Manuscript No.: egusphere-2025-1524
Manuscript Title: Variation characteristics of sporadic-E layer in East Asia based on long-term data

Replies to Editor

The authors have analyzed a considerable amount of ionosonde data, which is not a trivial task. Using the monthly medians, they have analyzed the climatology of the foEs parameter in the East Asia region chosen for the study. The analysis consisted of very simple climatology; no statistical analysis was employed. Many of the conclusions, such as higher values during the summer months and around noon, are already well known.

Reply: Thank you very much for taking the time to review this manuscript and provide valuable feedback. We greatly appreciate the constructive comments and suggestions, which have helped us improve the quality and clarity of our work.

As you rightly pointed out, the Es layer in East Asia generally follows the widely recognized common variation patterns typical of mid-latitude regions. Beyond these established patterns, however, we have also identified unique regional characteristics specific to East Asia that extend beyond the conventional scope of existing knowledge. The core value of this study lies in its use of long-term, multi-station ionospheric vertical sounding data spanning more than 60 years from East Asia to uncover new phenomena that cannot be captured using short-term or limited-site datasets. This kind of systematic investigation represents the first of its kind in the academic community. The new findings can be summarized in two main aspects: first, the intensity center of the Es layer in East Asia is not fixed but migrates with diurnal and seasonal variations; second, the long-term variation of the Es layer in East Asia exhibits a clear negative feedback characteristic. These discoveries provide valuable references for studying the formation mechanisms of the Es layer and the coupling processes between the atmosphere and ionosphere. Next, we will provide a detailed analysis and discussion of the two innovative findings mentioned above.

(1)The migration of the Es layer intensity center with diurnal and seasonal variations
Research indicates a strong positive correlation between the intensity of the Es layer in East Asia and surface air temperature, with a correlation coefficient as high as 0.82 [Zhao et al., 2024], suggesting a significant climate response relationship between the two. The surface temperature distribution is the fundamental driving factor of the lower atmosphere motion, and determines the motion state of the lower atmosphere. Then, the coupling mechanism between the lower atmosphere and the upper

atmosphere affects the atmospheric motion at the height of the Es layer, and then correlates with the intensity of the Es layer [Zhao et al., 2024; Tang et al., 2025, 2026].

[1] Zhao, H. S. Z. W. Xu, Kun X. et al.(2024) Probable Controls From the Lower Layers on Sporadic E Layer Over East Asia, J. Geophys. Res., 129, e2023JA032379.
[2] Tang Hui-Yan, Hai-Sheng Zhao, Kun Xue, Zheng-Wen Xu, Shou-Zhi Xie, Jie Feng, Pei-Pei Yang, Na Li, Zong-Hua Ding, Jian Wu, Variation Characteristics of the Ionospheric E Layer over the Tibetan Plateau and Surrounding Areas During a Full Solar Cycle, Remote Sensing, 2025, 17, 3713.
[3] Tang Hui-Yan , Hai-Sheng Zhao, Kun Xue, Pei-Pei Yang, Zheng-Wen Xu, Na Li Shou-Zhi Xie, Jie Feng, Jian Wu, Zong-Hua Ding, Spatiotemporal Variation Characteristics of hE in the Tibetan Plateau and Its Surrounding Areas, Journal of Geophysical Research Space Physics, 2026, 131,4566-4577.

Due to the significant difference in specific heat capacity between ocean and land in East Asia—where rocks and soil on land have a lower specific heat capacity, while seawater has a higher specific heat capacity—land areas experience faster heating and cooling processes compared to the ocean. Influenced by this thermal contrast, daytime surface temperatures on land are generally higher than those over the ocean at the same latitude, while nighttime temperatures are higher over the ocean than on land. Based on the correlation between Es layer intensity and surface temperature, the intensity center of the Es layer in this region exhibits a distinct diurnal spatial migration pattern: during the day, the intensity center is predominantly located over land areas around 30°N, while at night, it shifts northeastward to oceanic regions around 35°N.

Influenced by variations in solar radiation intensity and the subtropical high-pressure system, the high-temperature center in East Asia exhibits significant latitudinal migration: during summer, it is primarily located around 30°N, while in winter, it shifts southward to lower-latitude regions. Correspondingly, the intensity center of the Es layer also displays a similar seasonal displacement pattern—concentrated around 30°N in summer and moving southward to the South China Sea region in winter.

Overall, the intensity center of the Es layer in East Asia exhibits a tendency to follow the movement of the high-temperature center.

(2)Negative feedback characteristic of long-term variations in the Es layer over East Asia.

Although long-term variation trends of Es layer intensity differ across locations in this region, areas with higher intensity generally exhibit a downward trend, while those with lower intensity show an upward tendency. Since a detailed discussion of the causes behind the “negative feedback” characteristic in the long-term variation of the Es layer over East Asia will be provided in the following sections, a specific explanation of these causes is omitted here.

What is particularly interesting is whether there is a long-term variation trend of the foEs monthly median, shown in Figure 9. Is the trend at any of the stations statistically significant? If not, that is what should be reported in the paper - and compared with previous studies of long-term trends. If there is a significant trend, then the authors need to suggest reasons for it to stimulate further work.

Reply:Thank you for your comments. Based on the data analysis results, although the slopes of the linear fits at each station are generally small (with a maximum value of only 0.0025), the underlying variation patterns are distinctly evident. The long-term trend in the Es layer intensity over East Asia exhibits a pronounced“negative feedback” characteristic: regions with higher average intensity show a long-term decreasing trend, whereas regions with lower average intensity display a long-term increasing trend (see Table 4 in the manuscript). This phenomenon is likely closely related to long-term regional climatic changes, and the possible explanations are analyzed below:

With the acceleration of global industrialization and the continuous increase in greenhouse gas emissions, global warming and extreme weather events are becoming increasingly frequent. The long-term evolution trend of the Es layer in East Asia may be linked to abnormal climatic changes in the region. Research indicates a strong positive correlation between the intensity of the Es layer in East Asia and surface air temperature, with a correlation coefficient as high as 0.82 [Zhao et al., 2024]. In recent years, global warming has led to persistent abnormally high temperatures in summer in higher-latitude regions of East Asia, such as Northeast and Northwest China, where extreme heat events have increased significantly. At the same time, abnormally low temperatures have frequently occurred in winter in lower-latitude regions, exemplified by the historically rare widespread freezing rain disaster in southern China in 2008. Such regional climatic anomalies have exerted a noticeable impact on variations in Es layer intensity: in higher-latitude regions such as Manzhouli, Changchun, Urumchi, and Beijing, rising summer temperatures are accompanied by a long-term increasing trend in Es layer intensity, despite the overall relatively weak Es layer intensity in these areas. Meanwhile, in lower-latitude regions such as Chongqing, Guangzhou, Lhasa, and Wuhan, the phenomenon of abnormally low winter temperatures is closely associated with a weakening trend in Es layer intensity, even though these sites generally exhibit relatively strong average Es layer intensity.

Overall, the long-term changes in the Es layer in East Asia exhibit a "negative feedback" spatial structure: regions with weaker Es layer intensity show an upward trend, while those with stronger intensity display a downward trend. This trend reveals a regionally adaptive adjustment response mechanism of the Es layer under the influence of the climate system, providing important observational evidence for further understanding

the coupling between space weather and climate.

We have added a discussion section to the manuscript, where the new findings presented in this paper are thoroughly discussed and analyzed. Thank you for your great effort and valuable time spent in reviewing this paper. We sincerely wish that with the careful revision of the paper, the revised manuscript is acceptable for publication.