Response to referee #1:

We would like to thank the referee for his/her thoughtful comments and suggestions, which helped us greatly to improve the paper. In the following we quote the referee's comments in italics, followed by our response. Annales handles the process a little bit different than most other journal such that they only ask for our response at this point, but not for a revised manuscript. We therefore include new figures and text in the response and will include them in the final manuscript when the editor asks us to do so.

This paper attempts to show that:

Open GGCM used in the paper does a good job of predicting the location of the open-closed magnetic field boundary (OCB)
The minimum latitude reached by the polar cap expansion during a storm follows the IMF clock angle during periods of rotation of the IMF
During times of strongest southward IMF, the polar shifts towards the dayside.

Disappointingly, in my opinion, the paper does not demonstrate these points.

The claim that that the model does a good job of predicting the OCB is not supported by the data shown in the paper. The paper shows histograms of the error of the predicted OCB compared to the observations for each of four storms, and it is readily seen that the histograms and standard deviation are roughly what would be expected for a uniform distribution of error over the range +/-5 degrees in latitude. This indicates to me that the model is essentially giving a random location for the OCB over a 10 degree range of latitudes, a range that is larger than the typical width of the auroral oval. There is some trend for both the model and the data to show the well-known tendency for the OCB to move to lower latitudes with increasingly southward IMF Bz.

This criticism is well taken. We simply had not done a good job examining and displaying out results. The key 'product' of our investigation is a database of DMSP crossing of the OCB with date, magnetic latitude (MLAT), and MLT of the crossing, tagged with the IMF clock angle (CLK) at that time and the crossing MLAT from the model. This database has 297 entries and will be added to the paper as supplemental material. The database contains all the information necessary to address the referees' points, but requires a proper display. We will add the following figures to the paper (they are labelled consecutively here but will get the appropriate numbering when included in the manuscript):

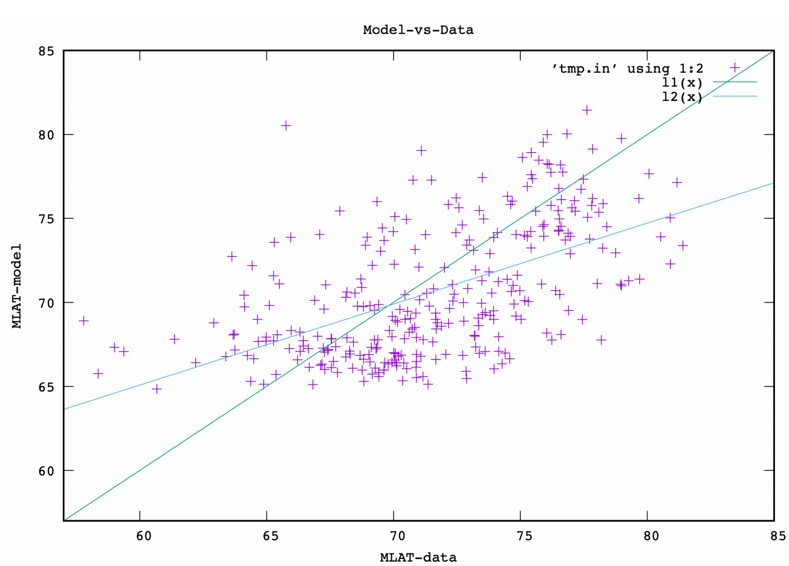

Figure 1. A simple correlation between the OCB latitudes obtained from DMSP and from OpenGGCM. The blue line is a linear fit, and the green line represents an ideal correlation.

Figure 1 shows that the model and the data indeed correlate, albeit with a large scatter. The model never produces an OCB lower that about 64 degrees MLAT, while DMSP sees some crossing at much lower latitudes, down to less that 60 degrees. That is obviously a deficiency of the model and explains shallower slope of the correlation.

