Response to Reviewer 2:

We thank the reviewer for the constructive and helpful comments, which helped us to improve the manuscript. We took all comments into account when revising the manuscript. In the text below we describe the modifications and list our responses together with the reviewer's comments that are repeated here in blue color. Our answers are given in black. In addition to the modifications listed below we make revisions to take into account the comments from Reviewer 1. We include a discussion of the statistical significance of the results. And we rephrase parts of the text to adjust the manuscript to the modifications made.

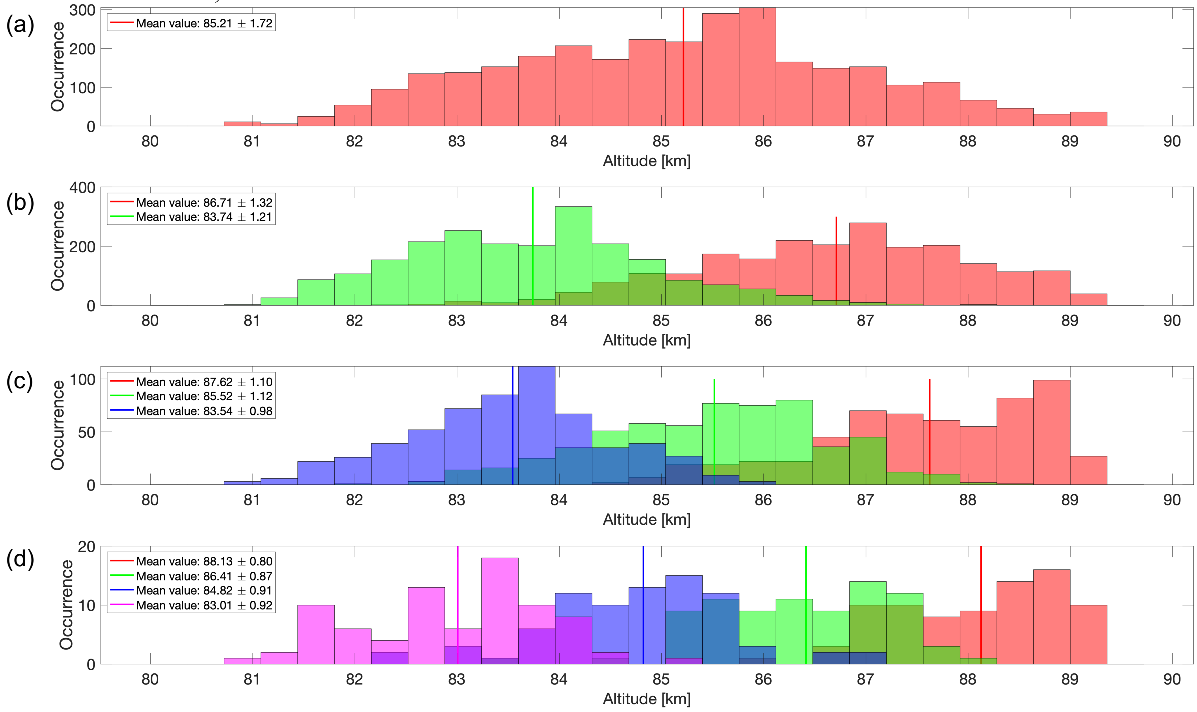
General comments

The article investigates properties of PMSE layers, more precisely of multiple layers, during periods of enhanced and minimum solar activity. The article is clearly structured. The literature review listed in the introduction covers the necessary background information on this topic. The data selection and analysis methods are presented and referenced in a very understandable way in section 2. The analysis of the data and discussion of the results is summarised in a structured way in one chapter. Overall, I see the article as a valuable contribution to the exploration of one aspect of the long-known but still complex phenomenon of PMSE. I would like to make a suggestion that I think could improve the readability of the paper and have listed some specific comments.

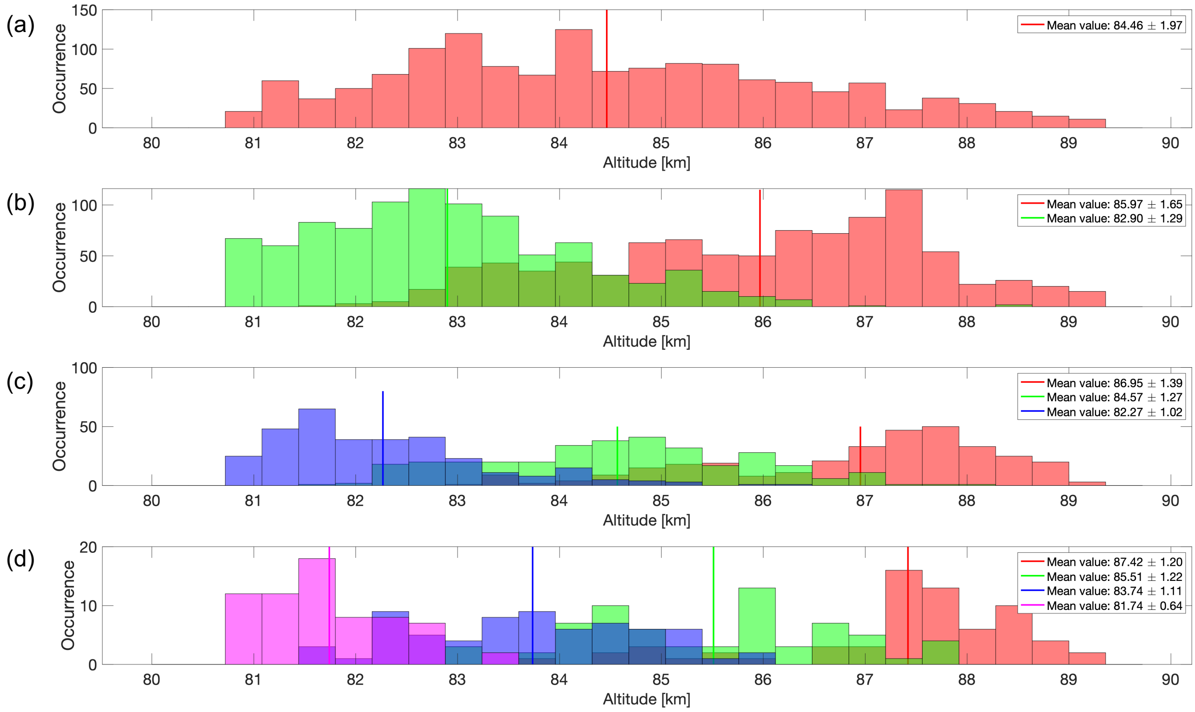
The study highlights the characteristics of PMSE in terms of their organisation into multi-layered structures, but the actual multi-layered structures are somewhat lost, at least in some illustrations. For example, the mean value of a distribution of parameters obtained from signals organised in multi-structures, as shown in Figures 4, 5, 10, 11, 13 and 14, says not much about the properties of the parameter with respect to the multi-structure. Rather, it represents the properties of a virtual layer that is organised into sub-layers. With the width of the layers considered further on, it then becomes complicated, as here the widths of the layers that occur simultaneously at different heights are combined. Therefore, I would recommend the authors to separate the distributions of the parameters in these figures for the multistructures found and to colour-code them, for example, and also to treat them separately in the analysis. Then, for example, in Fig.4b two distributions in two colours around two mean values would be shown in Fig.4c three distributions in three colours around three mean values and so on. With these separated parameters, detailed statements can be made about peak height, thickness, signal strength with regard to the occurrence in multilayer-structures and also in relation to the periods of solar maximum and minimum. This becomes particularly interesting and meaningful when, for example, the comparison to the NLC and the underlying mechanisms is made in chapter 3.4. Implementing this recommendation would, in my point of view, improve the readability of the article with regard to the multiple layers, because one would then see their distribution in combination with an improved bin resolution (see below) in the above-mentioned figures.

