

Answer to Referee 1:

Anonymous Referee #1

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General comments

This paper investigates the location of the external boundary of the outer radiation belt (ORB) relative to the equatorward edge of the auroral oval during quiet or moderately unsettled geomagnetic conditions. The study is based on precipitating electron flux data from the METEOR-M No 1 satellite at auroral (0.03–16 keV) and > 100 keV energies, collected between between November 2009 and March 2010. Three types of situations are exemplified in the paper: (i) external ORB boundary inside the auroral oval during moderately disturbed conditions, (ii) external ORB boundary equatorward from the auroral oval during quiet conditions, and (iii) external ORB boundary inside the auroral oval during quiet conditions. This gives motivation to carry out a statistical study by looking at the distribution of the separation between the external ORB boundary and the equatorward auroral oval boundary, named $d(\text{lat})$ in the paper, as a function of geomagnetic activity. The distributions are plotted separately for quiet conditions ($AE < 150 \text{ nT}$ or $PC < 1$) and moderately disturbed conditions ($AE > 150 \text{ nT}$ or $PC > 1$). It is found that, during moderate geomagnetic activity, the ORB boundary is located within the auroral oval, whereas during quiet conditions its location can be either inside or outside the auroral oval.

We are grateful for the great work done by you with our article and for the list of useful comments and corrections! We hope that the new version of the paper become better and more understandable for readers.

1. *The title of the article is somewhat misleading, as it contains the word “relation” which leads one to expect to find an equation (be it empirical) linking the positions of the two studied boundaries. Since no such relation is obtained in the paper, the title should be modified to better reflect the conclusions of the study.*

Thank you, the new title is: “Relative locations of the polar boundary of outer electron radiation belt and the equatorial boundary of the auroral oval”

2. *The caption of Figure 1 should be expanded to describe each panel in more detail. It is currently not easy for the reader to understand the data which are plotted, especially what the vertical dashed lines represent. I have not found in the text what the blue and red lines represent, for instance. Moreover, there are many of these lines which seem to be superposed on top of one another, but since the alignment is not perfect, I am not sure whether this is coincidental or done on purpose (same issue with Figure 3). Would it be possible to clarify this and improve the legibility of the figure? Also, it is not so clear why, in the lower panel, the flux energy is plotted, since (if I understood correctly) the criterion for determining the ORB boundary is the > 100 keV flux. Unless the blue curve is the integrated version of the fluxes displayed in the top panel? Please clarify this too, since I am not sure whether my guess is correct without additional information in the figure caption (or at the very least in the text describing the figure).*

We corrected the figures 1-3, trying to make them clearer and added the corresponding notation for all the curves. Also we added some additional comments to the text, see p. 4 l. 27-32

3. *I did not manage to understand the reasoning exposed on p. 3 l. 2–8 (and also mentioned on p. 8 l. 10–14). Why is it so that the energetic electron detector becomes less sensitive when it is outside of the auroral oval? Since we are here considering a same detector measuring fluxes in one given energy range (> 100 keV), why should it not be possible to compare the measurements when they are made inside or outside the auroral oval? To my mind, if such a comparison were not possible to make, this would question the validity of the entire study, since it would be difficult to conclude anything from the*

data analysis! Could you please explain in more detail or rephrase the idea behind your reasoning in this paragraph?

Thank you for the comment! We did not explain our idea sufficiently accurately in the text, which is now corrected.

The sensitivity of the detector is naturally fixed, and does not depend on the location and time of the measurements. We mean the well-known effect of decreasing of the electron fluxes inside the ORB with decreasing level of geomagnetic activity; for example during the periods of minimum solar activity (see, for example, McIlwain C.E., Processes Acting Upon Outer Zone Electrons, Radiation Belts: Model and Standard, Geophysical Monograph, pp. 15-26, 1996.). The observations presented were obtained during such period (September 2009 - April 2010) and sometimes the electron flux in the ORB were very weak, close to the sensitivity limit of the detector. In these cases, we can only detect the beginning of the decline from the ORB maximum to the background level of the electron intensity. In such situations, the detected boundary can be shifted to the equator relative to the true boundary of this low intensity ORB, which could be observed by a detector with better sensitivity. That's why we believe that the discussed effects could be clearer in the period of solar maximum activity or if the sensitivity of the detector was better. We added some additional comments on p. 3 1.1-4 and 1. 24-31

4. *On p. 8 l. 5–6: “Our analysis shows that the differences in the positions of both boundaries are typically smaller than the statistical scattering in the position of each boundary.” I think this statement should be justified with numbers, since currently the “statistical scattering in the position of each boundary” is not quantified in the paper. This should be easy to add, as you already have made a statistical study of the boundary locations, and there are certainly many references in the literature that could be cited to support the said statement.*

Thank you for the comment! We added some additional comments and statistical numbers at the end of the section 3 (p.8. l. 13-20 p.9 l.1-2) with corresponding references.

