Anonymous Referee #2 (RC2)

We would like to thank the referee for his/her contributions to the improvement of our paper. We tried to respond to every question and we made various changes according to some of the reviewer requests. Corrections and enhancements appear in blue on the text.

Referee Report for the AnGeo-2021-52,

Summary:

This article interestingly describes a case report for the intermediate layers to the geomagnetic activity over the Brazilian sector during the deep solar minimum of SCs 23/24 (2009). While the authors show unique data and discussions, their descriptions look slightly excessive and require additional justifications and modifications.

Major Comments:

RC2-1. The authors described their target interval (2009) as "the deepest solar minimum of the last 500 years" (e.g., P1L13-14). This is not true. Recent studies have proven that the solar activity was much more quiet during the Maunder Minimum than during 2009, on the basis of the cosmogenic isotopes (DOI: 10.1051/0004-6361/201526652; DOI: 10.1051/0004-6361/202140711), the sunspot records (DOI: 10.1093/mnras/stab1155; DOI: 10.3847/1538-4357/abd949), and the visual coronal structures (DOI: 10.1051/swsc/2020035). The authors should explicitly compare this deep minimum with the Maunder Minimum, to better contextualize their result in the longer-term space climate studies.

Some comparisons between this deep minimum with Maunder Minimum were included in the text as can be seen below:

"Schrijver et al. (2011) showed that in agreement with the yearly-averaged sunspot number, only 5 of 28 cycles since 1700 had a minimum lower than in early 2009. From mid-2008 until 2009/09, the fraction of spot-free days fluctuated around 82%, unprecedented in the age of modern instrumentation. Using Johann Heinrich M¨uller's sunspot observations from 1709, Carrasco et al. (2021) concluded that one of the most active years in the Maunder Minimum (1709), it was still less active than most years in the Dalton Minimum and those of the most recent solar cycles. As commented by the authors, the solar activity level in 2009 was similar to that in 1709 according to its most probable value. All the characteristics mentioned above reinforce the importance of the period chosen here to analyze the possible dependence of ILs on geomagnetic activity since 2009 can be in some way comparable to the Maunder Minimum epoch of greatly suppressed solar activity and considered as the weakest cycle of the past 100+ years (Zharkova, 2020)".

RC2-2. In this context, the authors should also address why the solar minimum in 2008/2009 was that significant. The authors have cited F10.7, whereas this lasted only after 1947 according to Ken Tapping's works (DOI: 10.1002/swe.20064; DOI: 10.1007/s11207-017-1111-6), which is missing in their reference list. This minimum was somewhat comparable with the deep minima of SCs 24/25 and SCs 13/14 (DOI: 10.1007/s11207-016-1014-y; DOI: 10.1093/mnras/stab1155). The authors should explicitly address such a long-term context.

We thank reviewer by these comments. Please see our answer in the previous question (RC2-1). The Tapping 's works are now cited in our manuscript as suggested by the reviewer.

RC2-3. The authors have used 3 paragraphs of their introduction to (mainly) describe their own studies. The readership would wish to know if this topic is only researched in their laboratory. Therefore, I have to strongly recommend the authors to address other teams' achievements. Otherwise, the authors have to explicitly clarify why other teams have not researched this topic.

The reviewer has reason when says that there are at least 3 paragraphs describing our own results. These paragraphs were included in the manuscript because we thought it is important to present a review for the readers about the behaviour of ILs over Brazil as it was mentioned in the first version of the manuscript (page 3, lines 55-56 in this new version). This is because there is a very limited number of studies showing the behavior of ILs using Digisonde data. We were the first authors to give focus to this specific region over Brazil using this kind of instrument. In the discussion section, the reviewer can find the citation of other papers of different authors.

RC2-4. The authors should describe more about the digisond dataset. From when to when these data are available? Which instruments were used here? How these data have been calibrated? It would be better to let the readership to understand the data within this manuscript.

The Digisonde (Digital Ionospheric Goniometric IonoSONDE) is an ionospheric radar that uses high-frequency radio waves for the remote sensing of the ionosphere. It is composed by a transreceiver system that emits pulses of electromagnetic energy at frequencies ranging from 0.5 to 30 MHz. As shown in Figure 1, simultaneous ionospheric observations are made at each 5 -15 minutes in more than 60 locations around the globe.