In the following section comprising three pairs of graphs, we address the reviewer's comments mentioned above, by providing and subsequently discussing the requested graphs. In each case, the solar maximum data is displayed at the top of the graph pair, while the solar minimum data is presented below it.

Altitude distribution, solar maximum:



Altitude distribution, solar minimum:



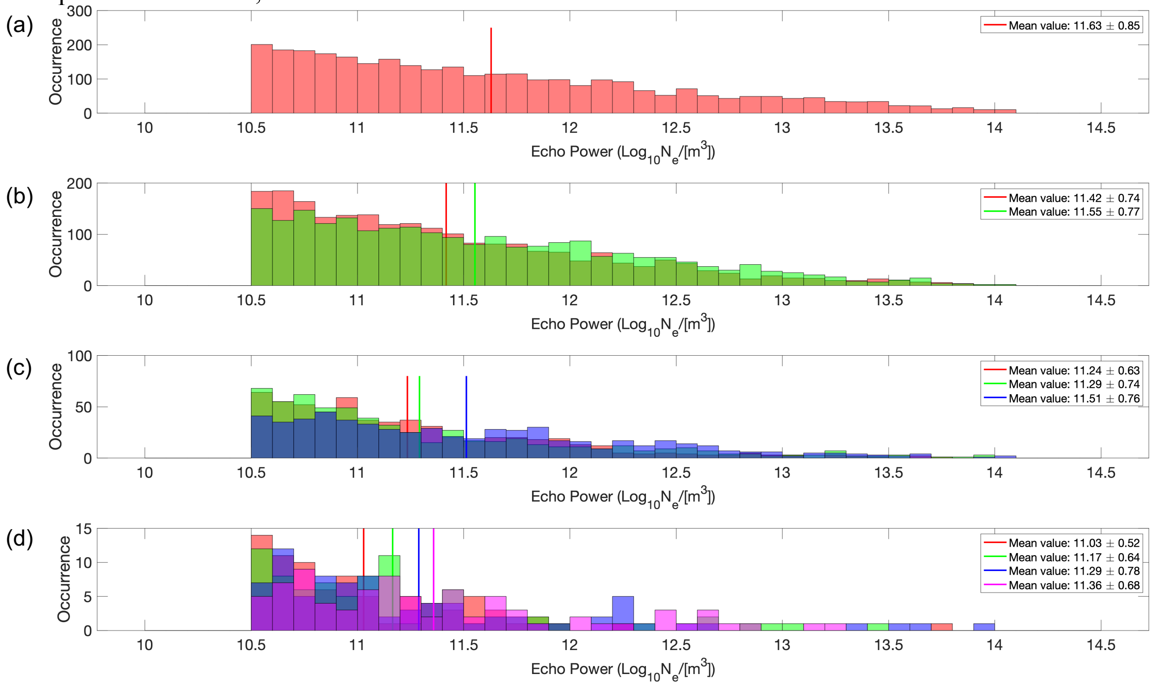
These graphs are quite intriguing, revealing new insights that were not apparent in the previous averaged representations. These figures are now present in the revised version of the manuscript (New Figures 4 and 5), and the manuscript's text has been changed accordingly, mentioning the new information and results that these graphs bring. Prior to the separation of layers within each set of multilayers, we encountered challenges in achieving statistical significance, with some p-values exceeding 0.05. As a reminder, the p-values for the different altitude distribution graphs before layer separation are presented in the following Table:

SOL MAX	P- value
Layers 1-2	P = 0.6462
Layers 1-3	P < 0.0001
Layers 1-4	P = 0.0002
Layers 2-3	P < 0.0001
Layers 2-4	P = 0.0014
Layers 3-4	P = 0.8035
SOL MIN	**P- value**
Layers 1-2	P = 0.6808
Layers 1-3	P = 0.1098
Layers 1-4	P = 0.3030
Layers 2-3	P = 0.0481
Layers 2-4	P = 0.2284
Layers 3-4	P = 1.0000
ALL LAYERS	**P- value**
Sol Max-Min	P < 0.0001

