Kinetics of CO_2 and nitrogen oxides in air plasmas produced by the action of sprites and halos in the Earth mesosphere

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We present results related to a kinetic model of air plasmas generated in the presence of sprites and halos. The model includes a detailed scheme of the vibrational kinetics of CO_2, which has allowed us to calculate the concentrations of the (ground electronic state) vibrational levels of CO_2, responsible for its major optical emissions in the IR and, among others, of those observed at 4.3 μm and 14.9 μm. In addition, we have identified the main collision mechanisms responsible for the excitation/deexcitation of CO_2 by considering the electric fields associated with halos and the plasma filaments (streamers) of sprites. We have found that sprite activity in the mesosphere produces a considerable enhancement (of more than five orders of magnitude) in the concentration of the vibrational level CO_2 (00^01) responsible for the CO_2 IR emission in 4.3 μm. Our results indicate that the CO_2 emission enhancement in the 4.3 μm lasts for more than 100 seconds after the passage of the sprite streamers, which suggests that this IR emission could be detected by dedicated sensors in space platforms.

1. Variation of the concentration of CO_2 (00^01) and CO_2 (01^10) in the mesosphere due to the action of sprite streamers

In the case of streamers, the concentration of $CO_2(00^01)$, whose radiative emission decay occurs in the band of 4.26 μm, increases to a maximum of five orders of magnitude, staying at values 1000 times higher than its environmental value for almost 100 s. Subsequently, the $CO_2(00^01)$ density decays to background values. On the other hand, the concentration of CO_2 (01^10), whose radiative emission decay occurs in the band of 14.9 microns, increases a little more than an order of magnitude, being roughly stationary for about 10 s and decaying afterwards below its environmental value [Figure 1]. By contrast, we have found that the presence of halos does not influence the concentrations of $CO_2(00^01)$ and CO_2 (01^10) because the halo electric field is weaker than the one of sprite streamers.

The main production processes of $CO_2(00^01)$ and CO_2 (01^10) under the action of a streamer electric field, are electron impact excitations. In addition, the VV collision involving $N_2(X^1\Sigma^+_g,v=1)$ and CO_2 is a relevant mechanism in the production of CO_2 (00^01). The most important mechanism of vibrational de-excitation of CO_2 (00^01) and CO_2 (01^10) is the radiative decay from these levels to the fundamental level. The radiative decay is responsible for the infrared emission bands at 4.26 microns and 14.9 microns, respectively.

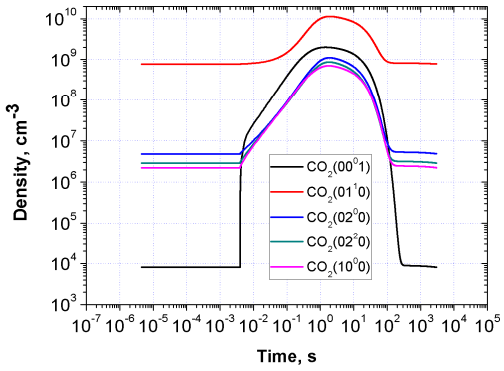

Figure 1: *Calculated nighttime lowest CO_2 vibrational levels density variation under the action of sprite streamers in the Earth mesosphere.*

2. Variation of the concentration of nitrogen oxides (N_2O and NO_x, x = 1, 2, 3) in the mesosphere as a result of the presence of sprites

We have estimated that the increases in the concentration of N_2O and NO due to sprite streamers are of four and one orders of magnitude, respectively. Moreover, the densities of NO_2 and NO_3 decrease three orders of magnitude, with a tendency to recover after long times (~ 10^6 s) [Figure 2]. Under the action of a halo electric field, NO_x concentrations (x = 1, 2, 3), are not affected, while the density of N_2O increases by 4 %.

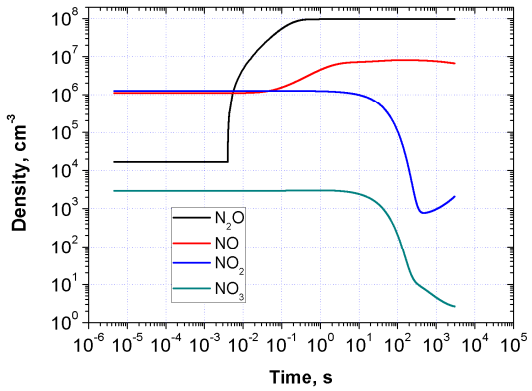

Figure 2: *Calculated nighttime N_2O and NO_x (x = 1, 2, 3) density variation under the action of sprite streamers in the Earth mesosphere.*

The main production mechanism of N_2O, under the action of a streamer and a halo electric field, is the collision of molecular oxygen (O_2) with N_2 in its first electronically excited state ($N_2(A^3\Sigma^+_u)$). In the case of sprite streamers, we must note the key role played by associative detachment (AD) of O^- with N_2 in the production of N_2O and in the removal of electrons in air plasmas generated at relatively low pressure (above 10 – 15 km altitude) [5]. The AD rate depends strongly on the reduced electric field [5].

3. Possible IR spectra of sprites and halos

If we could locate a spectrograph with a camera working at 30 frames per second (fps) in the position of occurrence of sprite streamers and halos, we would obtain an unique IR spectrum in which we would see the characteristic CO_2 IR spectral fingerprints of sprite streamers and halos [Figure 3].

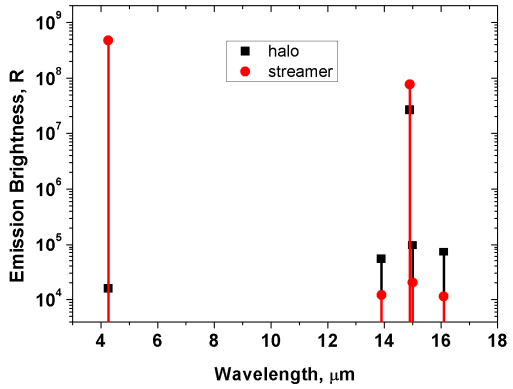

Figure 3: *Calculated IR emission spectra of a sprite streamer (75 km) and a halo (80 km) integrated during 30 fps (standard video camera). The spectra show the brightness (in Rayleigh (R)) associated with the CO_2 emission bands considered as excited by sprite streamers and halos.*

4. References

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