10.7}$)~~, and the correlation between PMSE layered occurrence ratios~~ and geomagnetic K index ~~were~~ is proposed~~analyzed respectively in this study~~. And base on it, the correlation of layered PMSE OR with solar and geomagnetic activities is not expected to affect by discontinuous PMSE. It ~~can be obtained~~is found that PMSE mono-, double- and tri-layer OR are positively correlated with the K index. The correlation ~~coefficient~~ of~~between~~ PMSE mono- and double-layer OR ~~and~~ with $F_{10.7}$ is weak, ~~and~~ whereas the PMSE tri-layer OR ~~has~~ shows a negative correlation with $F_{10.7}$.

Keywords: Polar Mesosphere Summer Echoes; ~~European Incoherent Scatter Scientific Association Very high frequency Radar~~EISCAT VHF radar; solar 10.7 cm flux index（$F_{10.7}$）; geomagnetic K index

1 Introduction

The ionosphere is an important part of near the ~~earth~~ Earth space environment and the mesosphere is the coldest region in the ~~earth's~~ Earth's atmosphere. Polar Mesosphere Summer Echoes (PMSE) are strong echoes detected by radars from medium frequency (MF) to ultra-high frequency (UHF) bands in polar summer mesopause, and PMSE has been considered to be possible indicators of global climate change (Thomas and Olivero, 2001). ~~On average, the strongest echo occurs at the altitude of about 86 km, and the~~ The observation range is from 75~~-~~ to 100 km where on average, the strongest echo occurs at the altitude of about 86 km (Czechowsky et al., 1979). Radar waves in the very high frequency (VHF) band are backscattered ~~by~~ due to irregularities of ~~the~~ electron density with spatial scales of about half the radar wavelength: This was confirmed by Blix et al. (2003) from simultaneous rocket and radar observations. ~~(Blix et al., 2003). These polar mesospheric summer echoes (PMSE) are fundamentally related to the ice particles in mesospheric ice clouds (Rapp and Lübken, 2004). Even though this theory has been presented incompletely, it still provides a great impetus for the research of PMSE generation mechanism.~~ The most extensively accepted theory is that the irregularities of electron density is sustained due to the reduction in electron diffusion characterized by the slowest ambipolar diffusion mode associated with the charged ice grains (Cho et al., 1992). ~~The most extensively accepted theory is that the electron diffusion was characterized by the slowest ambipolar diffusion mode associated with the charged ice grains (Cho et al., 1992).~~ Varney et al. (2011) scrutinized one particular aspect of the turbulent theory of PMSE: the electron density dependence of the echo strength. One remarkable feature of all PMSE is the fact that the radar echoes often occur in the form of two or more distinct layers that can persist for periods of up to several hours. Until now, the layering mechanism leading to these multiple structures is only poorly understood in spite of some previous attempts involving gravity waves, the general thermal structure, and Kelvin-Helmholtz-instabilities (Röttger, 1994; Klostermeyer, 1997; Hill et al., 1999, Hoffmann et al., 2005).

Palmer et al. (1996) statistically analyzed the PMSE in northern hemisphere observed by the EISCAT VHF radar during 1988-1993. ~~Palmer et al. (1996) presented a statistical study of PMSE, after analyzed the observations of the EISCAT VHF radar during 1988–1993.~~ They suggested that~~confirmed that~~: (1) PMSE are summer phenomena, lasting from June to August;~~these echoes are a summer phenomenon in the Northern hemisphere, lasting from June to August~~; (2) PMSE occur mostly around noon and midnight, following a semidiurnal pattern; (3) the echoing structures move bodily, perhaps in response to gravity waves. based Based on measurements at 53.5 MHz in at Andenes, Norway, observed by thewith the 53.5 MHz ALOMAR SOUSY radar during 1994-1997 and with the ALWIN radar during 1999-2001. Bremer et al. (2003) derivedfound that the variation of PMSE is markedly controlled by solar cycle variations and precipitating high energetic particle fluxes. Bremer et al. (2006) discussed that the strength of PMSE depends on the level of ionization because of the long-term changes of mesospheric summer echoes caused by the incident solar wave radiation and precipitating high energetic particle fluxes from about 20 May to the end of August during 1998–2006. Smirnova et al. (2010) used the ESRAD MST radar's measurements; Yi et al.(2017)and found that the inter-annual variations of PMSE OR (occurrence ratio) and length of the season anticorrelated with solar activity represented by the(($F_{10.7}$ index, the daily solar activity proxysolar 10.7 cm radio flux) but not significant, and correlate with geomagnetic activity represented by (AP index) based on ESRAD MST radar measurements in Kiruna, Sweden. NeverthelessHowever, no statistically significant trends in PMSE yearly strengthsoccurrence ratio or in the length of the PMSE season were found in their paperwork. Smirnova et al. (2011) concentrated on the accurate calculation of PMSE absolute strength as expressed by radar volume reflectivity and found that the inter-annual variations of PMSE volume reflectivity strongly correlate with the local geomagnetic K-index and anticorrelate with solar 10.7 cm flux. but However, they did not find any statistically significant trend in PMSE volume reflectivity during 1997-2009. Li and Rapp (2011) reported that the correlations of the occurrence ratio of PMSE OR at 224 MHz shows a positive correlation with the both the solar and geomagnetic activities both show positive correlations. PMSE have been detected and widely studied based on long-term observations of many different MST radars (Reid et al., 20131989; Thomas et al., 1992; Smirnova et al., 2011) (Reid et al. 1989; Thomas et al. 1992; and Smirnova et al. 2011),. since Since from the first observation of PMSE in 1979, it is well-known that the PMSE observations results are different when PMSE are observed by different frequency radar even at the same sites, and PMSEs often show obvious layered events.

Many studies have widely reported that there is significant correlation between the ionization level and PMSE observed by 53.5 MHz radar (Inhester et al., 1990; Belova et al., 2007; Latteck et al., 2008). Previous study by 53.5MHz radar has provided the basic characteristics, the short-term statistical variations of PMSE and the relation among the PMSE, solar activity and geomagnetic activity detected. The The correlation of the ionization level with PMSE at 224 MHz to the ionization level , however, is as significant as that the correlation of the ionization level with PMSE at 53.5 MHz ~~to the ionization level~~, then previous studies~~it~~ provide~~s~~ the research basis and ideas for the ~~research~~ PMSE study detected by ~~of~~ 224MHz radar. There are still a few significant problems that must be solved with the characteristics of layered PMSE OR. Hence, it is necessary to analyze the layered PMSE ~~layered~~ OR and study layered PMSE characteristics deeply with data measured by 224 MHz EISCAT VHF radar under different observation conditions. The statistical results of layered PMSE ~~layered~~ OR with the same radar at the same site over the period 2004-2015 are given in this paper, which was based on the experiment data detected by 224 MHz EISCAT VHF radar. In addition, the correlation~~relationships~~ of PMSE OR with~~,~~ geomagnetic K index and $F_{10.7}$ ~~are~~ is analyzed and discussed. The ~~PMSE OR calculation~~ method of the correlation analysis between layered PMSE OR and solar activity and between layered PMSE OR and geomagnetic activity given in this paper without being affected by ~~solves~~ the defect of discontinuous PMSE measurements ~~that the measurements~~ of EISCAT radar. ~~is discontinuous, which~~ It makes a significant breakthrough in the ~~calculation and~~ characterization of the layered PMSE ~~layered~~ OR. ~~detected by EISCAT radar and~~ The aim of the current work is to provide ~~the results could provide~~ definitive data foundation for further analysis and the investigation of the physical mechanism of PMSE.

2 radar and experiment data description

The ~~experiment data of~~ PMSE observations used here were~~was~~ obtained ~~by~~ with 224MHz EISCAT VHF radar from 2004 to 2015. EISCAT VHF~~The~~ radar is located at Tromsø, Norway (69.35°N, 19.14°E), used ~~and~~ a parabolic cylindrical 120m×~~×46m~~ 40m antenna~~, with beam-widths of 1.8° north-south and 0.6° east-west~~. It is powerful tool for studying the lower ionosphere. Detailed descriptions of the radar can be found in Baron (1986). The measurements by EISCAT radar are very well suited for investigating the characteristics of PMSE. (for previous work, see e.g. Li et al., 2010 and references therein). It has frequency and phase modulation capability with pulse length of 1 μs to 2 ms . ~~Furthermore, reliable information of the raw electron density about PMSE, which is not derived by analysis of the incoherent scatter spectrum, but power profiles or near-zero-lag data can be obtained by EISCAT radar. The level of electron density represents the intensity of echoes.~~ The parameters ~~described~~ are shown in Table 1for accuracy control of EISCAT VHF radar.

EISCAT VHF radar ran several standard experiment modes: “manda, beata, bella, tau7, arcd (arc_dlayer) and tau1”. The main differences between the arcd and manda these experiment modes are illustrated in Table 2. The manda and arcd modes mainly used for low altitude detection, and provide spectral measurements at mesospheric altitude. Therefore, the accurate data used in this study is mainly givenprovided by manda and arcd modes. The Grand Unified Incoherent Scatter Design and Analysis Program (GUISDAP) software package have been used for analyzing the EISCAT VHF radar data. The electron density N_e analyzed by GUISDAP software was obtained between 10^6 and 10^{14} m^{-3}.

. **Table 1** Parameters of the radars.

