Usage Report for Fiscal Year 2021

Project Title:

Particle Analysis Regarding Macro-Effects in Thunderstorms

Name:

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1. Background and purpose of the project, relationship of the project with other projects

High Energy Atmospheric Phenomena (HEAP), although the late discovery with the Terrestrial Gamma-ray Flashes (TGFs) [Fishman et al., 1994], are thought since much earlier as in (Wilson [1924], Wilson [1925] and Libby and Lukens [1973]). Different HEAP aspects have been observed over the years as; TGF spatial distribution and energy spectrum (Briggs et al [2010], Smith et al. [2005] and Tavani et al. [2011]), particle production – in particular, neutron production (Shah et al. [1985], Shyam and Kaushik [1999], Gurevich et al. [2012], Bratolyubova-Tsulukidze et al. [2004], Martin and Alves [2010]), as well as extended gamma-ray emissions so-called gamma-ray glows or Thunderstorm Ground Enhancements (TGE) (Tsuchiya et al. [2007], Tsuchiya et al. [2012], Chilingarian [2013], Kelley et al. [2015] Wada et al. [2019]). All the HEAP sets have a common starting point with Relativistic Runaway Electron Avalanches (RREA) which implies a large multiplication of high-energy electrons (~1 MeV).

Alternatively, gamma-ray glows may occur under thunderstorm electric fields with strengths lower than the required for RREA through the Modification Of Spectra (MOS) process (Chilingarian et al. [2012]) that consists basically of modify the cosmic-ray spectrum by accelerating the charged particles passing through the thundercloud.

The project analyses how weak to moderate electric fields extend the electron spatial range without causing RREA, as thunderstorm electric fields below the RREA threshold (0.284 MV/m) are more common, by Monte Carlo simulations with the GEometry ANd Tracking 4 (GEANT4) toolkit which provides required physics and statistics to solve such event with large number of particles. Monte Carlo simulations require high computational power, and the super-computer usage allows analysis time reduction while also improve the statistics for the study. A series of theoretical papers are planned to explain the gamma-ray phenomenon, the first one being published in this fiscal year as indicated. Our future results will be compared with Gamma-Ray Observation of Winter Thunderclouds (GROWTH) collaboration measurements.

2. Specific usage status of the system and calculation method

The current project uses HOKUSAI services to simulate particles' motion in the air with Monte Carlo program GEANT4 as described in (1). Extensive use of bulk jobs aimed the reported objective. Currently 4.3% of the disk quota is occupied. The project started in June/2020 and providing ongoing results parallel to the presented publication.

3. Result

The MOS phenomenon is a viable mechanism to produce gamma-ray glows as it relies on electric field strengths that easier to sustain in thundercloud environment. Such field magnitude makes electrons able to travel further in the air by effectively reducing the energy loss which alter their spectra for a given altitude although not allowing electrons to reach avalanche regime thus any electron beam accelerated by weak to moderate electric fields will eventually vanish.

The published publication explains and quantify how weak to moderate electric fields expands the passing electron range and provide the possibility for enhanced gamma-ray emission. Our results shows that MeV electron beams already has a fully recovered energy under 0.280 MV/m indicating a transition to avalanche regime, meanwhile, we estimated through hybrid calculations with both analytical and computational approaches that weaker electric fields can extend the electron spatial range by a factor of 2-10.

4. Conclusion

HOKUSAI services were able to provide the laboratory high quality simulation data. The high resolution calculation allowed the perception with correlation with previous measurements that displayed simultaneous research work possibilities.

5. Schedule and prospect for the future

Following the proposed schedule, this is the first publication to analyze the role of moderate electric fields in electron motion and gamma-ray production. A new simulation setup is under preparation with new data sets to expand the study on gamma-ray production and compare with GROWTH measurement data.

6. If no job was executed, specify the reason.

N/A

Fiscal Year 2021 List of Publications Resulting from the Use of the supercomputer

[Paper accepted by a journal]

Gabriel Sousa Diniz, Yuuki Wada, Yutaka Ohira, Kazuhiro Nakazawa, Teruaki Enoto, Atmospheric electron spatial range extended by thundercloud electric field below the relativistic runaway electron avalanche threshold, Journal of Geophysical Research: Atmospheres, 127, e2021JD035958. https://doi.org/10.1029/2021JD035958

[Oral presentation]

Gabriel Sousa Diniz, Yuuki Wada, Yutaka Ohira, Kazuhiro Nakazawa, Teruaki Enoto, Atmospheric electron range extended by thundercloud electric field below the relativistic runaway electron avalanche threshold. AGU 2021, New Orleans, USA, remote presentation.