

Ann. Geophys. Discuss., referee comment RC2  
<https://doi.org/10.5194/angeo-2021-56-RC2>, 2021  
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## Comment on angeo-2021-56

Anonymous Referee #2

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Referee comment on "The "SafeSpace" database of ULF power spectral density and radial diffusion coefficients: dependencies and application to simulations " by Christos Katsavrias et al., Ann. Geophys. Discuss., <https://doi.org/10.5194/angeo-2021-56-RC2>, 2021

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**Summary:** This work sets out an analysis of the SafeSpace electron diffusion coefficients database, comparing the magnitude of the magnetic and electric parts (relating to the formulation of Fei et al., 2006) under different environmental conditions parameterised by a number of indices. The method of calculating DLL using data from the THEMIS spacecraft is first described, followed by the main analysis. The time evolution of the ratio between DLLB and DLLE is discussed, and a comparison with various empirical models of DLL is then made, followed by an application of the SafeSpace coefficients using a physical model in order to simulate the outer electron belt over a month-long period. As part of the conclusion, the manuscript makes the claim that empirical models tend to underestimate DLL "at low levels of geomagnetic activity at all L\*" based on results of the earlier comparison, and that DLLB can reach values comparable to, or in excess of, DLLE for periods following ICMEs.

**General Comments:** The authors show some interesting details about the time evolution of DLL following geomagnetic disturbances (Fig. 5). The authors also show correlations between changes in DLL and various indices, and relate this to the physical processes driving each index (Fig. 3, 4). However, the method for calculating DLL from spacecraft data for the SafeSpace database is not clearly explained, and the authors do not clearly present evidence to support later claims that empirical models under/over-estimate just because they do not agree with SafeSpace. Some further discussion about the MLT-dependence of provided DLL is also required.

### Major comments:

#### 1. Section 2

As the authors are aware, DLL is used to quantify the time evolution of phase space density over many drift orbits due to small, repeated electromagnetic fluctuations. In this

work DLL is presented as MLT-dependent (or perhaps, the authors' method of calculating DLL from THEMIS data is sensitive to the MLT at which data was collected). In any case, Section 2 should address the physical meaning of the MLT dependence of SafeSpace DLL, and where this arises from.

In addition, Section 2 jumps directly into describing measurements, without describing what these measurements are being used for. In general, the structure of Section 2 should be reworked. As a starting point, an example way to order things might be:

DLL was calculated directly from measurements in order to construct a database parameterised by solar wind and geomagnetic parameters. To calculate DLL, we used an approach based on the Fei et al. (2006) formulation. This approach involved considering "the compressional component of the magnetic field..." . The calculation of DLLB and DLLE depends on ... These parameters were first determined using measurements from the THEMIS satellite.

[Then, describing how:] "We use 4-sec resolution measurements of the magnetic field vector..." "Complementary 1-min measurements of solar wind..." (etc.) "The THEMIS magnetic and electric field data were pre-processed by transforming them into a Mean 90 Field Aligned (MFA) coordinate system..." etc. [Then elaborate on the data processing method in more detail to put the MLT dependence in context.]

## 2. Section 4

The authors discuss the underestimation/overestimation by empirical models compared with the SafeSpace DLL. However, I feel it is important for the authors to also discuss the uncertainty in the SafeSpace DLL that may also be a cause of disagreement versus empirical models. This would strengthen the author's claim that the SafeSpace DLL are accurate.

### **Minor comments:**

#### 1. first paragraph

The first paragraph is vague. It is important to 'draw the reader in' at this stage. The authors could cut the first sentence down to something like, "The outer radiation belt

exhibits electrons at energies from a few hundred keV to several MeV [reference]."

Then the authors could go straight to the topic of radial diffusion, e.g.: "Radial diffusion has been established as one of the most important mechanisms causing energization [references] and loss [references] of relativistic electrons."

## 2. second paragraph

Again, the first sentence could be omitted. The second sentence could be expanded on like so:

"Ultra-Low Frequency (ULF) waves in the Pc4-5 band (1 and 22 mHz) can violate the third adiabatic invariant  $L^*$  of..." Next sentence: "This drives radial diffusion by..."

