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On the peak amplitude of lightning return stroke currents striking the sea

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ABSTRACT

Data gathered from the US National Lightning Detection Network (TM) (NLDN) show that the peak currents of lightning flashes striking the sea are significantly higher than those of lightning flashes striking the land. We suggest that the unfavorable conditions for the formation of positive charge pockets in maritime clouds lead to lightning initiation at higher cloud potentials compared to their land counterparts, resulting in larger peak currents in negative lightning flashes striking the sea. As the positive charge pocket does not promote positive ground strokes, no such discontinuity should be expected in positive first return strokes to ground between land and sea.

1. Introduction

Lightning return stroke peak current is an important parameter in lightning protection (Cooray and Becerra, 2012; Uman, 2008; Rakov and Rachidi, 2009) and the factors that govern the magnitude of the peak current are of interest to scientists studying thunderstorm electrification and behavior (MacGorman and Morgenstern, 1998). Estimates of return stroke peak current statistics obtained from lightning locating systems (LLSs) show that there is a variation depending on geographical region and season (Orville et al., 2011). This dependence is not well understood, and is an area of on-going research.

LLS observations also show that within a single geographical region, lightning flashes striking the sea have larger estimated first return stroke currents than their counterparts striking the land (Orville et al., 2011; Cummins et al., 2005; Cummins and Murphy, 2009). Fig. 1a shows the peak current distribution across the coast of Florida. Note that there is a clear tendency for the first return strokes of lightning flashes striking the sea to be higher than those of lightning flashes striking the land. One can also notice that the transition from high currents to low currents is not sharp at the boundary. Fig. 1b shows a similar distribution for the subsequent stroke currents. Note that even in the case of subsequent strokes there is a slight tendency for the peak currents in lightning flashes striking the sea to be high but the tendency is not as strong as that of first return strokes. On the other hand, according to the unpublished studies conducted by one of us (KC), lightning distribution over the Great Lakes area in the US does not show a water–land contrast.

In lightning detection networks, the return stroke peak current is inferred from the measured peak of the return stroke radiation field using the simple transmission-line model (Uman and McLain, 1970). Thus, the presence of a physical mechanism during lightning attachment that enhances the first return stroke radiation field of lightning flashes striking the sea, without a corresponding increase in the first return stroke peak current, could also be the reason for the experimental observation. In the following section we consider such mechanisms and show that they could not fully account for the experimental observation. In Section 3, we provide a new explanation for the experimental data based on difference in aerosol content over land and ocean. A discussion and conclusions are given in Sections 4 and 5, respectively.

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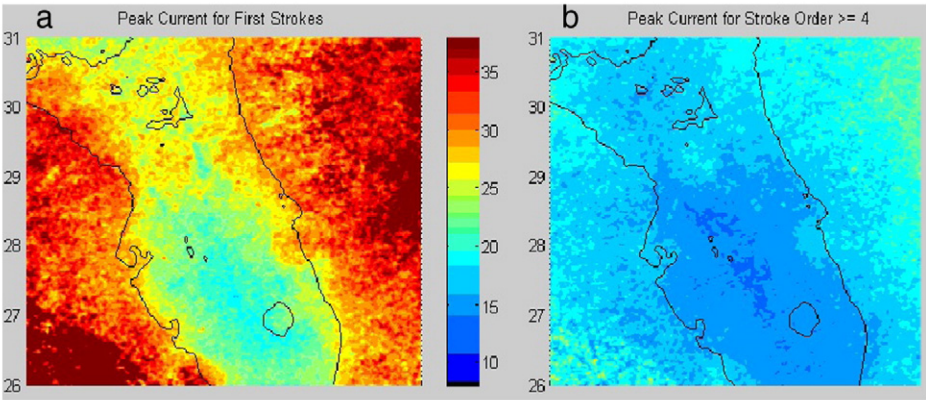

Fig. 1. Distribution of peak currents in lightning flashes striking the sea and land in the region of Florida as determined by the NLDN system of the United States. (a) First return strokes and (b) subsequent return strokes with an order higher than 4.

