

Interactive comment on “A New Perspective and Explanation to the Formation of Plasmaspheric Shoulder Structure” by Hua Zhang et al.

Hua Zhang et al.

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Dear anonymous Referee2:

I am very happy to receive your recommendation and very grateful for your advice. We make effort to revise this manuscript following your comments. Then, due to poor English make readers understand difficulty, we make efforts to revise and hope that you could be satisfied. In the resubmitted paper, new text is emphasis as red text. The Referee Comments is abbreviated to “RC”, and Authors’ Response is abbreviated to “AR”.

The following are the response of major comments: RC 1: Line 83: Plasmasphere ions are defined in the introduction as having energies of less than 1 eV. Here the definition

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given is that the plasmasphere consists of “several eV or less”. The two descriptions need to agree; <1 eV is generally used, but there is flexibility. Citing a source for whatever is used is worthwhile. AR 1: I am agree with the advice, and have revised this problem in line 86.

RC 2: Line 85: It is stated that the intensity of the electric field model is a superposition of the convection and corotation electric fields. The electric field model this line refers to is not directly stated. Line 54 states that the TPM uses the Weimer statistical electric field model. The Weimer model is empirical, based on observations. It is not a superposition of simple electric fields. The extent to which the Weimer model accurately represents measured electric fields and those measurements accurately represent actual electric fields, then this empirical model incorporates all the physical processes that produce large to small-scale features in inner magnetospheric electric fields. It also means that nothing about the underlying physical processes are available to be determined by use of the Weimer model in the TPM simulation. This point is of particular importance in the Section 4 Discussion and in the conclusions stated for the paper. AR 2: Line 85 state that the the intensity of E-model is the electric field in formula $E \times B/B_2$. Where after, lines 87-89 states that the TPM uses the Weimer statistical electric field model as the convection electric field. Other convection electric field have been used to study evolution of the Plume and the Shoulder structure (like Pierrard and Cabrera, 2006; Pierrard, et al., 2008, used E5D model). So, I think that the Weimer electric field model mapping to inner magnetosphere can use in the TPM simulation.

RC 3: Line 94: Only 10 particles per simulation box is quite course. What are the boundary conditions for the simulation? Are particles allowed to leave or enter the simulation to maintain the number within the simulation? Only black and white is used to represent model results in Figure 3. If black means there is at least one particle in a simulation box, then that needs to be stated. AR 3: The calculation regions is radial range of 2-7 R_e , and the TMP runs 3 days under the low activity condition to obtain the boundary conditions for the simulation. The caption of Figure 3 is rewrote.

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RC 4: Line 96: Why is it stated that the density variation goes as L^{-3} ? Most authors report a variation of approximately L^{-4} . Whatever is used here needs to be justified in the text or by citation. AR 4: I am agree with the advice, and have revised “ L^{-3} ” to “ L^{-4} ”.

RC 5: Lines 114-116: Can this simulation produce a smooth plasmopause boundary when there are so few particles in the simulation? What is considered to be smooth given the small number of particles in each simulation box? AR 5: I rewrite this sentence “ The results of EUV observation show that the plasmopause is seldom smooth or irregular, due to the fluctuations in plasmopause region cause by successive particles injection during a disturbance period (Goldstein et al., 2002; Gallagher et al., 2005), in agreement with previous whistler observations (Carpenter and Anderson,1992). Contrary, The simulation of plasmapauses by TPM is better smooth”. The observation (red lines in Figure 3) is no smooth. The simulation boundary is a skeleton (also called an artifact) which consists of continuous particles distribution

RC 6: Lines 114-116: What particle injections are referred to here? An “injection” of particles would normally be expected to come from outside the simulation, whether along the field or transverse to it. Quantitatively, what does smooth or irregular mean as it is used here and how can it be “seldom smooth or irregular” as stated? AR 6: An “injection” of particles reported by Goldstein et al (2002) and Gallagher et al (2005) come from plasma sheet. And “seldom smooth or irregular” is small-scale structure of the plasmopause explained in AR5.

