Reply to Referees

Firstly, we thank for reviewers' comments and questions. They are beneficial to our research works. The point-to-point responses are as follows:

Reply to **Comment on angeo-2021-4**

Anonymous Referee #1

This paper claims to show that adiabatic effects dominate the changes in proton fluxes in the outer part of the proton radiation belts (sometimes referred to as the inner zone).

A first (more minor point compared to my latter concerns) is that much of the cited literature concerns changes in the proton belts that are more long-lasting. For example, losses due to field line curvature scattering are true losses as opposed to temporary (adiabatic) changes. This paper does not contradict those other studies. It has a different objective.

The major problems with this paper are that (a) the methodology is not presented with enough detail to understand how the authors actually analyzed the data and (b) the methodology itself appears responsible for the results that are presented.

Specifically, the authors present formulas that they claim quantify the changes in flux due to adiabatic processes that preserve mu and L. Those are listed in equations 1-4 which represent the flux during the storm (subscript m) as a function of flux prior to the storm (subscript p). The two are related by three variables: Energy, L-shell, and Magnetic field strength. The variables during and prior to the storm are represented by _p and _m.

The first problem is that the equations that relate E_m to E_p and L_m to L_p are not given so the quantities in figure 3 cannot be verified.

We have added the equation (3) and (4), from which we can infer the parameters E_p and L_p. They are obtained from the conversation of fist and third invariants. In the paper they are emphasis with red color at line 120-127.

The second problem is that figure 3 plots E_p, L_p, and j_p as a function of time for fixed values of L_m and E_m. Surely it should be the other way around. For a given pre-storm condition (_p) the quantities during the storm (_m) are a function of time. It is not at all helpful to present it in terms of the "pre-storm" conditions vary as a function of time during the storm.

Let us explain the “pre-storm" conditions vary as a function of time during the storm. Firstly, as we know parameters Lm=2.0 and Em=21.25MeV, then we can infer parameters Lp and Ep based on the first and third invariant [equation 3 and 4 in our paper, equation 3 and 4 are added lately] and magnetic field model. Secondly, we constructed the quiet time flux profile over four years. We obtained monthly average fluxes with L bin from 1.1 to 3.0 and width 0.01 for all 48 months like black and blue lines in Figure 2(a). Each energy channel for each month has been analyzed repeatedly like the black and blue lines in Figure 2(b). Therefore we got the quiet time flux distribution J (E, L), which actually is the function of parameters E and L. During the main phase, the magnetic field changes and the corresponding Ep and Lp are also changes. Thirdly, we have obtained Lp and Ep at above obtained, and we can trace back the quiet time J (Ep, Lp) by linear interpolation with parameters Lp and Ep. We added some information at line 164-166 and 188-190.

The third, and biggest, problem is that the relationship between all of the variables (e.g.L_p to L_m, E_p to E_M) are all a function of B_p/B_m. Since B == B_dip +dB and dB =-symH (for symH<0) then all of the pre-storm and storm-time variables are related to one another as a function of dB == -symH. This can be seen very clearly in figure 3 where all predicted variables follow every bump and wiggle of symH.

The similarity between the variation in SYM-H index and the all predicted variables appear naturally for fully adiabatic flux changes. The prestorm time Lp and Ep changes roughly linear with decreasing SYM-H index, so from equation (5) and the quiet time proton flux model, the storm time proton flux Jm decreases exponentially with SYM-H index; thus the changes in the parameter Jm will be similar to changes in SYM-H index.

For true calculations of adiabatic effects the radial gradients of PSD are critical (as is the second invariant which is ignored here). For example, a flat radial gradient produces no change in flux when B changes. This analysis simply samples the fluxes (j_p) at different values of L and E that are related to an arbitrarily-chosen value of L_m and E_m where the relationship is defined by symH. It is a totology to conclude that adiabatic changes (defined by dB == -symH) "explain" the flux variations.

We have revised Figure 6. In Figure 6 we present two PSD radial distributions in time inferred from different L*. We also have computed the ratio for two different L* and we find the ratio for storm time is comparable to the quiet time. In Figure 6 (d) and (e), PSD changes not much before and after storm time in most small and medium intensive cases. We agree that the flat radial gradient produces no changes in fluxes when magnetic field changes. We don't know if we have answered your question accurately. If not, please make comments.

The brief discussion of phase space density in section 3.3 does not contain enough information to know what the authors have done or what is being plotted in figure 6. Is the PSD at fixed third invariant (L*)? If so, what L*? It is currently impossibe to know if the PSD results support the preceding conclusions or not.

The proton phase space density can be deduced by equation $f_{ch} = \left\{\frac{j_{ch}}{\langle p^2c^2\rangle_{ch}}[1.66 * 10^{-10}]\right\} * 200.3$ (Equation (1) in Chen et al. [2005]) with the observed flux data and modified dipole field. jch is the flux and $\langle p^2c^2\rangle_{ch} = 0.5 * [K_{min}^{ch}(K_{min}^{ch} + 2m_0c^2) + K_{max}^{ch}(K_{max}^{ch} + 2m_0c^2)]$. $K_{min}^{ch}$and K_{max}^{ch} are the lower and upper limit of each energy channel in MeV respectively. m_0c^2 is the rest energy of an proton. The L* is defined as Roederer [1970],$L^* = 2\pi k_0/(\Phi R_E)$, where k0 is the earth's dipole magnetic moment, RE is the earth's radius, and Φ is the third invariant.

Figure (d) and (e) are phase space density for u=535MeV/G and u=700MeV/G at equatorial plane (J=0) for two different L* (black represents L*=2.0 and red for L*=2.3).

We added some information at line 247-253 and 256-258.