Figures 2 and 3 are scatterplots of the OCB latitude versus the IMF clock angle CLK, for the data and the model, respectively. In both plots a clock angle dependence is obvious such that the lowest latitudes correspond to southward IMF. There is large scatter both in the data and in the model results. In order to make a quantitative comparison we fitted a cosine to each of the scatterplots. A cosine fit is a natural choice because the clock angle is periodic and the distribution has a minimum at 180 degrees. In spite of the large scatter, the fits are very similar. The model is biased to lower latitudes by about 1 degree, i.e., 74 degrees versus 75 degrees maximum and 69 degrees versus 70 degrees minimum.

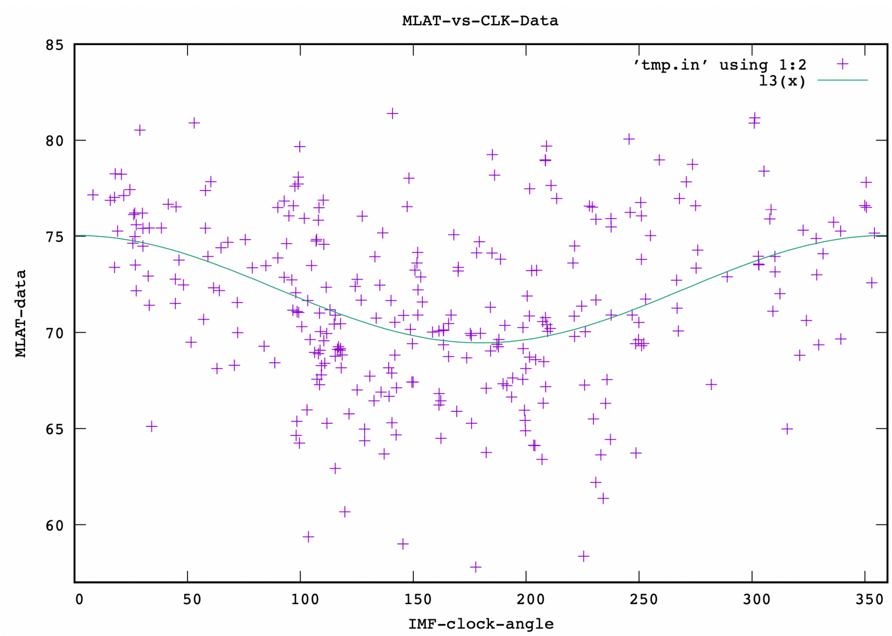

Figure 2. Scatterplot of MLAT versus IMF clock angle for the data. The green curve is a fit to the data with a simple cosine function.

