Monte Carlo Simulation of Terrestrial Gamma-ray Flashes

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Introduction

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Monte Carlo Model
Results
Conclusions

- Electron-positron annihilation
- Pair production
- Compton scattering
- Photoelectric absorption
- Bremsstrahlung Radiation
- E > E_t (~2 kV/cm at ground pressure)
- IC lightning

EARTH
Lightning Leader Tip
Terrestrial Gamma-ray Flashes (TGFs) are high-energy photon bursts originating from the Earth’s atmosphere. TGFs were first discovered in 1994 by the Burst and Transient Source Experiment (BATSE) detector aboard the Compton Gamma-Ray Observatory (CGRO) [Fishman et al., Science, 264, 1313, 1994].

This phenomenon has been further observed by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), the Fermi Gamma-ray Space Telescope and the Astrorivelatore Gamma a Immagini Leggero (AGILE) satellite.

In theory, potential and fluence of energetic electrons produced during negative corona flashes of +IC lightning leaders are high enough to produce TGFs [Celestin and Pasko, JGR, 116, A03315, 2011].
Is the photon spectrum produced by energetic electrons accelerated in lightning leader tip fields consistent with satellite measurement of TGFs?
Monte Carlo Model

The Monte Carlo code we developed is based on the model described in [Østgaard et al., JGR, 113, A02307, 2008]. It simulates bremsstrahlung radiation and photon transport.

- **Bremsstrahlung radiation** (or “braking radiation”) is produced by the acceleration of charged particles. Braking of energetic electrons in the high-field of atomic nuclei produces a copious amount of X-rays. The bremsstrahlung differential cross section formula is taken from [Lehtinen., PhD thesis, Stanford Univ., 2000, Section 3.2.1].

- As for the **photon transport**, three different photon collision types are considered.
Accelration of energetic electrons

- We studied the production and transport of energetic electrons by lightning leader with given electrical properties [Celestin and Pasko, 2011].
- We use a long unbranched intracloud lightning discharge in our model transporting negative charges upward (+IC): length 4 km, radius 1 cm, propagating under an ambient large-scale electric field of 0.5 kV/cm.
Photon transport

- We consider three collision types: photoelectric absorption (main process for energies <30 keV), Compton scattering (main process from 30 keV to 30 MeV) and electron-positron pair production (main process for energies >30 MeV).
Results

(a) The solid curves are simulated TGFs spectra at 500 km corresponding to sources with the same broad-beam geometry (isotropic within a 45° angle) positioned at different altitudes. (b) The solid curves are simulated TGF spectra at 500 km corresponding to narrow-beam geometry sources positioned at different altitudes. The RHESSI data are taken from [Dwyer and Smith, 2005] and the detector response matrix is taken from http://scipp.ucsc.edu/~dsmith/tgflib_public/data/.

- The photon spectrum produced by acceleration of electrons during negative corona flashes matches the TGF spectrum measured!
- We found that a TGF source located at around 10 km best fits the RHESSI spectrum.
Test surfaces with horizontal orientation are placed in source region to record the counts of gamma-rays.
This simulation is done to be compared with results of the ADELE experiment [Smith et al., GRL, 38, L08807, 2011]. A test surface of 65 cm² that represents a “perfect” detector is placed at 14 km altitude while the source is launched from different altitudes (10 km–19 km) and different radial distance (0 km–9 km).

Our results are in good agreement with [Smith et al., 2011, Figure 1].
Conclusions

- A detailed Monte Carlo model that simulates bremsstrahlung radiation and photon transport has been developed.

- TGF spectrum is reproduced by the bremsstrahlung radiation produced by electrons accelerated during negative corona flashes.

- We found that a TGF source of photons produced by the stepping of a long unbranched lightning leader, located at around 10 km best fits the RHESSI spectrum. As expected, the initial altitude and the angular distribution both contribute to the TGFs spectrum. However, a broad-beam geometry is consistent with the electric field in the vicinity of a lightning leader tip [Carlson et al., JGR, 114, A00E08, 2009].

- Studies about fluence of TGF photons in thunderstorm launched from 10 km to 19 km altitude have been carried out. Our results are in good agreement with [Smith et al., GRL, 38, L08807, 2011, Figure 1].
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Thank you for your attention!