

# The impacts of particle precipitation spectrum on the 30MHz cosmic noise absorption over the under the South Atlantic Anomaly Region.

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## Abstract

The energetic particle precipitation strongly affects the lower ionosphere, since these particles play an important role in the production of ionic pairs. Numerical simulations of ionospheric cosmic noise absorption at 30 MHz are shown, for the South Atlantic Magnetic Anomaly (SAMA) region. Simulations were carried out for aeronomic conditions of Cachoeira Paulista (22,50°S; 45,00°W) Simulation analysis were done for nighttime hours and moderate solar activity conditions. The simulations here presented include precipitation processes of electrons and galactic cosmic rays, photo-ionization processes, and processes of ionospheric absorption of cosmic noise. Also, the simulations take into account chemical equilibrium conditions for 25 positive ions and 10 negative ions described by 175 chemical reactions. Height profiles of cosmic noise absorption and its response to different characteristic energy levels (energy spectrum) and different ranges of energy of the precipitating electron flux were studied. As expected, absorption increases with precipitating electron flux and characteristic energy. An interesting feature observed is the presence of two peaks of absorption at different heights. For a fixed value of characteristic energy, an increase in the precipitating electron flux raises the height of the lower peak and lowers the height of the upper peak. Our results also show that for a fixed range of energy of precipitating electron flux, the heights of both absorption peaks decrease with the increase of the characteristic energy.

## **1** Introduction

The main objective of this study is to examine the effects of energetic particle precipitation on the lower ionosphere in the South Atlantic Magnetic Anomaly (SAMA) region. This work shows numerical simulations of ionospheric cosmic noise absorption at 30 MHz, for the SAMA region. Simulations were carried out for aeronomic conditions of Cachoeira Paulista (22,50°S; 45,00°W) for nighttime hours and moderate solar activity.

## 2 Model Description

The numerical model developed in this work describes the physical and chemical interactions of the lower ionosphere (from 50 to 120 km of altitude) under the supposition that the system is in a stationary state. The ionization by

precipitation processes of the electrons (Rees, 1963) and by galactic cosmic rays in the lower ionosphere (Heaps, 1978), photoionization processes and the ionospheric cosmic noise absorption (Davies, 1990) are included in this model. Transport effects are neglected.

Part of the concentration of the neutral atmosphere constituents (O,  $O_2$ , N,  $N_2$ , H, and He) and the temperature necessary to the simulations (varying with altitude, time, and geographic position) were obtained from the MSIS-90 model (Labitizke et al., 1985; Hedin, 1991). The molecular concentrations of  $CO_2$  and  $H_2O$  are calculated using mixing rates of  $3\times10^4$  and  $1\times10^6$  respectively, relative to the total molecular concentration of the neutral atmosphere (Turunen et al., 1996). The *NO* concentration is also obtained through a mixing rate (as a function of altitude and local time) provided by Barth et al. (1996). For the further constituents of the neutral atmosphere ( $NO_2$ ,  $O_2({}^{I}\Delta_g)$ ,  $O_3$ , OH, and  $HO_2$ ) fixed values of molecular concentration were used (Brum et al., 2006; Brum, 2004).

The ion-chemical scheme of the ionospheric D region is extremely complex, due to a large number of positive and negative ions. The chemical scheme used in our modeling includes 25 positive ions and 10 negative ions (Figure 1), to which the reaction rates were obtained from Swider (1996), Turunen et al. (1996), Reid (1977), Mikhailov (2003), Mitra (1968) and Keneshea et al.(1970).



**Figure 1.** Schematic representation of chemical reactions evolving the series of negative and positive ions.

# **3** Results and Discussion

Basically, computations of the spectrum and flux variations of the electrons precipitated were performed. The results obtained from these interactions are shown in ionospheric cosmic noise absorption terms and electronic profiles by the altitude. Also, its absorption peaks are presented and discussed.

#### **3** Response to the energy spectrum

The precipitated electrum energy spectrum plays an important role in the lower ionosphere ion-pair production distribution in altitude. We adopted the energy spectrum shape based on satellite observations over the SAMA region, which can be expressed in logarithmic terms such as:

$$\boldsymbol{J} = \boldsymbol{J}_0 \boldsymbol{e}^{(-\boldsymbol{E}/\boldsymbol{E}_0)} \tag{1}$$

where  $J_0$  is the electron total flux in the top of the atmosphere,  $E_0$  is the characteristic energy, E is the electron energy, and J the electron flux to electrons with the same energy. In fact, this work only uses the spectrum analytical function of the precipitated electrons, being its variables obtained and discussed.

The characteristic energy  $(E_0)$  controls the ion-pair production peak height. The bigger the characteristic energy the lower would be the ion-pair production peak height. Figure 2 presents the simulation of the electron precipitation, through the ion-pair production, for 3 different characteristic energies with the same precipitated electron fluxes (100 electrons.cm<sup>-2</sup>.s<sup>-1</sup>).