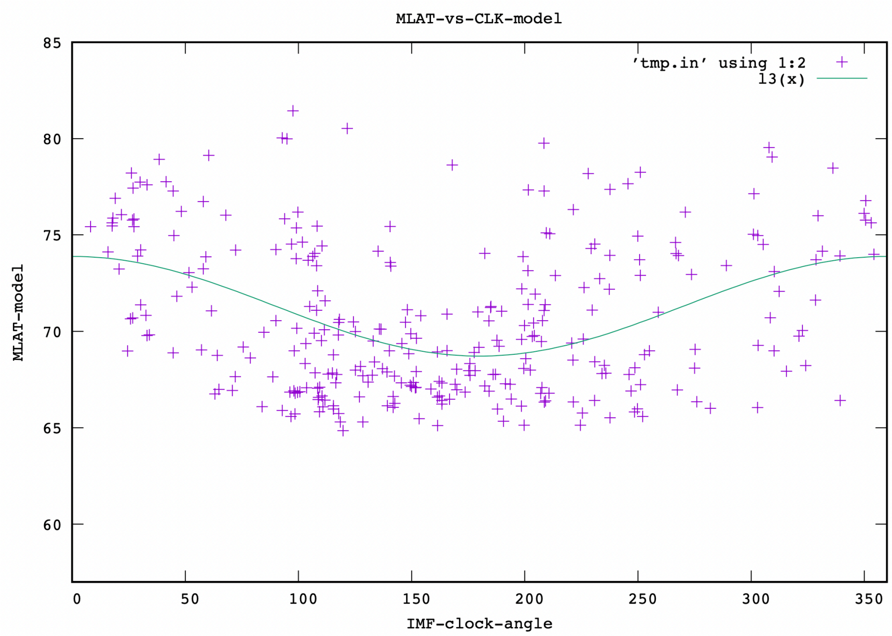

Figure 3. Scatterplot of MLAT versus IMF clock angle for the model. The green curve is a fit to the data with a simple cosine function.

The two conclusions about the polar cap location and shape are obtained solely from the model and no attempt is made to consider whether these trends are also seen in the data. It would be interesting if such trends could also be discerned from the data, and perhaps the authors would consider whether they are able make such a determination.

It is not possible (or useful) to create plots of MLAT versus time and MLT like we did for the model results, because the data are too sparse. On the other hand, the database should contain this information, but a proper visualization needed to be found. We proceed as follows: For both the data and the model we bin and average MLAT as a function of MLT and IMF clock angle (CLK). Since the data are sparse and there are MLT/CLK combinations the have no data (primarily near noon and near midnight because of the DMSP orbits) we displayed the grid with colored dots according to the mean latitude of the crossings in a given MLT/CLK bin. We choose 12 bins in each variable. Finer bins may reveal more structure but also produce more empty bins, but our choice is sufficient to support our conclusions. Figures 4 and 5 show the result. For both the model (we knew that already) and for the data there is a clear pattern such that the lowest MLAT (largest polar cap expansion) at a given MLT follows the clock angle CLK, or, vice versa, for a given CLK the maximum expansion occurs at a specific MLT, and the result is essentially identical for the model and the data. We believe this should take care of the reviewer's concern that the data would not support our original conclusions.

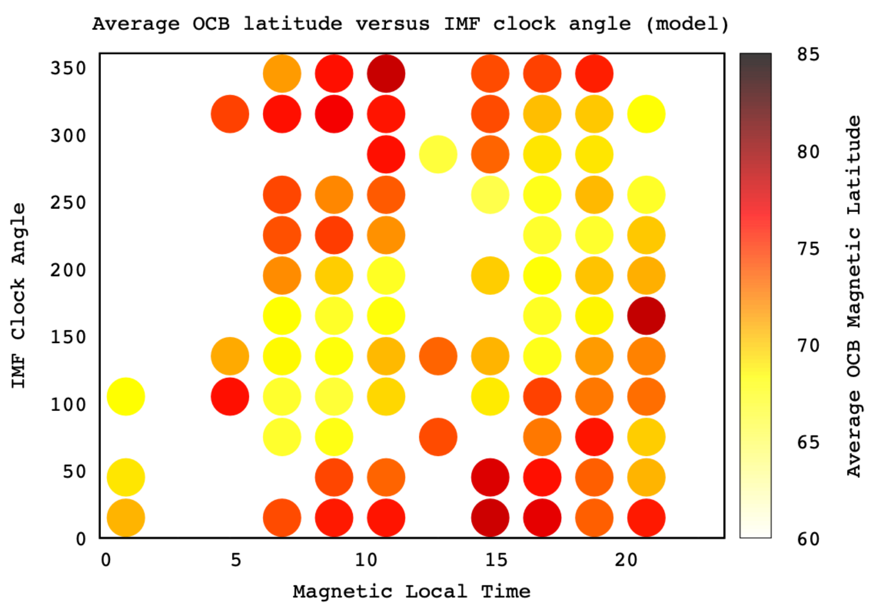

Figure 4. Average MLAT as a function of MLT and CLK for the model. This is essentially just a different presentation of the relation averaged of all cases as were already presented in figures xx-yy.

