2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Gas heating and chemical impact of plasma-related Transient Luminous Events in planetary upper atmospheres

F.C. Parra-Rojas(1,2), A. Luque(2), and F.J. Gordillo-Vázquez(2)
(1) Inter American University of Puerto Rico, Bayamón, Puerto Rico, fparraro@gmail.com
(2) Instituto de Astrofísica de Andalucía, Granada, Spain, http://www.trappa.es

Abstract

We present results obtained through a kinetic model of air plasmas generated in the presence of Sprites and Halos. The model included a sophisticated chemical scheme as well as the resolution, in a self-consistent way, of the energy conservation equation to investigate the thermal impact of sprite streamers in the surrounding gas. We have identified the main kinetic mechanisms responsible of the gas heating as well as the evolution of the chemical species in the air plasma. We have found that the activity of the sprite streamers and halos in the mesosphere considerably affects not only the electron density but also the concentration of neutral key species such as NO and N_2O, both responsible of the mesospheric ozone balance. Our results also show an increase, of about 1 K at 65 km, in the gas temperature that becomes less important as altitude grows.

1. Introduction

Sprites are the most commonly observed TLEs. They are huge electrical discharges in the Earth mesosphere due to positive cloud to ground lightning strokes in the troposphere. Halos can be associated with sprites or not and they are produced by both positive and negative cloud-to-ground lightning strokes.The chemical evolution of the mesospheric species due to the action of sprite streamers is still being studied. Sentman et al. [1] and Gordillo-Vázquez [2], both in 2008, proposed two different kinetic models which can explain the important chemical evolution of a great set of atmospheric components, i.e. neutral species like NO or N_2O.

The possibility of the gas heating in sprite streamer channels is still a subject of ongoing research. In 1998, Pasko et al. [3] estimated a gas heating between 2 - 0.2 % of the gas temperature at altitudes from 50 km to 60 km and in a time scale of 10 ms under the action of sprite streamers. Later, in 2014, da Silva and Pasko [4] proposed that fast heating could be the mechanism responsible of the gas heating in the first stages of the sprite streamer.

2. Enhancement of the electron density in the mesosphere due to the action of sprite and halos

Through simulations, we have estimated the temporal evolution of a large number of chemical species under the action of the sprite streamer channel [5] and halos [6]. The electrons are the most important species in a plasma since they are responsible of a large number of ionization and excitation processes among others.

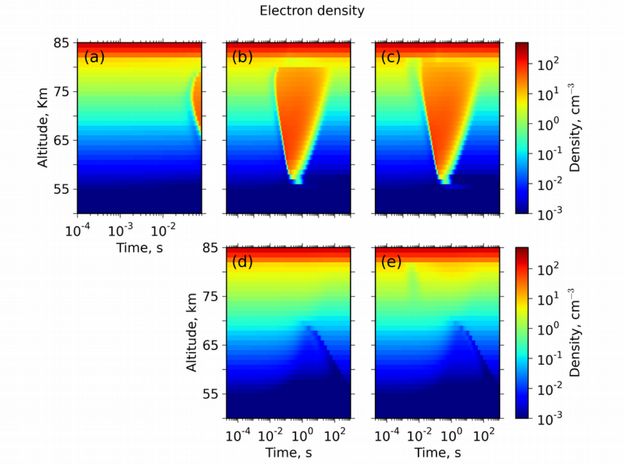

Figure 1: Altitude-time evolution of the electron density due to cloud-to-ground lightnings with (a) realistic current moment, (b) 100 kAkm peak current moment and 20 kAkm continuous current moment, (c) 200 kAkm peak current moment and 20 kAkm continuous current moment, (d) 100 kAkm peak current moment and (e) 200 kAkm peak current moment.

Concerning sprites, we have used sprite streamer profiles with three different driving current durations (5 ms, 50 ms and 100 ms) between 50 and 80 km of altitude and considering a kinetic scheme of air with 20 chemical species. Our model predicts strong increases in practically all the concentrations of the species studied at the moment of the streamer head passage. Moreover, their densities remain high during the streamer afterglow phase. The electron concentration can reach values of up to 10^8 cm^{-3} in the three cases analysed [7].

