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LIGHTNING TO THE UPPER ATMOSPHERE: A VERTICAL LIGHT PULSE FROM THE TOP OF A THUNDERSTORM AS SEEN BY A PAYLOAD BAY TV CAMERA OF THE SPACE SHUTTLE

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ABSTRACT

An examination and preliminary analysis of video images of thunderstorms as seen by a payload bay TV camera of the Space Shuttle has provided examples of lightning in the stratosphere above thunderstorms. These images were obtained on several recent Shuttle flights while conducting the Mesoscale Lightning Experiment (MLE). MLE was an experiment to obtain night time images from space of large storm complexes with lightning. These images are being used to provide data for the design of specialized instrumentation which will provide quantitative measurements of global lightning. Eight video sequences have been selected because they illustrate near vertical discharges in the stratosphere above thunderstorms. Although there are previous reports in the literature, these are the first images from the viewpoint of an orbiting spacecraft. The written material is primarily a companion to a video presentation.

BACKGROUND

An examination of video imagery, obtained from space, has revealed several examples of electrical discharges, associated with thunderstorms, that penetrate the stratosphere. This phenomena is now being studied in detail and this paper will present several examples and preliminary conjectures about these unusual discharges. This paper is intended to be a companion to a video poster presentation. The content of this paper will provide notes and ancillary information to supplement the video imagery. The full motion video is emphasized because the human vision system does a good job of identifying a transient event in the presence of a noisy background scene. Most of the events are poorly illustrated by still photographs of the original video.

The video was obtained by the Mesoscale Lightning Experiment (MLE) which employed Shuttle payload bay cameras to observe lightning discharges from large thunderstorm complexes. The video is being analyzed to develop storm flash rate statistics, and location information to simulate observations that are to be made in the future by the Lightning Imaging Sensor (LIS), now a part of the Earth Observing System Program. A summary of data from the first MLE Shuttle flight (STS-26) was prepared by Vaughan[1].

There have previous reports of discharges above thunderstorms that do not seem to be descriptions of ordinary lightning channels that terminate in the clear air. In particular some descriptions mention discharges that extend to extreme heights. In the last century C. V. Boys [2] wrote "...I should like to refer to an observation which I made about the year 1876, as in a life's observation of lightning the phenomenon then accompanying every flash is one I have seen on no other occasion." "A storm one evening in the autumn had passed directly over the village of Wing in Rutland and moved away to the north, leaving a clear starlit sky above the thundercloud, with the stars of the Great Bear in their lowest position far above. When the storm was distant about ten miles and more, for every flash seen in the rain cloud and below, and simultaneous with it, there was one or more very slender flashes of typical lightning form from the cloud upwards and many times as long as the usual kind of lightning below. According to my recollection, these reached one-third or perhaps half-way towards the stars of the Great Bear, and in one instance there were seven of these flashes going simultaneously into the clear sky."

Recently Vaughan et al [3] reported a number of eye witness accounts of vertical lightning observations. Although most of the reports could be taken as descriptions of lightning channels that terminate in clear air rather than in a cloud, there are exceptional cases. In particular Lloyd F. Willett reports "About 50 mi west of San Antonio, Texas, at a flight level 41,000 msl, I observed a strong shaft of lightning go directly up and discharge into the ionosphere." J. Richard Fisher [4] has written a detailed description of his observations. ..."I noticed that some of the lightning flashes were accompanied by a faint plume of light extending from the top of the thunderhead above the pool of light from the lightning discharge. The tops of these thunderheads were quite dark, so the light plume was definitely not diffuse light from the lightning in the lower clouds. My only size scale was the height of the tallest clouds, which I assumed to be about 10 km. From this I estimate that the light plumes were about 10-20 km high and a few kilometers wide with their bases at the tops of the clouds. All the plumes were vertical as best I could determine at night, and they appeared at exactly the same time as the lightning flash."

A strange slow moving upward discharge was reported by Everett [5]. "- a luminous trail shot straight up to 15 degrees or so, about as fast as, or rather faster than, a rocket, and of very similar appearance, but with minute waves, like ribbon lightning. It was hardly as bright as most lightning. ... One of the trails turned off, as shown; the others were about vertical as seen from here. Each grew up steadily from below, and then disappeared at once. The upper end was definite, and did not branch or spread."

Franz et al [6] have captured a video image of two vertical plume discharges simultaneously extending into the clear sky above a thunderstorm. The report of Franz et al provided further incentive for a more detailed examination of the video scenes of lightning obtained during recent Shuttle missions. Two of the vertical events that occurred during Mission STS-32 have been presented in a previous video poster paper [7].

VIDEO OBSERVATIONS

Some of the authors describe lightning events that they have observed visually to be similar in appearance to a rocket launch [5] with a glowing trail and one video example we have seen seems to fit the description of rocket lightning. The general appearance is of bright peak appearing at the top of the cumulus tower which then moves upward leaving a luminous trail behind.

Case 1. While the Space Shuttle STS-34 was on orbital pass 45, a storm was observed over Australia. The storm came into view at 12:07:10 GMT on October 21, 1989 and was tracked until it passed out of view at 12:12:20 GMT. The camera strayed off the storm from 12:7:34 GMT until 12:08:42 GMT. The storm appeared to be a supercell storm which had a thick anvil that obscured the illuminated cloud except along the side and at a central location, which we presume to be an overshooting turret. This same storm was observed by a satellite of the USAF Defense Meteorological Satellite Program (DMSP) about ten minutes later. The storm complex had frequent multiple stroke lightning with an average rate of 33.2 flashes per minute. One hundred thirty five flashes were recorded, fifty five before the "rocket" lightning and seventy nine afterwards. None of the other flashes appeared to be abnormal.

