Anonymous Referee #1 (RC1)

We thank the reviewer for their careful reading of the manuscript and their constructive remarks. Please, see below our responses in blue.

Review of "Intermediate layers responses to geomagnetic activity during the 2009 deep solar minimum over the Brazil low latitude sector" by Santos, Brum, Batista, Sobral, Abdu and Souza

The paper has interesting results about "intermediate layers" but I find the physical explanation wanting. I suggest that the authors do a little more research to establish the physical cause of the ILs in a more convincing way.

Major Comments:

RC1-**1.** If the authors read JGR, 113, A05311, 2008, doi:10.1029/2007JA012879 carefullly, you will find that in the model/theory, northward interplanetary magnetic fields will lead to dusk to dawn electric fields that will cause downward convection of the dayside equatorial ionosphere. This is not "overshielding", but simple PPEF inputs (see their Figure 7). This electric field will cause upward convection on the nightside. Thus, if this is your scenario, the term "overshielding" is being misused. On the other hand, if the interplanetary magnetic field is southward and the dayside near equatorial ionosphere is indeed convected downward, this would indeed be due to "overshielding" effects. So in that case, the term would be used correctly.

We thank the reviewer in clarifying the definition of overshielding effects. We read attentively our manuscript and included some changes about this. For more information, please see the answer of question RC1-7.

RC1-**2.** The paper is very confusing in that both scenarios are quoted, which cannot be correct. My suggestion is to look at the interplanetary magnetic field direction during some of your IL formations and show them to your readership. Then there should not be any confusion. Unless of course you see both cases? But then you should state so in the paper.

The purpose of this work was to analyze the responses of the IL to variations of geomagnetic activity, here represented by Kp index. For this, one year of data over CP (2009) was studied in respect to Kp and some tendencies were found as the lowering or the highering h'IL with the increase of Kp when compared to the quiet day's pattern. So, in this context, we believe that it is not necessary to show separately one case or another because our focus is the statistical analysis, or in other words, what would be the more likely responses of the IL's parameters to changes in geomagnetic activity. About the confusion in the use of the term "overshielding", some changes were included in the text as mentioned above and in the answer of question RC1-7.

RC1-**3.** In any, case the above paper should be cited, which it is not at the present time.

Ok, the paper in this new version was included.

*Minor Comments:*

RC1-**4.** Lines 44 to 48. "overshielding is used in the correct sense here".

Ok.

RC1-**5.** Line 83. An upward movement of an IL would be consistent with a dawn to dusk electric PPEF caused by a southward IMF.

Ok.

RC1-**6.** Line 90-91. This is an okay description of a PPEF and southward IMF.

Ok.

RC1-**7.** Lines 103-104. Kp is not the best parameter to use to study this effect. Why don't you simple use the interplanetary magnetic field to do this study? There are many causes of geomagnetic activity, not only southward magnetic fields. Solar wind pressure pulses can cause substorms, even during northward IMFs. And some scientists believe that northward turnings of the IMF trigger substorms.

Similarly, the referee # 2 also questioned the use of the kp index instead of the Dst index. We have used the Kp index because the purpose of this paper is to investigate the responses of the IL to the overall level of geomagnetic activity, independent of how the disturbance was triggered. For all intents and purposes and to support the usage of the planetary magnetic index, we have compared the Bz direction-and-intensity and also the solar wind velocity with the kp values for the period in study (see Figure 1 below). It is clearly seen that with the increase of Bz towards the south and with the increase velocity at the same quadrant there is an increase of kp index up to 4.5, the same does not occur for Bz positive (northward), wherein the kp average is around 1.12 ±0.4 with a maximum of 1.9, which is still considered geomagnetically quiet time condition. Thus, our methodology is consistent because the periods more disturbed (for instance, over 1.12) can statistically be considered when Bz is southward and also becomes more disturbed with the increase of the solar wind velocity.

