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Geoscientific Model Development Discussions

# *Interactive comment on* "Evaluation of Monte Carlo tools for high energy atmospheric physics II: relativistic runaway electron avalanches" *by* David Sarria et al.

**Anonymous Referee #2**

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General comments:

The authors compare three different codes (Geant 4 with two different input parameters, GRRR and REAM) with respect to the formation of relativstic runaway electron avalanches (RREA). They compare fundamental properties such as the avalanche length, the mean electron energy or the photon energy distribution. They find that these three codes show a good agreement with each other. Where they do not, the authors try to elaborate which parameters might be responsible for the deviation. Finally, the authors give a recommendations regaring RREA simulations. In my opinion, this paper is valuable for the community. However, before publication, I have a few



suggestions on the presentation; I also think that some parts need further clarification.

Specific comments:

Abstract:

The authors mention the "effects of electric fields" (l. 5). I assume, this study is only about ambient fields and does not include self-consistent electric fields by solving the Poisson equation. Also, in line 10, it would already good to mention what kind of "stepping methodology" (line 10) is meant, i.e. of particles. The authors mention that they only tested electric fields until 3 MV/m; however, the electric field for thermal runaway, i.e. for all electrons to run away irrespective of their initial energy, is approx. 26 MV/m, why not consider fields between 3 MV/m and 26 MV/m?

1. Introduction:

1.1:

line 4: If it is about observations of high-energy phenomena, I would suggest to cite Fishman et al., 1994 in addition to Williams, 2010.

1.2:

In line 14, the authors talk about the energy regime of HEAP. However, they do not define this energy regime. Please be more precise in defining the energy range.

Futhermore, the authors write that some inidividual electrons do not survive. Especially, for high-energy electron beam, it would be good to name the reason for this. Also, please specify what values you consider "much larger than the ionisation threshold" (page 3, lines 23-24). On page 4, lines 14-15, the authors write "The minimum energy $\epsilon_2^{min}$ that can runaway is given by the requirement $F(\epsilon_2^{min}) > E$ [...]." But should the friction force not be smaller for runaway. Please clarify this. On page 5, the authors discuss the angular dependency (between the electron motion and electric field direction) on the run-away process. This has already been discussd very extensively by [O.

Chanrion et al., 2016. Influence of the angular scattering of electrons on the runaway threshold in air. Plasma Phys. Contr. Fus., vol. 58, 044001]. Please cite this article.

2. Model descriptions:

2.1:

The authors say that different sets of electro-magnetic cross sections are used. However, the authors do not state (neither in the main text nor in the supplementary material) which processes are actually taken into account. This is clearly missing, but crucial since simulation results strongly depend on the chosen processes and cross sections. The authors state where the cross sections come from and they make some comparison plots in section 8 of the supplementary material, but only for a few processes. Say, in the future, other researchers want to compare their results. Then, the knowledge of the used cross section data is crucial to interpret results. I would thus suggest to elaborate more on the processes and cross sections.

2.2:

On page 8/line 29, the authors say that GRRR uses the "energy at that instant" to calculate the collision rate $\nu_k$. However, it is not clear which energy: the energy of each individual particle, the maximum energy of all particles or the mean energy of all particles. Please clarify.

2.4.1:

For space-oriented codes, "a single particle is simulated over its entire life-time" (page 9/line 21). However, what is the reason to lose an electron (especially in the regime above several keV). The only reason to lose an electron would be attachment to air molecules. However, for this process to occur the electron normally needs to lose more energy than down to 10 keV. Please be more precise here.

2.4.2:



Why would "acceptable values of $\delta\ell_{max}$ depend on the electric field" (page 10/line 28)? It is very clear that it should be smaller than the electron's mean free path. But the mean free path depends on the electron energy rather than on the electric field. Please clarify the dependence on the electric field.

3. Probability of generating RREA:

In Figure 1, the authors present the probability that a single electron with an initial energy of 75 keV in an ambient field of 0.8 MV/m creates an RREA. As a criterion, they use that at least 20 electrons with an energy of 1 MeV are created. Please specify which value for $\delta\ell_{max}$ is used in panel a) and which value for $\alpha_R$ is used in panel b). However, I am confused, though. The friction force based on [A.V. Gurevich, 1961. On the theory of runaway electrons. Sov. Phys. JETP-USSR, vol. 12, pp. 904–912] is supposed to be 0.65 MeV/m for a 75 keV electron, thus the ambient field is definitely sufficient to accelerate the electron into the run-away regime. Of course, this does not mean that 20 electrons with energies are above 1 MeV, but 12% seems low. But this might depend on the simulation time. How long has the shower been simulated? It would also be good to see the RREA percentage for different criteria (20 electrons above 1 MeV, 10 electrons above 1 MeV, 5 electrons and finally 1 electron above 1 MeV which should give almost 100%). In Figure 2, the authors show the avalanche probabilities (10%, 50% and 90%) as a function of initial electron energy and ambient electric field. What about the right top (high energy, high field) and bottom left (low energy, low field) part? What are the probabilities there? There is so much space in this figure. Why not add some curves or values for these two regimes.

