Space Weather Alerts for Air Navigation

Sergio Pinilla[1], Hernán Asorey[1,2], Luis Núñez[1]

1. Escuela de física, Universidad Industrial de Santander, Bucaramanga, Colombia
2. DPRLab, Centro Atómico Bariloche & Instituto Balseiro, Bariloche, Argentina

Introduction

As altitude increases, the atmosphere protective layer becomes thinner and less dense, that's why the incidence of cosmic radiation on an airplane flying between 10 km - 12 km is $\sim 100-300$ times higher than at ground levels. Besides altitude, there are other factors that may affect the dose received, such as latitude, space weather, and time of exposure.

The aim of this work is to determine the total integrated flux of cosmic radiation which a commercial aircraft is exposed to along specific flight trajectories. In order to study the radiation background during a flight and its modulation by effects such as altitude, latitude, exposure time and solar events, we perform simulations based on codes *Magnetocosmics* and *CORSIKA*, the former designed to calculate the geomagnetical effects on cosmic rays propagation and the latter allows us to simulate the development of extended air showers.

Rigidity of a particle

The motion of a charged particle through a magnetic field is described by the relativistic Lorentz equation of motion:

$$\frac{d\vec{p}}{dt} = \frac{q}{c}\vec{v} \times \vec{B}$$

This equation of motion conserves the magnitude of the momentum p, and therefore the energy of the particle. After some transformations, it becomes:

$$\frac{d\hat{\boldsymbol{I}}_{\boldsymbol{v}}}{ds} = \frac{q}{pc}\hat{\boldsymbol{I}}_{\boldsymbol{v}} \times \vec{B}$$

where $\hat{\boldsymbol{I}}_{\boldsymbol{v}}$ is the unit vector in the direction of velocity and s is the path length along the particle trajectory. The rigidity of the particle is defined by:

$$R = \frac{pc}{q}$$

And it is a measure of the resistance of the particle to the bending of its trajectory by the magnetic field.

Rigidity cut-off: It is the lower rigidity limit above which cosmic rays can cross the Earth magnetosphere and reach a specific position from a specific observational direction. It depends on the geographical coordinates and on particle's direction of arrival.

Earth magnetic field models

Internal field ($r < 5R_E$)

The International Geomagnetic Reference Field (IGRF) is an internationally agreed and widely used mathematical model of the Earth magnetic field of internal origin. In this model:

$$\vec{B} = -\vec{\nabla}V \qquad \nabla^2 V = 0$$

Each constituent model of the IGRF is a set of spherical harmonics of degree n and order m, representing a solution to Laplace's equation for the magnetic potential arising from sources inside the Earth at a given epoch; the harmonics are associated with the Gauss coefficients g_n^m and h_n^m:

$$V(r,\theta,\lambda) = a\sum_{n=1}^{n_{max}}\left(\frac{a}{r}\right)^{n+1}\sum_{m=0}^{n}(g_n^m \cos m\lambda + h_n^m \sin m\lambda)\, P_n^m(\theta)$$

External field ($r > 5R_E$)

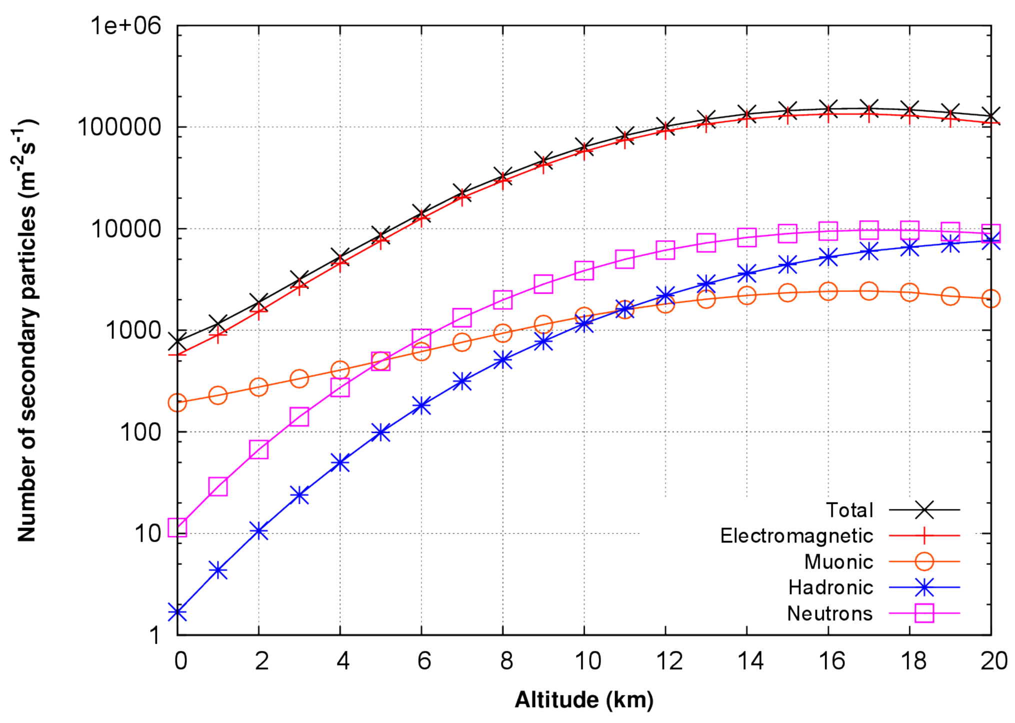
Beyond five Earth radii, the Earth magnetic field is increasingly affected by the solar wind interaction with the Earth magnetosphere. The distortions can be described by several external source fields caused by magnetospheric current systems.

