Sprites/Halo Influence on the Mesosphere Chemistry: Self-Consistent Modeling, Electric Field Dynamics

Andrey A. Evtushenko, Fedor A. Kuterin, Evgeny A. Mareev

Institute of Applied Physics Russian Academy of Science, Nizhny Novgorod, Russia

ABSTRACT: We have developed a new plasma-chemical model which describes perturbation dynamics of the chemical composition of the mesosphere at altitudes between 60 and 90 km due to sprite/halo generation for night conditions, and apply it for the self-consistent 1D modeling for sprite and axial-symmetry modeling for halo. In our model we use a simple representation for electric field, where it is related to the flash current (uncompensated electric charge in the troposphere) and depends on the conductivity perturbation in the mesosphere. The perturbed concentrations of electrons, neutrals, ions, cluster ions, excited atoms, and molecules have been estimated for typical flash parameters as altitude dependent.

INTRODUCTION

We develop one-dimensional plasma-chemical self-consistent model to describe influence of high altitude discharges – sprite and halo – on the chemical balance of the mesosphere. To describe chemical composition of mesosphere we take into account 61 chemical components (neutrals, electrons, positive and negative ions) and use 267 chemical reactions (Evtushenko, Kuterin, and Mareev 2013; Evtushenko and Mareev 2011). The electric field on the heights of mesosphere is determined as a solution of the differential equation. It depends on the conductivity of the mesosphere and external electric field, which is created by uncompensated electric charge in the troposphere after strong lightning discharges. Taking into account the high conductivity of the Earth's surface, we use dipole approach for external field. We use the freeware solver of Boltzmann equation BOLSIG+ (Hagelaar and Pitchford 2005) to get the electron temperature dependence on the reduced electric field on the mesosphere heights. Basic concentrations of chemical components are taken from WACCM.

1D SPRITE MODELING

Our modeling is applicable to the diffuse and upper part of transition region of sprite. For the used mesosphere parameters the discharge begins at the height near 78 km several hundred microseconds after the beginning of current flow in a lightning channel in the troposphere (electric field exceeds 128 Td) and reaches a height of 70 km after one millisecond (Fig. 1). Maximum dipole moment of uncompensated charge 740 C·km was used for modeling sprite, which is a typical value for night sprites. The conductivity of mesosphere is reduced by practically 2 orders of magnitude at the beginning of the discharge (because of electron temperature and collision frequency increase and concentration of electrons is a constant), which may play a significant role for the initiation of the discharge especially for daytime conditions.

