OPTICAL OBSERVATION OF LIGHTNING ON GROUND AND FROM SPACE

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Abstract: The recent progress in the optical observation of lightning on ground and from space has been reviewed. The progress in the former can be mainly summarized as follows: (1) Leader pulses were observed to propagate backward in relative to leader propagation with a speed comparable to return stroke speeds; (2) Upward connecting leaders have been confirmed to occur for both the first return strokes and subsequent strokes. The lightning observation from space was enabled by launching the Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS) aboard the Tropical Rainfall Measuring Mission (TRMM). These sensors clearly show how the lightning distribution changes on a global scale.

1. Introduction

Optical observations of lightning on ground provide a direct and significant mean to study lightning physics. About 80 years ago Boys took the first time-resolved photograph showing progression feature of lightning with his own invented camera, later referred as Boys camera (Boys, 1926). Since then, many time-resolved photographs have been documented with such type of camera and their analysis has founded the basis of nowadays lightning physics (e.g., Schonland and Collens, 1934; Schonland et al., 1935; Malan and Collens, 1937; Malan and Schonland, 1947; Berger, 1967; Orville and Idone, 1982). However, the use of film as a recording medium has some drawbacks including limited time resolution and difficulty in operation. In recent years, rapid development of electronics has made possible the observation through digital electronic image systems. A representative equipment of such digital electronic image systems is called as ALPS (Automatic Lightning Progressing Feature Observation System). ALPS is very similar to digital cameras, but with only 256 image elements (pin-photodiode). A detailed description of ALPS can be found in the paper by Wang et al. (1999a). ALPS has not only the features of pre-trigger and automatic functions but also better temporal resolution than those film image systems used previously for lightning observations. Due to these advantages, ALPS has been used in the observations of stepped leaders, initial stage of return strokes, M-components, lightning branches and so on. In this paper, the new findings primarily obtained by using ALPS are reviewed, and their implications are also discussed.

Optical observations of lightning from space could provide useful information on global lightning occurrences, mesocyclone occurrences, atmospheric chemistry and so on. To perform such global observations in real time the most desired means would be the so called geostationary lightning mappers (GLM). However, for several reasons GLM has yet to be realized. As a prototype of GLM, the Lightning Imaging Sensor (LIS) and the Optical Transient Detector (OTD) were launched several years ago. After their launching, the sensor characteristics have been evaluated and the scientific results have been obtained by using these sensors. In this paper, some results regarding to the ground validation of the LIS and the global analysis on the relationship between the lightning rate and the storm

height are presented. First, the mapping of the lightning optical pulse detected by the LIS is compared with the radiation sources by the LDAR at KSC and the NLDN data sets. Second, the relationship between cloud height and lightning activity obtained from the TRMM/PR and the LIS is examined.

2. Optical observation of lightning on ground

2.1 Propagation characteristics of leader pulses and its implication

Leader pulses have been photographed in the early days of high-speed optical observation by many authors. However, due to the time resolution limit of their camera systems, the propagation of leader pulses could not resolved. By using a streak camera, Idone (1992) has shown some direct evidence of the luminosity propagation of leader pulses.   Idone (1992) reported that particularly well developed illuminations propagate back down the channel in association with the individual step pulses of an upward positive leader. By using two of the most pronounced illuminations, Idone (1992) estimated the lower bound of the propagation speeds being 5×10^7 m/s and 6×10^7 m/s.   By

Figure 1. Leader light versus time waveforms at different heights above ground. Adapted from Wang et al. (1999b)

using ALPS, Wang et al. (1999b) and Chen et al. (1999) have documented the propagation characteristics of several negative leader pulses. As an example, Figure 1 presents the light waveforms as a function of time at various heights of 12 leader pulses which are contained in a dart-stepped leader in triggered lightning (Wang et al., 1999b).   The optical step pulses appeared to originate at the downward-moving leader tip in the process of step formation and propagate upward over a distance from several tens of meters to more than 200 m.   The upward propagation speeds of the step pulses ranged from 1.9 x 10^7 to 1.0 x 10^8 m/s with a mean value of 6.7 x 10^7 m/s, comparable to the return-stroke speed. The pulses attenuate significantly during their upward propagation, to about 10% of the original value within the first 50 m.