Our model also predicts, in the case of halos [Figure 2], an increase of up to 70 cm^{-3} in the electron density from ambient electron density values between 55-81 km of altitude in the +CG lightning cases and a negligible mesospheric electron density perturbation in the -CG lightning case [8].

These strong variations in the electron density are a consequence of a continuous fight between N_2 and O_2 electron-impact ionization and the associative detachment (AD) of O^- by N_2 [7,8,9].

3. Gas heating within the streamer channel

We have estimated the variation of the gas temperature within the streamer channel solving the gas energy conservation equation [10] in a self-consistent way. We can see in Figure 2 how the gas temperature changes in time after the sprite streamer passage. At 50 km, the variation from the background value is almost 15 K for large times while, at 70 km, the increase in the gas temperature is a little higher than 0.2 K. The more substantial increase occurs at the low reduced electric field stage of the streamer, mainly due to the energetic balance of the vibrational-translational (V-T) reactions which involve vibrationally excited CO_2 and N_2 species. However, at the moment of the sprite streamer head, we have a negligible increase in the gas temperature (a few mK) caused by the rotational deexcitation of N_2 and the fast quenching processes (fast heating) of electronically excited species (mainly metastable species). Finally, at the time in which the gas temperature begins to grow (between 1 ms and 100 ms), the mechanisms responsible of this increase are a mix between V-T and fast quenching processes together with rotational deexcitation of N_2 [7].

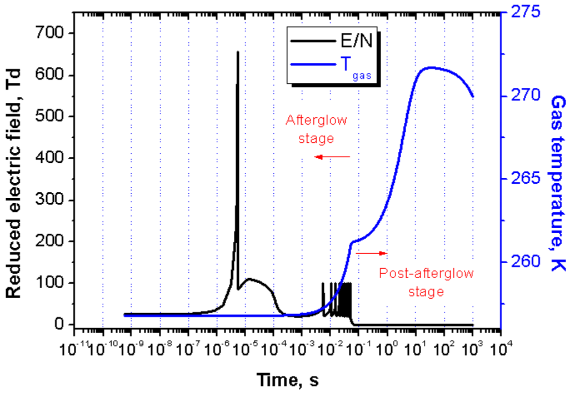

Figure 2: Temporal evolution of the gas temperature (blue line) and the reduced electric field (black line) at 50 km of altitude for the 50 ms driving current.

We have obtained these results through simulations, in an array of 36 altitudes (between 50 km and 86 km) using a sophisticated kinetics model [7] based in Gordillo-Vázquez's scheme [2,11], that allowed us to obtain the reduced electric field and the plasma gas temperature of sprite streamers in a self-consistent way.

6. Acknowledgements

This work was supported by the Spanish Ministry of Economy and Competitiveness, MINECO, under project AYA2011-29936-C05-02 and by the Junta de Andalucía, Proyecto de Excelencia FQM-5965. F.C.P.R. acknowledges MINECO for the FPI grant BES-2010-042367. A.L. was supported by a Ramón y Cajal contract, code RYC-2011-07801.

7. References

[1] D.D. Sentman et al., J. Geophys. Res. 113, D11112 (2008).

[2] F.J. Gordillo-Vázquez, J. Phys. D: Appl. Phys. 41, 234016 (2008).

[3] V. Pasko et al., Geophys. Res. Lett. 25, 2123-2126 (1998).

[4] C.L. da Silva and V. Pasko, J. Geophys. Res. doi: 10.1002/2013GL059164 (2014).

[5] A. Luque and U. Ebert, Geophys. Res. Lett. 37, L06806 (2010).

[6] W.R. Gamerota et al., J. Geophys. Res. 116, A02317, (2011).

[7] F.C. Parra-Rojas et al., J. Geophys. Res. 120 (10), 8899-8933, (2015).

[8] F.C. Parra-Rojas et al., J. Geophys. Res. 118, 1-25 (2013).

[9] A. Luque and F.J. Gordillo-Vázquez, Nature Geoscience, doi:10.1038/NGEO1314 (2011).

[10] A. Flitti and S. Pancheshnyi, Eur. Phys. J. Appl. Phys. 45, 21001 (2009).

[11] F.J. Gordillo-Vázquez, J. Geophys. Res. 115, A00E25 (2010).