Radar	EISCAT VHF
Location	69.59° N 19.23° E
Operating frequency	224 MHz
Transmitter peak power	1.5 MW
Antenna 3-dB beam width	1.7° NS ×× 1.2° EW
Antenna effective area	5690 m^2
Pulse length (altitude resolution)	300 m
Pulse repetition frequency	741 Hz
No. of bits in code	64
No. of code permutations	128
No. of coherent integrations	1
Lag resolution	1.35 ms
Maximum lag	0.17 s

Table 2 EISCAT VHF radar standard experiments.

Name	Code length [bit]	Baud length [μs]	Sampling rate[μs]	Range span[km]	Time resolution [s]	Plasma line	Raw data
manda	61	2.4	1.2	19–209	4.8	-	Yes
arc_dlayer	64	2	2	60–139	5.0	-	-
beata	32	20	20	52–663	5.0	Yes	-
bella	30	45	45	63–1344	3.6	Yes	-
tau7	16	96	12	50–2001	5.0	-	-
tau1	16	72	24	104–2061	5.0	-	-

3 Data analysis

In this study we have used the EISCAT VHF radar data from 2004 to 2015. The software package GUISDAP (Grand Unified Incoherent Scatter Design and Analysis Program) (see Lehtinen and Huuskonen, 1996 and www.eiscat.se for details) was used for analyzing radar data. The electron density N_e analyzed by GUISDAP software was obtained between 10^6 and 10^{14} m^{-3}. The level of electron density represents the intensity of echoes.

First of all, the heating parts were removed from the data set to avoid the heating effect. After that, the presence of PMSE was defined as the threshold of electron density ($N_e > 2.6 \times 10^{11}$ m^{-3}). We used the PMSE threshold given by Hocking and Röttger (1997) and Qiang Li (2011b) (see Appendix A Table A.2). Besides, some abnormal echoes are related to the meteor are not considered to be PMSE and is neglected in later discussion. PMSE is not continuous in time, so if the electron density satisfies the threshold ($N_e > 2.6 \times 10^{11}$ m^{-3}), we considered it as a PMSE event. We have considered only those events for which PMSE echoes are continuous for time ($t \geq 1$ min).

4 Results

~~3~~4.1 Layered PMSE ~~Occurrence ratios~~events

PMSE occur in thin layers having thickness up to 3-4 km, and the mean altitude distribution of PMSE events is 80-90km. It is considered to be the area of independent ~~abnormal~~ anomalous echoes. Fig. 1 (a), (b) and (c) show the typical events of PMSE monolayer, double-layer and tri-layer, respectively. As mentioned in the introduction, a notable feature of PMSE observed by radar is that radar echoes typically occur in the form of two or more layers. However, the system theories of the layering mechanism led to these multiple structures didn't come into being. ~~One remarkable feature of all PMSE is the fact that the radar echoes often occur in the form of two or more distinct layers that can persist for periods of up to several hours. Until now, the layering mechanism leading to these multiple structures is not well understood.~~ Here we ~~are~~ will study~~ing~~ the occurrence of these layered PMSE~~multiple layer~~ events and its relationship with solar and geomagnetic activity. This content will be discussed in detail later in the ~~article~~paper.

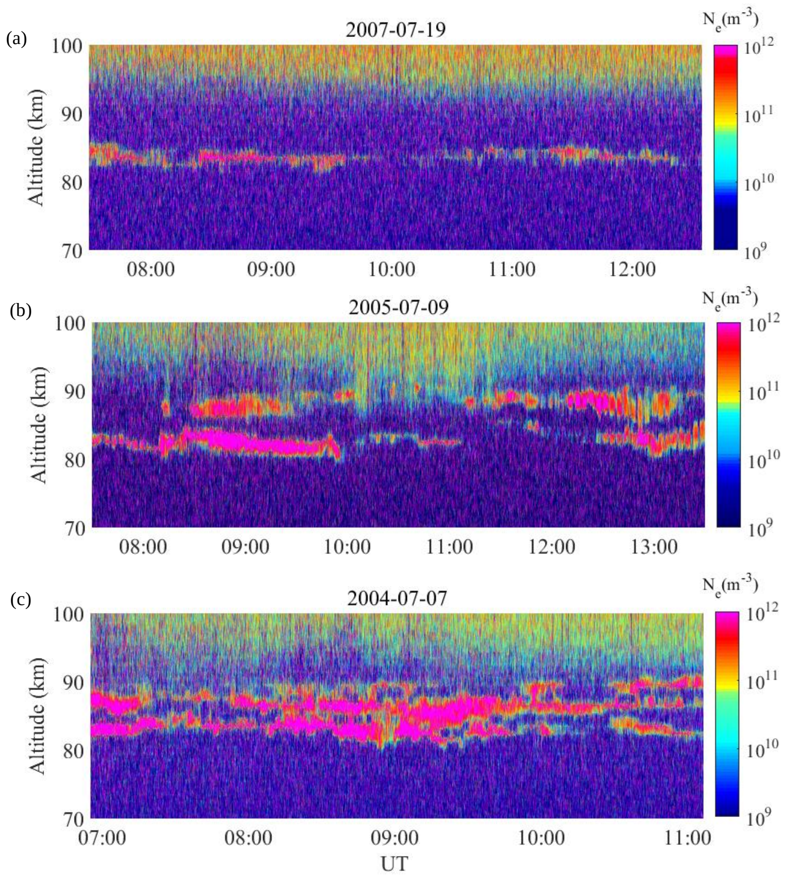


Fig. 1 The typical layered PMSE events observed by EISCAT 224MHz VHF radar. a) ~~The observation on 19 July, 2007 (Upper panel)~~Monolayer PMSE; b) ~~The observation on 9 July, 2005 (Middle panel)~~Double layer PMSE; c) ~~The observation on 7 July, 2004 (lower panel)~~Tri-layer PMSE. ~~The red circle marks the obvious layered phenomenon of PMSE events.~~

~~3~~4.~~1~~ 2 Layered PMSE OR ~~Calculation~~ calculation method

The calculation method is based on individual horizontal profiles. When the electron density satisfies the PMSE threshold ($N_e > 2.6\times10^{11}$ m^{-3}), then that time was taken as the starting time of the PMSE occurrence and until 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. The time interval not be regarded as PMSE occurrence time, if the time interval between them is shorter than 1 minute (t<1 min). Taking the calculation method of monolayer PMSE OR as an example: We defined that the ratio between the sustained time of monolayer PMSE and the total observation time as the monolayer PMSE OR. The applied procedure for the detection of multiple PMSE layers is based on individual vertical profiles with a high temporal resolution (Hoffmann, 2004). The layer ranges are identified by an electron density threshold of $2.6\times10^{11}m^{-3}$ (N_e> $2.6\times10^{11}m^{-3}$). Once a vertical profile of the electron density has two peaks and these two peaks are higher than the threshold (N_e>$2.6\times10^{11}m^{-3}$), 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 by using the same way.

To find the characteristic of PMSE occurrence ratio (OR), a computing method and threshold must be defined. First of all, the data during radar heating experiments has been eliminated. After that, the number of data points satisfying the threshold of electron density (N_e>2.6×10^{11} m^{-3}) was calculated (Hocking and Röttger ,1997). PMSE is not continuous in time, so if the number of data points satisfying the electron density threshold of PMSE were less than 8 data points in any time interval, these data points were replaced with the average of electron density (N_e) of 80-90 km regardless of the threshold (Rauf et al., 2018). It maintained the original electron density values at the corresponding time, so that the correlation is not influenced. The correlation coefficients have been calculated between PMSE OR and the 10.7cm of the solar flux index (F10.7), PMSE OR and geomagnetic events K indices, respectively. Because we chose the integration time of manda and arcd models are 4.8s and 2s respectively, on the basis of the condition (t⩾1 min), the PMSE is needed to be simultaneous for⩾12 and 30 data points, respectively. What's more, some abnormal echoes are related to the precipitation particle areas are not considered to be PMSE and is neglected in later discussion.

The emphasis of this paper is to present a hybrid algorithm based on grid partitioning. The calculation method is based on time. Taking the calculation method of PMSE monolayer occurrence ratio as an example, the all electron density detected by the EISCAT VHF radar are counted, and the electron density with the value larger than the threshold in this time period are taken out. The ratio between the sustained time of monolayer PMSE and the total observation time is obtained. At different heights, when an electron density value greater than the threshold and less than the threshold is continuously alternate observed in an observation region with altitude range from 3-4km, we consider that double-layer or multi-

~~layer PMSE events occur. 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.~~

~~3~~4.~~2~~ 3 The variations of layered PMSE ~~layered~~ occurrence ratios

~~For studying the~~ The layered PMSE ~~layered~~ OR, layered PMSE ~~layered~~ occurrence time (OT) and total observing time detected by EISCAT VHF radar from 2004 to 2015 ~~were~~ are illustrated in Table 3. PMSE mono-, double-, tri-layer and total OR ~~were~~ are also presented in Table 3 ~~as well~~.

Table 3 Statistical data from 2004 to 2015.

