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On the nature of bipolar flashes that share the same channel to ground

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ABSTRACT

The paper examines the relationship between sequential events in bipolar flashes of two groups sharing the same channel to ground: one initiated by an upward positive leader, the other by a natural flash. Two quite different mechanisms are involved in the occurrence of the bipolar flashes of each group: The bipolar events that start as a natural flash are results of recoil leaders sharing parts of the initial branching structure; the bipolar events that start as upward positive leaders are the result of the interaction between these leaders' initial branching structures and the branches of the intracloud flashes they triggered.

1. Introduction

Bipolar cloud-to-ground (CG) flashes with return strokes sharing the same channel to ground are rare events, and constitute an intriguing, but poorly understood phenomenon. Bipolar CG flashes, identified as such in the current records, have been reported in the lightning literature since the 1940s (see review in Rakov [13]).

The bipolar events are observed starting as both natural and triggered CG flashes, but the manner of their initiation determines the differences in their subsequent development. The initial classification of bipolar CG flashes into three types was suggested by Rakov [13]; and is depicted in Fig. 1. While Types 1 and 2 are cases with reversed polarity of current in the channel to ground of the upward leader, only Types 3a and 3b are actually bipolar CG flashes. The common feature in the initial development of Types 1, 2, and 3a bipolar flashes is the upward positive leader triggered either by a rocket-and-wire technique, or by a tall tower, which provides the rationale for putting these flashes into the same category newly identified here as Group A. Type 3b is different, starting as a naturally-occurring positive CG flash (hereafter called a "natural" CG flash), which is the first event in a bipolar CG flash sequence. For this reason, flashes of this type are newly identified here as belonging to Group B.

From the limited number of bipolar CG flashes described in the literature, it appears that the amplitudes of first CG flashes are usually much greater than the amplitudes of sequential CG flashes of opposite polarity (see Table 1). From the same data, the time intervals between sequential CG flashes of Group B are much longer than the time intervals in the bipolar CG flashes of group A (see Table 2). Observation of a single case of a natural bipolar CG flash that started as a negative CG flash, followed by a positive one, have been presented in Ref. [20]. This bipolar CG flash is similar in its late-stage dynamic to flashes of Type 3a (see Fig. 1), and, therefore, also belongs to Group A.

The interpretation of the bipolar lightning events offered by Narita et al. [11]; who observed bipolar CG flashes in winter storms in Japan, suggests that sequential discharges originate from different, oppositely-charged regions of a thunderstorm cloud, but use the same channel to ground. Rakov [13] suggested that this rather general hypothesis by Narita et al. [11] is also applicable to bipolar events in summer thunderstorms.

Saba et al. [14] and Saraiva et al. [15] offered a more specific explanation of the mechanism of bipolar CG events that start as positive CG flashes. Their interpretation is based on the bidirectional, bipolar leader concept in recoil leaders that occur in branches of positively-charged leaders, and was supported by analysis of high-speed video observations of bipolar events. Quoting from Saba et al. [14]:" … positive leader branches, which do not participate in the initial return stroke of a positive CG flash, later generate recoil leaders whose negative ends, upon reaching the branch point, traverse the return stroke channel path to the ground resulting in a subsequent return stroke of opposite polarity."

The intention of this paper is, while in searching of the mechanism(s) that produce the bipolar flash phenomenon, to examine the relationship between sequential events in two groups of bipolar flashes that share the same channel to ground, but which differ in the polarity of the initial CG flash.

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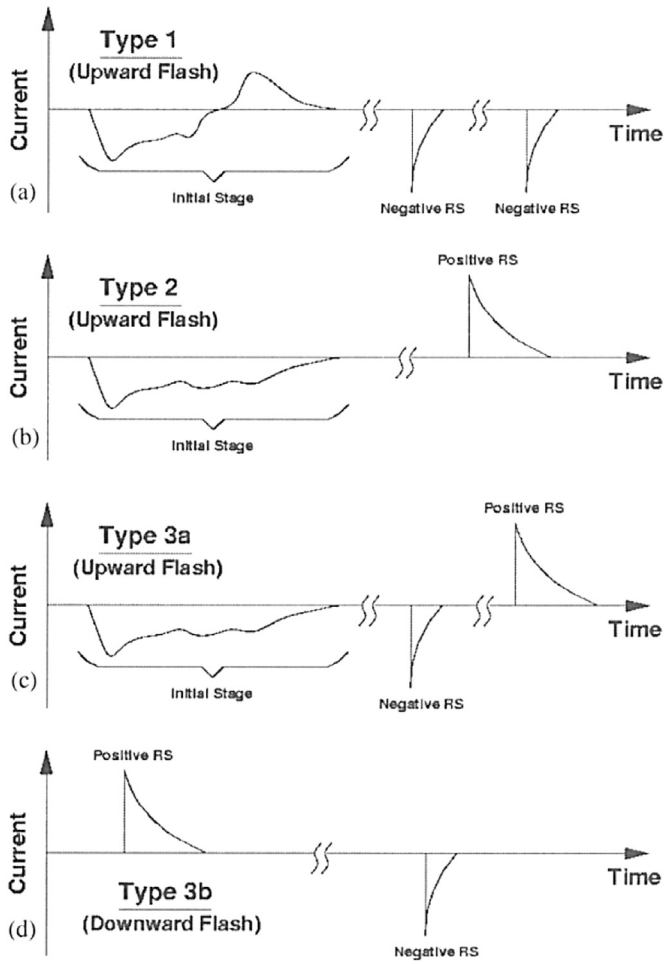