The Tsyganenko model is a semi-empirical best-fit representation for the magnetic field, based on a large number of satellite observations (IMP, HEOS, ISEE, POLAR, Geotail, etc). The model includes the contributions from external magnetospheric sources: ring current, magnetotail current system, magnetopause currents and large-scale system of field-aligned currents.

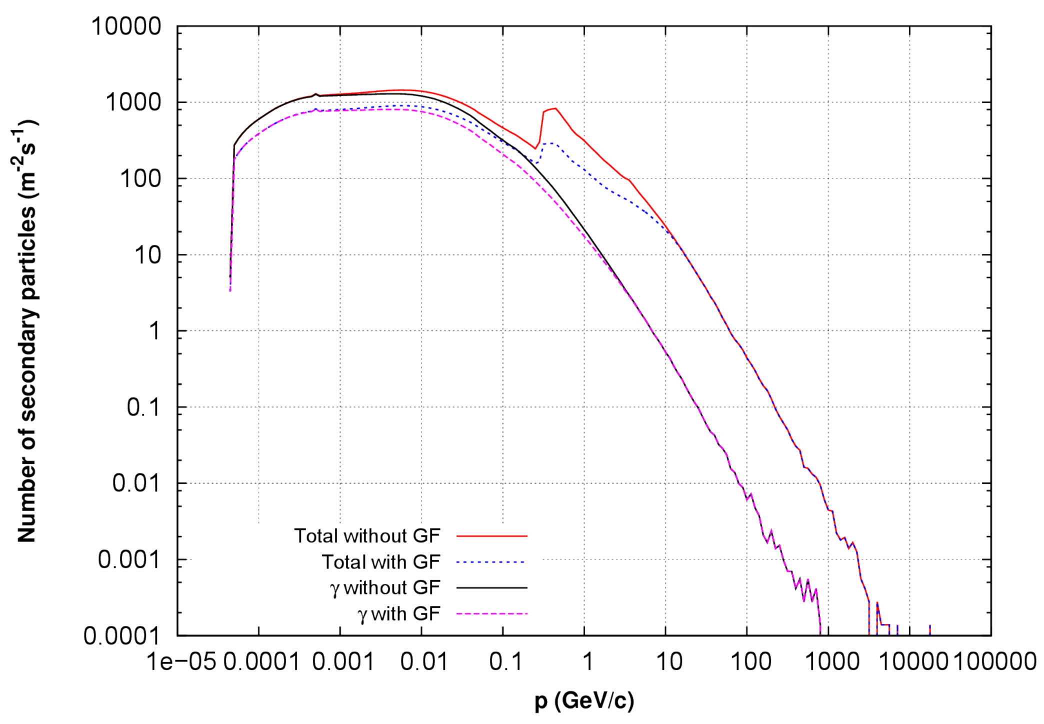
Strategy

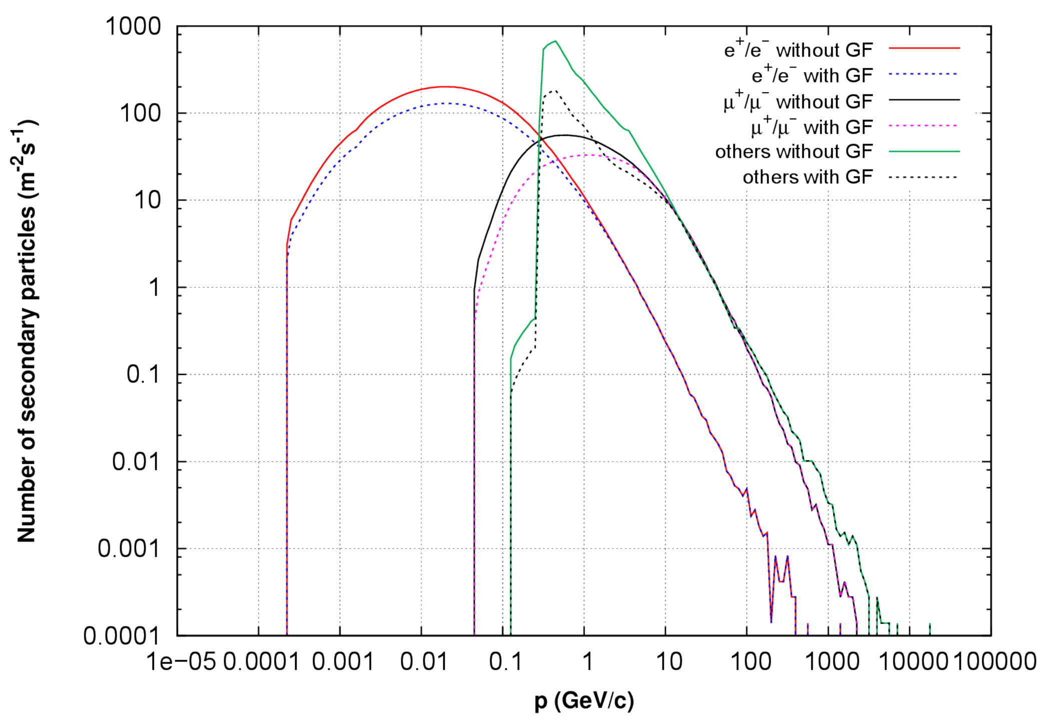
1. Simulation of showers at a specific site (longitude, latitude, altitude) using *CORSIKA*. Features of injected primaries at the top of the atmosphere:
   - Nuclei considered: $1 \leq Z_p \leq 26$, $1 \leq A_p \leq 56$
   - Very low cut-off rigidity: $R_c = 4GV$
   - Energy and direction of arrival: $(R_c \times Z_p) \leq (E_p/GeV) \leq 10^6$, $0° \leq \theta_p \leq 90°$, $0° \leq \phi_p \leq 360°$
   - Simulation time: $t = 7200s$ (primary particles flux is constant and isotropic)
2. Selection and discretization of routes.
3. Computation of cut-off rigidities for each point in the trajectory using *Magnetocosmics*.
4. Filter of the first simulated showers according to the cut-off rigidities computed for each point of the trajectory: showers generated by primary particles with rigidities below the cut-off rigidities are discarded.
5. Computation of the total amount of particles that hit the aircraft. This is done asuming a constant flux of secondaries on each interval of the trajectory and adding them together.
6. To consider diferent magnetospheric conditions, it is possible to vary the DST index (Disturbance Storm Index).