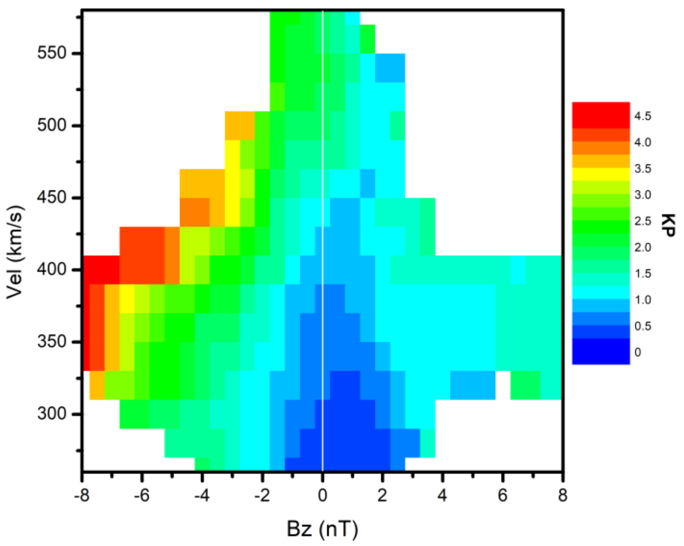


Figure 1. Kp average values in function of IMF's Bz component and solar wind velocity recorded by the OMNI satellite.

Similarly, to Figure 1, we have computed the dependence of Kp to variations of Dst/Sym-H values for the period in this study. Figure 2 shows the Kp average for different ranges of Sym-H (from -68nT to 16nT, steps of 2±1nT). It is clearly seen that with the decrease of Sym-H starting in 0 up to -68nT there is an increase of Kp as well. On the other hand, variations from 0 to 16nT also is noticed an increase of Kp up to Kp about 1.3, which is considered quiet condition. In a certain way, the Sym-H from 16 to -16nT nulls each other for periods of quiet condition. This statement is tested in Figure 3.

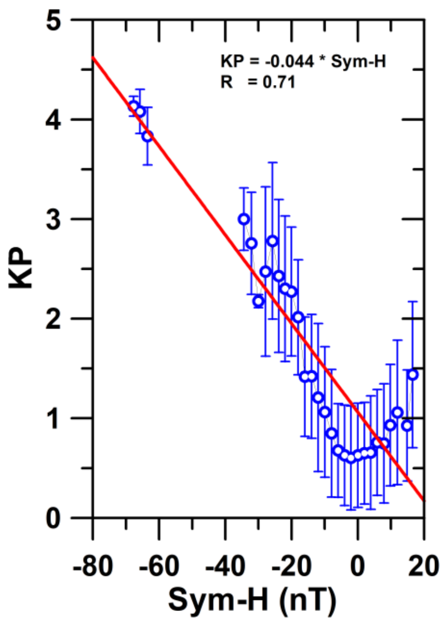


Figure 2. Dispersion diagram between the kp index in respect to Sym-H values for the year of 2009.

As a matter of comparison, using the same methodology proposed in the manuscript (see Figure 6 of the manuscript text), but considering now only data after 17:00 UT in order to increase the sample space (note in Figure 6 that the behavior of the IL is similar, i.e., the h'IL and ftIL tends to increase/decrease with the increase of kp, respectively) and the same range of Kp, Figure 3 below shows the variability of Sym-H, IMF Bz, solar wind velocity, ΔftIL and Δh'IL in respect to Δkp. It is clearly noticed that with the increase of ΔKp Bz increases to south while Sym-H decreases. This pattern is well defined, evidencing that the magnetic disturbances considered in our study are associated with the direction and intensity of Bz and with the intensity of Sym-H. In this Figure, it is also seen the analysis with solar wind velocity (third panel from the top), delta frequency (fourth panel) and delta height (fifth panel). This presented analysis corroborates with the statement made by the referee and reported by JGR, 113, A05311, 2008, doi:10.1029/2007JA012879, which also corroborates with the statement of question RC1-5 *"An upward movement of an IL would be consistent with a dawn to dusk electric PPEF caused by a southward IMF"*. Summarizing, in comparison of results presented in the manuscript, we can point out that similar results were found and thus validating our study using kp index.

