Dear Reviewer,

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 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.

Reply to Referee comments:

Reply to comment: before to reply this comment, first the authors would like to thanks 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 >2.6×10^{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 >2.6×10^{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 >2.6×10^{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 > $2.6\times10^{11}m^{-3}$ 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).

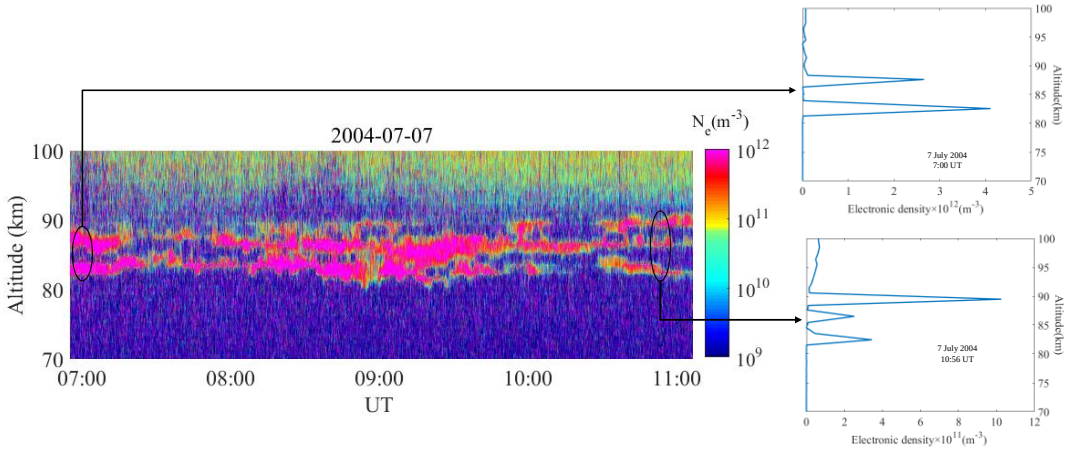


Fig.1 left panel: The layered phonmenon of PMSE. Upper right panel: double-layer PMSE phenomenon. Lower right panel: three-layer PMSE phenomenon.

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.

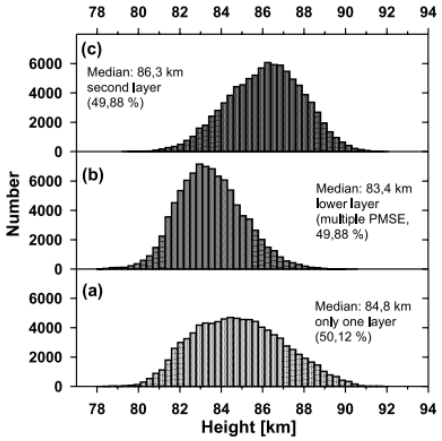


Fig. 2. Histogram of the preferred centroid heights of PMSE, based on observations during June and July for seven years (1996-1997, 1999-2003): (a) for single layer PMSE, (b) for the lower layer in the case of multiple PMSE layer structures, and (c) for the second layer in the case of multiple PMSE layer 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 ($Ne>2.6\times10^{11}$ 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 ($Ne>2.6\times10^{11}$ 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

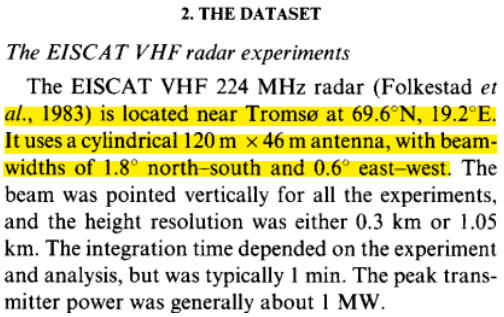
correlation of the ionization level with PMSE at 53.5 MHz, then previous studies provide the research basis and ideas for the PMSE study detected by 224MHz radar".

(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

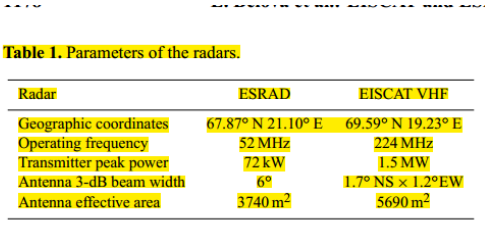


Table 1. Parameters of the radars.

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 $N_e > 2.6\times10^{11}m^{-3}$, 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.

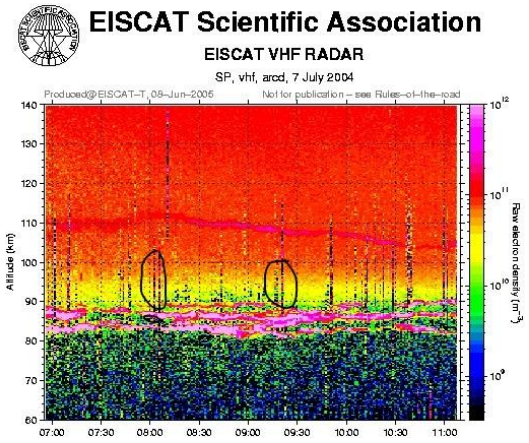


Fig.4 PMSE obsevered by EISCAT. The black curve circle indicates the abnormal echo not PMSE.

(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.

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