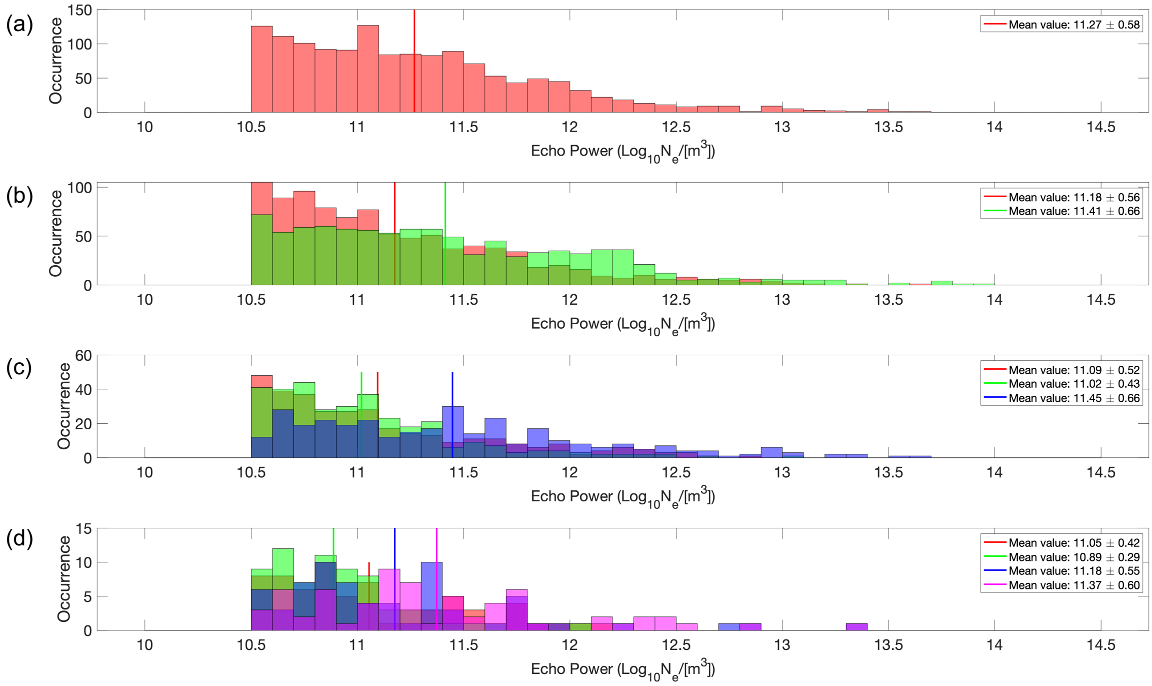
However, following the layer separation, it is noteworthy that almost all p-values (except for 1 case) associated with all the possible combinations of all the individual layers have now attained statistical significance, as shown in the following Table (This table is now present in the appendix of the revised manuscript):

P-Values		Solar Minimum									
		Mono Layers	Layers 1 of 2	Layers 2 of 2	Layers 1 of 3	Layers 2 of 3	Layers 3 of 3	Layers 1 of 4	Layers 2 of 4	Layers 3 of 4	Layers 4 of 4
Solar Maximum	Mono Layers		P<0.0001	P<0.0001	P<0.0001	0.3618	P<0.0001	P<0.0001	P<0.0001	0.0027	P<0.0001
	Layers 1 of 2	P<0.0001		P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	0.0268	P<0.0001	P<0.0001
	Layers 2 of 2	P<0.0001	P<0.0001		P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001
	Layers 1 of 3	P<0.0001	P<0.0001	P<0.0001		P<0.0001	P<0.0001	0.0106	P<0.0001	P<0.0001	P<0.0001
	Layers 2 of 3	P<0.0001	P<0.0001	P<0.0001	P<0.0001		P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001
	Layers 3 of 3	P<0.0001	P<0.0001	0.0002	P<0.0001	P<0.0001		P<0.0001	P<0.0001	P<0.0001	0.0001
	Layers 1 of 4	P<0.0001	P<0.0001	P<0.0001	0.0001	P<0.0001	P<0.0001		P<0.0001	P<0.0001	P<0.0001
	Layers 2 of 4	P<0.0001	0.0448	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001		P<0.0001	P<0.0001
	Layers 3 of 4	0.0411	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001		P<0.0001
	Layers 4 of 4	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	

Echo power distribution, solar maximum:

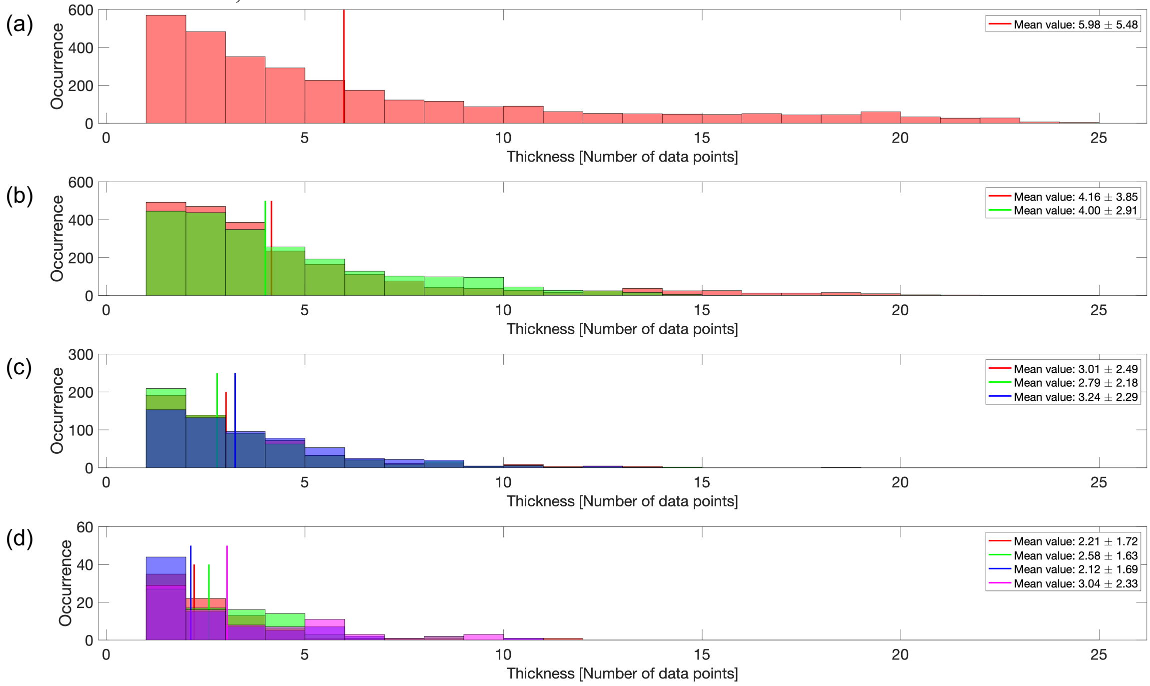


Echo power distribution, solar minimum:

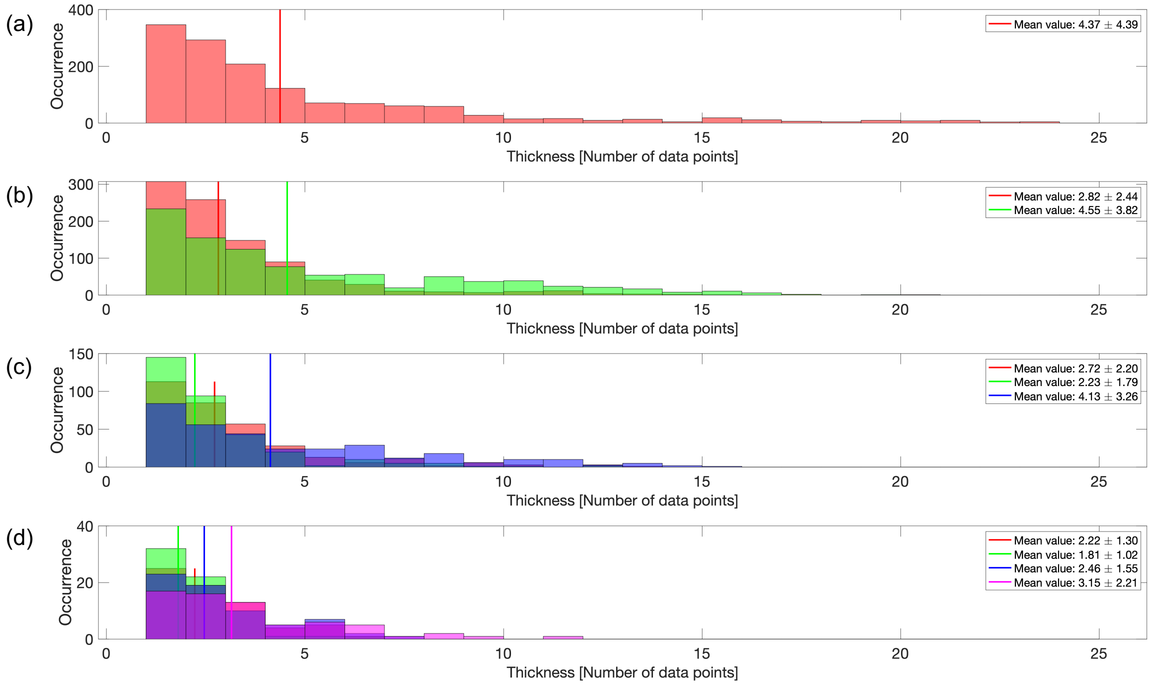


In the case of echo power distribution, it's notable that after layer separation, the graphs depicting echo power distribution present challenges in terms of readability. We observe slightly higher values during solar maximum compared to solar minimum, however this trend was already apparent in the previous averaged versions of the graphs. Additionally, it is possible to see that with increasing number of multilayers, the echo power tends to decrease. However, this insight was also discernible in the previous averaged version of the graphs. In summary, the graphs depicting separated layers do not introduce novel information. Consequently, we have chosen to include them exclusively in our response to the reviewer, but not into the revised version of the manuscript.

Thickness distribution, solar maximum:



Thickness distribution, solar minimum:



In the case of thickness distribution, after separating the different sets of multilayers into individual layers, the graphs depicting thickness distribution present challenges in terms of readability. Moreover, this did not bring novel insights, and for this reason, we have chosen to present these graphs only in our response to the reviewer, and not in the revised version of the manuscript. It is possible to see that as the number of multilayers increases within our 10 km altitude span, each individual layer tends to become thinner. However, it was already possible to see this trend in the previous averaged versions of the graphs. Visual inspection seems to indicate that the lower layer seems to be consistently the thickest layer for solar minimum.

In the manuscript, we explicitly note that we have generated separate figures for both echo power distribution and thickness distribution when considering separated layers. However, upon careful consideration, we have opted not to include these figures in the final manuscript.

Below are some specific suggestions to the authors that I think could be included in the article:

Specific comments

- P1, L18: I would not say that the waveform is characteristic of PMSE, even though it occurs occasionally if not frequently, especially in the thin layers. The authors have modified the manuscript accordingly to the reviewer's comment, in the following way:

"PMSE are strong radar echoes that are linked to extremely cold temperatures, and their height and thickness varies over time, Rapp and Lübken (2004) ~~they have a characteristic wavy pattern of their height and thickness variation over time~~."

- P2, L27: Latteck et al. (2021) deals with PMSE and should not be used as a reference for NLC. The authors have modified the manuscript accordingly to the reviewer's comment:

The reference by Latteck et al. (2021) was replaced by the reference by Schäfer et al. (2020).

- P3, L49ff: I would suggest to move the sentence starting with "The mesopause ..." further up in this section e.g. after the references in L23. The authors have modified the manuscript accordingly to the reviewer's comment, in the following way:

"... The charged aerosols contain water ice, which requires the presence of low temperatures, sufficient water vapor, and nucleation centers to foster heterogeneous condensation, (Latteck et al., 2021), (Cho and Röttger, 1997), (Rapp and Lübken, 2004). The mesopause, which marks the boundary between the mesosphere and the thermosphere, is characterized by the lowest temperatures in the atmosphere. Such low temperatures at PMSE altitudes are conducive to ice formation, and PMSE are known to be influenced by ice formation through the slowing of diffusion processes ..."