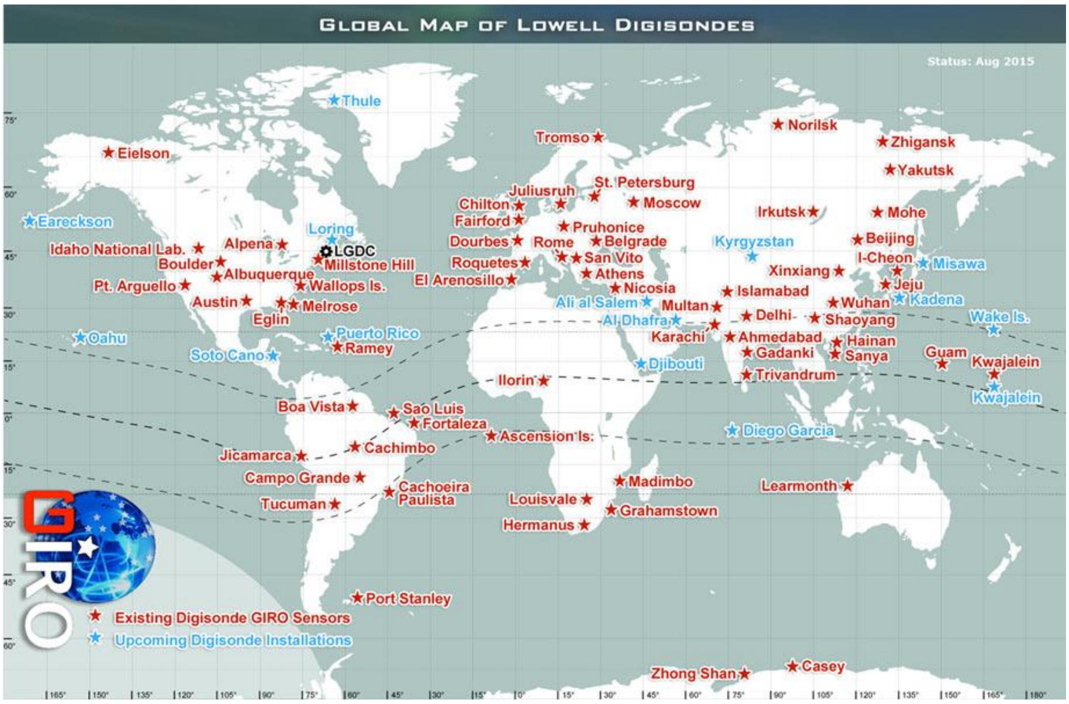

Figure 1 – Distribution of Digisondes installed around the world.

Although this instrument does not provide the electron density profile in the valley region where the ILs usually occur, some interesting characteristics of the general behavior of the ILs can be explored. Essentially, the ionospheric survey made by this instrument is based on the reflection of the electromagnetic signal transmitted vertically to the ionosphere with a peak power of the order of 10kW (for the case of Digisonde DGS256, that is the model used to collect data from 2009 over CP) at frequencies ranging from 0.5 to 30 MHz. The vertical radio sounding makes use of the fact that radio waves are reflected in the ionosphere at the height where the local cutoff frequency equals the frequency of the radio wave. The ionospheric information is recorded in the form of ionograms that display the virtual height of the returned echoes versus their frequency, registered at 10 and/or 15-min intervals. The Digisonde data used in this work were preprocessed through the ARTIST software (Automatic Real Time Ionogram Scaler with True Height) and after manually scaled by the SAO-explorer software using the same criteria described by Dos Santos et al. (2019). For more details about Digisonde, see for example Reisnish (1986) and Reinish et al. (2009). All the aforementioned description of the Digisonde and data reduction method is very known by the community, because of this we neglected further information about this in our manuscript. About the description of Digisonde, see also the site *https://ulcar.uml.edu/digisonde_dps.html* and the references cited there. We included a briefly description about the Digisonde as can be see below:

"The ionospheric survey made by the Digisonde is based on the reflection of the electromagnetic signal transmitted vertically to the ionosphere with a peak power of the order of 10kW (for the case of Digisonde DGS256, that is the model used to collected data from 2009 over CP) at frequencies ranging from 0.5 to 30 MHz. The vertical radio sounding makes use of the fact that radio waves are reflected in the ionosphere at the height where the local cut-off frequency equals the frequency of the radio wave. The ionospheric information is recorded in the form of ionograms that display the virtual height of the returned echoes versus their frequency, generally registered at 10 and/or 15-min intervals. The Digisonde data used in this work were pre-processed through the ARTIST software (Automatic Real Time Ionogram Scaler with True Height) and after manually scaled by the SAO-explorer software using the same criteria described by Dos Santos et al. (2019). For more details about Digisonde, see for example Reisnish (1986) and Reisnish et al. (2009)."

References

Reinisch, B. W.: New techniques in ground-based ionospheric sounding and studies, Radio Sci., 21, 331–341, 1986.

Reinisch, B. W., Galkin, I. A., Khmyrov, G. M., Kozlov, A. V., Bibl, K., Lisysyan, I. A., ... & Luo, Y. New Digisonde for research and monitoring applications. Radio Science, 44(01), 1-15, 2009.