Year	Total Observing Time (~~/~~min)	Monolayer PMSE OT (min)~~/min~~	Double Layer PMSE OT (min)~~/min~~	Tri-~~ple~~ layer PMSE OT (min)~~/min~~	Monolayer OR [%]	Double layer OR [%]	~~Triple~~ Tri-layer OR [%]	Total OR [%]
2004	16054	4701	2774	151	29.28~~%~~	17.28~~%~~	0.94~~%~~	47.50~~%~~
2005	8165	3564	1491	182	43.65~~%~~	18.26~~%~~	2.23~~%~~	64.14~~%~~
2006	9248	2950	910	93	31.78~~%~~	9.84~~%~~	1.01~~%~~	42.63~~%~~
2007	9341	3027	804	0	32.41~~%~~	8.61~~%~~	0.00~~%~~	41.02~~%~~
2008	3310	763	97	0	23.06~~%~~	2.92~~%~~	0.00~~%~~	25.98~~%~~
2009	2264	424	76	8	18.72~~%~~	3.34~~%~~	0.35~~%~~	22.41~~%~~
2010	6303	1799	498	53	28.54~~%~~	7.90~~%~~	0.84~~%~~	37.28~~%~~
2011	9638	3624	2692	202	37.60~~%~~	27.93~~%~~	2.10~~%~~	67.63~~%~~
2012	7497	3550	1554	207	47.35~~%~~	20.73~~%~~	2.76~~%~~	70.84~~%~~
2013	14037	6906	3873	532	49.20~~%~~	27.59~~%~~	3.79~~%~~	80.59~~%~~
2014	2971	998	731	64	33.60~~%~~	24.6~~%~~	2.15~~%~~	60.35~~%~~
2015	4776	2019	1022	22	42.28~~%~~	21.40~~%~~	0.46~~%~~	64.14~~%~~

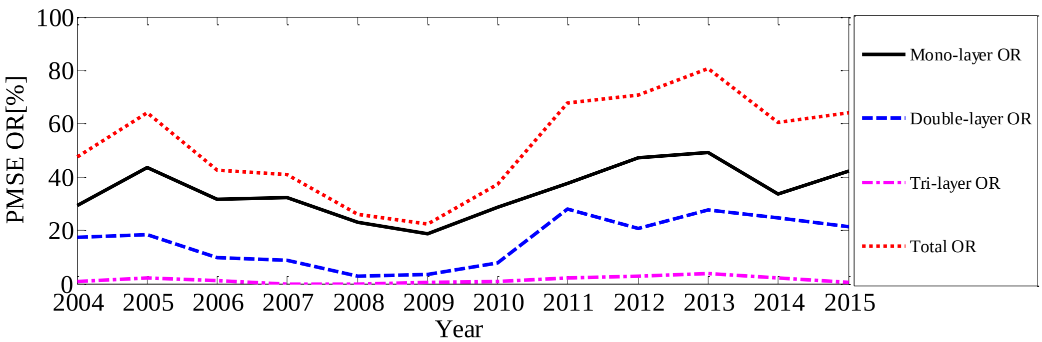


Fig. 2 Layered PMSE ~~layered~~ occurrence ratio. The OR of total (red dot line). The OR of monolayer (black solid line). The OR of double-layer (blue dashed line). The OR of tri~~ple~~-layer (pink dot-dashed line).

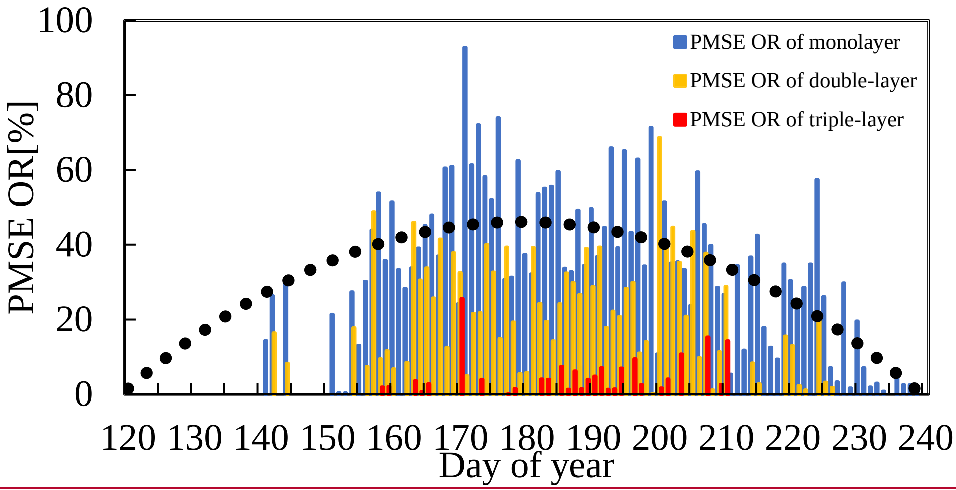
Fig. 2 shows that the mono- double- and tri~~ple~~-layer OR agrees with the total PMSE OR. We calculated the correlation of mono-layer with double-layer OR, tri-layer OR and total OR using the Spearman rank correlation coefficients (It will be particular described in section 4.3.2). ~~between mono-layer OR and double-layer OR, mono-layer OR and tri-layer OR, mono-layer OR and Total OR, respectively.~~ The correlation coefficients (r_s) of mono-layer with double-layer OR, tri-layer OR and total OR are 0.7922, 0.7718 and 1, respectively. All the correlation coefficients are statistically significant with ~~reached very significant level(~~P<0.05~~), respectively~~. These high values of correlation coefficients show that the correlation of mono-layer with double-layer OR, tri-layer OR, and total OR is very high. ~~–~~In addition, the layered PMSE ~~layered~~ OR from 2008 to 2010 is relatively low, and the solar activity ~~was~~ is relative 'quiet' in these years.

Fig. 2 shows ~~Two~~ two significant phenomena ~~can be discovered from Fig. 2~~: ~~One was~~ (1) ~~the~~The variation trends of ~~layered~~ mono-, double- and tri-layer PMSE OR ~~of PMSE is~~ is rules to follow~~different but regular.~~, ~~That is~~i.e., the OR of monolayer is the highest, double-layer lies in the middle and the tri~~ple~~-layer is the lowest~~;~~. ~~The other~~(2) ~~was~~ The layered PMSE ~~layered~~ and total OR values show similar shape of sinusoidal, which has obvious wave peak and wave valley. One wave peak lies in ~~the year about~~ 2005 and~~,~~ the other lies in ~~the year~~ 2013. The values of two wave peaks are different~~,~~ and the values in 2005 are smaller than that in 2013. The values of wave valley lie in 2008-2009. ~~Meanwhile, the gap between two peaks of PMSE OR is about 7 or 8 years.~~ Here we only give the results of the data analysis, no longer do the cause analysis, because the stratification of PMSE is affected by many factors and has yet to be decided. The analyzing method and ~~the~~ results ~~drawn during the process of~~given in this paper have a significant~~certain~~ reference value for ~~right and in depth researching~~ studying the PMSE phenomenon.

~~3~~4.~~3~~ 4 Seasonal behaviour

The mean seasonal variations of the layered PMSE ~~layered~~ OR and PMSE total OR observed by EISCAT VHF radar during 2004-2015 ~~were~~ is shown in Fig. 3 and Fig. 4, respectively. Fig. 3 illustrates the mean seasonal variation of the mono- (blue bars) double- (yellow bars) and tri-layer (red bars) PMSE OR and quartic~~second order~~ polynomial fitting for the monolayer PMSE OR (black dot-curve) during 2004-2015. Fig. 4 shows the mean seasonal variation of PMSE total OR (blue bars) and 3/π harmonic fitting ~~second order polynomial fit~~ for total PMSE OR (black dot-curve) during 2004-2015. It ~~can be~~is ~~derived~~ clear from Fig. 3 and Fig. 4 that the monolayer PMSE events in the Tromsø, Norway, often begins in late May, reaches its maximum in early June or mid-June, keeps this level until the end of July or beginning of August, and gradually decreases or vanishes when it is close to the end of August or the beginning of September in general, which waiis in agreement with references(-Smirnova et al., (2011). The double-layer PMSE also begins in late May, but its maximum appears in mid-July. In addition, it keeps the larger value in June and July, and simply fade away in early August. The triple-layer PMSE appears a lot less in comparison to mono- and, double- layer PMSE. In terms of time, it appears later and disappears earlier. What's Furthermore, the triple tri- layer PMSE OR is large in end of June and early July, which is different than monolayer and double layer PMSE OR.

According to the statistical results, PMSE monolayer, double-layer and multilayer tri-layer PMSE OR have seasonal variation. Moreover, there is fluctuation in the trends of $F_{10.7}$ and geomagnetic K-indices.In addition, the trends of F10.7 and geomagnetic K index also fluctuates. Therefore, it is necessary to investigate the correlation of solar and geomagnetic activity on with different layered PMSE OR during 2004-2015, and better try to explain the occurrence mechanism of PMSE. It is well known that other missions apart from PMSE regular observations are performed by EISCAT VHF radar, so EISCAT radar does not provide continuous PMSE observations. Just by noting that there have a few deviations by methods of calculating layered PMSE OR, we We raise an important question: Table 3 indicates a difference in total observation time for the individual years. How has this been taken into account for the determination of occurrence ratios? To solve this problemTherefore, we use another method to recalculate the layered PMSE layered OR. Then the correlation between the layered PMSE layered OR and the $F_{10.7}$ and between the layered PMSE layered OR and K index were are studied. As mentioned in the calculation method section, we only select the days when where PMSE is existedpresent and calculate the layered occurrence ratioOR of PMSE.