Section 2.1 : I suggest to include this section into the introduction section and rewrite the introduction section since some parts as e.g. gravitiy wave breaking and turbulence is already mentioned there.

The authors have modified the manuscript accordingly to the reviewer's comment. We re-wrote the Introduction section incorporating the old Section 2.1 in it. As a consequence, we removed the previous section 2.1, "Theory behind the formation of PMSE" and rearranged accordingly the beginning of the section 2.

- P4, L104: I suggest writing "manda"-experiment instead of manda code and either giving a reference to a publication describing this experiment configuration in detail or summarising the most important experiment parameters here in the text. The authors have modified the manuscript accordingly to the reviewer's comment, in the following way:

"...The utilized pulse coding for the PMSE measurements we analyzed is referred to as 'Manda'. Some parameters of the EISCAT VHF radar using the 'Manda' experiment are listed in Table 2. Detailed information regarding this ~~coding~~ experiment can be found on the EISCAT website (https://eiscat.se/scientist/document/experiments/). For this study, we specifically analyzed data obtained using the 'Manda' ~~code~~ experiment, because it is designed to detect low-altitude signals and layers in the mesosphere. We chose a time resolution of 60 seconds and a height resolution of 0.360 km ..."

Table 2. Some parameters of the EISCAT VHF radar, the source of data for this paper. More information about the EISCAT documentation and radar system parameters can be found at: https://eiscat.se/scientist/document/experiments/

EISCAT VHF parameters	
Frequency	223.4 MHz
Wavelength	1.34 m
Bragg scale	0.67 m
Peak power	1.2 MW
Transmitted pulse scheme	Manda v 4.0
Interpulse period	1.5 ms
Time resolution	4.8 s
Range resolution	360 m
Spectral resolution	2.6 Hz
Antenna Elevation	90 deg, zenith

- Fig.3, 4 and 5: Why are the height or altitude distributions of PMSE detections shown in bins of 1km in these figures, when the experimental height resolution is 0.36m? The authors have modified the manuscript accordingly to the reviewer's comment. Old Figures 3, 4 and 5 might be now in the Appendix section, but they have been re-plotted using bins of 0.36 km. Here are the new Figure 3, Figure A1 and Figure A2:

Figure 3:

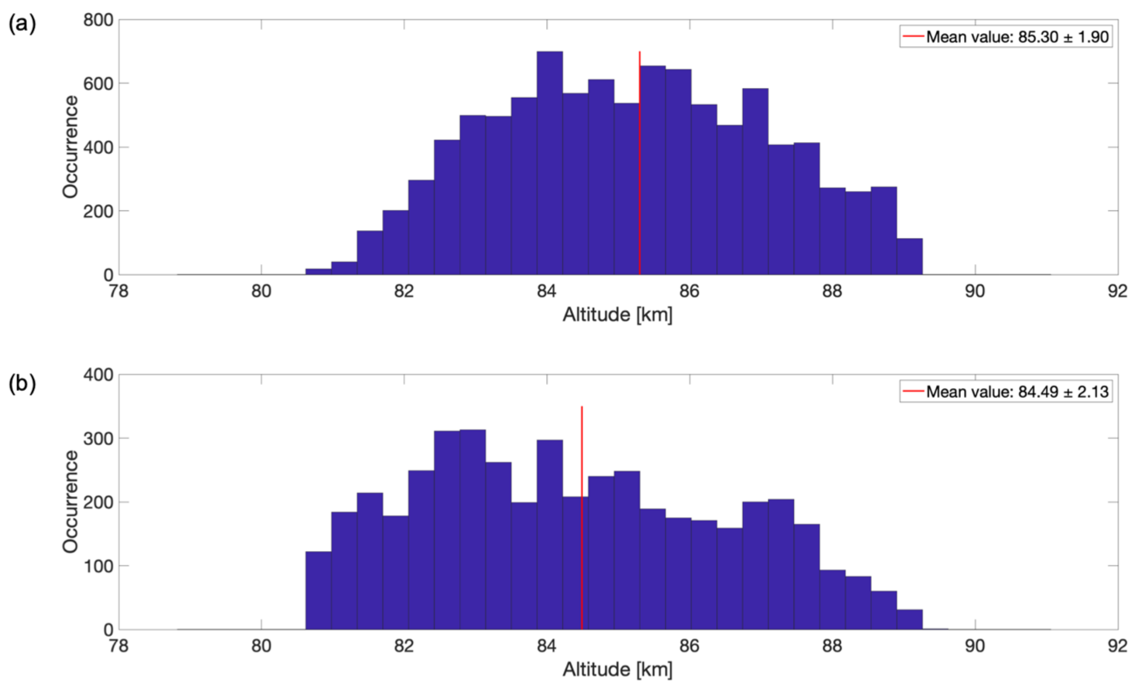
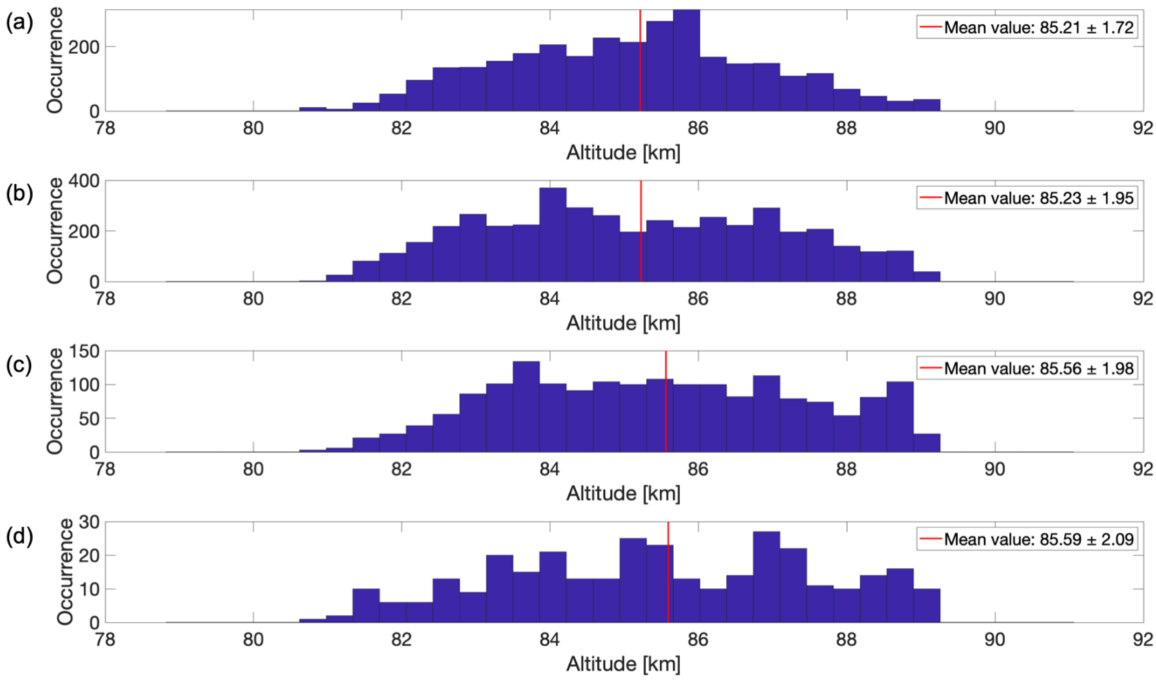
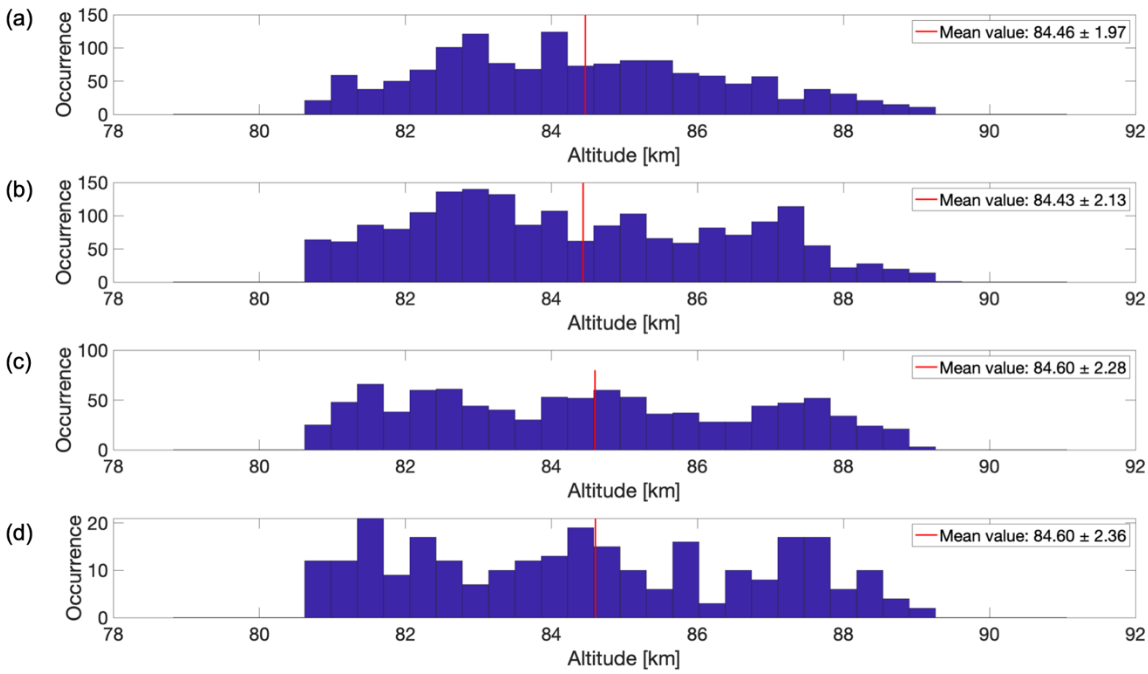


