Response to Reviewer #1

1、The authors describe the depletion of the meteoric Na, Ni, and Ca layers observed with lidars at several mid-latitude sites in eastern China during a Super Substorm in Nov 2021. The paper is well-organized, clearly written, and certainly of interest to the upper atmosphere science community. The metal layer depletion, coincident with the substorm, is unequivocal and the authors provide a well-reasoned description of a chemical mechanism that is plausibly responsible for the depletions. The paper is easy to read, logically organized, and shows convincingly that the depletions are unusual and highly correlated with standard indices used to characterize geomagnetic activity.

I recommend the paper be accepted for publication in its current form, subject to some minor editorial corrections and suggestions listed below.

Response:

We appreciate your thorough evaluation and constructive feedback on our manuscript. Your recognition of the organization, clarity, and scientific merit of our manuscript is highly encouraging. We have carefully addressed the minor editorial corrections and suggestions, hereby provide a detailed account of the revisions, and the manuscript has been revised according to all of your suggestions and comments.

Thank you again for your valuable input, which has significantly improved the manuscript's rigor and readability. We believe the revisions address all concerns and we hope this revised manuscript can make you satisfied.

2、Line 33 typo "field"

3、Line 46 typo "winter"

4、Line 55 typo "geomagnetic"

Response:

We are grateful for your careful reading and for identifying the typographical errors in our

manuscript. All noted mistakes have been corrected, and we have performed additional proofreading to enhance the overall quality of the text.

" wind filed" is revised to " wind field".

" the density peak in winder" is revised to " the density peak in winter".

" geomengnetic storm on the earth" is revised to " geomagnetic storm on the earth".

5、Figure 2 this is an important figure that contains a large amount of relevant information, but in its current form it is hard read because the panels and text are small. I suggest rotating the figure 180˚to make it a 4x5 figure (which could be expanded to a full page), and perhaps consider using a color scale for the density contours. Alternatively, perhaps the authors could prepare separate figures for the different metals, although there is value in including all the metals in a single figure.

Response:

Thank you so much for your valuable feedback. We have carefully considered your suggestions and implemented the following revisions.

This figure is rotated 180˚ to make it consist of 4×5 subplots, and we enlarge this figure to make it occupy an entire page. The text in the figure has also been enlarged by two font sizes. The first version of the figure is coloured. To make the figure more friendly for people with color vision deficiencies, we used grayscale images. And we also find that the grayscale images can present more details of the metal layer variations. Presenting four sets of data in four separate figures can not provide readers with an intuitive understanding of the metal layer depletion. Different data with common features will have a better display effect when presented in one figure.