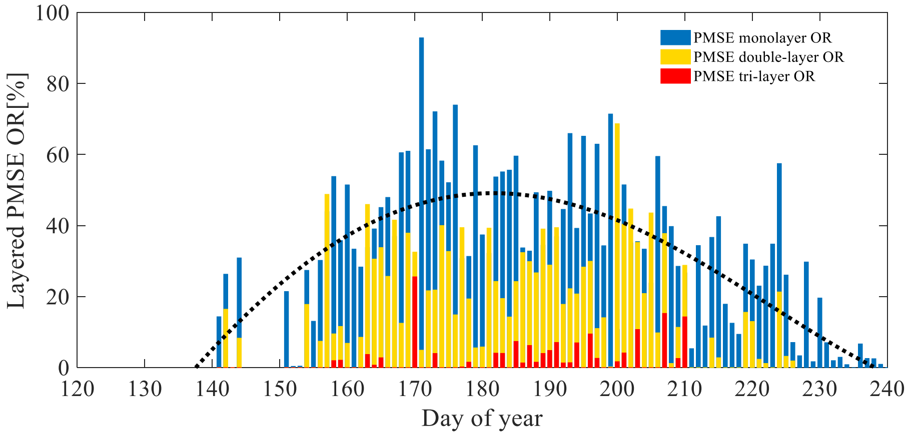
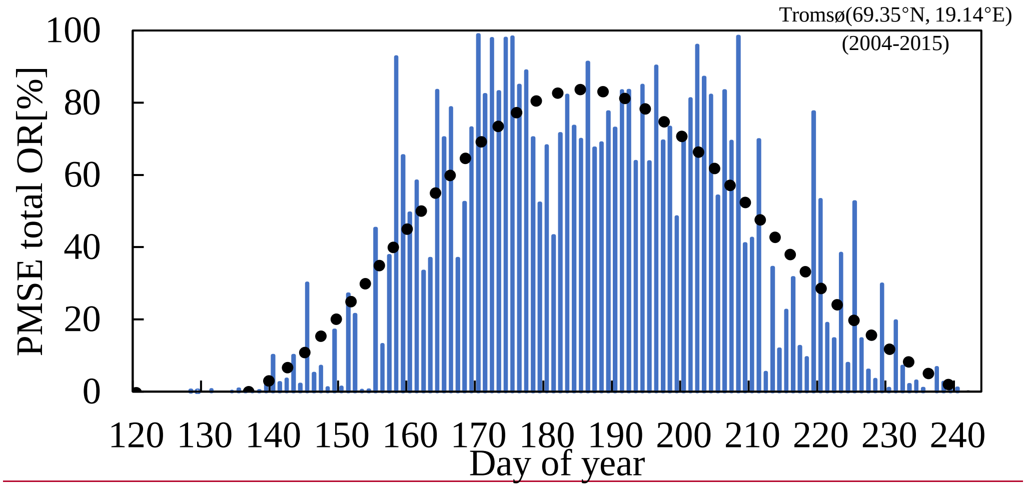


Fig. 3 Mean seasonal variation of ~~the PMSE~~ mono-(in blue), double-(in yellow), tri~~ple~~-layer (in red) PMSE occurrence ratio ~~at Tromso using observations~~ from 2004 to 2015.



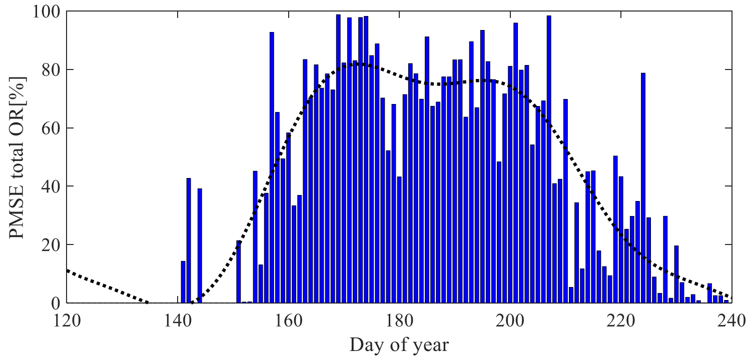


Fig. 4 Mean seasonal variation of ~~the PMSE~~ total PMSE occurrence ratio.

~~4~~ 5 Discussion

~~We have calculated the~~ The layered PMSE ~~layered~~ OR was calculated and the relations among PMSE mono-, double- and tri~~ple~~- layer OR ~~were~~ was analyzed statistically. At the same time, the mean seasonal variations of the layered PMSE OR and PMSE total OR have been presented.~~were given.~~ Hoffmann (2004) shows that the layering occurs because of subsequent nucleation cycles of ice particles in the uppermost (and coldest) gravity wave induced temperature minimum (see Hoffmann, 2004, Figure 3a). Subsequently, these newly created ice particles grow and sediment down and lead to the distinct layering. Besides, ~~It is now generally accepted that both~~ Rapp and Lübken (2004) found that charged ice particles and atmospheric turbulence play major roles in the change of the electron number density that leads to PMSE in the mesopause region ~~(Rapp and Lübken, 2004)~~. We know that solar and geomagnetic activities have a certain degree of influence on the occurrence of PMSE, ~~but~~ however, the effects of solar and geomagnetic activities on layered PMSE are not ~~clear~~understood well. Therefore, it is necessary to study the effects of solar and geomagnetic activities on layered PMSE. The occurrence ratio obtained by the ratio of the occurrence time of PMSE to the total observation time is the calculation method in the traditional sense. It is easy to understand and accurately analyze the short-term variations, such as diurnal variation and seasonal variation of PMSE. However, the long-term trend is subject to error and dispute~~inaccurate~~ by using this calculation method~~, because the radar measurement data is not continuous~~. ~~And~~ Furthermore, it is difficult to discuss and analyze the correlation of layered PMSE OR with solar~~relations between PMSE and solar activities and between PMSE~~ and geomagnetic activities. Therefore, we have ~~designed~~ presented a new calculation method for calculating the layered PMSE ~~layered~~ occurrence ratio, which is ~~based on the height~~different from the method given in section 4.2. S~~s~~o that, the layered ~~occurrence of~~ PMSE ~~becomes continuous, and the long-term variations of PMSE~~ OR is~~becomes~~ ~~easy and~~ relatively accurate. The correlation of PMSE with solar and geomagnetic activities is not expected to affect by discontinuous PMSE. The study of relations between PMSE and solar activities and between PMSE and geomagnetic activities ~~can be studied~~are significative.

~~4~~5.1 Another method for layered PMSE OR ~~Calculation~~ Calculation ~~method~~

~~The calculation method is based on altitude. A large number of literatures and experimental observations have shown that the altitude range of PMSE is 80-90km (Li and Rapp, 2011;Smirnova et al., 2010;Latteck and Bremer, 2013). Among all the altitude and electron density observed by EISCAT VHF radar, we only take the apparent electron density in the altitude range of 80-90km, and then take out the electron density greater than the threshold in the period when the PMSE is known to be present. The ratio between the numbers of layered PMSE electron densities values greater than the threshold and the numbers of total electron density in the range of 80-90 km was calculated respectively. The double-layer and tri-layer PMSE OR obtained by this method have a higher occurrence ratio than the first method.~~

The emphasis of this section is to present a hybrid algorithm based on grid partitioning. The calculation method is based on altitude. A large number of literatures and experimental observations have shown that the altitude range of PMSE is 80-90km (Li and Rapp, 2011; Smirnova et al., 2010; Latteck and Bremer, 2013). Hoffmann (2004) shows a mean height of 84.8 km for monolayer PMSE, whereas in the case of multiple layers PMSE, the lower layer occurs at a mean height of ~83.4 km. For the second layer in the case of multiple PMSE layer structures shows a maximum at about 86.3 km (The judging criteria in regard to the multiple layer PMSE see section 4.3). Firstly, we counted the total number of electron density at altitude of 80-90km and then counted the number of electron density satisfying the PMSE threshold (N_e＞$2.6×10^{11}m^{-3}$) in the period when the PMSE is known to be present (if electron density satisfies the threshold N_e＞$2.6×10^{11}m^{-3}$, we identify layered PMSE exist at this moment). The ratio between the numbers of layered PMSE electron densities values larger than threshold and the numbers of total electron density at altitude of 80-90 km was calculated. The double-layer and tri-layer PMSE OR calculated by this method is higher than the layered PMSE OR calculated by the method given in section 4.2. The correlation coefficients were calculated between PMSE OR and the 10.7cm of the solar flux index ($F_{10.7}$) and between PMSE OR and geomagnetic K index, respectively. The PMSE have been identified only for the time of PMSE duration lager than 1 min (t≥1 min). Because the integration time of manda and arcd models are 4.8s and 2s respectively, on the basis of the condition (t≥1 min), the PMSE is needed to be for≥12 and 30 data points, respectively.

