New Features of the Field-Aligned-Integrated Conductivity Model for the Brazilian Equatorial E-Region and the Implication on the Collision Rates

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Abstract

In this paper we present the new feature of the field-aligned-integrated ionospheric conductivity model developed for the Brazilian equatorial region. A brief historical of model development is remembered and original features are summarized to allow a straight comparison with the new features introduced in the 2009 version. Some special aspects related to the changes in the neutral atmosphere model are discussed in terms of the impact in the collision frequency.

Historical Aspects and Original Features

Denardini (2007) stated the development of a geomagnetic field-line-integrated local ionospheric conductivity model for the Brazilian E region aiming to calculate the E-region electric fields that drive the plasma irregularities of the equatorial electrojet. The model uses a neutral atmosphere model, an ionospheric model, a geomagnetic field model and a set of collision rates equation as input parameter. The neutral atmosphere was described as an invariant height distributed given by Banks and Kockarts (1973), which is basically constituted by the gases: molecular nitrogen (N_2), molecular oxygen (O_2), atomic oxygen (O) and argon (Ar). The ionosphere was assumed to be constituted basically by nitric oxide (NO^+), molecular oxygen (O_2^+) and atomic oxygen (O^+); and the vertical electron density profiles and the relative ion composition were obtained from the International Reference Ionosphere Model - IRI Model (Bilitza, 2001). The geomagnetic field was approximate by the eccentric dipole model, which is 20° inclined with respect to the Earth rotation axis. This approach was adopted due to the large magnetic declination angle (being ~ 21 westward from geographic northward) that the geomagnetic field possess in the Brazilian equatorial region. The ions-neutral collision rates were calculated as per equation (Chapman, 1956):

$$\nu_i = \left(2,6 \times 10^{-9}\right) \cdot N_n \cdot A_n^{-1/2} \ , \qquad (1)$$

where N_n is the neutral atmosphere density and A_n is the neutral molecular mass. The electron-neutral collision rates were calculated as per equation (Kelley, 1989):

$$\nu_e = \left(5,4 \times 10^{-9}\right) \cdot N_n \cdot T_e^{1/2} \ , \qquad (2)$$

where T_e is the electron temperature, but was approximated to the neutral atmosphere temperature (T_n) at the E-region heights.

New Features of the 2009 Version

The 2007 version have recently been modified to include a new neutral atmosphere model, and to update the magnetic field model and to the ionospheric model. Also, the collision rate calculations have been changed to include several ionic and neutral species, and the momentum transfer collision frequency equation were used to balance these rates (Schunk and Nagy, 2004; Banks and Kockarts, 1973).

The neutral atmosphere used the Mass Spectrometer and Incoherent Scatter (NRLMSISE 2000) model (Picone et al., 2002) as input for the present conductivity model. The magnetic field model is still approximated with a dipole not located at the center of the Earth, but now the field line strength is given by the International Geomagnetic Reference Field (IGRF10) model (Macmillan and Maus, 2005). In order to represent the large magnetic declination angle in the Brazilian sector, the eccentricity of the dipole was set to an inclination of 20° with respect to the Earth rotation axis. The description of the ionosphere was updated to the version 2007 of the International Reference Ionosphere (IRI) model (Bilitza, 2001).

Abdu et al. (2004) have compared the E-layer frequency *f*oE values predicted by IRI with those measured over three locations that formed a conjugated points station pair: Campo Grande in south (20.45° S, 54.65° W, dip: -22.5) and Boa Vista in north (02.80° N, 60.66º W, dip: 22.5), and an equatorial station, Cachimbo (09.47º S, 54.83º W, dip: -3.9). They have found that the daytime equatorial E-layer *f*oE is reasonably well represented by the IRI, but also pointed out that the IRI model underestimates the E-region peak density in the Brazilian sector (see, for example, Figure 4 in Abdu et al., 2004). Thereafter, we have adjusted the absolute electron density given by IRI to the mean electron density obtained from *f*oE at these three stations. All E-region peak density values obtained from simulations at the dip equator were set to the peak density calculated from the mean *f*oE measured at the corresponding local time. The remaining part of the electron density vertical profile was adjusted proportionally to its previous value considering an α-Chapman layer decay. For latitudes outside the dip equator, the simulated vertical profiles were corrected by a factor given by the ratio between the peak density obtained from *fo*E and that given by IRI.