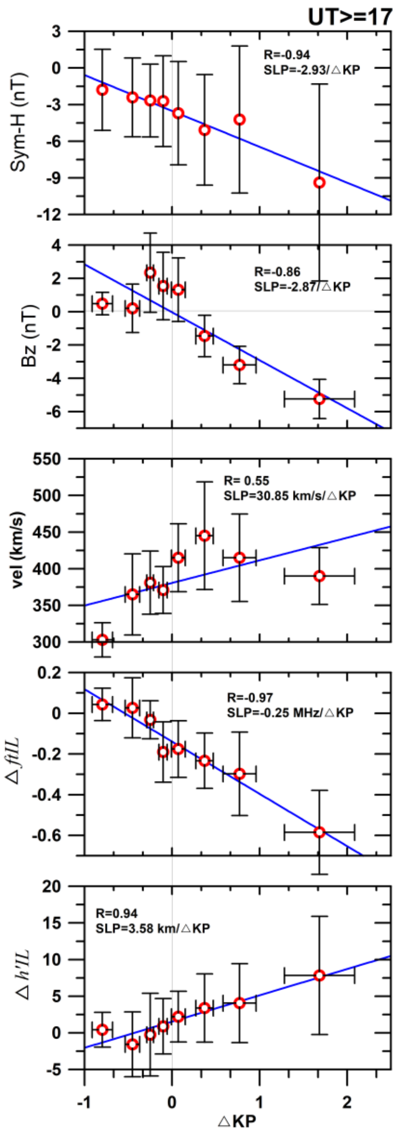


Figure 3. Variability of Sym-H, IMF Bz intensity, solar wind velocity, ΔftIL and Δh'IL in respect to Δkp.

RC1-**8.** Lines 165-166. The paper AG, 29, 839-849, 2011 should be quoted here. This paper points out the low geomagnetic activity during this extreme solar minimum, which is of importance for your paper.

The reference was included.

RC1-**9.** Line 190. See above comment.

Ok.

RC1-**10.** Lines 220-222. These altitudes are regions where precipitating electrons deposit their energy. I think you need to tell the reader why you think this is not a problem.

Figure 4 below shows the variability of cosmic noise absorption at 30MHz with respect to sunspot number obtained from 1989 to 1996 using riometer data (daytime only). Most of the absorption at this frequency occurs at D-E region altitudes over Cachoeira Paulista by non-deviative absorption with a small contribution of deviative absorption for altitudes of F-region. Note that for the low solar activity there is very little variation of the absorption, which excludes the contribution of electron precipitation under such conditions (we are excluding the proton precipitation because it occurs eastward of the South Atlantic Magnetic Anomaly, region where CP is located).

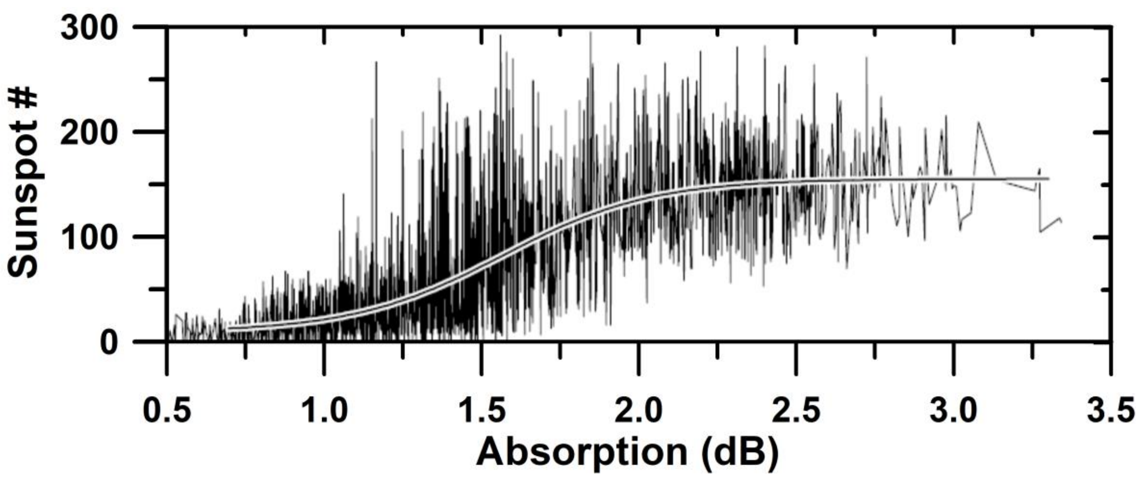


Figure 4. Cosmic noise absorption registered for almost one complete solar cycle over Cachoeira Paulista (from 1989 to 1996).