RC2-5. Why do the authors use the Kp index here? The authors should redo their analyses, replacing the Kp index with the Dst index (or at least some more quantitative indices). Here, they have to explain why the authors chose the specific geomagnetic index.

Referee #1 also questioned about not using a different proxy for our analysis as well. In his/her case was suggested to use IMF parameters instead kp. 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.

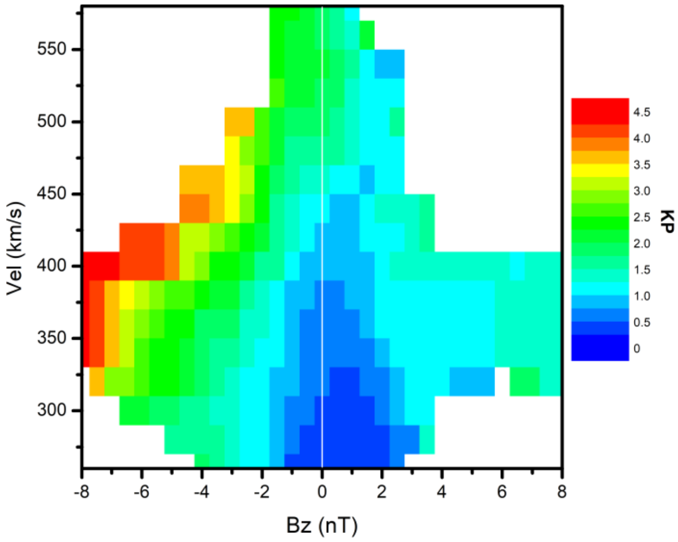

Figure 1. Kp average values in function of IMF's Bz component and solar wind velocity recorded by the OMNI satellite.

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.

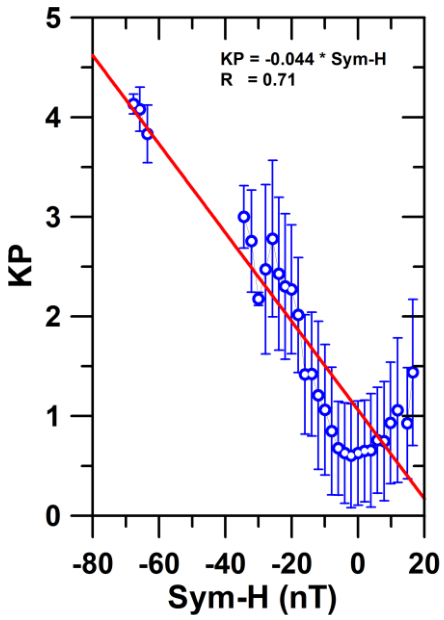

Figure 2. Dispersion diagram between the kp index in respect to Sym-H values for the year of 2009.

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.

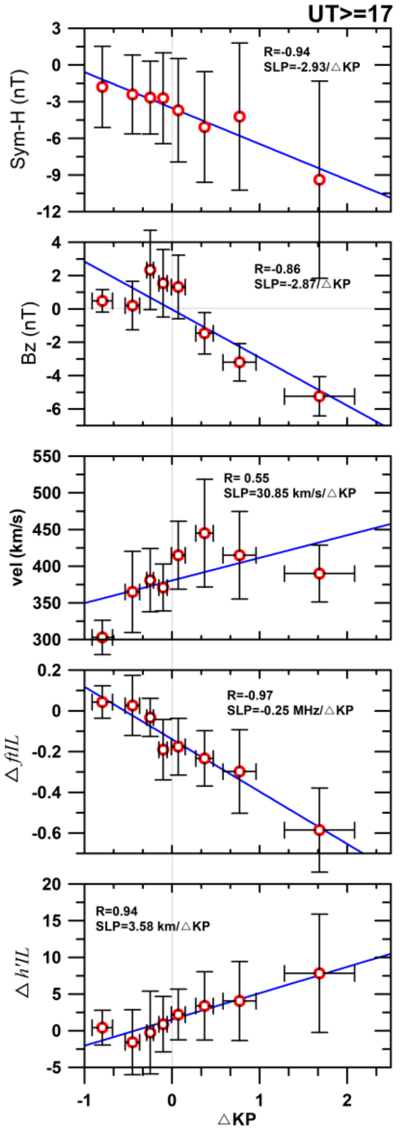

Figure 3. Variability of Sym-H, IMF Bz intensity, solar wind velocity, ΔftIL and Δh'IL in respect to Δkp.

RC2-6. Their grammar should be thoroughly improved. They have to send their manuscript to professional grammatical corrections before further review processes.

We carefully read the manuscript and made some corrections in the English grammar. So we hope it now matches the journal standard.