The simple ions-neutral collision frequency given by Chapman (1956) was replaced by a set of equations given by Schunk (1996). Each set of equations relates one ionic species to the neutral atmosphere. The set of collision rates for the Molecular Oxygen (O_2^+) is:

$$\begin{aligned} \nu_{O_2^+\to O} &= 2{,}31\times10^{-10}\cdot n(\mathrm{O}) \\ \nu_{O_2^+\to O_2} &= 2{,}55\times10^{-11}\cdot n(\mathrm{O_2}).T^{1/2}.(1-0{,}073.\log T)^2 \\ \nu_{O_2^+\to N_2} &= 4{,}13\times10^{-10}\cdot n(\mathrm{N_2}) \end{aligned} \quad (3)$$

The set of equations that describes the collision rates for the Nitric Oxide (NO^+) is:

$$\begin{aligned} \nu_{NO^+\to O} &= 2{,}44\times10^{-10}\cdot n(\mathrm{O}) \\ \nu_{NO^+\to O_2} &= 4{,}27\times10^{-10}\cdot n(\mathrm{O_2}) \\ \nu_{NO^+\to N_2} &= 4{,}34\times10^{-10}\cdot n(\mathrm{N_2}) \end{aligned} \quad (4)$$

and the set of collision rates for the Atomic Oxygen (O^+) is now written as:

$$\begin{aligned} \nu_{O^+\to O} &= 4{,}45\times10^{-11}\cdot n(\mathrm{O}).T^{1/2}.(1{,}04-0{,}067.\log T)^2 \\ \nu_{O^+\to O_2} &= 6{,}64\times10^{-10}\cdot n(\mathrm{O_2}) \\ \nu_{O^+\to N_2} &= 6{,}82\times10^{-10}\cdot n(\mathrm{N_2}) \end{aligned} \quad (5)$$

In this all these sets, $n(X)$ represents the density of the generic constituent X and T is the electron temperature, which was approximated to the neutral temperature in the lower E region without significant effect in the conductivities (Denardini, 2007). Finally, the momentum transfer collision frequency equation is used to balance these rates (Schunk, 1996).

The electron - neutron collision rates were also updated to the following set:

$$\begin{aligned} e\to \mathrm{O} \quad & \nu_a = 8{,}2\times10^{-10}\cdot n(\mathrm{O}).T^{1/2} \\ e\to \mathrm{O_2} \quad & \nu_b = 1{,}8\times10^{-10}\cdot n(\mathrm{O_2}).[1+3{,}6\times10^{-2}.T^{1/2}].T^{1/2} \\ e\to \mathrm{N_2} \quad & \nu_c = 2{,}33\times10^{-11}\cdot n(\mathrm{N_2}).[1-1{,}2\times10^{-4}.T].T. \end{aligned} \quad (6)$$

which was combined through a single summatory function since almost all the energy is conserved in the pseudo-elastic collision between the electron with the neutral constituents (Schunk and Nagy, 2004).

Results

Since that the NRLMSISE 2000 model was incorporated to the conductivity model and that the IRI was updated to the 2007 version, the neutral and electron densities and temperatures were certainly changed. As a consequence, several parameters obtained along the ionospheric conductivities calculation will change as well. In order to track the implications of such actualizations we have implemented the model updates step-by-step. The results are discussed in terms of the observed impacts on the collision frequency profiles calculated to a specific geographic location 2.3° S, 44.2° W (dip: ~ -0.5°) for the range height between 90 and 130 km, at 12 h (LT) during equinox. The red lines in the profiles of Figure 1give such profiles for the ions-neutral collision rate while the blue lines show the electrons-neutral profiles. The upper left profile shows the profiles for model version 2007 (as indicated above the graph), when the neutral atmosphere was invariant and the ionospheric model was the IRI 2001. The upper right panel shows the new profiles after switching the equation (1) and (2) for the set of equation (3), (4), (5) and (6), which were basically combined through the momentum transfer collision frequency equation. The neutral atmosphere and the ionosphere model were not changed up to this point. This version was labeled Intermediate 1. The bottom left panel shows the resulting profiles when the ionospheric model was updated in the intermediate 1 version, i. e., the new set of collision equation and the IRI 2007 are running now. This version was named Intermediate 2. Finally, the NRLMSISE 2000 atmospheric model was added to the conductivity model, which is now running with the entire new feature (2009 version). The resulting profiles are shown in the bottom right graph of the Figure 1.

Analyzing the evolution of these graphs, we clearly observe that the changes introduced by the implementation of the new set of collision rate equation (first step) or due to the update of the ionospheric model (second step) do not bring any drastic modification to the collision profiles. The slant of the curve was slightly modified changing the values by no more than a few percents. A substantial modification to the profiles was introduced when the neutral model was replaced by the NRLMSISE 2000, only. A rough comparison between the curves from the version 2007 and 2009 reveals an increase of values in the whole ions-neutral collision rate profile and in the most of the electrons-neutral profile. In terms of values, the number of ions-neutral collisions increased from 3 x 10^4 to 6 x 10^4 s^{-1} at the lower portion (around 90 km). In the upper portion (close to 130 km) the variation was higher, increasing from 15 to 80 s^{-1}. The same comparison applied to the ions-neutrals collision profiles show that number of collision reduced from 5 x 10^5 to 3 x 10^5 s^{-1} at 90 km, but increased from 4 x 10^2 to 1.5 x 10^3 s^{-1} around 130 km.