To confirm the statement given above, Figure 5 shows the effects of the energetic particle precipitation (EPP) (in this case electrons) in the ion-pairs formation for different fluxes and spectrums given by simulation (Brum et al., 2006; Brum et al., 2021). Clearly, the ion-pairs production is considerably higher in the D and E regions, therefore, in altitudes lower to that in which IL is commonly observed (~ 150 km). It is seen that the ion-pair formed for different ranges of energy always present an ionization peak under 100 km, even changing the flux spectrum. Thus, theoretically the electron precipitation can be neglected in our analysis discussion. However, we believe that during the occurrence of strong geomagnetic storms (that is not the case in 2009), the EPP could impact in some way the ILs. Santos et al. (2016) for example showed a case in which a layer was formed at about 150 km over Cachoeira Paulista and Fortaleza during the occurrence of magnetic storm a 23 September 2003. The appearance of this layers, that in these cases presented some degree of spread in their trace was very similar to those layers formed by the EPP (see for example Batista and Abdu (1977) and Abdu et al. (1981). So, the EPP can impact the ILs, however as we are studying the deep solar minimum of 2009, we believe that if this influence occurred, it was not relevant. Some comments about this were include in this new version:

*"Eventually, the IL can be impacted by the energetic particle precipitation (EPP) (see for example Santos et al., 2016a, b), mainly during the occurrence of intense geomagnetic storms. Furthermore, as the present study refers to a period in which the geomagnetic storms were considerably weaker. That said, we believe that if ILs were impacted in any way by the EPP, it would not be relevant to our investigation at this moment. In addition, theoretical simulation of ion-pair production by EPP over Cachoeira Paulista have shown that the peak production of electrons is comfortable below the IL's minimum height used in this work (Brum et al., 2006; Brum et al., 2021)."*

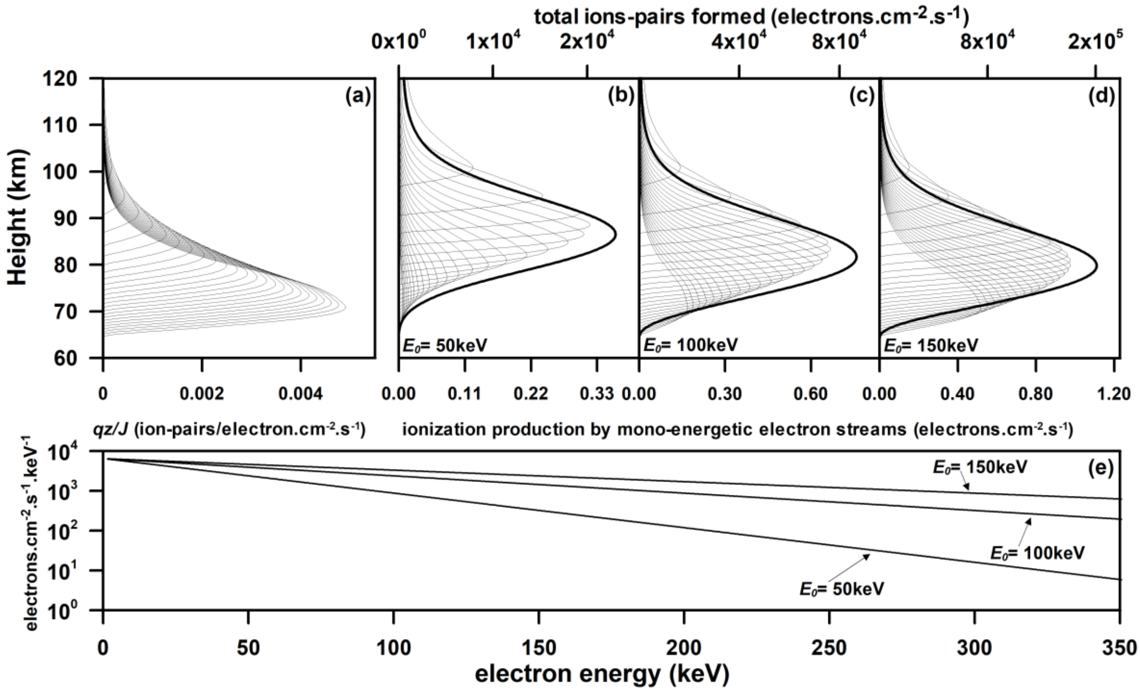


Figure 5. Ion-pairs formed by electron precipitation for different fluxes and spectrums for the Cachoeira Paulista region.

