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Annales Geophysicae Discussions

# *Interactive comment on* "Semiannual variation of Pc5 ULF waves and relativistic electrons over two solar cycles of observations: comparison with predictions of the classical hypotheses" *by* Facundo L. Poblet et al.

**Anonymous Referee #1**

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In their manuscript "Semiannual variations of Pc5 ULF waves and relativistic electrons over two solar cycles of observations: comparison with predictions of the classical hypotheses", Poblet et al. explore variations of power in the Pc5 frequency range observed by ground magnetometers and of relativistic electron fluence measured along the geosynchronous orbit. Through analysis of autocorrelation and superposed epoch analysis of data covering two solar cycles (22 and 23), the authors show variations in time scales ranging from days to months. Specifically, periodicities of approximately 9, 13 and 27 days, due to solar rotation have been identified in both relativistic elec-



tron fluence and Pc5 ULF wave power levels. Furthermore, an equinox maximum was observed in their seasonal variation, while lower level occurred around solstices throughout the year.

The presented results provide evidence pointing towards one order of magnitude higher electron fluence around solstices than equinoxes and 0.5 order of magnitude higher Pc5 ULF wave power around equinoxes than solstices. However, on the contrary to a previous publication by Lam (2011) that offered the starting point for this study, diurnal variation has not been considered even though it is expected to be of an order of magnitude in the electron flux measured along the geosynchronous orbit. If the author can address this concern such that their conclusions are clearly supported by the data presented and can improve the placement of this work in the context of previous literature, then this manuscript could become a valuable addition to the existing literature. Specifically, I could recommend this manuscript for publication in Annales Geophysicae subject to the specific points detailed below:

Page 1

There are minor issues with English language use and several typographical errors.

For example, in line 1 and 5, acronyms such as ULF and GOES as well as NOAA on page 3, YKC, PBQ, BLC and CBB on page 4 should be expanded at first mention with the acronym provided in parenthesis after the acronym expansion.

Further down, in line 7, "though not present in all years" is followed by "are seen in some years" that essentially says the again the same thing already said.

On the next page 2, in line 9, the work of Summers and Ma (2000) is cited among the references for acceleration mechanisms of electrons in which Pc5 ULF waves have a key role to play. In parenthesis, however, it reads "Summers and yu Ma (2000)".

Page 2

In line 14, the focus of the manuscript is introduced, namely variations in Pc5 ULF wave power observed on the ground throughout the two previous solar cycles. Specifically, it reads "ground-based Pc5 magnetic pulsations, which are a manifestations of Pc5 ULF waves", contrary to the terminology widely employed today, which it is described in Section 1.1. of the following publication:

- McPherron (2005), Magnetic pulsations: Their sources and relation to solar wind and geomagnetic activity, Surveys in Geophysics, doi: 10.1007/s10712-005-1758-7

Page 3

In Sections 2.1 and 2.2, the source of data used in this study is briefly described as well as the rationale behind their choice with key information missing. Although this manuscript presents the continuation of a previous study by Lam (2017), it has been submitted to published as a separate paper and should therefore stand on it own. Readers should not need to search for the publication of Lam (2017) to retrieve essential information about the data used to derive the presented results.

The choice of including measurements of Pc5 ULF wave power from the nightside magnetosphere along with those from the dayside magnetosphere and using electron fluence measurements from GOES satellites without considering the asymmetry in the dayside and nightside magnetosphere puzzles me as it seems inadequate to support the main conclusion of the study

Owing to the asymmetry of the magnetic field between the nightside and the dayside magnetosphere, satellites in almost circular orbits collect measurements from different (inner and outer) regions of the radiation belt. It is, therefore, difficult to separate temporal changes in the electron flux/fluence from changes due to the orbital motion of satellites.

Differences in measurements of electron flux/fluence along the satellite orbit could, however, be eliminated if they could be mapped at the same point. O'Brien et al. (2001) demonstrated a technique called Statistical Asynchronous Regression, which



determines the relationship between two time-varying quantities, without the need for simultaneous measurements of both quantities.

O'Brien et al. (2001) used this technique to map the flux round geosynchronous orbit to noon, as did Burin des Roziers and Li (2006) to map electron fluxes to other MLT. More recently, in Glauert et al. (2018), the technique has been employed to approximate the drift-averaged electron fluxes at a fixed L* from GOES data.

