Recent results in TGF research – observations and theories

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In this paper recent results from the research of terrestrial gamma flashes (TGFs) will be reviewed. In order to be seen from space by instruments like RHESSI these flashes have been found to require about 10^{16}-10^{18} electrons accelerated to relativistic energies (up to ~40 MeV or even above) in less than 1 ms. This paper will cover the latest observational results that can help us understand how these flashes are produced: the connection to IC+ lightning, the duration of TGFs, do TGFs occure before or after lightning, geometry of the electric fields, electron beams and positrons, and how common are TGFs? Some theories that have been suggested to explain how this large number of relativistic electrons can be produced in electric fields of thunderclouds will be presented. Focus will be given to the feedback-mechanism [34] and the streamer-leader electric field model [35].

1. Introduction

With the discovery of terrestrial gamma flashes (TGFs) above thunderstorms [1] by the Burst and Transient Source Experiment (BATSE) a new mechanism of the coupling between the lower atmosphere and space was found. The phenomenon involves gamma photons, relativistic electrons and positrons. Charged particles are accelerated in extremely strong electric fields (> 300 kV/m sea level equivalent) associated with lightning discharges and initiate a relativistic run-away process [2]. Through interaction with the neutral atmosphere bremsstrahlung is produced, resulting in the escape of electrons [3], positrons [4] and gamma photons into space. There are still many open questions related to TGFs. In this paper recent results that can help us understand how the large number of relativistic electrons needed to account for the observations of TGFs from space can be produced in the electric fields of thunderclouds will be reviewed.

2. Observed characteristics of TGFs

From the first observations it was believed that the TGFs are produced above 40 km and that they were related to transient luminous events [1], a reasonable suggestion given the relatively few observations of about 10 TGF/year by BATSE. However, results from Reuvan Ramaty High Energy Solar Spectroscopic Imager (RHESSI) ten years later indicated that their production altitude is most likely around 15-21 km [6]. Reanalyses of the BATSE data have also confirmed a production altitude of TGFs below 20 km [7, 8, 9]. Consistent with this production altitude and general lightning physics, Williams et al., [10] speculated that TGFs are related to positive intracloud lightning (IC+), a suggestion that has been supported by several studies comparing TGFs with electromagnetic characteristics of lightning [11, 12, 13, 14, 15].

When first discovered TGFs were estimated to have ~1 ms duration [1]. More recent results indicate an average duration of 200-300 μs [9, 16] but can be as short as 50 μs [17].

Several studies indicate that TGFs are observed slightly before the sferics from lightning [13, 14, 18]. However, these are based on RHESSI observations that have a well-known uncertainty in the timing. New studies based on Fermi detection of TGF [15, 19] may indicate that TGFs occur simultaneously with the sferics. On the other hand, all detections of X-rays from cloud-to-ground (IC-) [e.g., 20] and from laboratory discharges [22] show that X-ray bursts occur before the return stroke.

Some studies have estimated the spatial distribution of photons in a TGF and found that they are spread over a half cone-angle of about 30°-40° [23,24], which might be an indication of fairly vertical electric fields.

While BATSE identified energies >1MeV [1], RHESSI measured ~20 MeV [25] and Agile energies above 40 MeV [26] and even at 100 MeV [27]. From CG- lightning energies >1MeV [21] has been measured.

As IC lightning accounts for about 75% of all the lightning and most of these are IC+ lightning bringing negative charges upward, this may imply that TGFs are a rather common phenomenon. By applying a new search algorithm to the RHESSI data Gjesteland et al. [29] found twice as many TGFs in this dataset than previously reported [16]. On the other hand, Smith et al. [30] reported only one TGF from more than 1000 discharges. However, by comparing TGF distributions by RHESSI and Fermi and taking into account the instruments different sensitivity, Østgaard et al., [31], despite the non-detection by ADELE, found that from TGF observations so far, we can not rule out that all lightning may produce TGFs.

2. Theories to explain the production of TGFs

In the early days of TGF research two theories were suggested to explain the TGFs: the Quasi-Electro-Static (QES) [32] and the Electro-Magnetic Pulse (EMP) theory [33], but none of these models are really supported by recent observations. However, some new compelling theories have recently been presented.

The feed-back theory [34]: The seed electrons are provided by cosmic rays or streamer electric fields and a large ambient electric field provides a potential of ~100 MV, and the positron/gamma-ray feedback mechanism contributes to the RREA process by producing sufficient relativistic electrons to account for the observed flux of photons.

The leader/streamer theory [35]: The seed electrons are produced in the steamer electric fields and further accelerated in the stepped leader electric field.

Related to this is the current pulse model [36].

Both these theories are consistent with the few observations we have so far. With new and more comprehensive datasets of TGF observations we might be able to verify or falsify these theories.

3. References

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