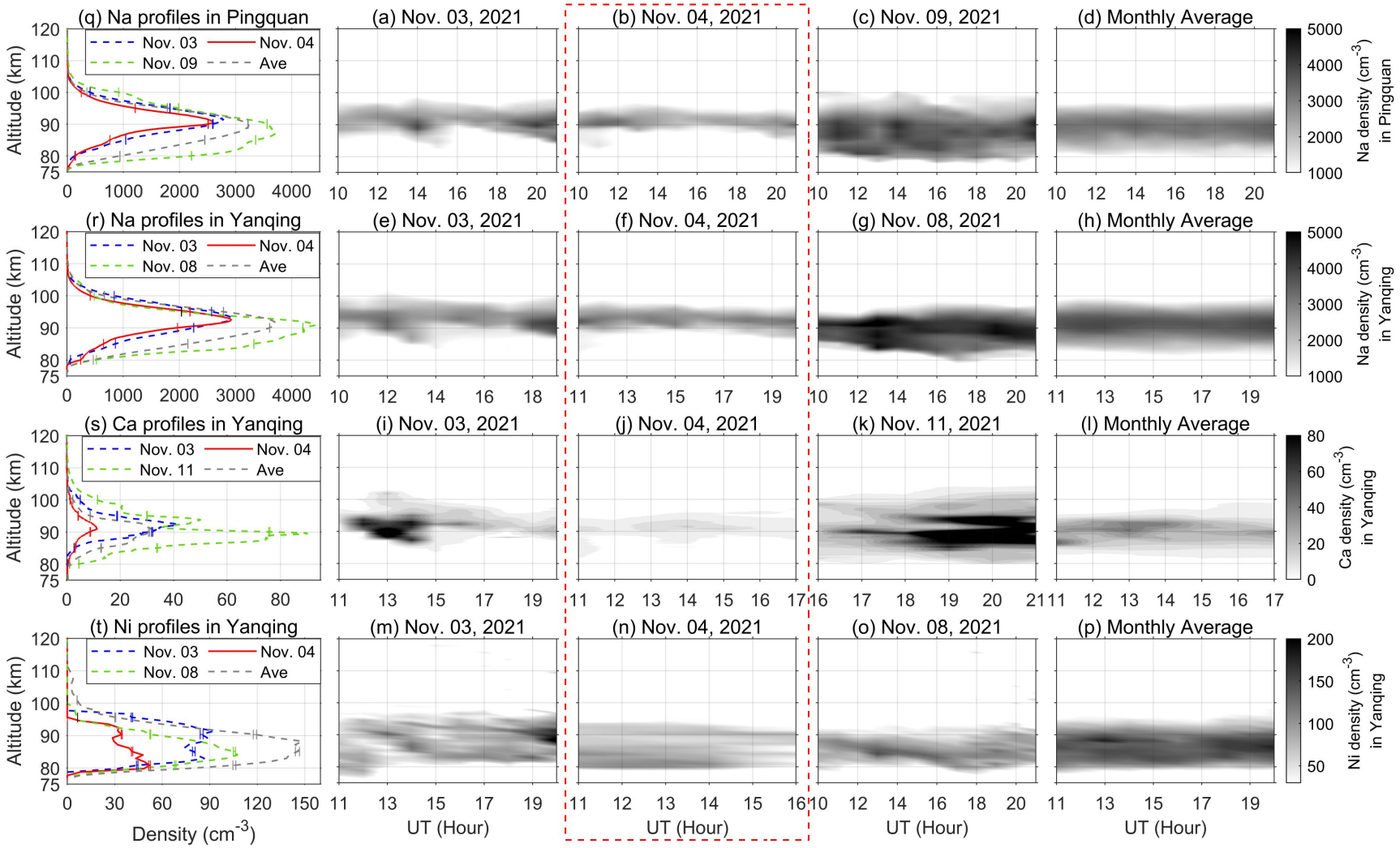

Figure 2. Lidar observations of the metal layers. The lidar observations of the Na density in Pingquan, as well as the Na, Ca and Ni density in Yanqing are listed from top to bottom row. The observations on the substorm day of 4 Nov. 2021 are displayed in the third column and highlighted by the red dashed box. The observations on the reference days are shown in the second and forth columns. The monthly average of November is shown in the fifth column. The first column shows the altitude profiles of the average metal density for a day, and the error bar indicates the uncertainty in density measurements. LT = UT + 8.

6、Lines 133-140 change the density units from "particles/cm^3" to "atoms/cm^3"

Response:

We sincerely appreciate your valuable suggestion. We also consider the suggestion of Reviewer #2.

All the unit "particles/cm^3" in the manuscript are revised to "atoms·cm^{-3}".

7、Figure 3 I could not see the error bars. Perhaps it is sufficient to just quote an upper bound such less than x% in the caption.

Response:

Thanks so much for your suggestion. We have added the column abundance on the top of each bar in Figure 3.