5. *The conclusions presented on p. 9 (“there [is] strong evidence that [the] trapping boundary of energetic electrons [...] is located inside the auroral oval”) do not reflect the interpretation of Figures 4 and 5. One cannot neglect the relatively high number of events for which this trapping boundary is situated equatorwards from the auroral oval, so the quoted statement is misleading.*

Thank you for the comment! You are right this statement is too categorical. We have corrected it and aligned with the discussed results (see p.10. l 31-33)

6. *Finally, I think it could be extremely interesting to go a bit further in the analysis before the final publication of the manuscript, by trying to determine why $d(\text{lat})$ changes with increasing geomagnetic activity (from totally quiet to moderate activity). Is it so that only the auroral oval equatorward boundary moves equatorwards, while the ORB external boundary does not change, or does the ORB boundary also migrate equatorwards/polewards when geomagnetic activity is enhanced? If such a result could be obtained, this would to my mind greatly increase the impact of the paper, and this would enable one to deepen the interpretation of the results.*

Thank you for the comment! The increasing of geomagnetic activity affects first of all the position of the equator boundary of the auroral oval (see, for example, Feldstein et al. (2014, doi: doi:10.5194/hgss-5-81-2014). The position of the polar ORB boundary is more stable (see Kanekal et al. (1998)). The figures 1.1 below show the distributions of the position of both boundaries by Meteor-M1 measurements in McIlwain coordinates (separately for Northern Hemisphere, Southern Hemisphere, for $AE < 150$ nT and $AE > 150$ nT). The distributions are rather wide, but you can clearly see that the maximum of distributions for polar boundary of ORB is rather stable and don't show any clear dependence on geomagnetic activity. On the other hand the maximum of distributions of equator boundary of auroral oval clearly moves toward the equator with increasing geomagnetic activity. Nevertheless, this is not a simple question because the distributions are rather wide and their widths

increase with enhanced geomagnetic activity (for both boundaries). This means that the boundaries position (including polar ORB boundary) are unstable in these cases, and we cannot unequivocally confirm that the polar ORB boundary does not depend on geomagnetic activity. This question needs more thorough study and we don't want to add this discussion to the paper. The main aim of this paper is to show that the polar ORB boundary can be observed rather often inside the auroral oval. It is a very important point for the problem of the ORB formation. So, we introduce new figure (fig.6) and text in the paper with the discussion of the dependence of studied boundaries on geomagnetic activity (section 3 p.9 l. 3-9).

