ANALYSIS OF SOME LIGHTNING FEATURES BASED ON THE NUMERICAL STEPPED LEADER PATH SIMULATION.

Odim Mendes Jr., Margarete O. Domingues, José Celso Thomaz Jr.

Instituto Nacional de Pesquisas Espaciais, P.O. Box 515, 12245-970, Brazil

ABSTRACT: A numerical simulation for the stepped leader path in the earth atmosphere has been developed to study the influence of atmospheric parameters on the lightning behavior. This model has been based on the assumption that the leader path follows the current density vector, obeying an empirical tensor formalism, instead of only a gradient of the electric potential. The influence of the charge configuration (amount of charge and locations, obeying either the dipole model or the continuity current model) and the variations of the atmospheric conductivity (considered according to isotropic model and non-isotropic model, under some adopted profile functions) were studied. The results of simulations showed that different behaviors in the lightning path were reached. In consequence, for instance, different percentages of positive cloud-to-ground flashes in comparison to the total CG flashes were obtained and the occurrence of the long length lightning with safety risk implication was also confirmed. The importance of atmospheric conductivity and space charge in the troposphere on the development of lightning path were confirmed.

INTRODUCTION

The main difficulty to get a full quantitative understanding of the electrodynamics on lightning flash has been the lack of reliable data analyses between experiments and theoretical studies. The importance of lightning simulation concerns to understand the atmospheric parameters related to lightning electrodynamics. With the purpose to allow numerical simulations and to analyze experimental data, an empirical formalism are proposed for the stepped leader path development in the earth atmosphere. This model has been based on the assumption that the leader path follows the electric current density vector, instead of the gradient of the electric potential (Takagi et al., 1986; Mendes and Domingues, 2003).

MODEL DESCRIPTION

In the model, the charge configuration (amount of charge and location), the variation of the atmospheric conductivity, the charge deposited along the leader channel and the charge at the leader tip are considered. A perfectly conductor ground surface and a curl-free electric field assumption has been considered (Anderson and Freier, 1969). To establish the electrodynamical atmospheric model, the following basic ideas are considered. There is a difference between the electrical potential on the ground surface and the potential at the lowest Ionosphere, being these boundaries considered as perfectly electrical conductor surfaces. The atmosphere between them presents a certain electrical conductivity. The electrical structure of the thunderstorm cell (Cumulonimbus cloud) is represented by charged spheres: positive centers (charge Q+ at height Z+) and negative centers (charge Q- at height Z-). When a locally electrical field threshold is exceeded, there is an electric air breakdown and an electrical atmospheric discharge (lightning) can be produced. This discharge starts its path from a charge center through the atmosphere depositing charge along the channel and neutralizing progressively the electrical charge of this origin center. For the lightning development, it will be considered only the outside region from the charge sources.

In order to develop the numerical simulation, the solution of this differential equation has been used:

$$\nabla \cdot \left(-\mu_0 \vec{\sigma}_T \cdot \nabla - \varepsilon_0 \mu_0 \frac{\partial}{\partial t} \right) \phi = -\mu_0 \nabla \cdot \vec{J}$$

in which ϕ is the electrical potential, μ_0 the magnetic permeability, ε_0 the electric permitivity, σ_T the electric conductivity tensor, and J is the current density vector. This equation allows to solve the lightning path task. It is proposed the use of an empirical formulation, in which the conduction current density vector is an internal product between the electric conductivity tensor and the atmospheric electric field. It allows to split the effects of the atmospheric conductivity and the atmospheric electric field on the current trajectory by the use of linear transform (a matrix). According to atmospheric regions and local disturbance effects, this matrix could change. This formalism allows to obtain tortuosity in the lightning path.

On the other hand, there are two models for the electrical structure in a Cumulonimbus cloud: (a) dipolar model, in which the opposite charges at different height have the same magnitude and (b) continuity current model, in which opposite charges at different height have different values, according to an exponential rule:

$$q_1 = -q_0 \exp[-2K(z_1 - z_0)].$$

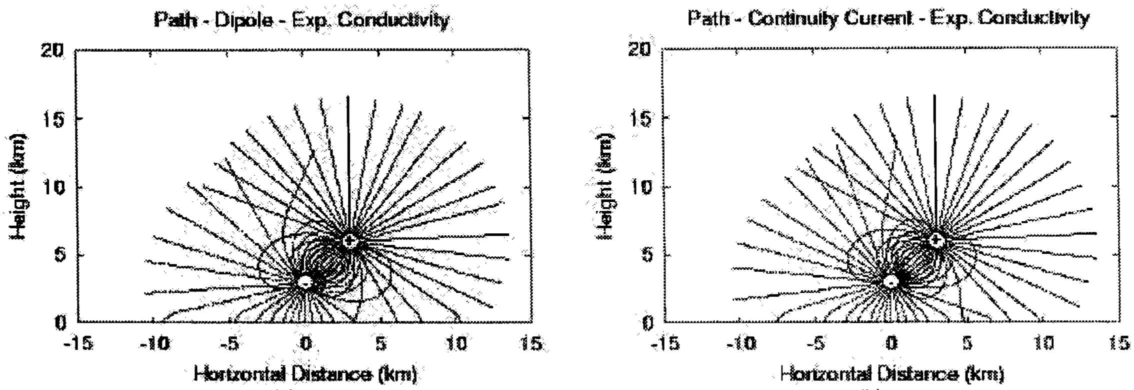
RESULTS AND DISCUSSION

Figure 1 shows the simulated path taking into account (a) the dipole model and (b) the continuity current model. Figure 2 presents (a) the percentage of positive flashes with constant conductivity profile and an exponentially increasing conductivity profile with height (dotted line) and (b) the upper bound limit for positive discharge considering the horizontal displacement between opposite charge centers. Figure 3 shows a long horizontal discharge (a) simulated with a standard atmosphere, (b) simulated with a locally disturbed atmosphere, and (c) compared to a natural discharge. This simulation has shown that the occurrence of the long length lightning also can occur, i. e., there is lightning in clear air at great distances from the thundercloud.