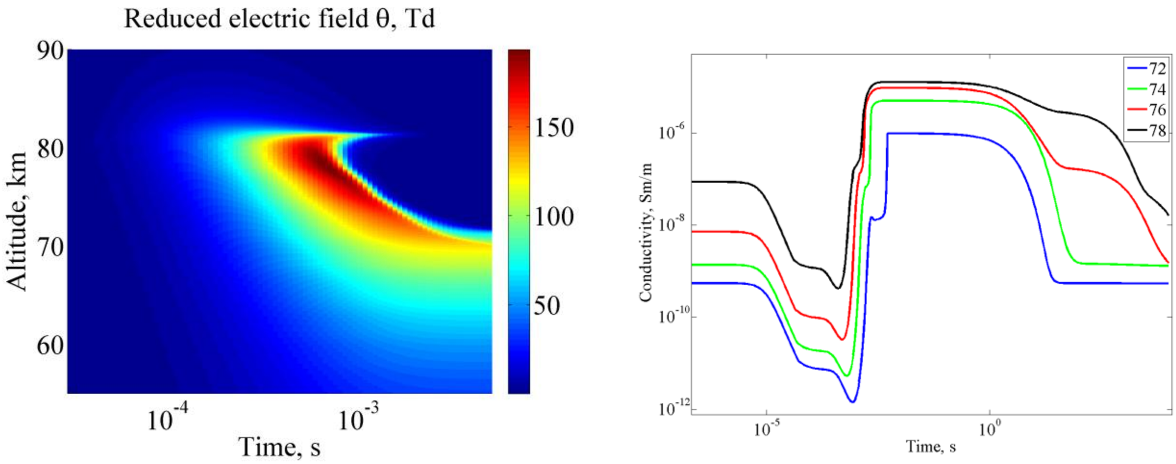

Fig.1 Perturbation of electric field and conductivity of mesosphere

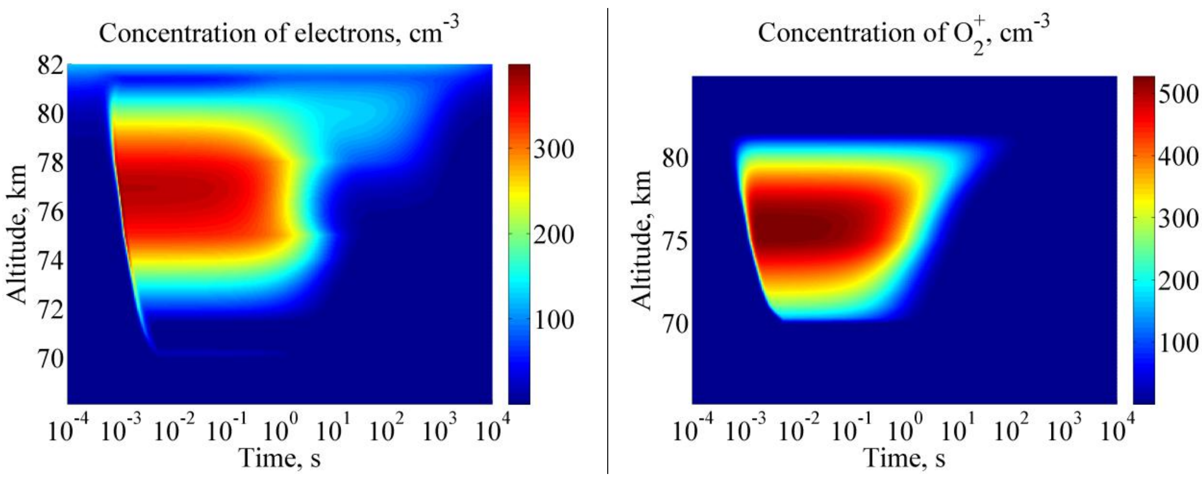

Fig.2 Perturbation of electron and O_2^+ concentrations

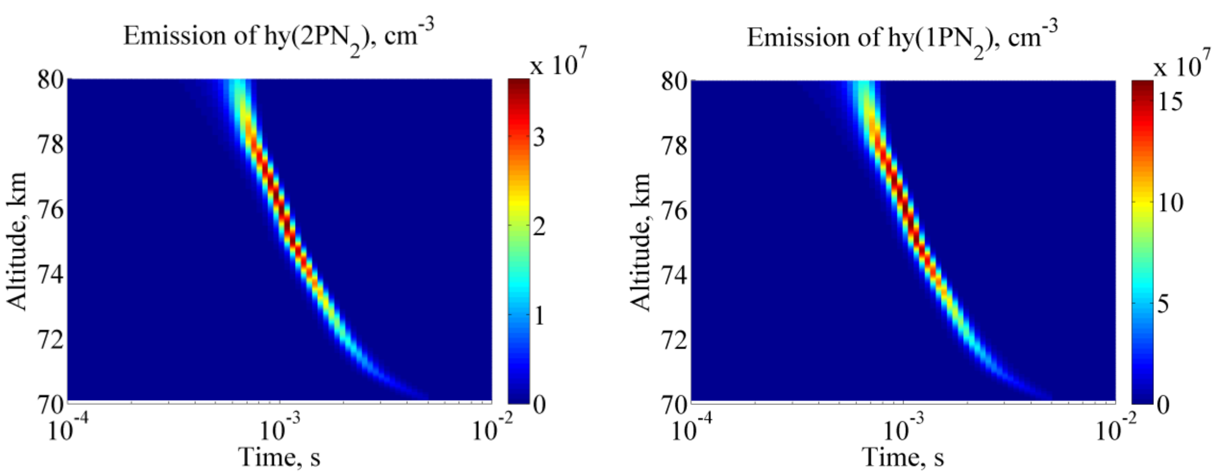

Fig.3 Emission rates in the 1 and 2 positive bands of nitrogen

During the sprite discharge the avalanche of electrons is developing and concentration of electrons and conductivity increase. Concentration of electrons after the end of discharge increases because the detachment from O_2^- and other negative ions (Fig. 2). Total perturbation of conductivity due to sprite discharge is more than 3 orders on the 72 km, and more than 2 orders on the 78 km. The perturbation of electron concentration reaches 390 cm^{-3}, O_2^+ – 520 cm^{-3}, $H_5O_2^+$ – 430 cm^{-3}, O_2^- – 250 cm^{-3}, and relaxation time is more than 100 s at the top of the sprite. Volume emission rate for first positive band of nitrogen reaches $1.5 \cdot 10^8$ $cm^{-3} \cdot s^{-1}$, and $3.5 \cdot 10^7$ $cm^{-3} \cdot s^{-1}$ for second positive band of nitrogen with maximum values on the heights between 74 and 78 km.

2D AXIAL-SYMMETRICAL HALO MODELING

We upgrade our 1D plasma-chemical model to axial-symmetrical model and apply it for halo modeling. As a source of electric field we take a disk with radius 10 km and 2D Gaussian distribution of electric charge density with standard deviation 2 km.