This way the explanation comes first.

## 3. line 34

The authors might consider replacing "something that runs counter to basic physical concepts of electromagnetism" with a more specific summary of the limitation. It is described well by Lejosne, 2019, and this paper is referenced in line 113. It can be referenced here as well.

## 4. line 51

Replace "limitations of" with "dependence on" (and in line 219)

## 5. a general comment about repetition

The word "moreover" beginning line 58 is repeated at the beginning of the next sentence, and it is also in the previous paragraph. Use an alternative here, for example, "Furthermore, observed DLL have been shown...". It can be omitted in the next sentence too, for example: "Several case studies have demonstrated..."

"Moreover" is used yet again on line 66, try instead something like:

"...overestimated by the empirical model of Ozeke et al. (2014). At times, the difference between empirically modelled values and event-specific diffusion coefficients was shown to be multiple orders of magnitude."

The word "Nevertheless" is also used three times from line 100 to 115. As before, it would read better with a substitute.

#### 6. line 75

There is a section 5 too, so don't use the word "finally" to describe section 4.

#### 7. Figure 1

The Figure 1 font is difficult to read, try something like Arial, Calibri, etc. and use a darker red background for the white text.

#### 8. line 139

The authors show that the CC between Psw and DLLE is weak. They then state that changes in Psw "are not really linked with the electric DLL component", yet mention that they are an important ULF wave generation mechanism. Are they implying the generation of ULF waves is not related to changes in DLLE? Be specific about this, rather than saying "not really linked".

#### 9. line 152

The distribution is shown in terms of the magnetic coordinate L\*, rather than a spatial coordinate. So if this is a spatial distribution, does it relate to the magnetic equator, or is there just no dependence on magnetic latitude, etc? Line 178 implies the dependence on latitude is weak, but, this should be clarified.

#### 10. line 170

"On the other hand, the observed asymmetry in the electric component indicates that DELL is not only linked with solar wind speed but with internal mechanisms such as substorm activity, something that is also in agreement with the results of figure 2. "

Explain briefly why the asymmetry indicates a link with internal mechanisms.

11. line 157 and line 190

"exceeds the value of 10..."

"a median value of 1000..."

Remember to always state units throughout

12. line 204 - 205

"up to two orders of magnitude compared with the magnetic component."

State that it is the ratio between the two which varies, from X up to  $\sim$ 100, etc.

13. line 212

"Also note that this feature present during SIR disturbances as well."

Where on Figure 5 is this shown? It's not as obvious as the change during ICMEs.

14. end of Section 3

In Section 3.1, line 124, the authors explain how the energy/first invariant dependence of DLL does not significantly change the CCs shown in Figure 2. Can the same be said for the ratio of DLLE to DLLB shown in Figure 4, for example, if DLLB is energy dependent, does it still increase above DLLE at other energies? A few words addressing this would be sufficient. However it is also necessary to elaborate on the following:

"Furthermore, at  $L^* > 6$ , the DBLL is comparable to the DELL up to approximately 12 hours after  $t_0$ ."

I am having trouble seeing this on Figure 5. What is meant by "comparable?" The conclusion on line 214 that DLL becomes energy dependent due to higher DLLB is only valid during the period following a disturbance, I presume. Therefore, it should be made clear how long this lasts, and what is the ratio of DLLE/DLLE, in order to show the reader this effect is important for radiation belt simulations.

#### 15. section 4 / figure 7

"As shown in the 500 keV electron energy, simulation results exhibit more injections at high  $L^*$  ( $4 < L^* < 5.5$ ) both during the relatively quiet period on early March and during the intense St. Patricks storm when using the calculated DLL..."

The injection events in Figure 7 seem to correspond to an external source of particles becoming trapped due to magnetic variability. Does this process involve diffusion? I am not sure why the different DLL leads to more injections.

The SafeSpace results do seem to show some improvement, but it would be better if the authors also addressed the disagreement between the MagEIS data and Salammbo results in either case, since it appears to be significant. I assume this disagreement is not just due to DLL, but rather a number of modelling factors.