Figure A1:



FigureA2:



- Fig.4 and 5: What is the average altitude of a multilayer and what can be deduced from this value? If you observe the PMSE over many years, you will notice that the distance between e.g. double layers can cover a very large range, whereas the actual layers can be very narrow.

We have modified the figures to allow for a detailed examination of individual layers in the different sets of multilayers, with respect to altitude. The average altitude for each of these distinct layers is now presented in the updated Figures 4 and 5, with corresponding discussions in the text. (These new figures are shown in the first answer we made to the reviewer in this document.) Within the text, among various topics, we delve into the lower layer within a set of two PMSE multilayers. We provide specific details about its altitude and discuss its potential correspondence to altitudes observed in Noctilucent clouds.

- P9, L179ff: Here, the lower altitude of the PMSE and especially of the NLC should be discussed, which, as far as I know, is hardly subject to annual fluctuations. The increased energy input during the solar maximum at lower altitudes might therefore have no influence on the formation of PMSE at lower altitudes, as the other necessary conditions such as ice are no longer present above a certain altitude.

Please refer to our response to the previous comment, where we discussed the altitude of the lower layer within a set of two multilayers. We drew a parallel with the NLC altitude and provided some new comments in the manuscript about this. We revised the manuscript's text in which we now propose that these observations may be attributed to trends unrelated to solar cycle effects, emphasizing the need for further investigations.

- Section 3.2 : There is still some discussion missing here. What does the distribution of the electron density as well as its maximum and standard deviation say about the organisation of the PMSE in mono or multilayer?

The standard deviation is just the spread of values around the mean, and statistical significance is addressed with the p-values in Table B2. Visual inspection shows us that the standard deviation decreases with increasing number of layers, but it is difficult to determine the physical significance of the trend. The authors are not aware of a missing discussion, however here is a summary of the different points discussed in Section 3.2:

The discussion in this section points out to the observer that electron density is consistently lower in monolayers, both during solar maximum and minimum conditions. This observation suggests that higher electron densities may be a prerequisite for the formation of multilayers. The relevant passage from the manuscript is as follows:

"A plausible argument could be made that higher electron densities at ionospheric altitudes might be necessary to observe multi-layered PMSEs."

