The journey of the Terrestrial Gamma Flashes: propagation through the atmosphere

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Just as important is to understand the mechanisms of ignigtion-production of TGFs like mechanisms of propagation of these through the atmosphere. For this purpose, the University of Valencia has developed different simulation tools. The analysis is carried out using the Geant4 toolkit. On the one hand it has developed a mass model for its use in Geant4 applications to characterize the response of the instrument to the incident high-energy radiation, and the effects of background from backscattered photons from the Columbus module. On the other hand it was developing a set of atmospheric models to set up Geant4 simulations of electron avalanche and gamma-ray propagation, with emphasis on the possible residual optical emission due to interaction with atmospheric components. This simulation tool allows us to test, calculate and analyze several important variables in the process of ignigtion and TGFs propagation through the atmosphere, such as different field geometries in and above storm clouds, ionizations, structure of electron tracks, the time evolution of photon-electron-positron density, flux fields, the influence of electric fields.

1. Introduction: ASIM mission, a brief overview

The Atmosphere-Space Interactions Monitor (ASIM) is an ESA mission which will be placed on the Columbus module on the International Space Station (ISS). ASIM will study the coupling of thunderstorms processes to the upper atmosphere,ionosphere and radiation belts and energetic space particle precipitation effects in the mesosphere and thermosphere.

The scientific objectives include inter alia investigations into sprites, jets, elves and relativistic electron beams injected into the magnetosphere above thunderstorms, lightning-induced precipitation of radiation belt electrons, ozone and NOx concentrations in the upper atmosphere, and the characterization of the optical and high-energy emission related to severe thunderstorms.

In this sense, it is setting up a set of simulations in order to analyse the expected detections from the sensors of ASIM , in particular from the Modular X-ray and Gamma-ray Sensor (MXGS) imager.

There are still no simultaneous observations of lightning, giant lightning and X- and gamma-radiation. ASIM will be the first dedicated scientific mission to try to observe all these at the same time.

2. Lightning field induced perturbations to the atmosphere

X- and gamma-radiation is a sign of ionisation in thunderclouds and ions are considered important for condensation of water vapour into cloud drops. The formation and development of thunderclouds are then affected by the electrical processes in the clouds [1].

The upper troposphere, lightning is the major source of nitrogen oxids (NO_x). NO in the troposphere is important because it modifies the ozone (O_3) and methane (CH_4) chemistry, increasing the concentration of the former and lowering that of the latter. Some important challenges remain, such as improving the quantification of NO production by lightning and understanding better the roles of lightning in global change. Likewise, the local effects of the TGFs production on upper atmospheric chemistry are not well understood. Better observations and kinetic models of the electric discharge are needed to answer these and other important questions.

For this purpose, on the one hand it has developed a mass model for its use in Geant4 applications to characterize the response of the instrument to the incident high-energy radiation, and the effects of background from backscattered photons from the Columbus module.

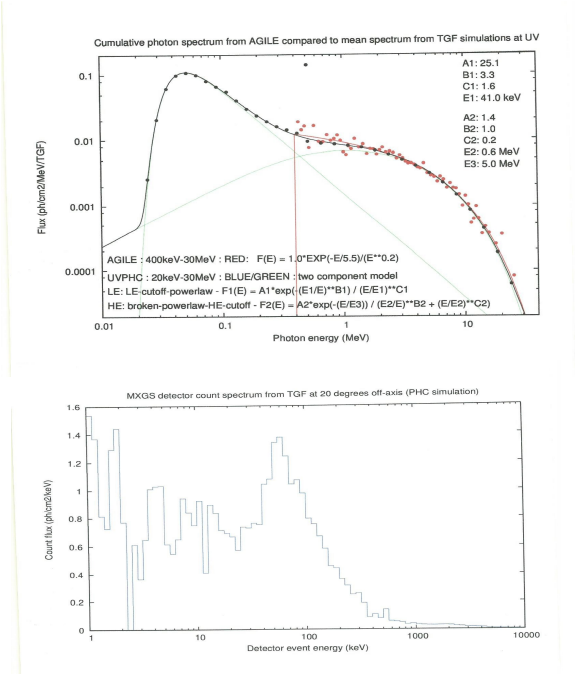

Figure 1: Some of the results of high-energy radiation and effects of the background simulated by UV-GEANT4 workspace (images provides by P.H.Connell).