**Figure 2.** (a) Production rate to the volume units, by the unitary flux to the electron incident to the different initial energy values; (b), (c) and, (d) ion-pairs formed by the precipitated electrons and (e) electron precipitated spectrum to the different characteristic energies.

Figure 3.a shows the height ion-pair production peak by the characteristic energy to the different ranges of the electron precipitated (202 keV to the 702keV with steps of the 100keV), where all these fluxes have the same number of electrons (100 electrons.cm<sup>-2</sup>.s<sup>-1</sup>). From this panel, it is possible to infer that the more extended the precipitant electron flux range, the lower will be the ion-pair production peak height, at least to the characteristic energies less than  $\pm 40$  keV, where the peak of ion-pair

production does not vary with the electron precipitated range flux. The ion-pair production quantitative response of its interaction is presented in panel (b). This panel shows that the bigger the electron precipitation of the spectrum interval for an equal total flux, the bigger will be the ionpair productions for equal characteristic energy.



Figure 3. (a) Height of the ion-pair production peak versus spectrum characteristic energy to the different energy ranges and; (b) ion-pair formed versus spectrum characteristic energy to the different energy ranges.

## **3.2** Response to the electron flux

In this section, the flux intensity variation associated whith the different spectrum profiles with different characteristic energies is performed. The ionospheric response to these interactions is presented in Figure 4. For this purpose, the precipitated electron energy values were fixed in 1keV and 350 keV as minimum and maximum of the electron spectrum, respectability. The characteristic energies applied were limited between 40keV and 200keV. A factor of two was applied to the variations of the flux intensity, started in 1.10<sup>2</sup> electrons.cm<sup>-2</sup>.s<sup>-1</sup> and finished in 1.10<sup>7.7</sup> electrons.cm<sup>-2</sup>.s<sup>-1</sup>. These results are shown in Figure 4. The response of the ionospheric absorption peak and the total of ionospheric cosmic noise absorption to the characteristic energy and the total electron flux variations are shown in the panels b and c, respectively. These panels present a smooth change with the variations applied, while it is noticed an abrupt variation in the absorption peak height and the electronic density in the absorption peak when subjected to the same condition. This phenomenon is easier observed in Figure 5 in the panels (a) to (d) that show the same interaction as Figure 4. However, just three ranges of the characteristic energy were chosen.



Figure 4. Cosmic noise absorption response to the precipitated electron spectrum obtained from different characteristic energies versus total electron flux simulations. (a) Height of the ionospheric absorption peak; (b) maximum ionospheric absorption; (c) cosmic noise absorption integral over 50 to 120 km and; (d) electronic density in the cosmic noise absorption peak.



Figure 5. (a) Ionospheric absorption peak height *versus* electron flux; (b) Ionospheric absorption maximum *versus* electron flux; (c) Total ionospheric absorption *versus* electron flux; (d) electronic density in the absorption peak and; (e) Ionospheric absorption maximum and electronic density concentration in the ionospheric absorption peak height *versus* the ionospheric absorption peak.

In fact, these simulations are showing that there is a change in the ionospheric absorption peak with the increase of the electron flux (Figure 6). It is noticed a "jump" in the absorption peak height close to the electron precipitated flux of the  $10^6$  electrons.cm<sup>-3</sup>.s<sup>-1</sup>. After that, there is a decrease of the absorption peak height with the increase of the electron flux.



**Figure 6.** Lower ionosphere electronic density simulated and its respective cosmic noise absorption profiles to the different electron incident fluxes and different characteristic energies.

## 4 Conclusions

This work presents the ionospheric responses to the electron flux incidence and the characteristic energy variation, which are associated with the electron energy spectrum shape. The cosmic noise absorption, the electronic density in the absorption peak, and the height peak absorption were performed by the simulation of the processes of the electron and cosmic ray precipitation, nocturnal photoionization processes, and the ionospheric cosmic noise absorption at 30MHz.

From these simulations, it was detected the ionospheric absorption peak susceptibility to the characteristic energy variation and to the range of the total electron flux precipitated. Also, it was noticed that the bigger the characteristic to the same electron flux range, the lower will be the cosmic noise absorption peak height, while to the more extended electron flux ranges to the same characteristic energy, the ionospheric absorption peak height raises.

For the same initial electron flux, the produced ion-pairs increase almost exponentially with the linear increase of the characteristic energy.

The quantitative response of the ion-pair production suggests that the bigger the range of the precipitated electron energy for the same flux, the bigger will be the ion-pairs production to the characteristic energy.

The most interesting result showed in this work is the change of the ionospheric absorption peak height with the electron flux variation, which presents a "jump" with the increase of the electron flux and after that, a gradual asymptotic return to the previous ionospheric absorption peak height, close to 74km.

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