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Comments on "On the Concepts Used in Return Stroke Models Applied in Engineering Practice"

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In the above paper [1], which is an important contribution to the lightning return stroke modeling literature, Cooray shows that any engineering model implying a lumped current source at the lightning channel base [any transmission-line (TL) type model] can be formulated in terms of sources distributed along the channel and progressively activated by the upward-moving return stroke front. This has previously been demonstrated for one model [modified transmission-line model with exponential (MTLE) current decay with height] by Rachidi and Nucci [2]. The approach suggested by Cooray [1] has already been used by Rachidi *et al.* [3] to generalize five engineering models in order to take into account a tall strike object. A few comments on the above-mentioned paper, follow.

Cooray [1, Appendix B2], states that the division of the total charge density into its "deposited" and "transferred" components given by Thottappillil *et al.* [4, Table 1] for the Diendorfer–Uman (DU) model is "not exactly correct" and suggests an alternative division, his equations (B11) and (B12), which he refers to as the "correct division." The two different divisions, however, are equivalent, since they both satisfy the definitions of the "deposited" and "transferred" charge density components introduced by Thottappillil *et al.* [4, p. 6991]. Indeed, the "transferred" charge density component is defined as having a nonzero value only when the current flows, and vanishing when $t \to \infty$. Both the "transferred" charge density component of Thottappillil *et al.* [4, Table 1], and [1, eq. (B12)], satisfy this criterion. Similarly, the definition of the "deposited" charge density component (nonzero both when the current flows and after the current ceases to flow) equally applies to this component given in Thottappillil *et al.* [4, Table 1] and to [1, eq. (B11)]. We do not see any reason to prefer either one of these two equivalent divisions, in view of the total charge densities being equal at all times. Note that the "deposited" charge density component is not required to be a function of time, as apparently is assumed by Cooray for the case of the DU model.

Further, it is worth noting that the division of the total charge density into its deposited and transferred components was originally introduced by Thottappillil *et al.* [4] for the TL-type models (the same as "current propagation" models in Cooray's terminology), and then the concept was formally extended to traveling current source (TCS) type models (the same as "current generation" models in Cooray's terminology). While for the TL-type models, the concept has a clear physical meaning (the transferred charge is associated with the longitudinal channel core current and the deposited charge with the radial current resulting in the neutralization of the corona sheath formed around the core by the preceding leader), for the TCS-type models the concept of the two charge density components appears to be largely a mathematical formalism.

Additionally, there is an apparent discrepancy in [1], in the definitions of the "transferred" charge density and the "deposited" charge density for different models. On the one hand, the first term on the right-hand side of equation (17), the negative of the total current divided by c (the speed of light), is interpreted as the "transferred" charge density, and the second term, the integral of the corona current, is interpreted as the "deposited" charge density. This charge density division is implied in the description that immediately follows equation (17). It is this division that was applied to the DU model, as is clear from equations (B6), (B5), and (B12). On the other hand, for the TL model, both terms on the right-hand side of equation 17 contribute to the "transferred" charge density in the TL model given by equation (18), which is the only charge density component in this model.

The charge-density formulation of engineering return-stroke models introduced in [4] reveals new aspects of the physical mechanisms behind the models that are not apparent in the traditional longitudinal-current formulation. For example, it is clear from the charge-density formulation of the TCS model (and the DU model) that the distribution of the total charge density along the channel is bipolar during the return-stroke process (see [4, p. 6992]). This distribution is such that there exists negative charge at and near the channel base, apparently due to inadequate rate of removal of charge from the bottom of the channel. The latter condition may be primarily associated with the unrealistic assumption that the current reflection coefficient at the ground is equal to zero in both the TCS and DU models. Such a bipolar charge density distribution near the bottom of the channel yields electric field waveforms at very close distances (some tens of meters or less) from the channel base that are inconsistent with measurements (Schoene *et al.* [5]), while more distant fields are predicted reasonably well. The expected value of the current reflection coefficient at ground in a practical situation is near 1, which corresponds to nearly short-circuit conditions. Heidler and Hopf [6], [7] have modified the TCS model to allow one to specify any current reflection coefficient at ground. This modification makes the model more realistic but requires taking into account multiple reflections within the lightning channel.

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