Charge Transfer to the Ionosphere and to the Ground during Thunderstorms

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Introduction

The global electric circuit

Bering et al., Physics Today, P. 24-30, October 1998

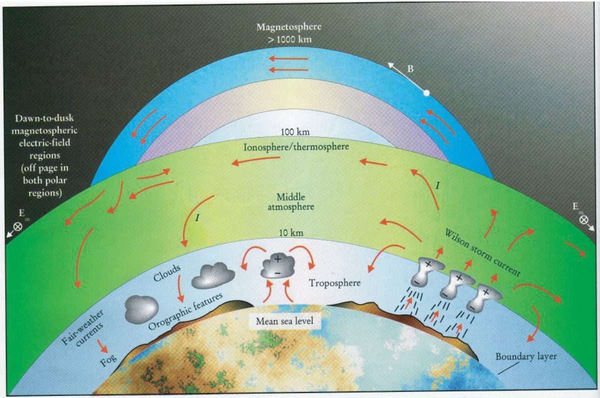


FIGURE 2. FLOW OF ELECTRIC CURRENT in the global circuit. All of the unlabeled arrows represent current flow. The strongest batteries in the circuit are the thunderstorms indicated on the right. They produce the Wilson current. The fair-weather currents are indicated by downward-pointing arrows away from the thunderstorms. (Based on a diagram by Ray G. Roble.)

Introduction

- The efficiency of a lightning flash as a contributor to the GEC is defined as the ratio of the total charge transfered to the Ionosphere to the net charge neutralized during the flash [*Mareev et al.*, GRL, 35, L15810, 2008].

Model Formulation

- A cylindrical two-dimensional coordinate system (r, z) is used, with the $z-$ axis representing the altitude.
- The ground ($z_0 = 0$ km), upper ($z_{max} = 40$ km) and the side ($r = 80$ km) boundaries are assumed to be perfectly conducting.
- The spatial distributions of positive and negative charges are considered to be Gaussian of the following form:

$$f_{\pm}(r, z) = \frac{Q_{\pm}}{(2\pi)^{3/2}\alpha_z\alpha_r^2} \exp\left(-\frac{(z - h_{\pm})^2}{2\alpha_z^2} - \frac{r^2}{2\alpha_r^2}\right)$$

  where $\alpha_z = 1$ km and $\alpha_r = 1$ km are the vertical and horizontal scales of the charge distributions, $h_{\pm}$ are the altitudes of their centers and $Q_{\pm} = \pm 1$ C are the total charge values that are deposited/removed from the system

- The continuous thundercloud charge distribution dynamics can be described as follows:
  - Linear in time charge accumulation for a time interval equal to 400 sec.
  - Charge removal during a 400 msec due to lightning.
  - Relaxation of the system for a time interval equal to 450 sec.

Model Formulation (cont.)

- The induced charge, the potential and the electric field are claculated by solving the following set of equations:

$$\nabla^2 \phi = -\frac{\rho_t}{\epsilon_0} \quad (1)$$

$$\frac{\partial \rho_t}{\partial t} - \nabla \sigma \cdot \nabla \phi = -\sigma \frac{\rho_t}{\epsilon_0} \quad (2)$$

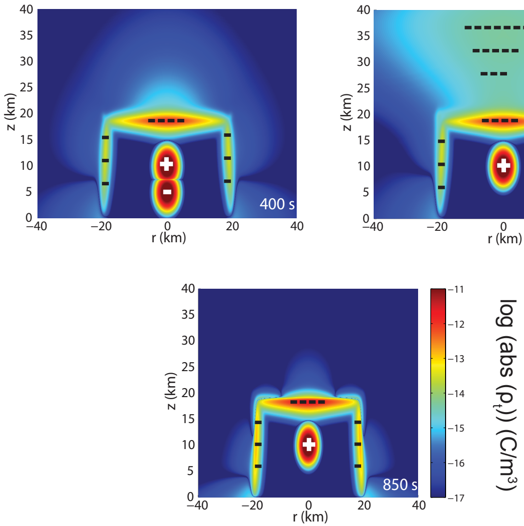
$$\mathbf{E} = -\nabla \phi \quad (3)$$

$$\sigma(r,z) = \sigma_0 e^{z/l} \left(1 - \frac{1 - \tanh(\frac{r - r_c}{\alpha})}{2} \times \frac{1 - \tanh(\frac{z - z_c}{\alpha})}{2} \right) \quad (4)$$