Conclusions

New modern features were introduced in the 2009 version of the field-aligned-integrated conductivity model for the Brazilian equatorial E-region. The impact of such actualization was investigated in terms of the changes in the collision rate profiles. A step-by-step update procedure revealed that the changes introduced by the implementation of the new set of collision rate equation (first step) or due to the update of the ionospheric model (second step) do not bring any drastic modification to the collision profile. Only when the neutral model was replaced by the NRLMSISE 2000, substantial modifications to the profiles were observed.

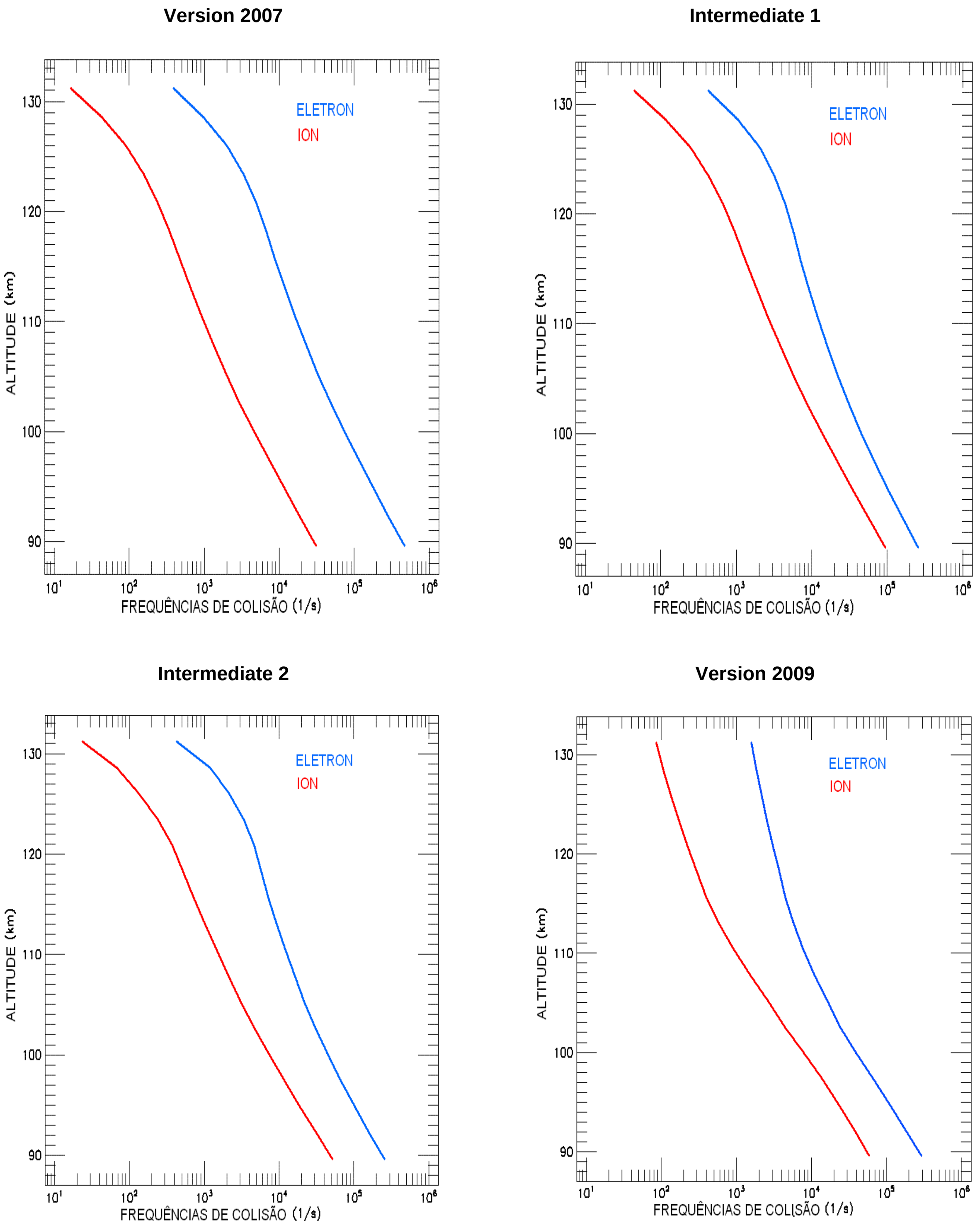

Figure 1. Collision rates profiles calculates at 2.3° S, 44.2° W (dip: ~ -0.5°) for the range height between 90 and 130 km, at 12 h (LT) during equinox. The red lines give the ions-neutral profiles while the blue lines show the electrons-neutral profiles.

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