## *References*


*Abdu, M. A.; Batista, I. S.; Piazza, l. R.; Massambani, O. Magnetic storm associated enhanced particle precipitation in the South Atlantic Anomaly evidence from VLF phase measurements. Journal of Geophysical Research, v.86, p. 7533-7542, set. 1981.*

*Brum, C.G.M. (2021), "The impacts of particle precipitation spectrum on the 30MHz cosmic noise absorption over the under the South Atlantic Anomaly Region," 2021 XXXIVth General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), pp. 1-4, doi: 10.23919/URSIGASS51995.2021.9560414.*

*Brum, C.G.M.; Abdu, M.A.; Batista, I.S.; Carrasco, A.J. and Santos, P.M.T. (2006). Numerical Simulation of Nighttime Electron Precipitation in the Lower Ionosphere over a Sub-Auroral Region. Advances in Space Research, v.37, p.1051 – 1057. doi:10.1016/j.asr.2006.02.003.*

*Santos, A. M., M. A. Abdu, J. R. Souza, J. H. A. Sobral, I. S. Batista, and C. M. Denardini (2016), Storm time equatorial plasma bubble zonal drift reversal due to disturbance Hall electric field over the Brazilian region, J. Geophys. Res. Space Physics, 121, doi:10.1002/2015JA022179.*

*BATISTA, I.S. AND ABDU, M.A (1977), Magnetic storm associated delayed sporadic E* *enhancements in the Brazilian Geomagnetic Anomaly. Journal of Geophysical Research 82: doi: 10.1029/JA082i029p04777. issn: 0148-0227.*

RC1-**11.** Lines 288-289. Here "overshielding electric fields" and northward turnings of the IMF Bz are contradictory.

This part of the text was re-written as following:

*"One of the hypotheses to explain such variation in the h'IL parameter is that this behaviour can be related to dusk-to-dawn directed PPEF (see for example Tsurutani et al., 2008). Such electric fields have westward polarity during daytime and therefore it may be one of the factors responsible for the occurrence of lower h'IL at this time."*

RC1-**12.** Lines 303-304. An eastward electric field would be consistent with a rise of the ILs if the IMF were southward. However, if the IMF were northward and overshielding occurred you could get this eastward electric field as well.

This part of the text *"…depending on the height at which the ILs are located, the disturbance electric field can affect considerably the vertical displacement of the intermediate layers. They showed some cases in which the uplift of the IL was noted during sunset times considering an inversion of Bz to south (see for example their Figure 6),* therefore, in agreement with the comment of reviewer.

*Santos, A. M., Batista, I. S., Brum, C. G. M., Sobral, J.H.A., Abdu, M. A., & Souza, J. R. (2021). F region electric field effects on the intermediate layer dynamics during the evening prereversal enhancement at equatorial region over Brazil. Journal of Geophysical Research: Space Physics, 126, e2020JA028429. https://doi.org/10.1029/2020JA028429.*

RC1-**13.** Lines 310-313. Such shielding/overshieding competition has not been observed in major magnetic storms caused by sheaths and ICMEs. See example in GRL, 32, L12S02, 2005. Doi:10.1029/2004GL021467. On the other hand, if these events occurred in high speed solar wind streams, such IMF north-south reversals are common. See JGR, 111, A07S01, 2006. Doi:10.1029/2005JA011273. Both of these examples are typical. It would help if you identified what type of solar winds your geomagnetic activity occurred in.

As shown in Figures 1 and 3, the highest geomagnetic condition occurred when Bz was to the south and increased with the increase of Bz intensity too. A point that may have been overlooked by the reviewer is that we are not using the actual kp values, but an average of the actual and the 6 hours before, which implies that the geomagnetic conditions represented here are very stable in time and IMF reversals will not greatly impact in our final results. Again, we don't want to know the origins of the geomagnetic conditions, but the statistical responses of the IL's to that.

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