First results

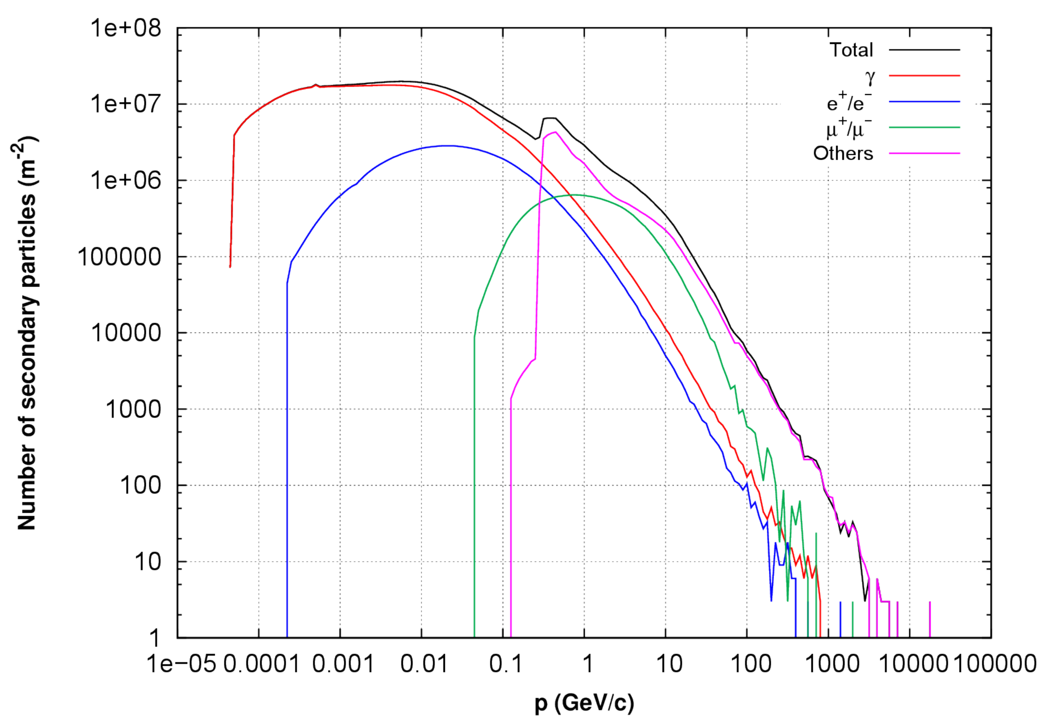


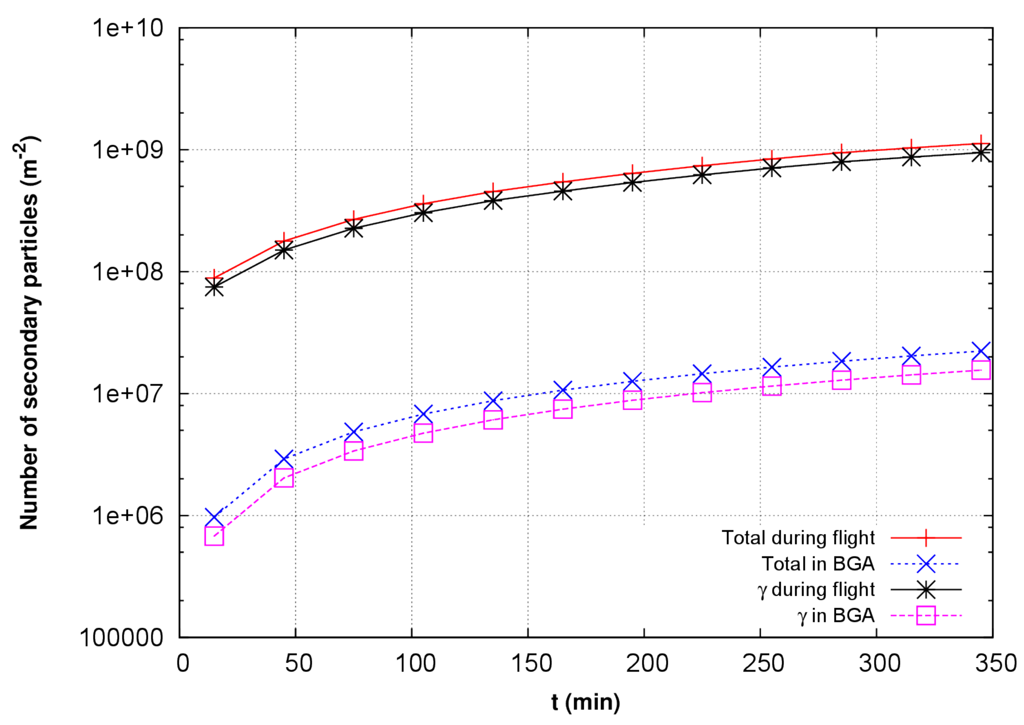
Figures 1,2: **1**(*Left):* Flux of particles as function of altitude in Bucaramanga ($7°07'N$ $73°07'W$, $h_0 = 1000\ m.a.s.l.$) **2**(*Right):* Bogotá - Buenos Aires: this route was divided into 12 intervals of equal flight time and the flux of secondaries along each of them was assumed to be constant and equal to the flux in the midpoint (blue dots). Takeoff and landing was not included in this preliminar analysis, the aircraft was supposed to fly at a constant altitude of 11 km along the whole trajectory. The data used corresponds to flight ARG1361, made on 24-11-2014.





Figures 3,4: Distribution of particles considering the Geomagnetic Field (GF) in $14.74°S$ $67.27°W$ (dashed lines), total flux=50198 $part.m^{-2}s^{-1}$, ratios: EM:MU:NE:HD=0.940:0.020:0.029:0.011. And not considering GF (continuous lines), total flux=82443 $part.m^{-2}s^{-1}$, ratios: EM:MU:NE:HD=0.900:0.019:0.061:0.020





Figures 5,6: **5**(*Left):* Distribution of particles during the flight Bogotá - Buenos Aires. **6**(*Right):* Integrated flux as function of time during the flight (continuous lines) and staying quiet in Bucaramanga (dashed lines).

Conclusions and acknowledgements

The simulations performed show that at flight level, the number of secondary particles is two orders of magnitude greater than at 1000 m.a.s.l. When calculating the dose absorbed, geomagnetical effects must be taken into account since they reduce the number of primary particles that generate showers. To make more accurate calculations, aircraft's takeoff and landing will be included in the simulations. In order to study space weather effects, simulations will be performed including geomagnectic storm conditions. The authors of this work want to thank the support of COLCIENCIAS under the Grant 617/2014 "Semillero de Investigación: Ciencia de datos y astropartículas".