The influence of the charge configuration (amount of charge and locations, obeying either the dipole model or the continuity current model) and the variations of the atmospheric conductivity (considered according to isotropic model and non-isotropic model, under some adopted profile functions) can affect the path of lightning.

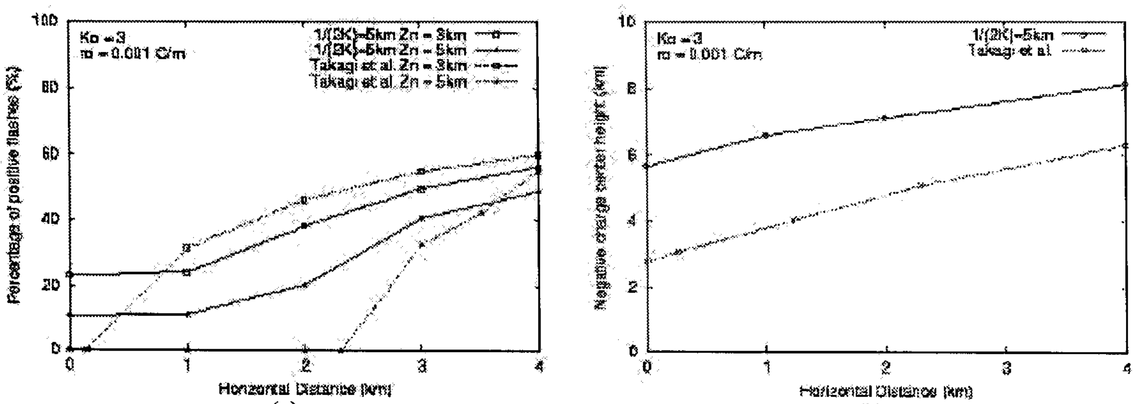
The result of the simulation is that the inclusion of an atmospheric conductivity of exponentially increasing value with height alters the percentage of positive cloud-to-ground flashes compared to that percentage obtained assuming a constant conductivity profile. A higher amount of positive flashes occur for high altitude (low latitude) clouds even in the case of little horizontal displacement between the positive and the negative dipole charges in the cloud, that is, with no significant wind shear in the horizontal wind.

The worked model confirms the importance of the atmospheric conductivity and space charge in the troposphere on the development of lightning path.



(a) (b)

Fig. 1 – Simulated path taking into account (a) the dipole model and (b) the continuity current model.



(a) (b)

Fig 2 – (a) Percentage of positive flashes with constant conductivity profile and an exponentially increasing conductivity profile with height (dotted line). (b) The upper bound limit for positive discharge considering the horizontal displacement between opposite charge centers.

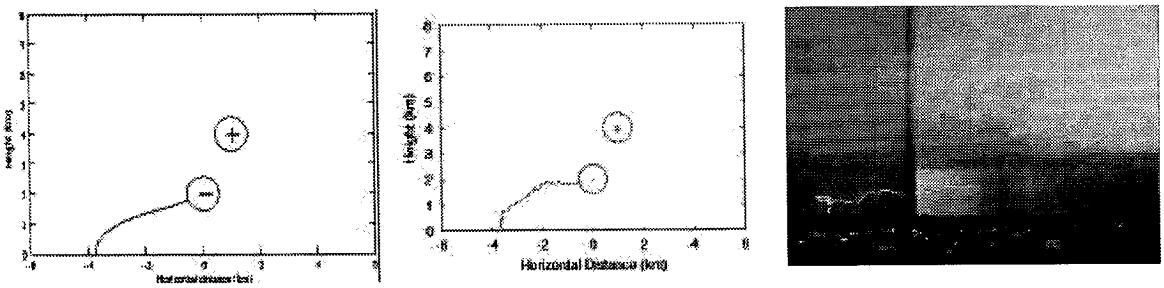


Fig. 3 – A long horizontal discharge: (a) a simulated path in a standard atmosphere, (b) a simulated path in a locally disturbed atmosphere, and (c) a natural discharge.

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REFERENCES:

Anderson, F. J.; Freier, G. D. (1969) Interactions of the thunderstorm with a conducting atmosphere. J. Geophys. Res., 74:53,90-5,396.

Mendes, O. Jr.; Domingues, M. O. (2003) Lightning path simulation based on the stepped leader: electrical conductivity effects. Journal of Atmospheric and Solar-Terrestrial Physics (submitted).

Takagi, N.; Takeuti, T.; Nakai, T. (1986) On the occurrence of positive ground flashes. J. Geophys. Res., 91:9,0905-9,909.