~~4~~5.2 Layered PMSE ~~layered~~ OR under different electron density threshold

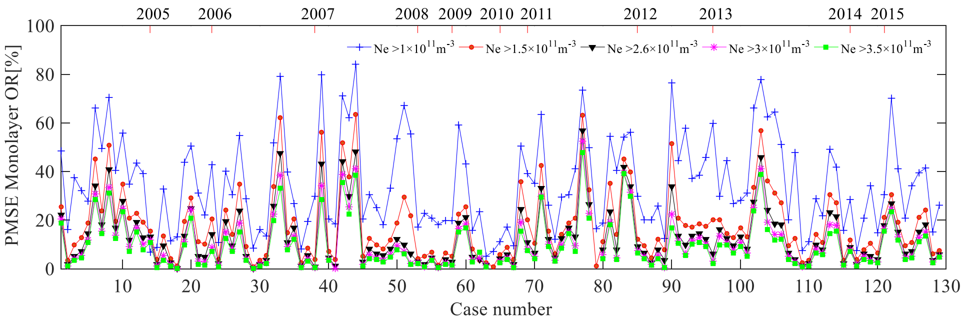


Fig. 5 PMSE monolayer occurrence ratio under different electron density threshold ~~conditions~~with axis at top showing the time in years. ~~Vertical lines are the end of 2006 and 2011, respectively (black dashed line). The legends on the figure is the average of PMSE occurrence rate in three time periods separated by the black dashed line.~~

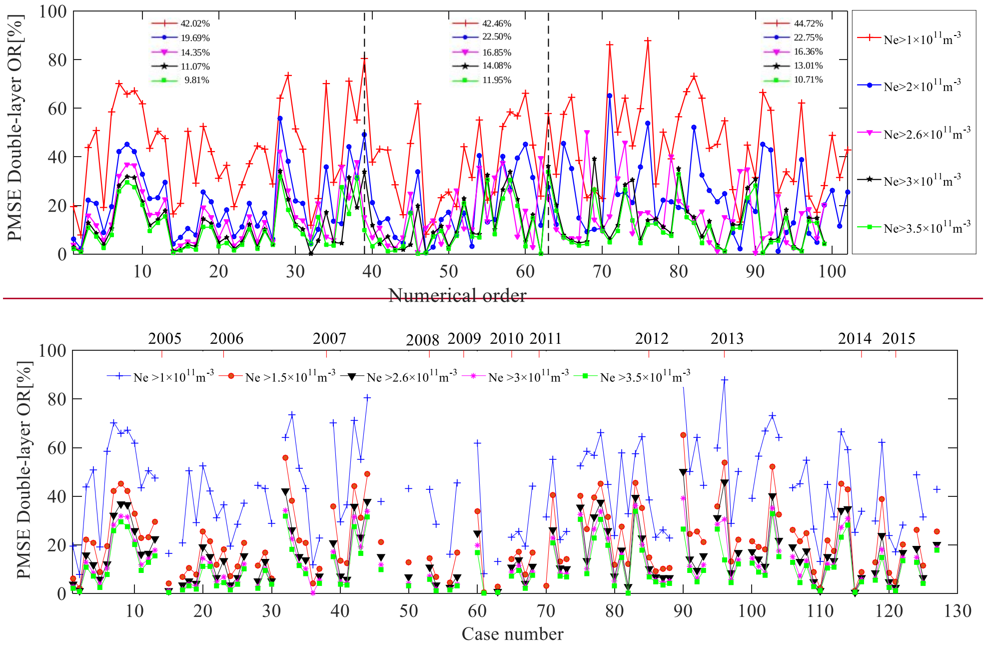


Fig. 6 PMSE double-layer occurrence ratio under different electron density threshold ~~conditions~~with axis at top showing the time in years. ~~Vertical lines are the end of 2006 and 2011(black dashed line). The legends on the figure is the average of PMSE occurrence rate in three time periods separated by the black dashed line.~~

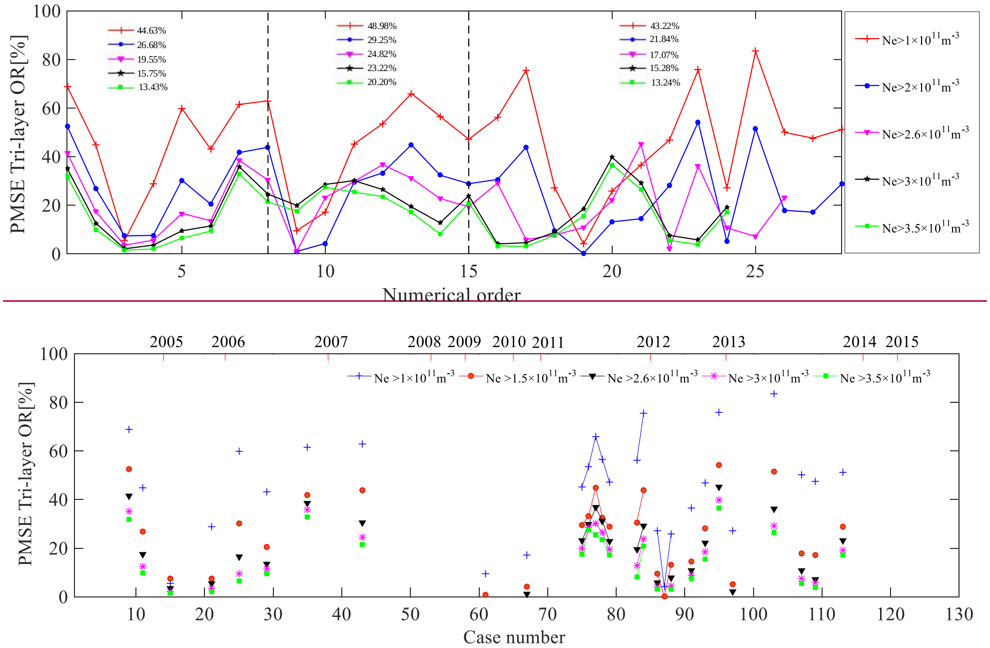


Fig.7 PMSE tri-layer occurrence ratio under different electron density threshold ~~conditions~~with axis at top showing the time in years. ~~Vertical lines are the end of 2006 and 2011(black dashed line). The legends on the figure is the average of PMSE occurrence rate in three time periods separated by the black dashed line.~~

In this section, the day when the first occurrence of PMSE in 2004 (regardless of duration) was recorded as 1, and the day with the later occurrence of PMSE increased by sequence. Using this sequence as the horizontal axis and ~~the~~ layered PMSE ~~layered~~ OR with different electron density threshold as the vertical axis, the results are shown in Fig. 5, 6, and 7. That is, Fig. 5, Fig. 6 and Fig. 7 show PMSE mono- double- and tri-layer OR under different electron density threshold ~~conditions~~, respectively. In the calculation method section ~~we said that~~ we have defined the electron density threshold (N_e ~~≥~~ ≥ 2.6 × ~~×~~ $10^{11}\mathrm{m}^{-3}$). Here, we give the layered PMSE ~~layered~~ OR with threshold ~~conditions of~~ N_e ~~≥~~ ≥ 1 × ~~×~~ $10^{11}\mathrm{m}^{-3}$, N_e ~~≥~~ ≥ 1.5 × ~~×~~ $10^{11}\mathrm{m}^{-3}$, N_e ~~≥~~ ≥ 2.6 × ~~×~~ $10^{11}\mathrm{m}^{-3}$, N_e ~~≥~~ ≥ 3 × ~~×~~ $10^{11}\mathrm{m}^{-3}$ and N_e ~~≥~~ ≥ 3.5 × ~~×~~ $10^{11}\mathrm{m}^{-3}$,respectively. We ~~can get their~~ found the variation trends of layered PMSE OR with different threshold ~~to be~~ are largely consistent~~,~~. ~~in~~ In addition, the larger the threshold, the smaller the ratio. Smirnova et al. (2010) analyzed day-to-day and year-to-year variations of PMSE OR for different thresholds. They found that the choice of the threshold does not influence the shape of the variation curves for PMSE OR. Zeller and Bremer (2009) indicated that different threshold values are for the investigations of the influence of geomagnetic activity on PMSE, however, of less importance. They both think that the variation trends of PMSE OR with different threshold are consistent. The aim of choosing 5 different thresholds is also to increase the number of samples for calculating the correlation coefficients between layered PMSE OR and F10.7 and between layered PMSE OR and K index. Since these occurrence ratios are calculated in the case where the occurrence of PMSE is determined, ~~there is no case of missing data~~so, ~~and~~ it ~~can be~~is recognized that these occurrence rates are reliable. ~~The legends on the figure is the average of PMSE mono-, double- and triple-layer OR with threshold conditions of N_e >1×$10^{11}\mathrm{m}^{-3}$, N_e >1.5×$10^{11}\mathrm{m}^{-3}$, N_e>2.6×$10^{11}\mathrm{m}^{-3}$, N_e>3×$10^{11}\mathrm{m}^{-3}$ and N_e>3.5×$10^{11}\mathrm{m}^{-3}$ during the periods of 2004-2006, 2007-2011 and 2012-2015.~~ It is well known that the period of 2006-2009 is solar minimum and 2012 is solar maximum, but the PMSE mono- and double-layer average OR in 2007 is not consistent with solar activity. In other words, there ~~has~~ is no obvious correlation between ~~PMSE~~ mono- and double-layer PMSE OR and solar activity. What's more, we found that PMSE tri~~ple~~- layer OR and solar activity in opposite directions. To prove the conclusion, we will calculate the correlation coefficient between layered PMSE ~~layered~~ OR and solar activity and between layered PMSE ~~layered~~ OR and geomagnetic activity in next section. Therefore, the correlation~~relation~~ between them can be judged directly.