4. Characterisation of RREA showers:

4.2:

When discussing the evolution of the self-similar state , the authors say that they used a different number of seed electrons for Geant4, REAM and GRRR (page 16, lines 12–13). For consistency, I suggest to add one more case where the same number of seed electrons is used.

Figure 5 shows the time to reach the self-similar state. Comparing all the different models, it seems that the time to reach that is consistent within one order of magnitude. I propose to add this to line 14 on page 16.

4.3.1:

In Figure 6, the authors present the mean energy (of the self-similar state) as a function of the ambient field. It might good to remind the reader in the figure caption which value for $\alpha_R$ was used here for O1 andd O4. I am wondering how the plots for O1 and O4 would look for $\alpha_R$. It would be good to plot one case for a different $\alpha_R$ to show the dependence of the mean electron energy as a function of $\alpha_R$.

In Table 2, the authors present the fit parameters $a_1$, $a_2$ and $a_3$ of Eq. (20) for different models. Please add the error bars in order to judge the quality of these fits.

In Figure 7, the authors present the electron spectra at 128 m. But does 128 m refer to the z-coordinate or to the travelled distance $r = (x^2 + y^2 + z^2)^{1/2}$. Please clarify this in the figure caption and in line 5 (page 19), line 2 (page 20) and in the caption of Figure 8.

4.3.2:

In section 4.3.2, the authors state that a comparison with photon measurements is difficult because of the attenuation of photons in air. Whereas I agree in general, there are some issues I would like to address. The authors say that a 100 keV photon at 12 km altitude travels 1540 m in average, a 50 keV photon 671 m and a 20 keV photon 63 m. Where do these values come from? Is this a result of their simulations (if so, how did you obtain these); if not, please cite your source. I made a brief comparison with NIST data (http://physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html) and obtained attenuation lengths of approx. 2000 m for 100 keV, 1600 m for 50 keV and 500 m for 20 keV. This needs to be clarified. Additionally, the authors say that the “photons



have no chance to escape the atmosphere and to be detected by a satellite” (pages 20/21). I would like to remind the authors that the “average path travelled” (page 20/line 14) or the attenuation length is only an average. Hence, there can always be photons which espace the atmosphere and may be detected at satellite altitudes even though the probability is low. Actually, Fermi has measured photons with energies between 10 and 500 keV (see https://gammaray.nsstc.nasa.gov/gbm/science/terr_grf.html). Please be more precise here.

4.4:

In the supplementary material, section 9.2., I cannot find any plot showing the parallel velocity $\beta_{\|}$ (only the mean Z speed; or is the mean Z speed meant to be $\beta_{\|}$). Maybe, it is there, but at least not apparent. Could the authors please point me to the correct plot?

Technical corrections:

Abstracts:

line 2: “particles and associated” → “particles associated”

1. Introduction:

1.1: page2/line 12 and overall the manuscript: It is rather common to abbreviate “Terrestrial gamma-ray flashes” with TGFs than with TGF.

page 2/lines 29/30: Köhn and Ebert, 2015. also discuss electron acceleration in the vicinity of lightning leaders instead of from streamer tips.

page 2/line 30: Kohn → Köhn

page 2/line 34: A fullstop is missing

page 3/line 6: lighting → lightning

1.2:

page 3/line 22: keeps → keep

page 4/line 13: 1-dimension → one dimension

page 5/line 5: equation → equations

1.3:

page 6/line 19: consists in → consists of

page 6/line 28: that energy the spectrum → that the energy spectrum

1.4:

page 7/line 3: Kohn et al. → Köhn et al.

2. Model description:

2.1:

page 8/line 15: this parameters was thought to be responsible major change → this parameter was thought to be responsible for a major change

2.4.1:

page 9/line 26: loose → lose

2.4.2:

page 10/line 13: in previous section → in the previous section

3. Probability of generating RREA:

page 11/line 29: as function → as a function of

page 12/line 1: for O1 → for O1 and O4

4. Characterisations of RREA showers:

4.1:



page 13/line 4: Figure → Figures

page 13/line 14: s. V/m → s· V/m

page 14/line 14: value → values

4.2:

page 14/line 24: spectra of relativistic → spectra of a relativistic

page 14/line 28: looking to the mean electron energy evolution as function of time → looking at the mean electron energy evolution as a function of time

page 14/line 30: all the energy of each individually recorded electrons → all the energies of each individually recorded electron

page 16/line 2: are → is

page 16/line 7: electrons → electron

page 16/line 20: conclude to an → conclude an

4.3 (page 17):

line 2: for photon → for photons

4.3.2:

page 20/line 2: O4/O4 → O1/O4

page 20/line 9: large large → large

6. Recommendations (page 23):

line 15: looses → loses

line 19: Maybe it s a good idea to define $\alpha_R$ as “dR over Range” earlier in the manuscript.

lines 24/25: The authors say that single Coulomb scattering would “increase the necessary computation time”. Should using a single scattering (instead of multiple scattering) not decrease the computation time?

line 26: we provide link → we provide a link

7. Code and/or data availability (page 24):

line 4: figure → figures

Appendix A: Geant4 relative performance:

page 24/line 24: Table A1 → Table 3 (Or change table 3 to table A1)

page 24/line 24: Electric field → electric field

Caption of Figure 3 (page 25): dRoverRange → dR over Range

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