The plasma-chemical self-consistent model for halo/sprite formation in the mesosphere

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We have developed a 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 radial-symmetry modeling of the perturbation region [1]. We apply this set of reactions to study vertical distribution of chemical species using a simple electric field representation, where the electric field is related to the flash current in dipole approach and depends on the conductivity perturbation. The perturbed concentrations of electrons, neutrals, ions, cluster ions, excited atoms, and molecules have been estimated for typical flash parameters as altitude dependent. For the model development we take into account results for electric field from lightning discharge [2]. Also we are preparing laboratory experiment in the long vacuum camera with pressure gradient to model sprites.

Sprites are high-altitude discharges occurring in the mesosphere and lower thermosphere at altitudes from 60 to 90 km, which correspond to the ionospheric D-layer. An optical flash usually appears in a few milliseconds after a positive cloud-to-ground discharge, sometimes at a horizontal distance of up to ten kilometers or more from the bottom of the lightning-flash channel. Statistical analysis shows that the sprites are quite frequently observed, namely, such events are several thousand per day all over the globe. The rates of the plasma chemical reactions depend strongly on the electron temperature and electric field. Thus, the sprites could strongly influence the chemical composition of the atmosphere, at least locally.

Due to the complicated nature of the numerous physical processes involved in the sprite appearance, comprehensive modeling of sprite chemistry is very difficult and employs different (necessarily simplified) approaches. Sprites often exhibit an amorphous unstructured glow at their tops which converts to highly structured (predominantly vertical) breakdown regions at lower altitudes. Namely, we generalize the plasma-chemical model suggested in [3], and apply it to a large-scale perturbation region of the mesosphere with certain effective values of the electric field intensity and electron temperature. We speculate that our approach could be applied to the diffuse and transition regions of sprites, and potentially for the upper part of the streamer region with some mean “effective” parameters [1].

Electric field on the mesosphere is determined as a solution of the differential equation $\partial E/\partial t + \sigma E/\varepsilon_0 = \partial E_{ext}/\partial t$. Taking into account the high conductivity of the Earth's surface, we could represent the external electric field E_{ext} from lightning discharge in dipole approach. To obtain the electron temperature dependence on the reduced electric field in self-consistent modeling, we use the freeware solver of the Boltzmann equation BOLSIG+. Initial values of the chemical components are obtained from WACCM.

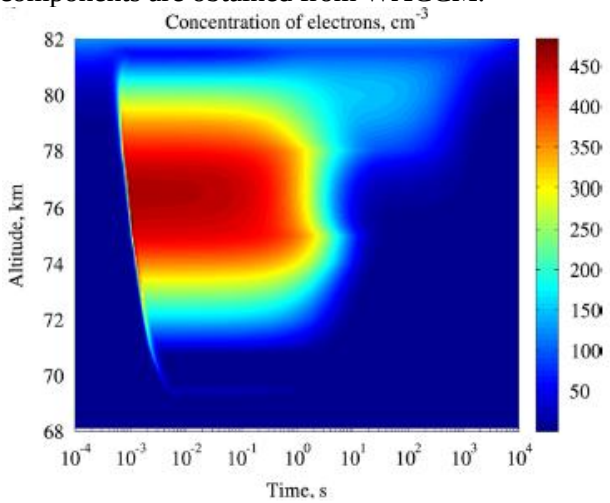

Fig. 1. Concentration of electrons, cm^{-3}

We take transferred charge 74 C and the maximum flash current 110 kA. The maximum value of normalized electric field θ is equal to about 200 Td. The discharge begins at a height of about 80 km several hundred microseconds after the beginning of current flow in a lightning channel in the troposphere. Discharge reaches a height of 70 km after one millisecond. Electron density perturbation is about 475 cm^{-3} on the height 76,2 km above the lightning discharge and relaxation time is

about 10 second (Fig. 1). The relaxation time of electrons and ions is much larger at the top of the sprite.

In the first stage of the sprite conductivity decreases practically by 2 orders due to heating of electrons in the electric field (Fig. 2). This fact could play significant importance in the initiation of sprite, especially in the day-time conditions. During the sprite discharge conductivity increases due to development of an electron avalanche and after discharge cooling of electrons.

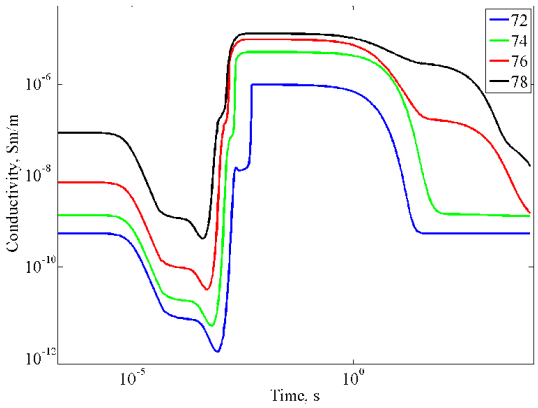

Fig. 2. Perturbation of conductivity, Sm/m

Now we are changing electric field source and adding axial symmetry in the model. Our colleagues have a model for electric field formation after lightning discharge [2]. An isolated cloud-to-ground discharge is considered as a source of the electromagnetic field on the heights of mesosphere. A temporal profile of the discharge current consists of the return stroke and continuous current components, so both the slow transient (quasistatic) electric field caused by the Maxwell relaxation of the charge density disturbance and fast transient (electromagnetic pulse) are calculated. Dependence of the disturbance in mesospheric composition on the distance to the discharge, value of the electric conductivity inside the thundercloud, altitude and lateral scale of the charge region, temporal profile of the discharge current, and velocity of the return stroke are considered.

Fig. 3. Vacuum camera for laboratory modeling of sprite

Vacuum camera 1.9 m long and 1.6 m diameter was taken for sprite/halo modeling in our laboratory (Fig. 3). We are planning to create pressure differential more than one order by magnitude and model diffuse and streamer part of sprite in the same time. Necessary instruments for diagnostics and measurements are in the process of installing now.

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References

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