45.3 Effect of solar and geomagnetic activity on PMSE OR

45.3.1 $F_{10.7}$ index and K -index

The $F_{10.7}$ index is a measure of the solar radio flux per unit frequency at a wavelength of 10.7 cm, near the peak of the observed solar radio emission. $F_{10.7}$ is often expressed in SFU or solar flux units (1 SFU = 10^{-22} W·m^{-2}·Hz^{-1}). It represents a measure of diffuse, nonradiative coronal plasma heating. It is an excellent indicator of overall solar activity levels and correlates well with solar UV emissions. The K-index quantifies disturbances in the horizontal component of earth's Earth's magnetic field with an integer in the range 0-9 with 1 being calm and 5 or more indicating a geomagnetic storm. It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a three-hour interval. The K-index was introduced by Julius Bartels in 19381939(Bartels et al., 1939). The K index values used in the paper is the median of the K index observed on a magnetometer during a day, which where has removed the effects of the heating experiments were removed.

45.3.2 Correlation coefficients

A correlation coefficient is a numerical measure of some type of correlation, meaning a statistical relationship between two variables (Boddy and Smith, 2009). The Pearson correlation coefficient known as Pearson's *r*, is a measure of the strength and direction of the linear relationship between two variables that is defined as the covariance of the variables divided by the product of their standard deviations. This is the best known and most commonly used type of correlation coefficient. Pearson's correlation coefficient Given a pair of random variables (X, Y), the formula for *r* is (Wilks, 1995):

$$r_{X,Y} = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y}$$

Where:

Cov is the covariance.

σ_X is the standard deviation of X

σ_Y is the standard deviation of Y.

Spearman's rank correlation coefficient is a measure of how well the relationship between two variables can be described by a monotonic function. The Spearman correlation between two variables is equal to the Pearson correlation between the rank values of those two variables. While Pearson's correlation assesses linear relationships, Spearman's correlation assesses monotonic relationships (whether linear or not) (Well and Myers, 2003). For a sample of size n, the n raw scores X_i, Y_i are converted to ranks rgX_i, rgY_i, and r_s is computed from:

$$r_S = \frac{\operatorname{cov}(rg_X, rg_Y)}{\sigma_{rg_X}\sigma_{rg_y}}$$

Where:

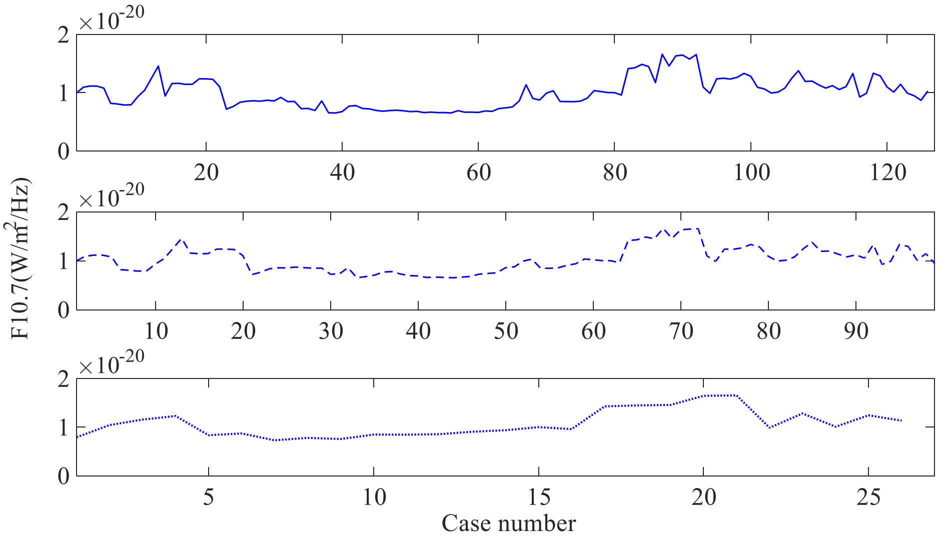
$\operatorname{cov}(rg_X, rg_Y)$ is the covariance of the rank variables.

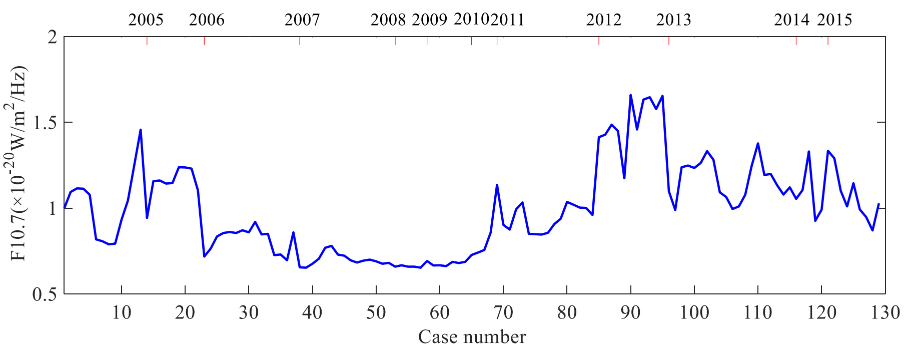
σ_{rg_X} and σ_{rg_Y} are the standard deviations of the rank variables.

A high value (approaching +1.00) is a strong direct relationship, values near 0.50 are considered moderate and values below 0.30 are considered to show weak relationship. A low negative value (approaching -1.00) is similarly a strong inverse relationship, and values near 0.00 indicate little, if any relationship.

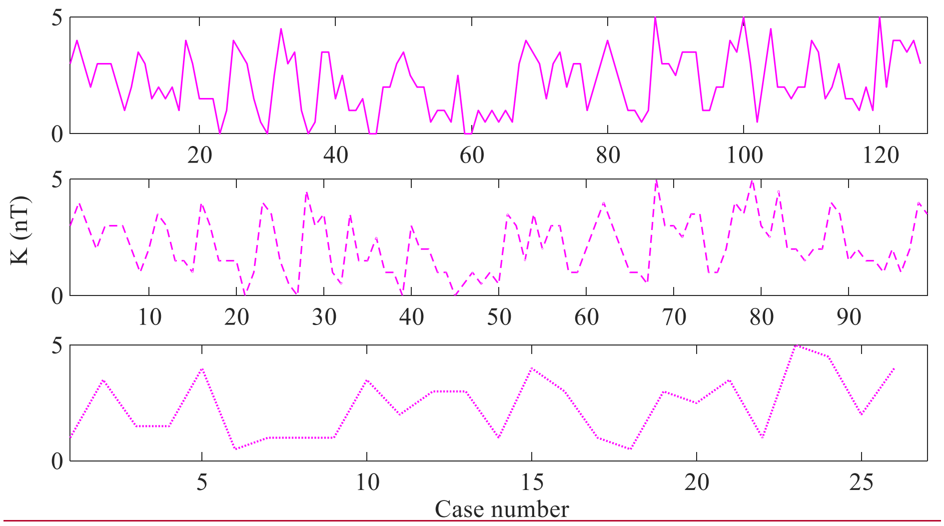
To determine whether a result is statistically significant, a P -value is calculated, which is the probability of observing an effect of the same magnitude or more extreme given that the null hypothesis is true (Devore, 2011). The null hypothesis is rejected if the P-value is less than a predetermined level (usually α=0.05). Where α is called the significance level, and is the probability of rejecting the null hypothesis given that it is true (a type I error).

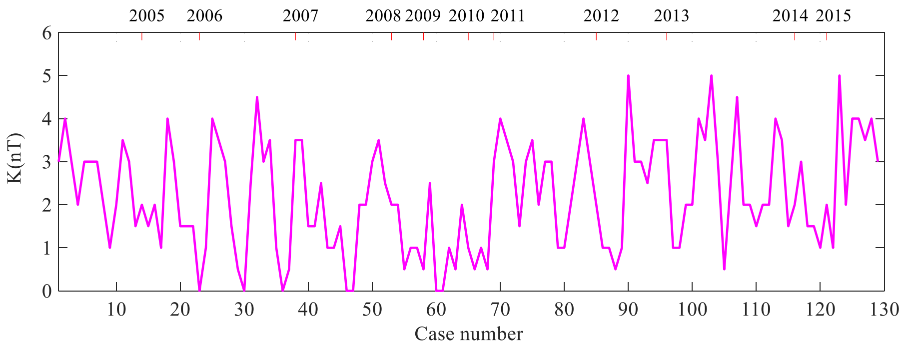
45.3.3 Correlation between layered PMSE OR, $F_{10.7}$ and K index





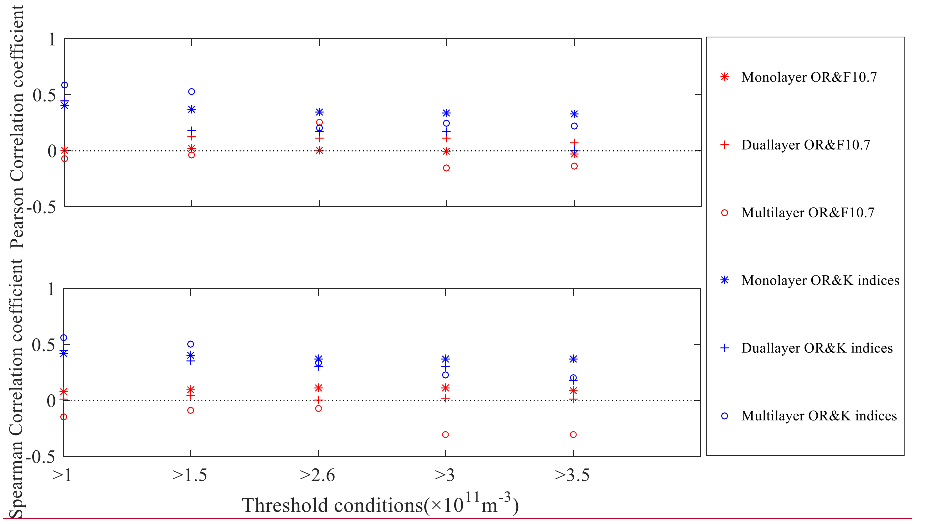
(a)