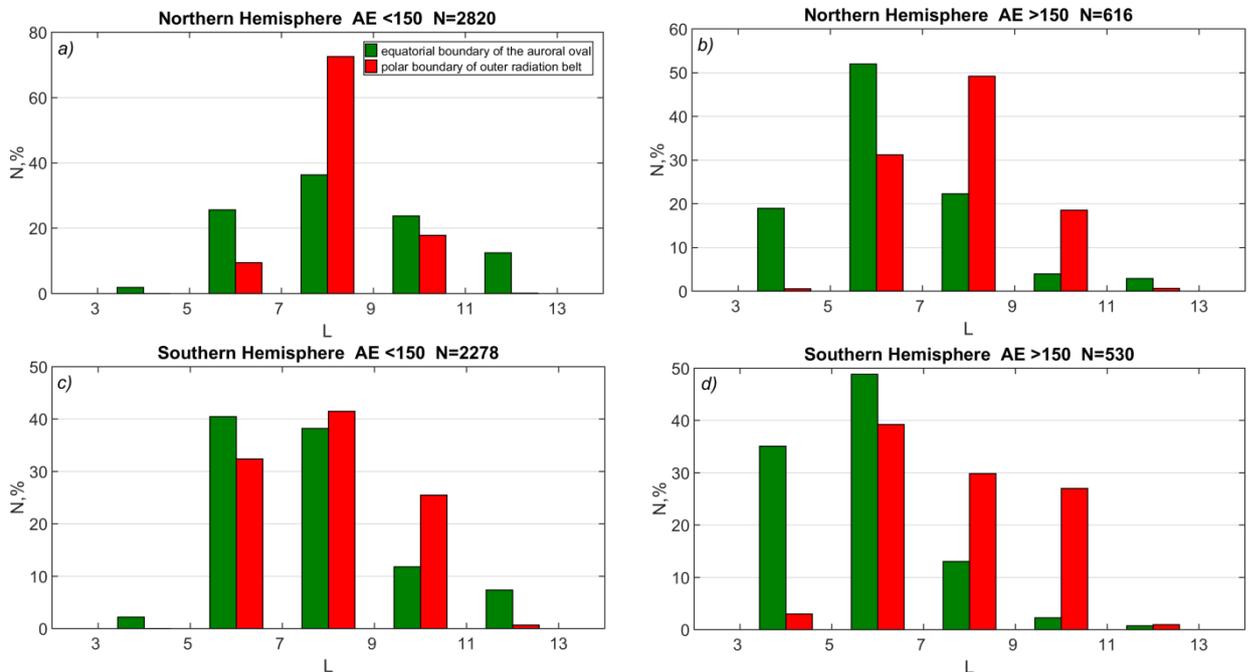


Figure 1.1: The distributions of the position of equatorial boundary of the auroral oval (green bins) and the polar ORB boundary (red bins) from the L (where L is the McIlwain parameter) for northern (a,b) and southern (c,d) hemispheres for AE <150 nT (a,c) and AE >150 nT (b,d).

Specific comments (minor)

– The acronym “ORB”, which first appears on p. 2 l. 24 (and most probably stands for “outer radiation belt”) should be defined in the introduction.

Thank you for the comment! We defined the acronym ORB in the Introduction (p.1 l.24)

– p. 2 l. 28: “After that we searched for the closest to the pole location of the ORB flux” does not sound very clear to the reader. This should be rephrased.

Thank you! We have tried to make this sentence clearer. (P.2 l. 2-3)

– p. 3 l. 14: I would suggest to add the reference to Davis and Sugiura (1966) on the AE index, since references are provided for the PC indices.

Davis, T. N., and M. Sugiura (1966), Auroral electrojet activity index AE and its universal time variations, *J. Geophys. Res.*, 71, 785–801, doi:10.1029/JZ071i003p00785.

Thank you for the reference! We have added it at p.4 l. 19.

– p. 4 l. 22–23: “According to the (<http://omniweb.gsfc.nasa.gov/>)...” → There must be several words missing here!

Thank you for the comment! We mean “According to the omniweb database...”. We corrected the corresponding phrase (p.5 l.1) .

– p. 7: Could you explain in a little more detail why you chose the value of 150 nT for the AE index to separate the events in the analysis? What would happen if you chose, say, AE = 100 nT instead? Would the trend for low geomagnetic activity become clearer? (cf l. 6)

Thank you for the comment! Unfortunately, geomagnetic activity was rather low during the observed period (November 2009 - March 2010), so we can't use traditional criteria for disturbed periods. AE~150 nT was selected as a compromise between the idea of separation of disturbed and quiet periods, and the volume of the statistic. If we change the selection criteria to AE = 100 nT, the results do not change significantly (see the figure 1.2 for AE>150 nT, AE<150 nT (a,b), and below for AE>100 nT, AE<100 nT (c,d)). If we changed the selection criteria significantly to make a strong difference between the geomagnetic conditions (for example to select AE>500 nT and AE<10nT (see the panel (e,f) on the figure 1.2)) we can see that the trapping boundary would always be located inside the auroral oval for AE>500 nT, but the statistic of such crossings is rather poor for the observed period.