Backward propagation of leader pulses is a very interesting phenomenon. In physics, whether a leader can continue to propagate depending on if the electric power absorbed from the ambient electric fields and then concentrated to the
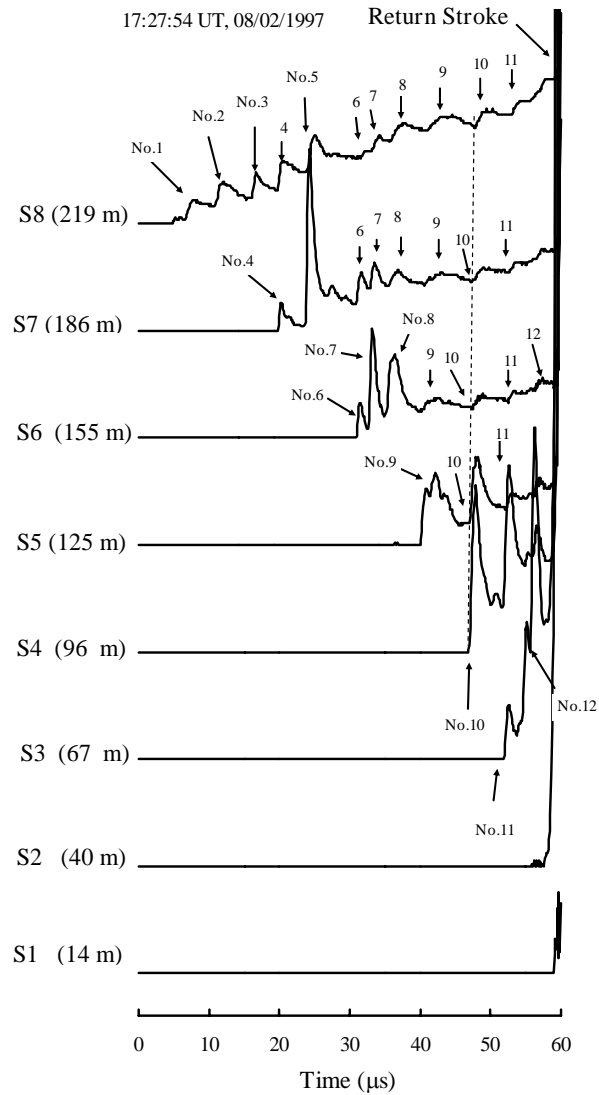
leader head is enough to sustain a continuous ionization process there. Such power absorption and concentration is made possible through the electric induction of a conductive leader channel. Due to cooling effects, if the leader channel conductivity becomes too low to absorb and concentrate enough power, the leader tends to stop. However, since the leader still has some conductivity, even the leader stops in propagation, it continues to absorb and concentrate energy to its tip. If such electric energy accumulates to a certain level, an electric breakdown will be triggered. This breakdown propagates backward to the leader channel and produces more ionization. As a result, the backward breakdown recovers the leader channel conductivity and also the power absorption efficiency.   This allows leader to propagate again. Apparently, leader pulse is not only an inevitable but also an indispensable phenomenon in leader propagation.

2.2. Characteristics of lightning attachment

Knowledge of lightning attachment is important for understanding lightning physics and is also fundamental to methods of lightning protection. By using ALPS, Wang et al. (1999a, 2001) have recently documented the evidence of upward connecting leaders for both the first return stroke and the subsequent strokes. For one of the natural first return stroke reported, the upward leader is stepped one with a length between 35 m to 141m, while for two subsequent strokes, the upward leaders are continuous with lengths, respectively, of 7 -11 m and 4-7 m. Prior to subsequent strokes of upward lightning initiated from high structures, on physical sense more apparent upward connecting leaders are expected, however, the observed results did not show such trend.

3.   Optical observation of lightning from space

   Ground validation of the space born sensor is necessary for the data qualification and future sensor design. In order to estimate the spatial and temporal differences between space born and ground sensors, the mapping of the lightning optical pulse detected by the Lightning Imaging Sensor (LIS) is compared with the radiation sources by Lightning Detection and Ranging (LDAR) at KSC and the National Lightning Detection Network (NLDN). Flash based comparisons are done for the 8/15 1998 case including 122 flashes.

    Figure 2 shows an example of a cloud flash as mapped by the LDAR system and the LIS. The upper panel is a plan view. The lower panel is a height versus time plot of the LDAR sources. This cloud flash occurs at 21:40:38 UTC on August 15, 1998. The overall structure of the flash exhibits bi-level structure connected by a single upward channel. The flash begins with horizontal activity which lasts about 100 ms at an altitude of 10 km., and later propagates upward in the cloud. During the upward progression, some sources are distributed in both the upper and lower part of the cloud, indicating that the K-change occurs. At the end of the flash, one optical pulse is detected by the LIS.

   A statistical examination of the co-incident flashes detected by the LIS and the LDAR shows that; 1) For ground flash, the time difference of the first LDAR source and first LIS event is a mean of the 0.23 second and the total duration of flash is a mean of 0.28 second, compared to 0.56 second by LDAR. The LIS records the subsequent return stroke or K-change component. 2) For cloud flash, the time difference is a mean of the 0.2 second and the total

duration of flash is a mean of 0.38 second, compared to 0.44 second by LDAR. The LIS records the cloud flashes with higher sources in altitude. 3) The location differences are about 4 km for cloud flash and 12 km for ground flash.

The TRMM satellite observes not only the lightning but also precipitation structure by radar, enabling the global examination of the connection between electrical and meteorological aspects of thunderstorms. Figure 3 shows one example of a thunderstorm observed by PR and LIS on August 1, 1998 in central Africa. The upper panel shows the radar reflectivity in a horizontal plane at an altitude of 5 km with LIS flashes indicated by 'X'. The lower panel shows the vertical cross section of the reflectivity through the storm as indicated in the upper panel. The thunderstorm exceeds 15 km height, and exhibits a reflectivity of 35 dBZ at 9 km, 4 km above the freezing level. Around the 45 dBz reflectivity of the thunderstorm, 6 flashes are seen during the 83 second LIS overpasses. The flash rate is obtained by dividing the total number of flash by total duration of observation time for the cell. In this case, 6/83=0.072 flashes/second is obtained. A statistical examination of the relationship between flash rate and storm height reveals that the taller thunderstorm tend to have larger flash rate with large variance. The fifth power dependency is not inconsisitent but is not necessarily require by the observed data.