(b)

Fig. 8 (a) The variations of $F_{10.7}$ values corresponding to the occurrence of PMSE with axis at top showing the time in years. ~~Upper panel: F10.7 values corresponding to the occurrence of mono-layer PMSE; Middle panel: F10.7 values corresponding to the occurrence of double-layer PMSE; lower panel: F10.7 values corresponding to the occurrence of triple-layer PMSE.~~ (b) The variations of geomagnetic K index values corresponding to the occurrence of ~~PMWE~~PMSE with axis at top showing the time in years. ~~Upper panel: K index values corresponding to the occurrence of mono-layer PMSE; Middle panel: K index values corresponding to the occurrence of double-layer PMSE; lower panel: K index values corresponding to the occurrence of triple-layer PMSE.~~



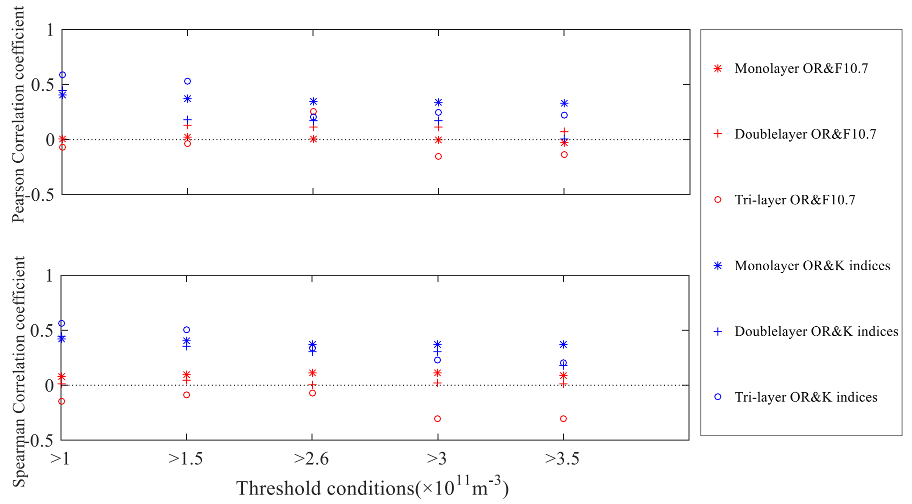


Fig. 9 Pearson linear and Spearman rank correlation computed between layered PMSE OR (with thresholds conditions of N_e >≥1×10^{11}m^{-3}, N_e >≥1.5×10^{11}m^{-3}, N_e >≥2.6×10^{11}m^{-3}, N_e >≥3×10^{11}m^{-3} and N_e >≥3.5×10^{11}m^{-3}, respectively) and $F_{10.7}$ corresponding to the occurrence of PMSE and between layered PMSE OR and K index corresponding to the occurrence of PMSE, respectively. For each correlation coefficient, *P* value is less than 0.05. The horizontal dotted line is drawn to separate positive and negative correlation coefficients.

Fig.8 shows that the variations of $F_{10.7}$ and geomagnetic K index values corresponding to the occurrence of PMSE. The correlation of PMSE with solar and geomagnetic activities is not expected to affect by discontinuous PMSE, Since the $F_{10.7}$ and K values corresponding to the occurrence of PMSE with threshold of N_e>2.6×10^{11}m^{-3}.The $F_{10.7}$ and K values corresponding to the occurrence of PMSE with threshold conditions of N_e>2.6×10^{11}m^{-3}. So, the study of relations between PMSE and solar activities and between PMSE and geomagnetic activities make sense. Combined The relation between layered PMSE OR and $F_{10.7}$ and between layered PMSE OR and K values can be analyzed for the results shown in conjunction with Figures 5 through 8.with Fig. 5, 6, and 7, we can roughly analyze the relationship

~~between the layered PMSE OR and the F10.7 and between the layered PMSE OR and K values, but the results may be relatively inaccurate.~~ In order to examine~~study~~ the correlation between layered PMSE OR and $F_{10.7}$ and between layered PMSE OR and K index, all the data points of PMSE OR, $F_{10.7}$ and K index with simultaneous occurrence were combined. Fig.9 shows the correlation coefficients computed by combing all the points of PMSE OR (with thresholds~~ conditions of~~ N_e ~~>~~ $\geq 1\times10^{11}\mathrm{m}^{-3}$, N_e ~~>~~ $\geq 1.5\times10^{11}\mathrm{m}^{-3}$, N_e ~~>~~ $\geq 2.6\times10^{11}\mathrm{m}^{-3}$, N_e ~~>~~ $\geq 3\times10^{11}\mathrm{m}^{-3}$ and N_e ~~>~~ $\geq 3.5\times10^{11}\mathrm{m}^{-3}$), $F_{10.7}$ and K index with simultaneous occurrence and apply significant test. It ~~can be~~is seen from Fig.9 that layered PMSE OR is positively correlated with the K index and the coefficients indicate moderate correlation between the variables~~,~~. ~~but~~ Whereas the correlation coefficient between PMSE mono- and $F_{10.7}$, double-layer OR and $F_{10.7}$ both are very low, indicating that their correlation is weak or even not relevant. Interestingly, we found that the PMSE tri-layer OR has a negative correlation with $F_{10.7}$, although the correlation was lower than what we have supposed~~,~~. ~~this~~ This finding ~~has~~ never published in previous~~any existing~~ literature. Hence, it is indicated that the cases with positive values play a decisive role when calculating the correlation coefficient between the data points of PMSE and K index occur simultaneously, and events with negative values dominate in the calculation of the correlation coefficient between ~~PMSE~~ tri-layer PMSE OR and $F_{10.7}$. But ~~PMSE~~ mono-, double- layer PMSE OR has hardly relevance with $F_{10.7}$.

The correlation between layered PMSE ~~layered~~ OR and $F_{10.7}$ and between layered PMSE ~~layered~~ OR and K index ~~were~~ have been obtained. It indicates that there are many complicated factors for the formation and development of PMSE besides the solar and geomagnetic activities. There are explanations for these results: on one hand, the enhanced solar activity increases the electron density due to the increase of ionization, and with the increase of solar radiation, the photodissociation enhance and the water vapor content is reduced. On the other hand, the positive correlation between PMSE OR and K index may be apprehensible as because of the enhanced magnetic activity caused precipitating particles increase in the mesosphere, and lead to increase in electron densities. Latteck and Bremer (2013) shows that PMSE are caused by inhomogeneities in the electron density of the radar Bragg scale within the plasma of the cold summer mesopause region in the presence of negatively charged ice particles. Thus, the occurrence of PMSE contains information about mesospheric temperature and water vapor content but also depends on the ionization due to solar electromagnetic radiation and precipitating high energetic particles. ~~But~~

However, ~~I~~still we ~~still can't~~ can not explain why there is a negative correlation between tri-layer PMSE OR and $F_{10.7}$~~,~~ .This should be focused in future~~or this may be our future~~ research~~ focus~~.

~~5~~ 6 Summary and Conclusions

In the paper, ~~we presented~~ the PMSE occurrence ratios with monolayer, double- and tri~~ple~~-layers ~~that were~~ detected by EISCAT VHF radar during a solar cycle have been presented. ~~It was obtained that the~~ The daily ~~variation~~ and seasonal variation of the layered PMSE was analysed. We implemented a~~ new~~ method to provide more accurate conclusions on the study of the long-term variation of PMSE with different thresholds. ~~Then the~~ The correlation~~relationship~~ between layered PMSE and solar radiation flux ($F_{10.7}$) and between layered PMSE and geomagnetic activity (K index) ~~were~~ was given. The following conclusions were reached:

(1) _Mono-, double- and tri-layer PMSE have different seasonal behavior. Monolayer PMSE events often begins in late May, reaches its maximum in early June or mid-June, keeps this level until the end of July or beginning of August, and gradually decreases or vanishes when it is close to the end of August or the beginning of September in general, which ~~was~~ is in agreement with earlier report~~references~~ (Smirnova et al., 2011). The double-layer PMSE OR reaches maximum in mid-July~~its maximum appears in mid-July~~ and simply fade away in early August. The tri~~ple~~-layer PMSE appears later and disappears earlier in comparison to mono~~-,~~ -and double--layer PMSE, and it is large in end of June and early July.

(2) The variation trends of ~~PMSE~~ mono- double- and tri-layer PMSE OR under different electron density thresholds~~ conditions~~ are ~~largely~~ greatly consistent. It is found~~was got~~ that the larger the threshold, the smaller the ratio. Beyond that, PMSE mono- and double-layer OR ~~were~~ are not associated with solar activity. and PMSE tri~~ple~~--layer OR is inversely proportional to solar activity.

(3) Layered PMSE~~ layered~~ OR is positively correlated with the K index. The correlation between PMSE mono- and double--layer OR and $F_{10.7}$ is relatively weak, and PMSE tri-layer OR has a negative correlation with $F_{10.7}$.

Data availability.

