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SCIENTIFIC CORRESPONDENCE

Lightning return stroke electric field escaping out and giving rise to optical and associated emissions

In connection with lightning, two new terminologies, namely 'Sprites[1]' and 'Elves[2]' have appeared in many of the papers on the topic. It did attract the attention of readers but the use of the nomenclatures for optical phenomena arising due to the upward propagation of lightning generated electric field continues to be a riddle for workers in this field of research. These phenomena are not at all new and are occasional manifestations of lightning that has been known for over a century[3]. Scanning through the scientific literature in this area, one finds scattered anecdotal descriptions of lightning popularly known as 'blue' or 'green' pillars and rocket discharge-like columns of optical emissions[4–7] which continue to be an occasional feature. Wilson[8] discussed the possibility of lightning discharges propagating upwards from the cloud-top and undergoing occasional multiple reflections between the cloud and the ionosphere. Vaughan *et al.*[9] and Bell *et al.*[10] have reported television observations from the space shuttle and showed that a large number of upward-directed cloud discharges, either 'red' or 'blue', are observed at altitudes around 60 km and above. Using a low light level All Sky Television System (ASTS), Sentman and Wescott[11] recorded a large number of upward-directed optical emission phenomena during NASA's single airborne DC-flight over thunderstorms in Iowa, Nebraska and Kansas. Initially, they estimated the most probable terminal heights of the events to be 60 km with error bars extending up to 100 km. The duration of this optical phenomenon was found to be 16 m sec or less, and brightness was estimated to be 25–50 kR, which is almost the same as that of bright aurora. The occurrence rate of this optical phenomenon was found to vary from time to time and region to region, and was estimated to occur once for every 200–300 cloud-to-ground strokes[12]. In addition, the 'Red Sprites' and the 'Blue Jets' were also video-recorded[13] and their properties studied. Further refinements in the ongoing measurements are being made and the results are being reported.

Continued observations have shown that high altitude luminous phenomena do take place and are thought to be arising due to the escaping part of the cloud-to-ionosphere lightning discharges[6,14]. The observed phenomenon is simple enough and occasionally it is seen to be generated and extending upwards and, at times, undergoing multiple reflections between the cloud and the ionosphere. A state of non-judgment prevails when it is observed by aeroplane flights[11]. The first definite observation with supporting details has been made by using the aeroplane 'Sprite-94', although the detailed mechanism of the optical features extending from cloud-to-troposphere and ionosphere was not known. The phenomenon of escaping out of the ground-to-cloud generated electric field and the generation of optical emission into the upper atmosphere is confined to the cloud-to-ionosphere[12,15] region and is known as 'Sprites'. Recorded features have shown that many of these events are spatially varying and one event is different from the other. It has been further shown that the 'Sprites' appearing at different altitudes[15] are 'Red Sprites' and 'Blue Jets'. The escaping out of the positive cloud-to-ground leader stroke and the geometry of the return stroke is schematically illustrated in Figure 1. The most prevalent lightning phenomenon is the cloud-to-ground discharge in which the negative charge is lowered giving rise to positive return stroke. However, 'Sprites' are associated with less frequent phenomena of positive cloud-to-ground discharges. The upward-directed electric field is known to generate this optical emission around 60 km. Depending on the cloud features and details of the cloud-to-ground

