REVIEW

Quantitative Analysis of Nighttime Effects of Radiation Belt Energetic Electron Precipitation on the D-Region Ionosphere during Lower Solar Activity Period

This study investigates the quantitative influence of EPP on the reflection height of ELF waves in the high latitudes of both hemispheres at low solar activity, considering the season. For the analysis, the wave and particle data measured by the Electric Field Detector (EFD) and High-Energy Particle Detector (HEPP) onboard the CSES-01 satellite during nighttime conditions between 2019 and 2021 were used. The reflection height is computed by applying two methods. The first approach derives the reflection height from the Wait and Spies formula by fitting the parameters "reflection height" and "sharpness" to a given electron density profile. In the second approach, the reflection height is computed using the cutoff frequency deduced from the spectral data obtained from the ELF band of the CSES satellite's EFD. Furthermore, the relationship between electron flux, X-ray rate, and D-region reflection height is investigated. The analysis revealed seasonal differences in the reflection heights, with lower reflection heights in winter than in summer. Moreover, an asymmetric influence of the EPP on the reflection height between the two hemispheres was found.

This work significantly contributes to understanding the influence of EPP on D-region ionization. The considerations of the seasons and the high latitudes in both hemispheres deliver new insights and raise questions for further investigations.
While the idea and approach of this study are very promising, the text is often imprecise and incomprehensible. The equations do not have a consistent notation. The structure of some figures is confusing, and the text information in the figures is not always readable due to a too-small font. Sometimes, there are just text segments (instead of complete sentences) or text duplications, giving an impression of inaccuracy. Before recommending it for publication, major revisions are suggested to be addressed. Please note the following points are listed in order of occurrence and not in order of minor and major revisions. Some points may appear minor and petty. However, the number of inaccuracies and inconsistencies sums up to a major category.

1. Line 70: *"However, the study on the global climatological characteristics of EEP effects is insufficient."* Does this statement refer to the study of Renkwitz et al., 2023? If yes, it would be good to be more specific. Why is the study insufficient? Generally, the sentence could also be removed, as it contains no information.
2. Line 115: Fang et al. (2008, 2010) are referred to twice in one sentence. One time is enough.
3. Line 120: reference style - *"Fang2010"*
4. Line 121: *"The Chemistry class contains the core of the GPI5 model (Glukhov et al., 1992)."* The GPI5 model needs to be introduced. In line 113, PyGPI is introduced, which is the Python implementation of the GPI5 D-region and ionization chemistry model. Using the terms PyGPI5 and GPI5 without a clear explanation makes it sound like two models.
5. Line 125*: "After inputting the ionization rate and precipitation duration, the model can produce the electron density profiles for a given location." Where did you get the ionization rate?*
6. Line 130: sentence duplication: *"After inputting the ionization rate and precipitation duration, the model can produce the electron density profiles for a given location"*
7. Line 137: Please explain in some words the Liouville's theorem and how the equation (1) was derived from it.
8. Line 140: *"By calculating the loss cone angle at satellite altitudes (507 km,* $\propto_{LC}$*)"* Please insert the equation for loss cone angle.
9. Line 147: *"To determine the cutoff frequency, we have improved the method of Toledo-Redondo et al. (2012), making it applicable to high-latitude regions."* This sentence is

confusing in this location. It can be removed since the topic is addressed later in the text (lines 163-165).