where $\rho_t = \rho_s + \rho_f$ the total charge density, $\sigma_0 = 5 \times 10^{-14}$ S/m is the conductivity at ground level, $l = 6$ km is the altitude scaling factor, $z_c = 20$ km and $r_c = 20$ km are the vertical and horizontal extends of the cloud and $\alpha = 800$ m is the thickness of the conductivity transition region between the cloud and the surrounding air.

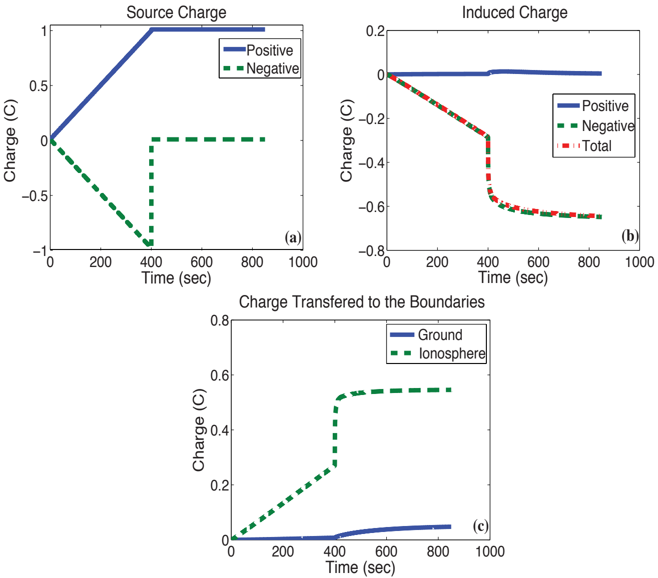
- The charges that are transferred to the ionosphere and to the ground are calculated by integrating the conduction current over horizontal planes, corresponting to the lower and upper boundaries.

Cloud-to-Groud Lightning

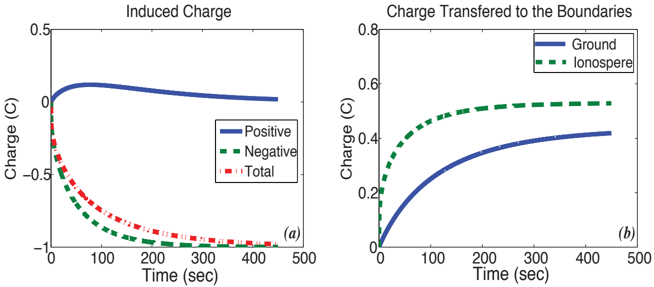


Cloud-to-Groud Lightning (cont.)

Cloud-to-Groud Lightning (cont.)



Cloud-to-Groud Lightning - *Mareev et al.*, [2008] Equivalent Model



Conclusions

- A more accurate description of the charge dynamics was presented by taking into account the charge accumulation stage as well as the difference in conductivity between the interior part of the cloud and the surrounding air.
- The equivalent model used in *Mareev et al.*, [GRL, 35, L15810, 2008] does not represent the actual charge dynamics and leads to inaccurate conclusions especially for the charge that is transfered to the ground.
- Extensive studies with our model on the charge alitudes show that the amount of charge that is transfered to the ionosphere during CG or IC flashes depends on the altitudes of the charges inside the thundercloud and on their spatial distance. We also find that typical efficiencies for the pre-lightning phase range between 23-60%, for the negative CG case range between 11-50% and for the IC case range 20-60%.

Thank you for your attention!