All EISCAT data used in this work have been downloaded at https://www.eiscat.se/schedule/schedule.cgi.

Competing interests. The authors declare that they have no conflict of interest.

Authors' contributions

Shucan Ge designed this study, carried out statistics, analyzed the results and wrote the manuscript. Hailong Li participated in the design of the study and the analysis of the results. Tong Xu and Mengyan Zhu helped with the conceptual ideas for the paper. Maoyan Wang and Lin Meng managed this study and participated in language grammar modification. Safi Ullah and Abdur Rauf participated in modifying language issues and provided a lot of suggestions about revised manuscript. All authors read and approved the final manuscript.

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References

Bartels, J., Heck, N. A. H., and Johnston, H. F.: The Three-Hour-Range Index Measuring Magnetic Activity, Journal of Geophysical Research, 44, 411-454, doi.org/10.1029/TE044i004p00411, 1939.

Baron, M.: EISCAT progress 1983–1985. Journal of Atmospheric and Terrestrial Physics, 48, 767–772, doi: 10.1016/0021-9169(86)90050-4, 1986.

Belova, E., P. Dalin, and Kirkwood, S.: Polar mesosphere summer echoes: A comparison of simultaneous observations at three wavelengths, Annales Geophysicae, 25, 2487–2496, doi: 10.5194/angeo-25-2487-2007, 2007

Blix, T. A., Rapp, M., and Lübken, F. J.: Relations between small scale electron number density fluctuations, radar backscatter, and charged aerosol particles, Journal of Geophysical Research Atmospheres, 108, 1-10, doi:org/10.1029/2002JD002430, 2003.

Boddy, R., and Smith, G.: Statistical Methods in Practice: for Scientists and Technologists, John Wiley & Sons Ltd Chichester, 2009.

Bremer, J., Hoffmann, P., Latteck, R., and Singer, W.: Seasonal and long-term variations of PMSE from VHF radar observations at Andenes, Norway, Journal of Geophysical Research Atmospheres, 108, doi:org/10.1029/2002JD002369, 2003.

Bremer, J., Hoffmann, P., Höffner, J., Latteck, R., Singer, W., Zecha, M., and Zeller, O.: Long-term changes of mesospheric summer echoes at polar and middle latitudes, Journal of Atmospheric and Solar-Terrestrial Physics, 68, 1940-1951, doi:org/10.1016/j.jastp.2006.02.012, 2006.

Cho, J. Y. N., Hall, T. M., and Kelley, M. C.: On the Role of Charged Aerosols in Polar Mesosphere Summer Echoes, Journal of Geophysical Research Atmospheres, 97, 875-886, doi:org/10.1029/91JD02836, 1992.

Czechowsky, P., Ruester, R., and Schmidt, G.: Variations of mesospheric structures in different seasons, Geophysical Research Letters, 6, 459-462, doi:org/10.1029/GL006i006p00459, 1979.

Devore, J. L.: Probability and Statistics for Engineering and the Sciences (8th ed.). Boston, MA: Cengage Learning, 300–344. ISBN 978-0-538-73352-6, 2011.

Hill, R. J., D. E. Gibson-Wilde, J. A. Werne and D. C. Fritts: Turbulence-induced fluctuations in ionization and application to PMSE, Earth Planets Space, 51, 499–513, doi: 10.1186/BF03353211, 1999.

Hocking, W. K., and Röttger, J.: Studies of polar mesosphere summer echoes over EISCAT using calibrated signal strengths and statistical parameters, Radio Science, 32, 1425-1444, doi:org/10.1029/97RS00716, 1997.

Hoffmann, P.: On the occurrence and formation of multiple layers of polar mesosphere summer echoes. Geophysical Research Letters, 32 (5), L05812, doi: 10.1029/2004gl021409, 2005.

Inhester, B., Ulwick, J., Cho, J., Kelley, M. and Schmidt, G.: Consistency of rocket and radar electron density observations: implications about the anisotropy of turbulence, Journal of Atmospheric and Solar-Terrestrial Physics, 52, 855–873, doi: 10.1016/0021-9169(90)90021-e, 1990.

Klostermeyer, J.: A height- and time-dependent model of polar mesosphere summer echoes. Journal of Geophysical Research: Atmospheres, 102(D6), doi: 10.1029/96JD03652, 1997.

Latteck, R., Singer, W., Morris, R. J., Hocking, W. K., Murphy, D. J., Holdsworth, D. A. and Swarnalingam, N.: Similarities and differences in polar mesosphere summer echoes observed in the Arctic and Antarctica, Annales Geophysicae, 26, 2795–2806, doi: 10.5194/angeo-26-2795-2008, 2008

Latteck, R., and Bremer, J.: Long-term changes of polar mesosphere summer echoes at 69°N, Journal of Geophysical Research Atmospheres, 118, 10441-10448, doi:10.1002/jgrd.50787, 2013.

Lehtinen, M.S., Huuskonen, A.: General incoherent scatter analysis and GUISDAP, Journal of Atmospheric and Solar-Terrestrial Physics, 58, 435–452, doi: 10.1016/0021-9169(95)00047-x, 1996.

Li, Q., Rapp, M., Röttger, J., Latteck, R., et al.: Microphysical parameters of mesospheric ice clouds derived from calibrated observations of polar mesosphere summer echoes at Bragg wavelengths of 2.8 m and 30 cm, Journal of Geophysical Research, 115, D00I13, doi:10.1029/2009JD012271, 2010.

Li, Q., and Rapp, M.: PMSE-observations with the EISCAT VHF and UHF-radars: Statistical properties, Journal of Atmospheric and Solar-Terrestrial Physics, 73, 944-956, doi:org/10.1016/j.jastp.2010.05.015, 2011.

Palmer, J. R., Rishbeth, H., Jones, G. O. L., and Williams, P. J. S.: A statistical study of polar mesosphere summer echoes observed by EISCAT, Journal of Atmospheric and Solar-Terrestrial Physics, 58, 307-315, doi:org/10.1016/0021-9169(95)00038-0, 1996.

~~Rapp, M., and Lübken, F. J.: Polar mesosphere summer echoes (PMSE): review of observations and current understanding, Atmospheric Chemistry and Physics, 4, 2601-2633, doi:org/10.5194/acp-4-2601-2004, 2004.~~

Rapp, M. and Lübken, F.-J.: Polar mesosphere summer echoes (PMSE): Review of observations and current understanding. Atmospheric Chemistry and Physics, 4(11/12), 2601-2633, doi:10.5194/acp-4-2601-2004, 2004.

Rauf, A., Li, H., Ullah, S., Meng, L., Wang, B., and Wang, M.: Statistical study about the influence of particle precipitation on mesosphere summer echoes in polar latitudes during July 2013, Earth Planets and Space, 108(70), doi:org/10.1186/s40623-018-0885-6, 2018.

Reid, I. M., Czechowsky, P., Ruster, R., and Schmidt, G.: First VHF radar measurements of mesopause summer echoes at mid-latitudes, Geophysical Research Letters, 16, 135-138, doi:org/10.1029/GL016i002p00135, 1989.

Röttger, J.: Middle atmosphere and lower thermosphere processes at high latitudes studied with the EISCAT radars. Journal of Atmospheric and Solar-Terrestrial Physics, 56(9):1173-1195, doi: 10.1016/0021-9169(94)90056-6, 1994.

Smirnova, M., Belova, E., Kirkwood, S., and Mitchell, N.: Polar mesosphere summer echoes with ESRAD, Kiruna, Sweden: Variations and trends over 1997–2008, Journal of Atmospheric and Solar-Terrestrial Physics, 72, 435-447, doi:10.1016/j.jastp.2009.12.014, 2010.

Smirnova, M., Belova, E., and Kirkwood, S.: Polar mesosphere summer echo strength in relation to solar variability and geomagnetic activity during 1997–2009, Annales Geophysicae, 29, 563-572, doi:10.5194/angeo-29-563-2011, 2011.

Thomas, L., Astin, I., Prichard, I. T.:The characteristics of VHF echoes from the summer mesopause region at mid-latitudes. Journal of Atmospheric and Terrestrial Physics, 54(7-8), 969-977, doi: 10.1016/0021-9169(92)90063-q, 1992.

Thomas, G. E., and Olivero, J.: Noctilucent clouds as possible indicators of global change in the mesosphere, Advances in Space Research, 28, 937-946, 2001.

Varney, R. H., Kelley, M. C., Nicolls, M. J., Heinselman, C. J., and Collins, R. L.: The electron density dependence of polar mesospheric summer echoes, Journal of Atmospheric and Solar-Terrestrial Physics, 73, 2153-2165, doi:org/10.1016/j.jastp.2010.07.020, 2011.

Well, A. D., and Myers, J. L.: Research design and statistical analysis, New York, 1-736, 2003.

Wilks, D. S.: Statistical Methods in the Atmospheric Sciences, Burlington, MA: Academic Press, 1995.

~~Yi, W., Reid, I. M., Xue, X., Younger, J. P., Murphy, D. J., Chen, T., and Dou, X.: Response of neutral mesospheric density to geomagnetic forcing, Geophysical Research Letters, 44, 8647-8655, doi:org/10.1002/2017GL074813, 2017.~~

Zeller O. and Bremer J., The influence of geomagnetic activity on mesospheric summer echoes in middle and polar latitudes, Annales Geophysicae, 27(2): 831-8372, DOI: 10.5194/angeo-27-831-2009, 2009.