Fig. 1. Sketches of overall flash current records to illustrate different types of bipolar lightning discharges. (Plot uses the atmospheric electricity sign convention). RS = Return Stroke [13].

1.1. Considerations essential for interpretations of bipolar CG flashes

In interpreting the dynamics of the phenomenon of bipolar CG flashes we should consider the following essential features of natural leaders occurring in virgin air, and recoil leaders occurring in decaying channels:

- Natural leaders are bipolar, bidirectional, and branch during their development inside the cloud, producing a bipolar and bidirectional double lightning "tree," the two parts of which develop at different speeds. The negatively-charged part of the lightning tree forms a highly dendritic structure of branches faster (~10^5 m s^{-1}), and completes its development sooner (usually in tens of milliseconds) than the positively-charged part of the lightning tree that is formed at slower speed (~10^4 m s^{-1}), consists of fewer branches, and takes longer to develop (usually in hundreds of ms) [10].
- As natural leaders, recoil leaders are also bidirectional and bipolar, but they form and propagate *only* along traces of the cooling channels of *branches of the preceding positively-charged leaders.* The negatively-charged parts of the recoil leaders move toward the branching points of the previously-existing branches [8].
- The negatively-charged branching structure of a bipolar lightning tree produces no recoil leaders after the current cutoff in its branches [10].

In bipolar CG flashes sharing the same channel to ground, it is reasonable to expect some interaction between processes in sequential flashes. Therefore, it makes sense to review the development of the branching structures of sequential events. *The initial branching structure* of the first event of a bipolar CG flash produces a downward leader, which is part of the first CG flash. The branching structure that is developed by the return stroke process of the first CG flash may be different from the initial branching structure, and is identified here as a *second branching structure*.

A common assumption in the lightning literature, also applied by the present author in the past, is that the return stroke energizes the entire structure of the bidirectional, bipolar leader, which precedes the return stroke occurrence. This assumption has not actually been verified. The validity of this assumption could be tested by analyzing changes in the lightning radiation map of all the leaders in CG flashes before and after the occurrence of return strokes. However, in the absence of such verification, video observations of negative CG flashes with multiple downward branches most often show only a channel to ground, and not the previously-visible downward leaders that were highly illuminated by return strokes. This observation supports the assumption that the return stroke creates a new branching structure upon reaching the cloud.

The concept of two different branching structures in a bipolar CG event, before and after the return stroke, is illustrated by the well-understood case of a rocket-triggered, upward positively -charged leader with a following, negative CG flash (see Fig. 2). The initial branching begins after the upward positively-charged leader enters the cloud (see Fig. 2A), and the current cutoffs in individual branches follow next (see Fig. 2B) [9]. Recoil leaders in these branches of the initial branching structure occur before and after the current cutoff in the upward leader trunk. One recoil leader

Table 1
Return stroke amplitudes of sequential bipolar CG flashes.

First return stroke (kA)	Following return stroke of opposite polarity (kA)	The order of occurrence of bipolar CG flashes (group type)	Reported by
+2.7	−10	Natural Positive to Negative CG (B)	[14]
+79	−5.8	Natural Positive to Negative CG (B)	[14]
+38.9	−8.3	Natural Positive to Negative CG (B)	[14]
+30.4	−8.0	Natural Positive to Negative CG (B)	[14]
+51.7	−20.3	Natural Positive to Negative CG (B)	[14]
+24.3	−4.4	Natural Positive to Negative CG (B)	[15]
+26	−5.2	Natural Positive to Negative CG (B)	[15]
+49.9	−14.2	Natural Positive to Negative CG (B)	[4]
−101.0	+10.0	Natural Negative to Positive CG (A)	[20]
−11	+5	Triggered[a] Negative to Positive CG (A)	[16]
−11.1	+5.0	Triggered Negative to Positive CG (A)	[3]
+0.6	- 3.3	Triggered leader with bipolar current (A)	[2]

[a] The word "triggered" in Tables 1 and 2 identifies a flash started as an upward positively-charged leader triggered either by a rocket-and-wire technique, or by a tall tower.