On the other hand it was developing a set of atmospheric models to set up Geant4 simulations of electron avalanche and gamma-ray propagation, with emphasis on the possible residual optical emission due to interaction with atmospheric components, and the expected spectral and timing properties of the resulting high-energy emission towards space including comparisons with other toolkit LEPTRACK (under developed at the University of Valencia, P.H. Connell).

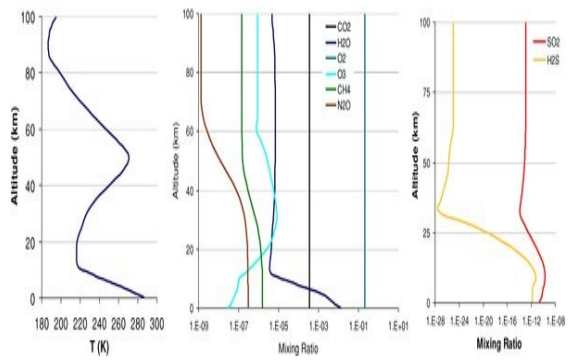

Figure 2: Profile of diverse pollutants (for study the possible interacctions with the RREA [2,3].

2. Simulation toolkit : GEANT4

Geant4 (**GEometry ANd Tracking)** is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science [4], [5]. Geant4 software is based on Monte Carlo simulations. It includes facilities for handling geometry, tracking, detector response, run management, visualization and friendly user interface. For many physics simulations, this means less time need be spent on the low level details.

2.1. Workspace and obtained results

The create workspace allows us to test, calculate and analyze several important variables in the process of ignigtion and TGFs propagation through the atmosphere, such as different field geometries in and above storm clouds, ionizations, structure of electron tracks, the time evolution of photon-electron-positron density, flux fields, the influence of electric fields.

We search a reasonable computer time with a sufficient accuracy and representationally. For this reason we try different configurations of simulation boxes in order to optimize the detail/time simulation. A box with 1x0.5x0.5 km with air in low density (14-17 km height) and a small box with 40x40x40 m within electric field inside seems to produce good detail/time results.

3. References

[1] A. J. Dean et al., “The gamma ray emissivity of Earth’s atmosphere,” Astron. Astrophys., vol. 219, pp. 358–361, 1989.

[2] A. E. Hedin, Extension of the MSIS Thermospheric Model into the Middle and Lower Atmosphere, J. Geophys. Res. 96, 1159, 1991.

[3] J.M. Picone, A.E. Hedin, D.P. Drob, and A.C. Aikin, NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues, J. Geophys. Res., 107(A12), 1468, doi:10.1029/2002JA009430, 2002.

[4] Agostinelli, S.; Allison, J.; Amako, K.; Apostolakis, J.; Araujo, H.; Arce, P.; Asai, M.; Axen, D. et al. (2003). "Geant4—a simulation toolkit". *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **506** (3): 250.

[5] Allison, J.; Amako, K.; Apostolakis, J.; Araujo, H.; Arce Dubois, P.; Asai, M.; Barrand, G.; Capra, R.; Chauvie, S.; Chytracek, R.; Cirrone, G.A.P.; Cooperman, G.; Cosmo, G.; Cuttone, G.; Daquino, G.G.; Donszelmann, M.; Dressel, M.; Folger, G.; Foppiano, F.; Generowicz, J.; Grichine, V.; Guatelli, S.; Gumplinger, P.; Heikkinen, A.; Hrivnacova, I.; Howard, A.; Incerti, S.; Ivanchenko, V.; Johnson, T. et al. (2006). "Geant4 developments and applications". *IEEE Transactions on Nuclear Science* **53**: 270.