2. Possible influence of the mechanism of lightning attachment on the peak return stroke radiation fields

The remote sensing of the lightning currents by lightning location systems is based on the conversion of the measured peak amplitude of the radiation field to current using a relationship derived from the simple transmission line model of return strokes (Cummins and Murphy, 2009). Thus, the measured enhancement of the peak current could be a result of an enhancement of the electric field without any enhancement in the peak current itself. This has been proposed by Cummins et al. (2005). There are three mechanisms that can increase the peak of the radiation field without increasing the peak current. The first mechanism is related to the length of the upward leader prior to attachment. Usually, as the stepped leader approaches the ground, it is met by a connecting leader propagating from the ground or from a grounded object. The return stroke is initiated at the point of contact between these two leaders. At the point of return stroke initiation two propagating current fronts that are moving in opposite directions, i.e. one towards the ground and the other towards the cloud, are created. The total radiation field produced is the sum of the contributions from the upward and downward propagating fronts. However, the duration of the radiation field generated by the downward moving front is limited to the time it takes for the front to travel from the meeting point of the two leaders to the ground, i.e. along the length of the connecting leader. The longer the connecting leader, the longer the duration of the radiation field generated by the downward moving front and the larger is its contribution to the peak of the radiation field. Thus, if the connecting leaders in lightning flashes striking the sea are longer than their counterparts over land this may enhance the radiation fields of first return strokes in comparison to the corresponding ones over ground. However, it is difficult to understand why the connecting leaders of first return strokes over the sea are longer than the ones associated with lightning flashes striking the land. Actually, one would expect the opposite behavior because natural and man-made structures over land can enhance the electric field of the stepped leader, initiating connecting leaders much earlier than in the case of stepped leaders approaching the sea surface which is void of such structures. Indeed, some experimental data gathered from Sri Lanka showed that the connecting leaders in lightning flashes striking the sea were shorter than over the land (Perera et al., 2012). For example, the maximum possible connecting leaders in three lightning flashes striking the sea were only about 50 m. On the other hand, a lightning flash that struck a crane located out in the sea had a longer connecting leader indicating that protrusions sticking out from the ground surface play an important role in the length of the connecting leader. Moreover, if the explanation is correct, the radiation field would be enhanced only during the time of propagation of the two pulses. The time of propagation for 100 m is about 1 μs or less and therefore the peak would be enhanced only during this time. This will generate a very narrow peak of about 1 μs width in the radiation field. If this is the case, this narrow peak would be rapidly attenuated both due to propagation effects and due to the finite band width of the electronics of the lightning locating system.

The second mechanism is based on the fact that radiation fields can also be enhanced without increasing the current by an increase in the return stroke velocity. Cummins et al. (2005) suggested the possibility of enhanced return stroke velocity in the lower portion of the channel due to the high conductivity of saltwater. If this is the correct explanation, one would observe a sharp transition from high to low current amplitudes when crossing the coast line. This is not what had been observed. Moreover, in a recent study, Cooray and Rakov (2011) studied the effect of ground conductivity on the return stroke current and concluded that the influence of the ground conductivity was minimal.

The third mechanism relates to the enhancement of peak field by multiple closely-spaced pulses (probably multiple upward leaders) that can occur just prior to attachment, as observed by Murray et al. (2005). These authors found that about 37% of the electric field (E) waveforms produced by first strokes striking ocean water contain multiple peaks in dE/dt that are large and that occur within 1 μs of the largest (dominant) peak. The average amplitude of the associated E waveforms is 36% larger than the amplitude of waveforms containing a single, large peak in dE/dt. It remains to be determined if multiple closely-spaced pulses in dE/dt are as common in strikes to land surfaces. If they are not, then