RC 7: Line 129: How is a sharper plasmopause boundary model result shown in Figure 3? “Sharper” has previously been used to qualitatively refer to the density gradient across the plasmopause. The black and white representation of the model result shown in Figure 3 cannot show a gradient. Small irregularities in the plasmopause can be seen in Figure 3, however this may be due to the small number of particles in simulation cells, a modeling artifact rather than a physical result. AC 7: I am agree with the advice. The “Sharper”represent the observation, and has been deleted. So, the sentence

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revised to “One can see that the plasmopause is closer to the Earth in the predawn sector .”

RC 8: Lines 129-131: The model result in Figure 3 does not show peeling off of plasmaspheric plasma in the predawn region. The formation of a shoulder does not constitute a peeling off of the plasmasphere. The plumes evident in all panels of Figure 3 show the plume extending sunward in afternoon and early evening magnetic local time. I am unaware of any observation of the outer plasmasphere being peeled away at predawn magnetic local times. The post-dawn outer plasmasphere has been found to sometimes contribute to a broad early-plume that then narrows to afternoon MLT only. AC 8: I am agree with the advice. This is a wrong statement. “peeling off” is replaced by “inward flow”. “The reason is the increase of rotation velocity resulting in plasmopause of inward flow in the predawn sector .” is rewrote in revised manuscript.

RC 9: Lines 352-354: I do not find this reference in the journal as cited. Could there be an error in the citation? AC 9: This reference is cited in lines 90-92. the sentence is “the Weimer’s electric field (Weimer, 2001) is mapped into the magnetosphere along magnetic lines to model the magnetospheric convection electric field (Zhang et al., 2012)”

RC10: Lines 141-142: The plume features shown in Figure 3 exist before the shoulder convects into afternoon magnetic local times where the plume(s) is(are) connected to the plasmasphere. The shoulder is first indicated in Figure 3c near 9 hours magnetic local time. In panel (d) three hours later a plume is forming between roughly 16 hours and 18 hours magnetic local time. This shoulder feature has not azimuthally convected further than about 13 hours MLT. Another 3 hours later in panel (c) a plume appears to be forming where the shoulder has come to be located. That does not mean the shoulder had a causal role in forming the plume. It is more likely it only happened to be there when geomagnetic activity increased, which changed the global convection pattern in your electric field model so as to form a new plume that would have formed whether the shoulder was there or not. A specific explanation must be provided in

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order to substantiate the statement that the shoulder is functionally responsible for the plume as currently stated. AC10: I am agree with the advice. This is only a case study. The lines 142-147 is same to your statements. So, Lines141-142 have revised to "The results of the simulation also reproduce the formation and the evolution of the Plumes, which derives from the Shoulder structure in this case, illustrated in panels of Fig.3 (d)-(f)."

RC 11: Lines 142-143: The simulation shows that the TPM simulation for the conditions during this event period resulted in a shoulder forming in at post-midnight MLT. One simulation cannot establish a pattern of shoulders forming at post-midnight MLTs as currently stated. AC11: The shoulder forming in at post-midnight MLT also have been investigated by Goldstein et al. (2002), Verbanac et al. (2018), Pierrard and Cabrera (2005), and so on. The simulation use TPM to study the formation of the Shoulder and get same results. In section 4, Trace test particles and obtain the conclusion that the shoulder arises at 3 hours MLT and explained by differential rotation rate.

RC12: Lines 148-150: The feature at 12 hours MLT in Figure 3a appears to be a remnant plume originally formed in at afternoon MLT due to earlier activity. It does not have the characteristics of a shoulder. The discussion in the last paragraph on page 8 is at least poorly expressed if not also poorly conceived, as suggested in the previous few comments. It needs to be corrected or removed. AC 12: I am agree with the advice. The shoulder adheres to the main plasmasphere, not is a deciduous remnant plume. Lines 148-153, the sentences have replaced by "The Shoulder1 firstly arises on Fig.3(a) in the morning sector (at 12 UT, 8 June 2001), and then corotates with the main body of the plasmasphere to the afternoon sector on Fig.3(c) (at 18 UT, 8 June 2001). During this period, Kp index increases to 3+ from 1 (see in Fig.2), and magnetosphere convection slightly enhance that triggers plasma elements in the Shoulder1 doing sunward convection, then produces the Plume1 at 21 UT on 8 June 2001 (see in Fig.3(d))"