A new argument about the statistical significance of these results is added to the manuscript:

"However, it is important to bear in mind that this trend is weak and that some P-values corresponding to the different combinations of layers in Fig. 7 and Fig. 8 are greater than 0.05, as shown in Table B2."

In fact, the standard deviation provides insight into the dispersion of electron density values around their respective means. It's important to note that the standard deviation alone does not convey statistical significance. To address the issue of statistical significance, we have included a table in the appendix (Table B2) containing, among other, the p-values for all combinations of layers presented in Figures 6, 7, and 8. This table offers relevant information, if one wants to compare the mean values with each other, specifically.

Returning to the discussion of standard deviations, they reflect the spread of electron density values around the mean. In Figure 7, representing solar maximum conditions, larger standard deviations indicate a greater diversity of electron densities during this period. Visual inspection confirms a wider range of electron densities, particularly at higher values, compared to Figure 8, which represents solar minimum conditions. This observation suggests that higher electron densities are recorded during solar maximum phases.

- Fig.12, 13 and 14: Why are the distributions of PMSE thickness shown in bins of 1km in these figures, when the experimental height resolution is 0.36m?

The resolution is not in bins of 1 km, but already in bins of one data point, where one data point is equivalent to a distance of 360 m altitude. Consequently, the bins are already equivalent to 0.360 km. Here is the corresponding text mentioned in Section 3.4 that already specified that:

"Each data point or altitude channel corresponds to a distance of 360m."

However, the Figures have been changed accordingly to a comment the Reviewer made in the following Technical Corrections section. The Figures 12, 13 and 14 have been re-plotted using kilometers as a unit for the x axis and the legend instead of the number of data points. The text has also been modified in the manuscript. Please see the new Figures 12, 13 and 14 in the section below.

Technical corrections

All the following points have been implemented in the revised version of the manuscript :

- P1, L21: Remove (km).

"These echoes occur between 80 and 90 kilometers ~~(km)~~ altitude."

- P1, L23: The correct use of references should be checked throughout the text, e.g. the references here should be placed in brackets. See also at [P2, L26], [P2, L27], [P4, L83], [P4, L90], [P4, L103] We modified the citations accordingly to the reviewer's comment.
- P2, L30: Remove (PMSE).

"Multi-layered Polar Mesospheric Summer Echoes ~~(PMSE)~~ have been the focus of several investigations."

- P2, L39: Remove (NLC). The text has been revised following the incorporation of comments from the first reviewer, and consequently, this particular comment has been resolved

- P8, L167: I would not write layers here but detections, e.g. "average peak altitude of PMSE height distribution", as the plots in Fig.3 are probably not a distribution of predetermined layers.

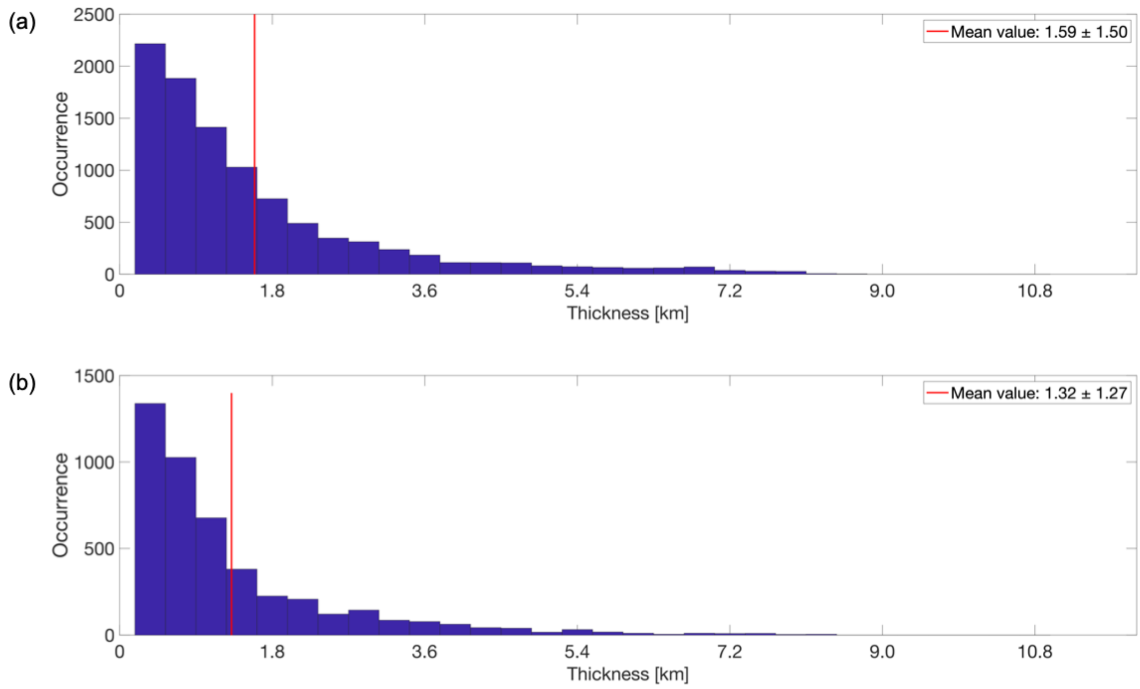
"The average peak altitude of PMSE height distribution, considering all PMSE detections, ~~The average altitude of all layers together~~ is higher during solar maximum than during solar minimum (see Fig. 3) "

- P11, L119ff : Replace echo power by average echo power.