The publications referenced above are the following:

- O'Brien, T. P., Sornette, D., & McPherron, R. L. (2001). Statistical asynchronous regression: Determining the relationship between two quantities that are not measured simultaneously. Journal of Geophysical Research, 106(A7), 13,247–13,259. https://doi.org/10.1029/2000JA900193

- Burin des Roziers, E., & Li, X. (2006). Specification of >2 MeV geo-synchronous electrons based on solar wind measurements. Space Weather, 4, S06007. https://doi.org/10.1029/2005SW000177

- Glauert, S. A., Horne, R. B., & Meredith, N. P. (2018). A 30-year simulation of the outer electron radiation belt. Space Weather, 16, 1498–1522. https://doi.org/10.1029/2018SW001981

Page 4

In lines 7 to 11, the choice to include data from the magnetosphere nightside is briefly explained. It would be noteworthy to add that a premidnight peak has been observed in GOES magnetic field data by Huang et al. (2010) and is likely the consequence of storm as well as substorm activity driven by tail processes, including substorm injections and dampened oscillatory flow in the plasma sheet. Lyons et al. (2002) has argued that ULF waves that strongly perturb the plasma sheet are a key component of tail dynamics during periods of enhanced convection. These ULF waves occasionally have amplitudes as large as plasma flow changes that occur in association with auroral zone disturbances, such as substorms.

The publications referenced above are the following:

- Huang, C.-L, Spence, H. E., Singer, H. J., & Hughes, W. J. (2010). Modeling radiation belt radial diffusion in ULF wave fields: 1. Quantifying ULF wave power at geosynchronous orbit in observations and in global MHD model. Journal of Geophysical Research, 115, A06215. https://doi.org/10.1029/2009JA014917

- Lyons, L. R., Zesta, E., Xu, Y., Sanchez, E. R., Samson, J. C., Reeves, G. D., Ruohoniemi, J. M. & Sigwarth, J. B. (2002). Auroral poleward boundary intensifications and tail bursty flows: A manifestation of a large-scale ULF oscillation? Journal of Geophysical Research, 107(A11), 1352. https://doi.org/10.1029/2001JA000242

Page 10

In lines 17 and 18, it would be more appropriate to read “horizontal axis” and “vertical axis” as the terms “abscissa” and “ordinate” are usually used to define the location of points in two-dimensional rectangular space.

Page 11

In lines 15 and 16, the authors note that, during 1996, relativistic electron fluence shows a different trend in Figures 2 and 4. However, how this is different from relativistic electron fluence observed during the remaining time series analysed has not been described.

Page 13

In line 4, it is not clear to me and perhaps the reader why the choice of displaying relativistic electron fluence and Pc5 ULF wave power has been selected to be displayed at intervals of three days. Would the choice of a longer or shorter intervals make a difference in the variation observed through the year?

Page 17



In line 9, could the cut-off value in the condition |tn – tn+1| < “small value” checked before every iteration be provided?

Page 19

In lines 16 to 19, the authors suggest that increases in Pc5 ULF wave power has been linked to relativistic electron fluence enhancements during individual events. However, I could not understand from the context whether geomagnetic storms are meant by individual events. In addition, references to such studies have not been provided.

The relationship with solar wind speed could also be discussed at this point along with seasonal variations in relativistic electron fluence and Pc5 ULF wave power. In the past, Lukianova et al. (2016) had looked into variations of solar wind speed over several solar cycles over the last 100 years.

Several studies have suggested that the solar wind speed is a dominant driver of relativistic electron fluxes in the outer radiation belt (e.g. Kellerman & Shprits, 2012, Paulikas & Blake, 1979). Furthemore, enhanced Pc5 ULF wave activity has associated with higher solar wind flow speed in the recovery phase of storms leading to enhanced electron fluxes (e.g. Georgiou et al., 2018, Mann et al., 2004).

The publication referenced above are the following:

- Lukianova, R., L. Holappa, & Mursula, K. (2017). Centennial evolution of monthly solar wind speeds: Fastest monthly solar wind speeds from long-duration coronal holes, Journal of Geophysical Research, 122, 2740–2747, https://doi.org/2016JA023683

- Kellerman, A. C., & Shprits, Y. Y. (2012), On the influence of solar wind conditions on the outer-electron radiation belt. Journal of Geophysical Research, 117, A05217. https://doi.org/10.1029/2011JA017253

- Paulikas, G. A., & Blake, J. B. (1979). Effects of the solar wind on magnetospheric dynamics: Energetic electrons at geosynchronous orbit, in Quantitative Modeling of Magnetospheric Processes. Geophysical Monograph Series, 21, 180–202

- Georgiou, M., Daglis, I. A., Rae, I. J., Zesta, E., Sibeck, D. G., Mann, I. R., Balasis, G., & Tsinganos, K. (2018). Ultra-low frequency waves as an intermediary for solar wind energy input into the radiation belts. Journal of Geophysical Research: Space Physics, 123, 10,090–10,108. https://doi.org/10.1029/2018JA025355

- Mann, I. R., O' Brien, T. P., & Milling, D. K. (2004), Correlations between ULF wave power, solar wind speed and relativistic electron flux in the magnetosphere: Solar cycle dependence. Journal of Atmospheric and Solar-Terrestrial Physics, 66(2), 187–198 (already included in the manuscript references)

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