RC 13: Line 168: Notch structures and the outer plasmasphere do not refill from the

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plasma sheet as currently stated in the text. The injection of plasma ions discussed by Gallagher et al. (2005) refers to a potential source of meso-scale electric field due to charge separation in the injected energetic plasma. It is suggested in that study that this meso-scale electric field may cause the interior "W" shaped feature. AC 13: I am agree with the advice and delete the sentence "Plasma refilling originating from plasma sheet, result in the Notch structure disappearance (Gallagher et al., 2005)." in revised manuscript.

RC14: Line 173: What is meant by "inward convection?" Convection inward to lower L-shell does not appear to happen during storm-time recovery. Isopotential contours are not axially symmetric, however, therefore there can be inward and outward radial motion of the plasmopause without a change in plasmasphere content. The dusk bulge is an example. AC 14: I am agree with the advice. The "inward convection" is replaced by "inward flow".

RC 15: The first paragraph of the Discussion section: Figure 4a shows paths taken by semi-corotating plasma, but does not show the formation of a sharp radial change in the plasmopause as stated. Goldstein et al. (2002) state that their model shows the shoulder forming across a narrow 3-5 hour MLT region. Figure 4a shows a gradual outward motion of a radial group of particles from 3-9 hours MLT. For a shoulder to form there must be a transient and narrow MLT region where plasma is differentially moved in L-shell, which cannot be shown with the test particle simulation presented. Even if an adjacent and leading parcel of plasma did not move outward in L-shell after 1300UT, only a difference of 0.1-0.2L appears to have taken place between 3-5 MLT, not 0.5-0.7L as stated. Figure 3b-c show shoulder-2 formation much better, though a shorter time interval between these panels would do that much better. In fact a sequence of model images between these two might provide a more useful display than the current Figure 4a. Reversal of relative semi-corotation with L-shell shown in 4b is interesting as an explanation for steepening the leading eastward edge of a shoulder. AC 15: I am agree with the advice. The shoulder forming across a at 03:00-06:00 MLT region

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(between blue vertical line and black vertical line in Figure 4(a)). The outermost particle move outward 0.7 L, and the fourth particle move outward 0.45 L, from 03:00 MLT to 08:00 MLT. the Shoulder's sharp eastern edge is differential L-shell. So, I revised it as "the Shoulder has a sharp eastern edge about $0.2R_E \sim 0.3R_E$ in radial extension and across a narrow 3-5 hours MLT region" in the manuscript.

RC16: Line 220: "increase of the MLT-profile of the shoulder" does not say what is needed here. Perhaps "steepening of the MLT-profile of the shoulder" would be a better word to use. AC16: I am agree with the advice, and the sentence is replace by "It indicates that the outer edge of the Shoulder rotates faster than the inner edge, resulting in steepening of the MLT-profile of the Shoulder".

RC 17: Lines 247-260: Which model does not include electric field shielding in the inner magnetosphere? Is this referring to your TPM? If so, the statement is not substantiated in the text. While shielding is not explicitly included in the Weimer electric field model, the fact that the Weimer model is empirical means that the model includes whatever physical processes are active. That will include shielding if it is happening, as discussed in previous papers. The Weimer model, hence TPM, provide no information about the physical processes taking place that produce the measured electric field. AC 17: I have revised the sentences 247-249 according to your advice. "And the second reason is that the Weimer electric field model is larger in practice, which results in a larger total electric field value in calculation (Goldstein et al., 2002; Pierrard et al., 2008) "

RC 18: Lines 259-260: Gallagher et al. (2005) specifically report not finding a day-night asymmetry in subcorotational flow. They also do not report finding supercorotational flow, only speculate that asymmetry in the dawn-dusk convection pattern may cause net subcorotational motion. AC18: I am agree with the advice, and deletes "supercorotational flow" in line 260.