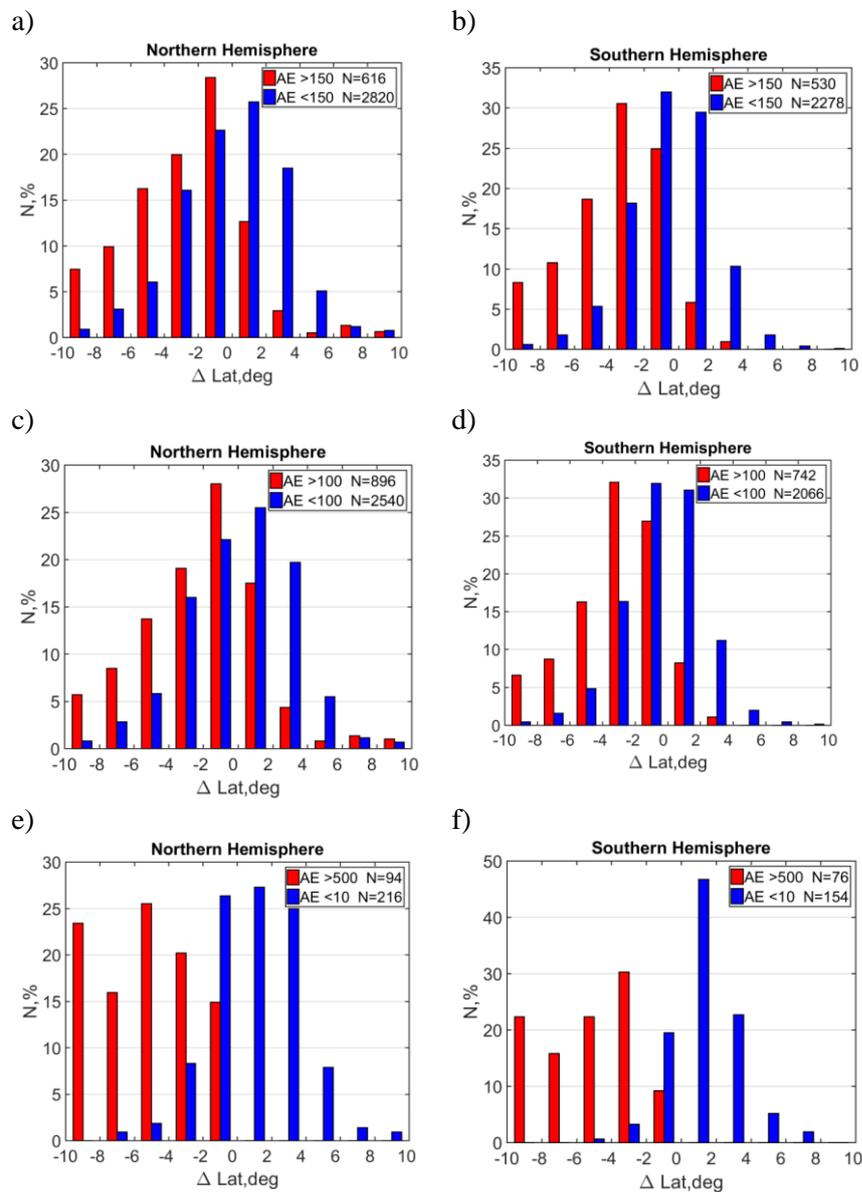


Figure 1.2: The distribution of ΔLat for AE>150 nT and <150 nT (a,b) for AE>100 nT and <100 nT (c,d) and for AE>500 nT and <10 nT (e,f) for northern (a,c,e) and southern (b,d,f) hemispheres

– p. 7 l. 14–15: “using the AE and PC ind[ices] as a measure of geomagnetic activity by separately” –
> there must be words missing here too

Thank you! I have changed slightly this sentence (p.8 l.11-12)

- “indexes” → “indices” (p. 1 l. 22; p. 3 l. 13–16; p. 4 l. 18–19; p. 7 l. 2–11–14)
- p. 1 l. 16: “at the absence of” → “**in** the absence of”
- p. 1 l. 18–19: “to the equator from” → “equatorward from” (same p. 2 l. 3) C4 ANGEOD
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- p. 1 l. 19, l. 22: “auroral precipitations” → “auroral precipitation” (“precipitation” is uncountable)
- p. 1 l. 24: “is discussed” → “are discussed”
- p. 1 l. 25: “the position of the trapping boundary **for** energetic electrons”
- p. 1 l. 26: “sing” → “using”
- p. 1 l. 26: “low orbiting and high apogee” → “low-orbiting and high-apogee” (same l. 28, p. 2 l. 4)
- p. 2 l. 32: remove comma after “it is well known”
- p. 3 l. 9: “location” → “locations” (or change “have” into “has” on l. 11; same l. 11)
- p. 3 l. 17: “high latitude” → “high-latitude”
- p. 3 l. 20: “of GGAK-M set” → “**of the** GGAK-M set”
- p. 3 l. 22: “with the energies from...” → “with energies from...” (twice on this line)
- p. 3 l. 29: “as a polar boundary” → “as **the** polar boundary”
- p. 4 l. 2–3: correct the location of parentheses for the citations
- p. 4 l. 6: “the visual inspection” → “**a** visual inspection”
- p. 4 l. 18–19: remove capitalisation of “Northern” and “Southern” (see guidelines: https://www.annales-geophysicae.net/for_authors/manuscript_preparation.html)
- p. 6 l. 13: “trapping boundary d(lat)” → “trapping boundary, d(lat)” (add comma)
- p. 7 l. 14: “behaviour” → “behavior” (to remain consistent with p. 9 l. 1 and the use of American English spelling throughout the paper)
- p. 7 l. 16: I think “1.2 Subsection (as Heading 2).” should be deleted.
- p. 8 l. 5: “using the data from” → “using data from”
- p. 8 l. 23: “quite time” → “quiet time”
- p. 8 l. 27: “with another pitch angles” → “with other pitch angles”
- p. 8 l. 29: “can be also” → “can also be”
- p. 9 l. 3: “there are strong evidences” → “there is strong evidence” (“evidence” is uncountable)
- p. 9 l. 3: “that trapping boundary” → “that **the** trapping boundary”

Thank you for careful reading of our paper! The text was corrected according to your comments and corrections!