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УСЛОВИЯ ОБРАЗОВАНИЯ ЭЛЕКТРИЧЕСКОГО ПРОБОЯ, ОБУСЛОВЛЕННОГО ГРОЗОВЫМ РАЗРЯДОМ, В НИЖНИХ СЛОЯХ ИОНОСФЕРЫ

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CONDITIONS FOR ELECTRIC BREAKDOWN IN THE LOWER IONOSPHERE DUE TO A LIGHTNING DISCHARGE

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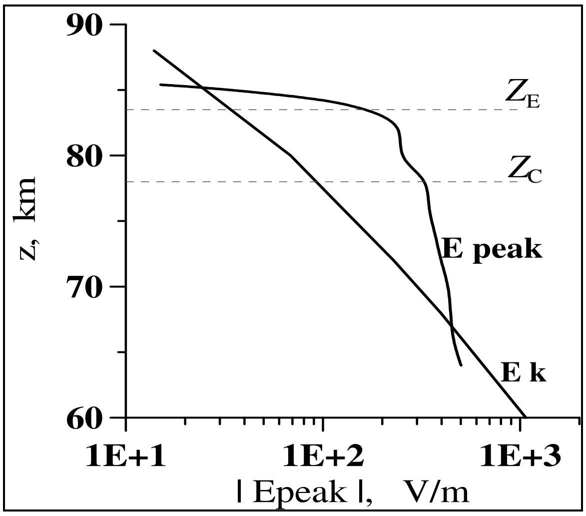
Теоретически изучаются условия, при которых происходит пробой в нижней ионосфере над грозой после позитивного разряда молнии облако–земля (+CG). В качестве возможных факторов, влияющих на возникновение пробоя, рассматриваются две высоты: (***i***) одна, при которой время релаксации равняется времени разряда, и (***ii***) вторая, с «коленом» в профиле проводимости. Согласно этому, можно сформулировать критерий возникновения пробоя. Ключевым фактором для начала пробоя (даже более важным, чем изменение момента заряда) является проводимость из-за ее большой изменчивости на этих высотах.

Conditions are theoretically studied, under which a breakdown is realized in the lower ionosphere above a thunderstorm after a positive cloud-to-ground (+CG) lightning discharge. Two altitudes are seen as candidates for a breakdown initiation: (***i***) at which the relaxation time equals the discharge time, and (***ii***) at the "knee" of the conductivity profile. According to this, a criterion of a breakdown occurrence is formulated. The conductivity is the key factor for a breakdown onset (i.e. more important than the charge moment change), due to its large variability at these heights.

Lightning discharges produce strong quasi-electrostatic fields (QSF) and electromagnetic pulses, which can provoke red sprites and haloes in the lower ionosphere [1], electron density variations in the middle ionosphere [2], etc. According to a hypothetical mechanism, sprites are realized through a conventional breakdown in the lower ionosphere above a lightning discharge due to the QSF. A breakdown is realized when the applied electric field |**E**| exceeds the breakdown threshold electric field $E_k=3.2\times10^6 N/N_0$ [V/m], where N is the neutral density at altitude z, and N_0 is the density at the sea level z=0 [3]. We examine the conditions, under which the time peak of the QSF exceeds the breakdown electric field E_k, by a 2D analytical quasi-static model [4] (the quasi-static conditions are relevant for horizontal scale typical for sprites [5]). Among simplifying assumptions used [4] we accept that the thundercloud charge involved in lightning is distributed at altitude Z_Q with surface density $\rho(t)$ at time t. We obtain the spatial and temporal distributions of the electric field **E** and of its potential U as solutions of the continuity equation $\nabla\cdot\mathbf{j}=0$ for the Maxwell's current density **j** (above a thunderstorm $\mathbf{j}=\mathbf{j}_C+\mathbf{j}_D$, where $\mathbf{j}_C$ and $\mathbf{j}_D$ are the conduction and displacement currents densities). The model region is bounded by altitudes z=0 (the sea level) and Z_E=100 km. The boundary conditions are: (**a**) U=0 at z=0 and Z_E; (**b**) the vertical electric field has a jump of amount ρ/ε_0 at height Z_Q (ε_0 is the dielectric constant). We accept as the initial condition at the lightning beginning at time t=0 that **E** is the DC electric field generated by the thundercloud charge at t=0.

In order to examine the conditions when $|\mathbf{E}|>E_k$, we study the height dependence of the QSF time peak E_{peak} above a causative +CG lightning discharge, as compared to the breakdown electric field profile $E_k(z)$. In our calculations we use day- and night-time profiles $\sigma(z)$ of the conductivity σ (which is assumed to be isotropic) at middle latitudes for quiet conditions [6]. First, E_{peak} caused by a +CG lightning discharge with an exponential charge decay $Q(t)=Q_0\exp(-t/\tau_L)$ is studied by using an idealized exponential conductivity profile $\sigma(z)$



QSF peak E_{peak} by lightning with parameters Q_0=200 C, Z_Q=10 km, τ_L=1 ms, as a function of altitude z, at nighttime conductivity [6] compared to breakdown electric field E_k. The QSF peak diminishes much slower than E_k below the 'knee' of the conductivity profile Z_C and much faster than E_k above Z_E.

with a scale height H_σ=const. In this case E_{peak} is expressed in the form $|E_{peak}|=Q_0 H_\sigma^{-2} P_{QS}(\zeta,\zeta_Q,\zeta_L)$, where Q_0 is the initial thundercloud charge, and ζ, ζ_Θ, ζ_L are dimensionless characteristics for the altitude, the charge altitude and the discharge time [7]. We revealed that, by different z, Z_Q, Q_0, τ_L and parameters of the conductivity profile, the dependence of E_{peak} on the altitude z is characterized by a scale height $H_E\approx C_\sigma H_\sigma$, where $C_\sigma\approx1$ above the altitude Z_E with a relaxation time $\tau_R=\tau_L$, and $C_\sigma\approx2.5$–2.7 below Z_E. This result is approximately valid also for a realistic conductivity profile (i.e. when the conductivity scale height H_σ varies with z), since E_{peak} at altitude z depends essentially on the conductivities at heights z and Z_Q, and it is and relatively independent from the conductivity values at other altitudes [7]. A realistic conductivity profile is characterized by a 'knee' at altitude Z_C~75–85 km (H_σ is much smaller above Z_C than below Z_C). Due to these features, the QSF peak E_{peak} decreases:

(***i***) much slower than E_k below both altitudes Z_E and Z_C; and (***ii***) much faster than E_k above Z_E and Z_C. This conclusion is demonstrated by our computational results for nighttime conductivity in figure. Thus, we conclude that a breakdown, if realized, is initiated in the lower ionosphere, either close to the altitude Z_E, or close to Z_C. Therefore, a breakdown occurs if at least one of the following conditions is fulfilled:

$$Q_0 > H_\sigma^2 E_k \Big/ P_{QS}\left(\zeta = Z_E / H_\sigma, \zeta_Q, \zeta_L\right),$$

$$\text{or } Q_0 > H_\sigma^2 E_k \Big/ P_{QS}\left(\zeta = Z_C / H_\sigma, \zeta_Q, \zeta_L\right).$$

These results show that the conductivity profile, being a highly variable characteristic in the lower ionosphere [6, 8], is more important factor for the occurrence of a breakdown than the charge moment change of the causative lightning. This can probably explain realization of sprites due to rather feeble lightning discharges and their occurrence usually at night.

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