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This article is a reply to *S. S. Davydenko and E. A. Mareev* [2014], doi:10.1002/2013JA019230.

Correspondence to:
S. A. Mallios,
sxm5245@psu.edu

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Reply to comments on the article by S. A. Mallios and V. P. Pasko "Charge transfer to the ionosphere and to the ground during thunderstorms"

Sotirios A. Mallios[1] and Victor P. Pasko[1]

[1] Communications and Space Sciences Laboratory, Department of Electrical Engineering, Penn State University, University Park, Pennsylvania, USA

Davydenko and Mareev [2014] question some considerations that were made in order to model and quantify the contribution of lightning discharges to the Global Electric Circuit (GEC), and the application of the model to the worldwide lightning activity as presented by *Mallios and Pasko* [2012]. In this reply we address their points believing that the reply along with the comment will contribute to a better understanding of the studied problem.

Davydenko and Mareev [2014] consider the proposed division of the whole charge transfer process into three discrete stages as artificial. The proposed last stage which is called "thundercloud dissipation" is discussed as being not physically correct, and they believe that the introduction of this stage is not justified clearly. We disagree with these statements. *Mareev et al.* [2008] developed a numerical model of the transient electric field due to the cloud-to-ground (CG) and intracloud (IC) flashes and their Maxwell relaxation (slow transients) and calculated the electric field, the current distributions, the decay time of the electric field, and the total charge that is transferred to the ionosphere and to the ground. They simulated the lightning discharge using an equivalent model, according to which the charge removal caused by the lightning can be viewed as a "placement" of an identical charge of opposite sign at the same altitude. They did not take into account the conductivity difference between the thundercloud and the ambient atmosphere. This simple model, gave many useful insights for the physical processes that are involved in the response of the system during and after lightning discharges. In our model, we extended this model to a more realistic case and placed the lightning discharge into the context of a thunderstorm life cycle. The new developed analysis methodology emphasizes the exact charge conservation during the different stages of the thunderstorm development. We have divided the charge transfer in three discrete stages, which correspond to the three main stages of the thunderstorm life cycle. The first stage corresponds to the electrification stage, during which the charge accumulation occurs favored by the conductivity difference between the thundercloud and the ambient atmosphere and it lasts until the occurrence of the first lightning discharge. The second stage is the active stage, during which multiple lightning discharges occur. The final stage represents the dissipation stage of the thundercloud. At this stage, the conductivity inside the thundercloud increases to the ambient level, and thus, any residual charge in the cloud dissipates. To make the interpretation of the results of this initial modeling more physically transparent, we assumed that during the whole thunderstorm, only one lightning discharge occurs. In contrast to *Mareev et al.* [2008], whose modeling of the lightning and the postlightning dynamics is essentially independent on the electrification stage, we believe that the accumulation of the charge that will be removed by the lightning should also be taken under consideration. Moreover, we quantitatively demonstrated in our paper that the charge dynamics in these two modeling approaches are different. An advantage we get by studying each stage separately is that we can define the partial efficiencies. By doing so, we can quantify the contribution of each stage independently without overestimating or underestimating the total contribution. This distinction was impossible to be made with previous models and without assuming a conductivity difference between the cloud and the ambient atmosphere that we introduced in our modeling.

Davydenko and Mareev [2014] have discussed implications of the definition of the cloud top and the cloud bottom altitude. An insightful analytical approximation that they include in their comment, shows that there is a dependence between the charge that is transferred to the ionosphere and the altitude of the cloud top. In our paper, we kept the altitude of the cloud top fixed at 20 km and focused on the exploration of the dependencies on other parameters involved in the system. We believe that the proposed analytical approximation is highly complementary to the results we present in the paper. On the other hand, we assumed that the cloud extends to the ground. Although for the studied cases the charge that is transferred to the ground is negligibly small, in the major conclusions of the paper, we state that the charge dynamics depend on the ambient conductivity distribution. Therefore, we acknowledge that a variation of the altitude of the bottom boundary of the cloud will lead to different charge dynamics at the ground.

Davydenko and Mareev [2014] question the application of the model to estimate the contribution of different types of lightning discharges to the Global Electric Circuit (GEC). They state that there is a contradiction regarding the contribution of the IC lightning discharges to the GEC and the main results of the article where we state that the efficiency of the IC lightning discharges is zero. On the same point, they state that we did not take into account the variability of the lightning discharges with respect to region, time of the day, season etc., and that the positive CG lightning discharges examined by our model do not describe accurately the positive CG lightning discharges. We would like to emphasize that at the beginning of section 5.6 of our paper, we mention that this application to the GEC is just an estimate, essentially to demonstrate how the developed methodology can be applied under the stated assumptions. We agree that further studies should be made regarding individual storms with different characteristics and charge configurations. The reason we present the application to the GEC is to show that the basic conclusions derived by our model agree with other models developed in the past [e.g., *Driscoll et al.*, 1992; *Williams*, 1992; *Fullekrug et al.*, 1999; *Williams and Satori*, 2004; *Markson*, 2007; *Rycroft et al.*, 2007]. We would also like to emphasize that since the average values we used refer to different stages of the thunderstorm, we took into account the efficiency of every stage, and the efficiency of IC/CG lightning discharge refers to the efficiency of the second stage. Thus, there is no contradiction between the calculations and the main conclusions of the paper.

Davydenko and Mareev [2014] question the modeling of the electrified clouds and their contribution to the GEC. In our work, we study the electrified clouds only in section 5.4, and we establish the efficiencies during the two stages of the electrified cloud life cycle. We treated the electrified clouds in the same way that we treated thunderclouds, with the difference that there is no lightning discharge (second stage). As *Davydenko and Mareev* [2014] mention, ideally, in the steady state, the conduction currents become equal to the permanent source currents, and there is no further charge accumulation inside the cloud. Given the fact that inside the cloud, the conductivity can be up to 2 orders of magnitude lower than the fair weather conductivity at the same altitude, the ideal steady state might not be able to be achieved during the life cycle of the cloud. Therefore, there can be always a slow charge accumulation (the permanent source currents are larger than the conduction currents) without the electric field being able to reach the lightning initiation threshold. Our approximation describes this case. Because the conductivity inside the cloud is zero for reasons mentioned above, the described by *Davydenko and Mareev* [2014] steady state is not achieved and there is a charge accumulation. Moreover, we showed in the paper that in principle, there is charge transfer to the ionosphere due to three processes: (1) the charge accumulation in the cloud, (2) the lightning discharge, and (3) the dissipation of the charge in the cloud as the conductivity increases over time. In electrified clouds, there is electrification current that leads to charge accumulation, but the electric field in the cloud never reaches the lightning initiation threshold and there is no lightning. Therefore, there will be charge transfer to the ionosphere only due to the processes (1) and (3). This is the reason why we decoupled the charge dynamics of an electrified cloud into the charge accumulation stage and cloud dissipation stage. We also emphasize that we performed the study of a generic type of electrified cloud to demonstrate the principal charge dynamics. We did not apply these results to the global-scale calculations as we did with lightning-producing storms.

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