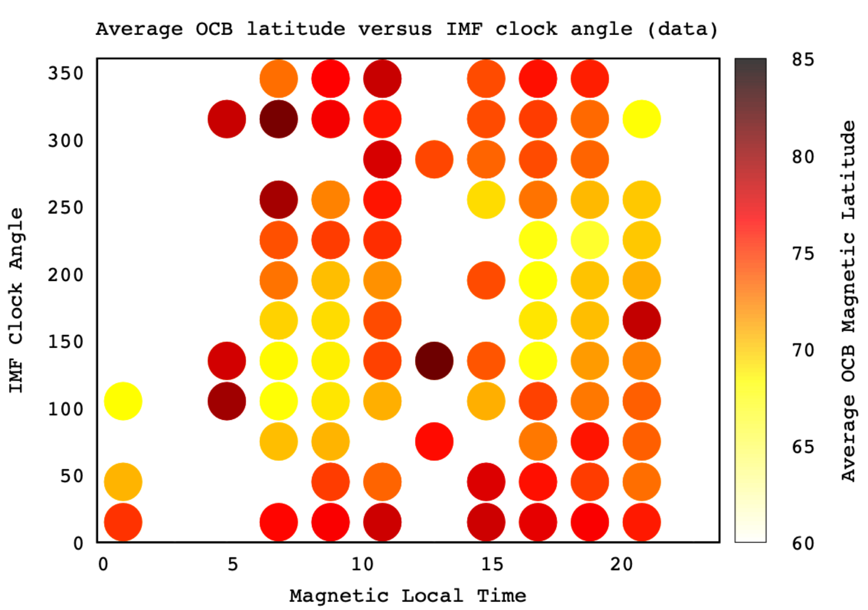

Figure 5. Average MLAT as a function of MLT and CLK for the DMSP data. The pattern follows closely the one seen in the model results of Figure 4.

A further point is that the paper does not adequately describe how the OCB was determined from the DMSP data. Many times the DMSP data shows a clean transition from the plasma sheet to polar rain, but this is far from always the case. For example, low-energy (<~1 keV) can extend roughly continuously from the plasma sheet to the mantle on the morning side, and, in the vicinity of the cusp, the OCB can lie at an equatorward boundary of precipitation because cusp precipitation is on open field lines. Enough information needs to be presented so that a knowledgeable person could reproduce the results, Simple saying "spectrograms of ion and electron differential *fluxes in a range from 30 eV to 30 keV were inspected to identify the polar cap boundary crossings of the satellites" is not sufficient.*

We agree that identifying the OCB in the data is subjective and not an easy task. An alternative is to use an automated algorithm as the APL group has done, but when we checked those determinations by inspecting them against spectrograms we found them not reliable. We thus inspected each crossing individually and also in a very conservative manner. Crossings that could not be clearly identified are not included in the data base. Also, when we could identify polar cap precipitation features such as polar cap arcs, these were not included. We also never used data below ~1 keV, so there should be no concerns about the cusp. All crossings are tabulated in the data base with a time tag, so in the event a reader wants to double check he/she can do so.

A minor point: I recommend not including statements of fact in a paper's Introduction without a reference. Examples in the current paper are:

"Convection can also change the shape of the OCB without changing the flux contained in the polar cap."

We will add the citation "M. Lockwood, S. W. H. Cowley, M. P. Freeman, The excitation of plasma convection in the high-latitude ionosphere, JGR, 1990, https://doi.org/10.1029/JA095iA06p07961"

"When the polar cape opens up, that plasma leaves the plasmasphere and convects away. Thus, the OCB shape also controls the shape of the plasmasphere."

We will add the citation: "A. Nishida, Plasmapause, Convection, and Reconnection, JGR, 2019, https://doi.org/10.1029/2019JA026898"

"During times of high geomagnetic activity these methods can fail because the precipitation is very intense, clobbering the radars' return signal."

This is a well-known fact and often mentioned, but apparently never put in writing, so we will remove this sentence.