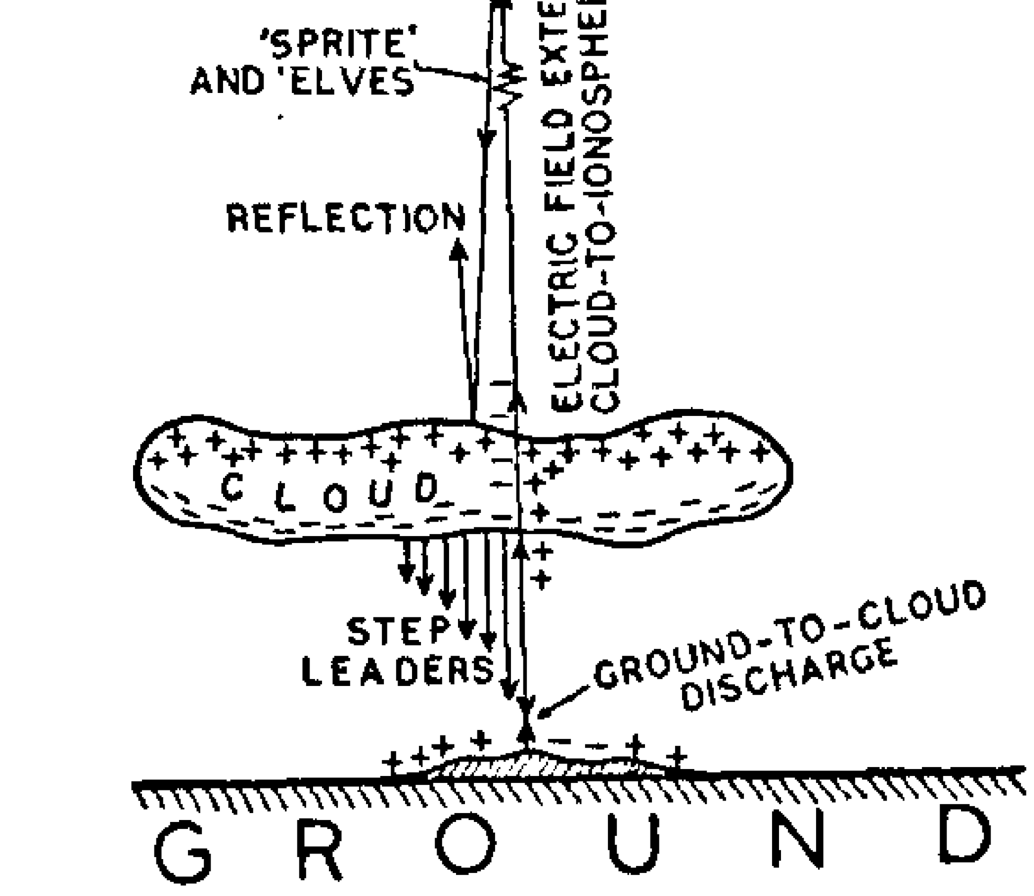

Figure 1. Schematic diagram of escaping out cloud-to-ground lightning discharges.

discharges, the return stroke is not terminated by the cloud-top and the electric field generated in the upper atmosphere is allowed to extend upwards towards the ionosphere. There are various possibilities which depend mainly on relative orientation of the return stroke; (i) stroke-generated electric field may accelerate charged particles that undergo multiple reflections between the cloud and the ionosphere; (ii) the electric field originating from the cloud-top and the extended return stroke may propagate through the cloud to the ionosphere. Whenever the electric field is large, the field-aligned plasma breaks down, giving rise to optical emissions. If the electric field is further increased, the transient charged particle accelerations may give rise to X-ray and even gamma-ray emissions. Some of these features can be clearly seen from the high altitude records of atmospherics, which are not routinely recorded. The statistical details of the 'Sprites' and fractured features of luminous traces known as 'Elves' are governed by detailed features of causative lightning and the physical features of the ionized layer above. These details have not been understood as yet. It is quite likely that nonlinear plasma processes may be playing an important role.

These upward propagating lightning are recorded by aircraft missions since these are not very common features. The 'Sprites' and 'Elves' brightness on ground are measured by a chain of photometers[16] known as 'Fly's Eye' with weak intensity measuring specification; time resolution of 30 μsec and field of view of 3.5° by 7°. The observed features of upward propagating lightning has drawn the attention of many people. However we find that this phenomenon has not yet fully developed so as to sustain itself scientifically[1,2]. The upward-directed lightning generated electric field forming 'Sprites' and 'Elves' freely propagates a much longer path in the lower ionosphere, and under suitable conditions interacts with the upper ionosphere giving rise to these optical effects. The heated optical channels carry a large current and seem to become unstable as a result of modulational instability. The fracturing features of these optical traces into smaller parts are known to result in short duration features known as 'Elves'. These phenomena can be better investigated in terms of theoretical models and can be compared with experimentally measured details only if results of such measurements are systemically collected over a long period of time. Although most of the reportings are made by a single major group of workers, one finds inconsistent and varying statements made, at times, about the observed optical phenomena. Without ascertaining the detailed nature of the optical phenomenon, it seems unjustified to name the phenomenon after the aeroplane used for the observing and recording mission. It is not well explained how the terminology 'Elves' came into being. This trend is still continuing and the optical traces are being named 'carrot', 'radish', etc. If this trend continues, we will have many interesting nomenclatures. The phenomenon is known to cover X-rays and gamma-rays. Suggestions and arguments are made that similar phenomena could also be generated during cloud-to-cloud discharges. When some of these suggestions take concrete shape, we will have a better picture. No doubt, the groups have freely and extensively used these terminologies and induced others to use these in their papers. However, it is clearly seen that an in-depth analysis of this phenomenon is still lacking due to absence of precise measurements with desired spatial and temporal resolutions[17]. The origin of the terminology 'Elves' is not adequately explained and seems to be arising from occasional fracturing of Sprites into smaller and smaller traces. If this be true, the notation 'Elves' which denotes the plural of 'ELF' is hardly justifiable. Since these details have not been given in the reported papers of the group, the reader's curiosity remains unquenched. It is hoped that the associated and interested research groups would make qualitative and extensive measurements of this phenomenon and leave the terminologies to be decided by the scientific community.

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