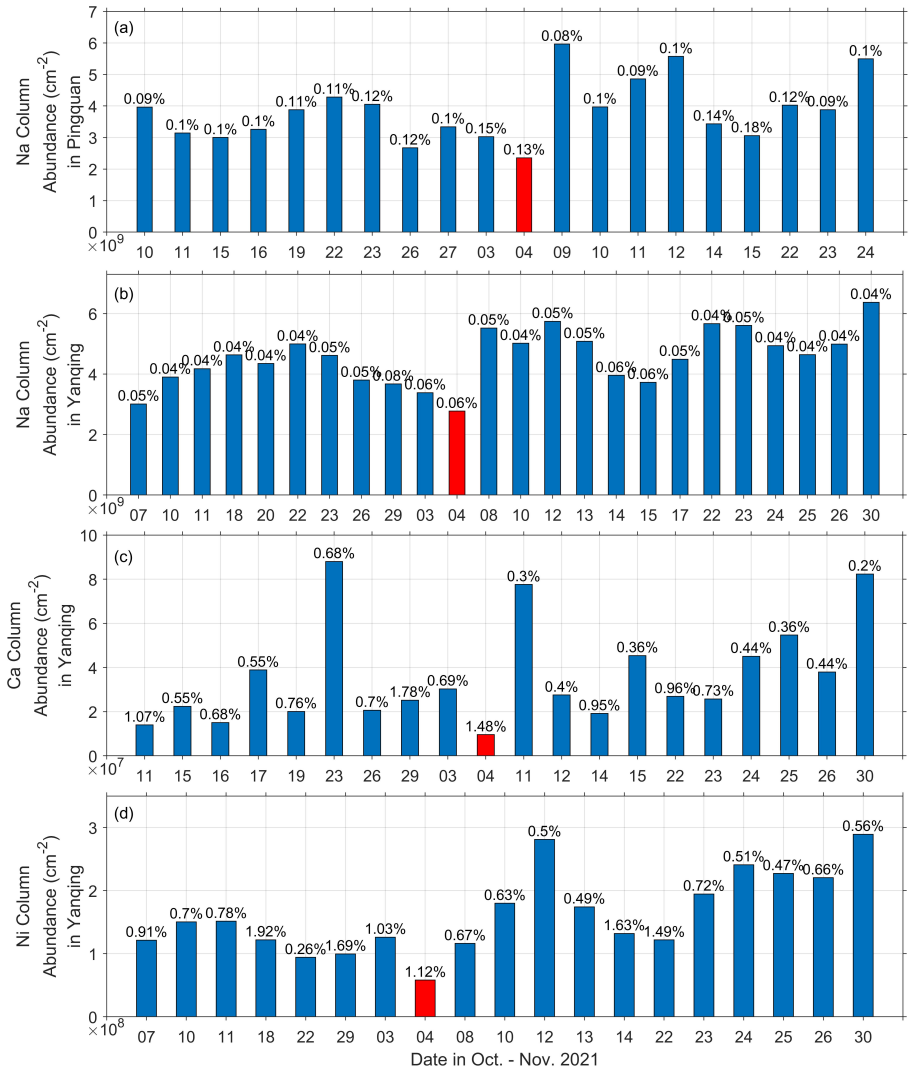

Figure 3. Average column abundances of the metal layers. The observations of the (a) Na lidar in Pingquan, as well as the (b) Na lidar, (c) Ca lidar and (d) Ni lidar in Yanqing are listed from top to bottom row. The red bars indicate the observations on the substorm day. Each vertical bar shows the average column abundance between 75-120 km altitude in one night and all the valid observation results in October and November 2021 are displayed. The uncertainty of the column abundance is exhibited on the top of each bar.

8、Lines 172-176 I found this sentence confusing and was especially surprised at the very low cross-correlation between the Pingquan Na and Yanqing Ca abundances. I wonder if this calculation should just be eliminated because Figs. 2 and 3 clearly show all measurements at the lidar sites showed significant depletion of the metals during the substorm. While the cross-correlation coefficients are interesting, the values may raise more questions than they answer.

Response:

We sincerely thank you for this helpful suggestion, which has improved our manuscript significantly.

As you anticipated, the second reviewer also raised the issue about the cross-correlation coefficients. Thus, we can no longer simply avoid this problem by just removing the corresponding context. We will answer the reviewers as best as we can.

Table 1. Cross-correlation coefficients of different data

Item	Pingquan Na-Yanqing Na	Pingquan Na-Yanqing Ca	Pingquan Na-Yanqing Ni	Yangqing Na-Ca	Yangqing Na-Ni	Yangqing Ca-Ni
Correlation coefficient	0.397	3.578×10^{-4}	0.507	0.346	0.603	0.169

All the correlation coefficients of the metal atom abundance variations are relatively low, indicating there are no much relationship between them. However, this does not mean that they are not correlated over a longer time scale, such as one year (Höffner and Friedman, 2004). We also can find that the abundance variation of the Ca has presented less correlation with other atoms, and the correlation coefficient of Pingquan Na-Yanqing Ca is only 3.578×10^{-4}. Observations indicate that the Ni and Na layers show close correlations on the scale of hours (Wu et al., 2022). And the calcium layer is somewhat unique. It find that although Ca abundance has a similar elemental abundance to Na in meteorites, the Ca atom abundance in metal layer is roughly 2 orders of magnitude smaller than Na. Plane et al., (2018) suggested that CaOH and $CaCO_3$ are stable reservoirs for Ca in metal layer, as a result, more Ca atoms are converted to compound and the Ca atom abundance in metal layer is much less than the Na atom abundance. The Ca abundance variation is more affected by chemical reactions, so it has less correlation with other metal atoms. The relevance between the Ca and Na in different places further decrease, thus the estimated correlation coefficient is very low.

This is our speculation based on the limited observations. It is not the focus of this manuscript and we do not intend to discuss more about this topic in this manuscript.

Reference

Höffner, J. and Friedman, J. S.: The mesospheric metal layer topside: a possible connection to meteoroids. Atmos. Chem. Phys., 4, 801-808. https://doi.org/10.5194/acp-4-801-2004, 2004.

Plane, J. M. C., Feng, W. H., Gómez Martín, J. C., Gerding, M., and Raizada, S.: A new model of meteoric calcium in the mesosphere and lower thermosphere. Atmospheric Chemistry and Physics, 18(20), 14,799–14,811. https://doi.org/10.5194/acp-18-14799-2018, 2018.

Wu, F., Chu, X., Du, L., Jiao, J., Zheng, H., Xun, Y., et al.: First simultaneous lidar observations of thermosphere-ionosphere sporadic Ni and Na (TISNi and TISNa) layers (~105-120 km) over Beijing (40.42°N, 116.02°E). Geophysical Research Letters, 49, e2022GL100397. https://doi.org/10.1029/2022GL100397, 2022.

9、Line 196 “there were no significant changes in the MLT…”

Response:

We greatly appreciate your helpful recommendations.

“there was no much changes in the MLT region wind field...” is revised to “there were no significant changes in the MLT region wind field...”