10. Line 152: f1=c/h' reference? In Saini (2010) the first order cut-off frequency looks different: fc = c/(2*h') (**https://doi.org/10.1029/2009JA014795** What causes the difference?
11. Line 155: *"An increase in electron density lowers the reflection height."* Inserting a reference would strengthen the statement.
12. Line 160: *"…and their downward propagation can influence the determination of the cutoff frequency."* Inserting a reference would strengthen the statement.
13. Line 149: Please explain in short words QTM1 and QTME.
14. Line 170: What window/kernel size and iteration step did you use? Why did you choose that specific window/kernel size? Please be more specific; the description is quite general.
15. Line 172-176: Why did you choose a different approach in the second step? Why didn't you use fftconvolve in the first step since it is more computationally efficient (as it is written in lines 174-175)?
16. Line 176: "After these two steps, the trend line of the ELF wave is extracted." The sentence is confusing. If I have understood correctly, the smoothed line is the trend line. However, it sounds like there is an extra extraction step. The term trend line is also confusing, as it is just the smoothed line.
17. Figure 1, caption*: "…and the red dots indicate the cutoff frequency…"* There is only one red dot.
18. Line 191*: "…(Shown in Fig. 2)"* No capitalisation at this point.
19. Figure 2: Confusing order of panels. 1500 keV is larger than 1 MeV; why is it in the middle? Switching between 1 MeV and 1500 keV is not consistent. Either 1000 keV and 1500 keV or 1 MeV and 1.5 MeV.
20. Please add some short words about what information we gain from Figure 2. Why did you choose 1 MeV and 1.5 MeV, as they are so close and there is no significant difference? Why is it essential for the study?
21. Line 212-214: There is a dot and a space in the brackets by mistake. It would be nice if equation (3) showed the formula described. However, it shows the formula that has already been rearranged according to the plasma frequency (it is not wrong, but inaccurate).
22. Line 216: Where is the h' in the equation? Is z=h'? Please add a reference for equation 4.
23. Line 221: Please insert reference for equation (5).
24. In equation (6) it says z and not h'. Notation is not consistent.
25. Line 225-226: *"Here, N_e is the corresponding electron density (in cm-3), which can be obtained from the PyGPI5 simulations, f_1 is the cutoff frequency calculated from modelled electron density profile. derived from observations, h' is the reflection height (in km)."*
    Corresponding to an altitude (->Ne(z))?
    The second yellow section is no sentence.
26. Figure 3: Same problem as in Figure 2. Confusing order of panels and switching between keV and MeV.
27. Line 265-267*: "The X-rays are generated through bremsstrahlung radiation of precipitation electrons with air molecules, which occurs deep in the atmosphere. The electrons that produce these bremsstrahlung X-rays are indeed precipitation ones."* Please rephrase the sentences and add references.
28. Lines 263-269: The discussion should also mention the low reflection height in 0°-(45°) longitude in Fig. 4e, whereas there is no notable X-ray rate in this area (Fig. 4c). Moreover, the discussion should include the striking high X-ray rate from 0°-70° longitude in Fig. 4d, while the reflection height is only slightly decreased from 45-90° longitude (Fig. 4f).

29. Line 279: Please describe Moran's I shortly. Why did you choose that approach, and what information is provided (e.g., Positive/negative correlation-> cumulation, dispersion, information from the value of Moran score)?
30. Line 294: A comparison with other studies would strengthen the conclusion.
31. Figure 5: The font in the legend is too small. The text is not readable.
32. Line 345-346: *"The X-ray measurements show that more ionization occurs in the Northern Hemisphere (mean X-ray rate is 78.8 counts/s), compared to the Southern Hemisphere (60°-180° longitude, mean X-ray rate is 71.2 counts/s)."* Where did you get the X-ray rates?
33. Line 348-349: *"The possible reason for the discrepancy is that the h' in the WS formula (Method 1) serves as only a rough approximation of the reflection height, rather than the actual reflection height."* Could one possible reason be that the Wait and Spies formula refers to VLF/LF waves? You compare with reflection heights of ELF waves, which, assumably, are lower by nature. Perhaps comparing the qualitative behavior as a function of the EPP at different energies is more meaningful than looking at the quantitative differences.
34. Line 352*: "These variations can fluctuate significantly, sometimes by several hundred percent."* Please insert a reference. Furthermore, it should be discussed, that both methods use the electron density profile from PyGDI5 what bases on IRI. Does IRI have any limitations?
35. Figure 6 e-h: The font of the information test below the title is too small. Text not readable.
36. Figure 7: The caption says "quiet conditions," but the legend denotes "Peace." Please be more consistent with the notation. I prefer quiet conditions.