RC 19: Conclusions: I posit that you cannot investigate the physical mechanisms for

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shoulder formation using the Weimer empirical electric field model, as that model only represents the measured net electric fields resulting from whatever physical processes are involved in their formation without distinction for those processes. Please substantiate how this can be done. AC1 9: The TPM uses the convection electric field which derives from the Weimer electric field mapping into the magnetosphere along magnetic lines. Other convection electric field have been used to study evolution of the Plume and the Shoulder structure (like Pierrard and Cabrera, 2006; used E5D model; Pierrard, et al., 2008, used Weimer model and Volland-Stern model). So, I think that the Weimer electric field model can use in the TPM simulation.

RC20: Conclusion 1: It has not been demonstrated that IMF Bz must be lower than the previous 24 hours for a shoulder to form. A statistical study or theory is required before there is adequate basis for the conclusion. The statement on lines 184-186 is an observation that might be used to suggest correlation or dependence, but no more than that. AC20: I am agree with the advice and delete it. I revises conclusion 1 merged into conclusion 2.

RC 21: Conclusion 2: The conclusion does not add to what has previously been found. It is incumbent on you to be clear how this new work contributes in the context of previous work. This statement does not do that. AC21: The conclusion 2 is rewrote as "The formation of Shoulder is association with IMF northward turning in the predawn sector. And the physical mechanism of Shoulder formation is the result of plasma extrusion in the predawn sector, caused by outer plasmasphere drifts radial outward and rotates faster. Reversal of corotation rate with L-shell in post-midnight sector compares with corotation rate in midnight sector. So, the shoulder forming across a at 03:00-06:00 MLT region. "

RC 22: Conclusion 3: No significance has been established between the position of a shoulder and the formation of a plume connected to the plasmasphere at that location. Given that plumes form at the onset of convection enhancement, which is not connected to the earlier formation of a shoulder, the presence of a shoulder where

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a plume begins to form is likely no more than coincidence. It is well established that plumes form in the afternoon/dusk region without the presence of a shoulder feature. AC22: Conclusion 3 is rewrote as "The formation and evolution of Plume and Channel have also been reproduce in this case. One can see single or double Plumes appear in the dusk or afternoon sector, and then become thinner with time, finally disappear. "

RC 23: Line 75: "Shoulder-like structure" is acceptable, but "shoulder-like" is not used by itself and if it is shoulder-like, then it would be better to simply refer to it as a shoulder. Lines 66-68 refer to the shoulder structure and define it in words and in Figure 1. That is adequate to subsequently refer to it as a "shoulder". Unless you consider the feature you are referring to as something different from what has previously been described as a plasmaspheric shoulder, then I recommend you simply use that description or just shoulder. AC23: I am agree with the advice, and "Shoulder-like structure" is replaced by "Shoulder structure".

RC24: Lines 12-14: This sentence is not grammatically correct. Perhaps the authors intend it to be something like, "The plasmopause formation is simulated using the Test Particle Model (TPM), which is based on drift motion, which reproduces various plasmopause structures and evolution of the Shoulder feature." AC 24: I am agree with the advice, and have revised this sentence in my manuscript.

RC25: Lines 14-18: These sentences are grammatically incorrect. English language usage needs to be improved throughout in the paper. No further comment about that will be made in this review. AC25: Lines 14-18, the sentence is replaced by "The analysis indicates that the Shoulder is created by sharp reduction and spatial nonuniform of a dawn-dusk convection electric field intensity. Combined action of the plasmaspheric rotation rate speeding up with L-shell and plasma flux doing radial outflow in the predawn sector, results in an asymmetric bulge rotating eastward to reproduce the Shoulder structure. "

RC 26: "Plume" is misspelled in Figure 3e as "plumer". AC26: "Plumer" in Figure 3e is

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replaced by "Plume1 and Plume2 "

You can see the detailed changes in the resubmitted manuscript. If you have any problems, please contact me immediately. I am very grateful for your comment. Thank you very much.

Best Regard Hua Zhang The 1th author of this manuscript

Interactive comment on Ann. Geophys. Discuss., <https://doi.org/10.5194/angeo-2020-86>, 2020.