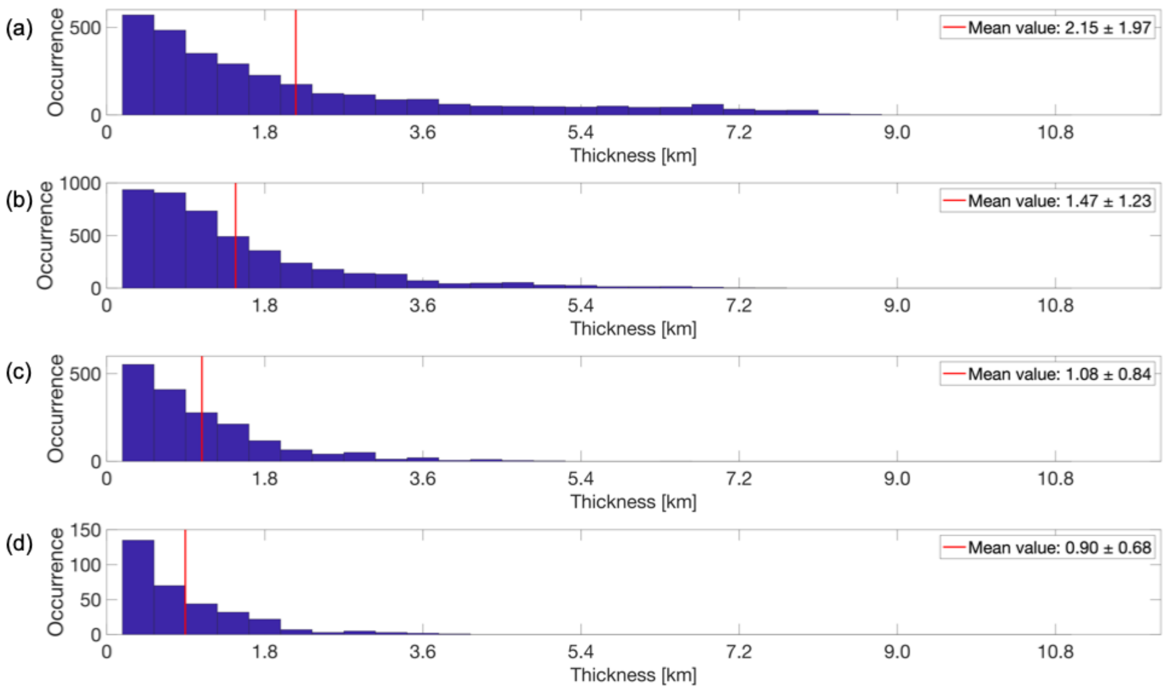
"Further, in Fig. 10, we observe that the average echo power decreases as the number of multi-layers increase for solar maximum and the individual layers considered."

- Fig. 12, 13, 14: I would suggest to use the correct thickness in m or km at the x-axes as well as in the text instead of altitude intervals.

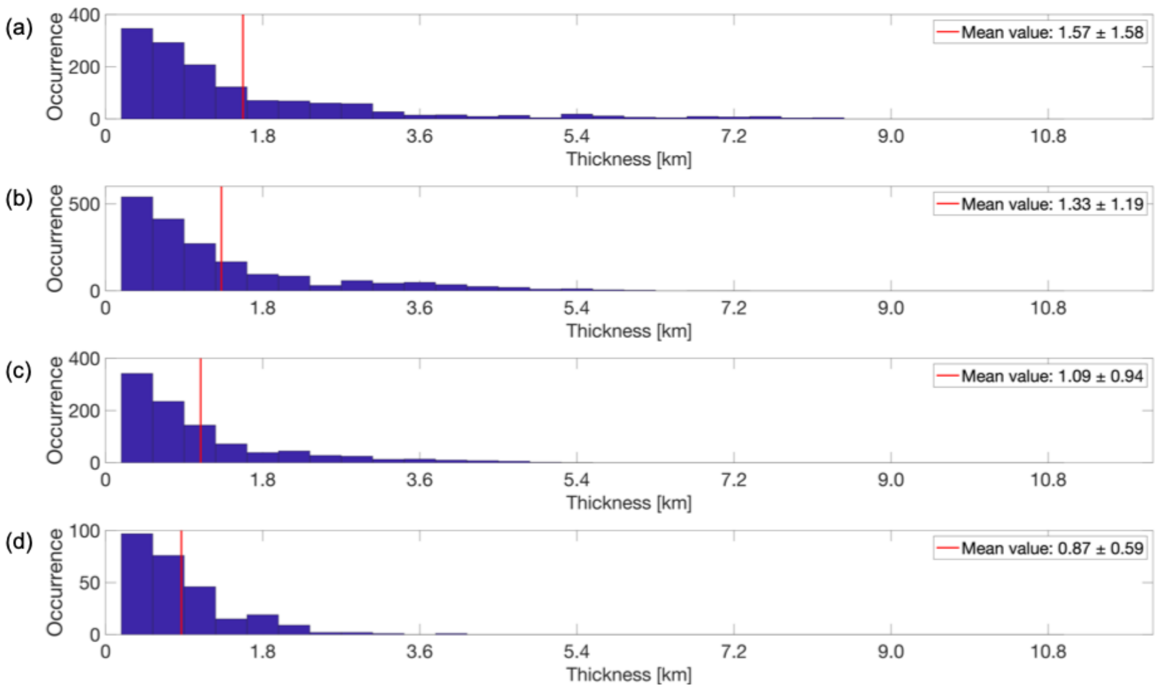
The following Figures have been included in the manuscript and replaced the old Figures 12, 13 and 14: New Figure 12:



New Figure 13:



New Figure 14:



The x axis has been changed in Figures 12, 13 and 14. Instead of showing a number of data points, now the thickness is expressed in km. The values of the mean and standard deviation in the legend have also been converted into km. Here are the modifications in the text:

"As shown in Fig. 12, the average thickness of the layers is higher during solar maximum, with an average of 1.59 km ~~4.42 altitude intervals (1591m)~~, compared to solar minimum, where the average thickness is 1.32 km ~~3.67 altitude intervals (1321m)~~."

"The highest average layer thickness is obtained during solar maximum for mono-layers with an average of 2.15 km ~~5.98 data points (2153m)~~, while the lowest average of 0.87 km ~~2.41 data points (868m)~~ is obtained during solar minimum, for 4 multi-layers."

"Knowing that one altitude channel corresponds to 360m, 3 altitude channels or more indicate a PMSE thickness of at least 1.08 km ~~1080m~~. Our findings show that 54.64 percent of PMSE occurrences resulted in thick layers of 1.08 km ~~1080m~~ or more. "

- P13, L256: Remove nanometers and the brackets.

"In their first experiment, Li et al. (2016) fixed the particle size at 10 nm ~~nanometers (nm)~~ ..."