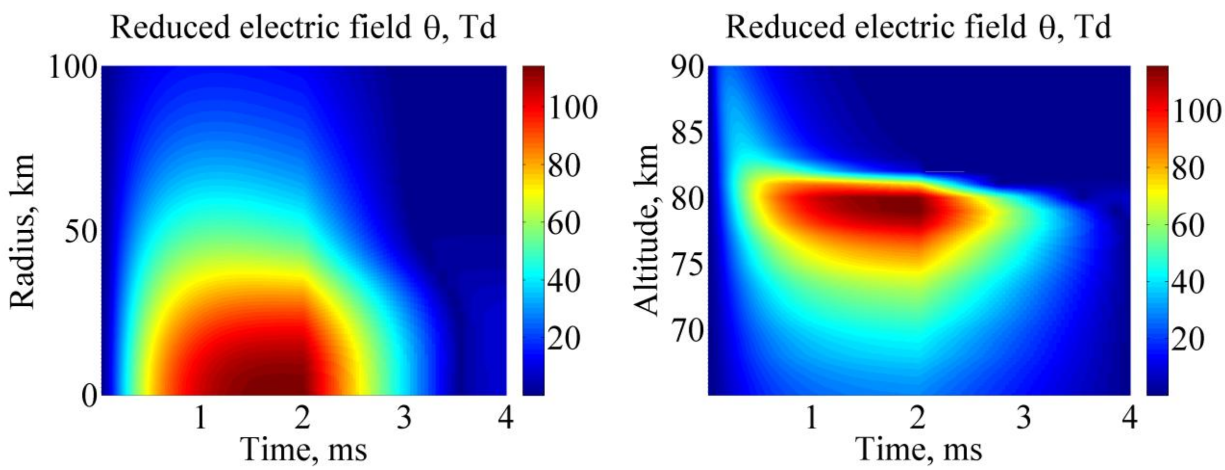

Fig. 4 Radial and altitude dependence of electric field

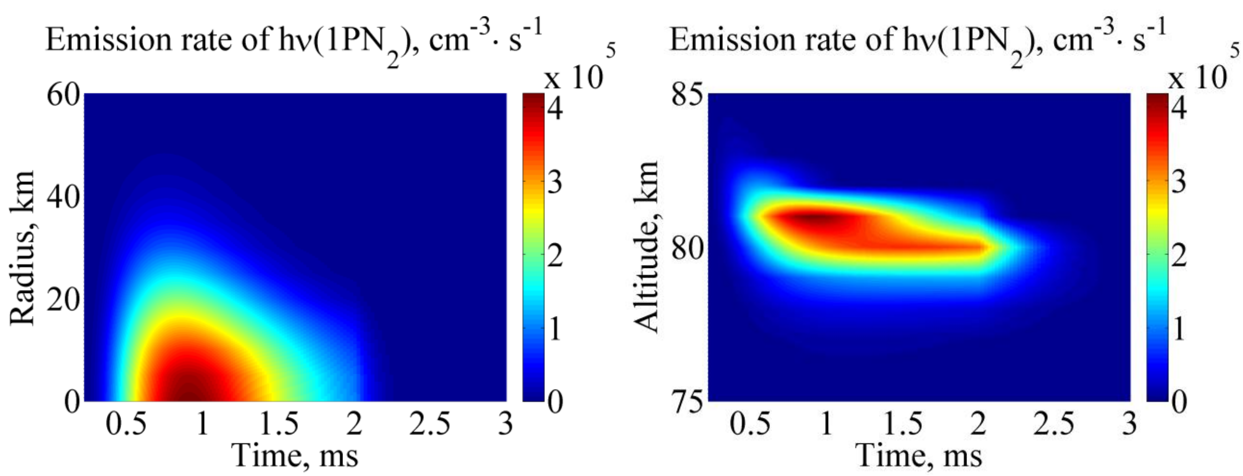

Fig. 5 Emission rate in the first positive band of nitrogen

Total electric charge on the disc is an integral of electric current in the lightning channel during discharge (2 ms) and after the end of current flow electric charge decreases exponentially during 2 ms. The maximum value of electric field in the mesosphere is around 110 Td on the height 80 km, exceeds 100 Td on the heights between 77.5 and 80.5 km and when radius is smaller than 20 km (Fig. 4). Characteristic relaxation time of electric field is several hundreds of microseconds. Duration of halo emission is about 2 ms on the bottom and 1 ms on the top of discharge. Emission rate in the center of halo (radius doesn't exceed 10 km) is 2 times more intensive then for radius 20 km.

CONCLUSIONS

We have developed a plasma-chemical self-consistent 1D model of the sprite influence on the chemical balance of mesosphere. The influence of perturbations of the electric field on the ions, electrons, neutrals, excited atoms, and molecules has been studied in detail. We upgrade our 1D model to axial-symmetrical model and apply it for halo modeling and pay special attention to the perturbation of electric field and optical emissions in the different diapasons.

ACKNOWLEDGMENTS

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