Usage Report for Fiscal Year 2022

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) is quite old and was already considered as early as the era of Wilson (Wilson [1924], Wilson [1925] and Libby and Lukens [1973]), although this field was eventually established after the late discovery of the Terrestrial Gamma-ray Flashes (TGFs) [Fishman et al., 1994]. 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 value for RREA through the Modification Of Spectra (MOS) process (Chilingarian et al. [2012]), which includes basically modification of the cosmic-ray air shower spectrum by accelerating charged particles passing through the electric field in thunderclouds.

The proposed project analyses how atmospheric electric fields interact with the cosmic-ray electron flux producing gamma-ray glows, by Monte Carlo simulations with the GEometry ANd Tracking 4 (GEANT4) toolkit which provides required physics and statistics to solve such physical event with large number of particles with the cosmic-ray spectral input from the EXcel-based Program for calculating Atmospheric Cosmic-ray Spectrum (EXPECS). Monte Carlo simulations require high computational resources and the super-computer usage allows us to reduce analysis time, while we can also improve the study's statistics. A series of theoretical papers are planned to explain the gamma-ray phenomenon, the first one being published in this fiscal year as scheduled. Our results are compared with the real measurements of the Gamma-Ray Observation of Winter Thunderclouds (GROWTH) collaboration. The comparison gave the parameter ranges of ambient atmospheric whether conditions required for the observed gamma-ray glow spectrum.

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 the paper (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 as well as the submitted publication.

3. Result

The MOS phenomenon is a viable mechanism to produce gamma-ray glows because it relies on electric field strengths that easier to sustain in thundercloud environment. Such field magnitude makes electrons to travel further in the air than the null field case by effectively reducing the energy loss, and alter electron spectra at a given altitude, although not allowing electrons to reach the avalanche multiplication regime. Thus any electron beam, accelerated by this weak or moderate electric field strengths will eventually vanish.

However, MOS mechanism is able only to explain dim glows. The average gamma-ray glow spectrum requires electric fields close to the RREA threshold within a region of approximately 1 km which is not enough for the avalanche reach steady state. Additionally, the observed spectrum also needs a region with no strong electric field between the cloud base and the observation site on the ground to attenuate the low-energy spectrum part and to reproduce the observed shape.

The submitted publication (1) maps the phase space composed by three parameters: electric field strength, electric field length, and attenuation region size, showing which of this three-dimensional phase space is capable of producing the average observed spectrum.

4. Conclusion

HOKUSAI services were able to provide the laboratory high quality simulation data. The high resolution calculation allowed comparison between the simulation and previous measurements that shows the ambient conditions requirements to produce the observed spectrum.

5. Schedule and prospect for the future

Following the proposed schedule, this is the second publication to analyze the role of moderate electric fields in electron motion and gamma-ray production. A new simulation setup is already running to analyze the behavior of under the developed RREA in realistic atmosphere.

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

N/A

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Fiscal Year 2022 List of Publications Resulting from the Use of the supercomputer

[Poster presentation]

Gabriel Sousa Diniz, Yuuki Wada, Yutaka Ohira, Kazuhiro Nakazawa, Teruaki Enoto, The Possible Role of Electric Fields Strengths Below Relativistic Runaway Electron Avalanche Threshold in Gamma-ray Glow Emissions. ICAE 2022, Tel'Aviv, Israel.