Six video examples (five from the viewpoint of space) have the appearance of thin luminous fingers of glowing gases stretching into the stratosphere above a thunderstorm. The term "cloud flash" will be used in this paper to describe a cloud mass that is illuminated from within by an electrical discharge. The lightning channel either within or below the cloud is not seen from space. Also the TV images do not have the time resolution to identify all lightning strokes in a flash. Consequently all phenomena, including cloud-to-ground strokes, that produce a continuous period of cloud illumination will be grouped together and called a cloud flash. All the examples are relatively low resolution images of events that were at a considerable distance from the TV camera.

Case 2. The first example was a storm as seen from the ground on the northwestern side of Lake Superior in North America by Franz et al [6]. "The flash was separated into two fountain-like jets as imaged by the TV, but the two structures were simultaneous within the 17-ms time resolution of the TV sweep." They recorded the flash on July 6, 1989 at 04:14:22 GMT. They estimate the flash was about 20 km in vertical extent at a distance of 250 km. This image contains more detailed structures than the images obtained by an orbiting camera. There was no cloud-to ground event detected by lightning location networks simultaneous with the flash.

Case 3. This event was identified in video imagery taken during orbit 140 of Space Shuttle STS-32 on January 18, 1990. The shuttle had passed over the Gulf of Mexico and proceeded East of Florida over the Atlantic Ocean. The camera was viewing the Southeastern section of the United States which was illuminated by moonlight. The video images showed that the cloud flash began with a relatively small spot which remained faint for 12 frames (30 frames per second). The size of the cloud flash expands to a maximum over the next five frames. Seventeen frames after the beginning of the event two fingers appeared at 07:23:26 GMT. The next two frames show the intensity of the fingers decreasing with a distinct blob at the upper end of each finger. The cloud illumination continued after the fingers disappeared for a total cloud flash time of 34 frames. The length of the discharge above the thunderstorm was estimated to be about 35 km.

Case 4. The third example of a finger like discharge was obtained on October 21, 1989 while the Shuttle STS-34 was on orbit 44. The camera was viewing Northern Australia. The earth was dark and cloud outlines could not be seen. The vertical event accompanies an extremely bright cloud flash which produced a reflection on the vertical stabilizer of the Shuttle. The vertical discharge appears near the horizon as two distinct fingers. There is some brightening at the top of the discharge at the beginning of the full discharge. This brightening is a common feature in other examples. The cloud flash begins six frames before the stratospheric event. The fingers appear at 10:34:20, brighten in the next frame then gradually fade in two more frames. The brightest part of the fingers was near the top while the dimmest section was at the cloud top. The total event occupies 26 frames. The next cloud flash from the vicinity of the vertical event was 42 seconds later.

Case 5. This example was obtained from the Shuttle STS-41 during orbit 9 on October 6, 1990. The camera was viewing central Africa. There were a number of active thunderstorm cells in a large cloud bank that was brightly illuminated by moonlight. The location of interest was in view for two minutes and 33 seconds. A total of four cloud flashes were observed at the location of the vertical flash. This area was adjacent to an area which was much more electrically active. A single vertical line is observed at 23:37:07 GMT and was visible in three frames. The cloud flash started ten frames earlier and continued for a total of 23 frames.

Case 6. This example is included for completeness. The vidicon had been exposed to extreme levels of light and several images were burnt into the screen. There are some features apparent in the full motion video that are obscured in the still frames. The images were obtained on October 8, 1990 while the Shuttle STS-41 was passing over West Africa on orbit 41. A moonlit scene of a large complex of thunderstorms comes into view at 23:41:45 GMT. The location of interest was visible for three minutes and only a few flashes were seen near there. The cloud flash lasted 41 frames in total. The single vertical line was seen at 23:43:31 GMT, 13 frames after the start of the cloud flash.

The next examples are grouped together because they appear to be single discharges with a width much greater than the thin finger like examples presented above. These examples will be referred to as columnar discharges. There is insufficient information to determine whether these are two distinct types of stratospheric discharges or merely an indication of the range of natural variation.

Case 7. The first example of what we call a columnar discharge was obtained from Shuttle STS-32 while on Orbit 132. The scene on January 17, 1990 was too dark identify cloud areas. Some of the stars appear enlarged either because of image saturation or because of poor lens focus. Although there may be some lack of precise focus, the width of the discharge is much wider than the finger type of discharge. The view is of East Africa with a active multi-cell thunderstorm complex near the horizon. The event starts as a small spot and then increases in size for 14 frames. The fifteenth frame at 18:53:28 GMT shows a semicircular glow around the edge of the cloud which is connected to a vertical column with a flat top. In the next frame the column intensifies and develops a small peak. The intensity of the column decreases over five frames form its first appearance with the upper blob remaining brighter that below. The cloud flash for the entire event continues for 112 frames total. In the absence of visual clues, no estimate is provided for the flash rate of the location of interest.

Case 8. The second example of a columnar discharge was found in video during Orbit 55 of the Shuttle STS-31. The scene on April 28, 1989 is dark with only a few other flashes visible over West Africa. The cloud flash was located at about 7.5 N, 4 E over the Gulf of Guinea. The discharge at 03:35:59 GMT appears to be a column with a distinct blob of illumination at the top (see fig 1.). Several stars were located in the scene. The angular separation of the stars was used to calibrate the distances in the scene. The length of the vertical column was approximately 34 km. Nine frames of the cloud flash pass before the stratospheric discharge appears. The columns are visible for four frames out of a total of twenty-five frames for the event. There was no apparent lightning activity on the horizon for a minute before the vertical event. A weak flash was seen on the horizon 40 seconds after the vertical flash.

Case 9. The third example is also a columnar type of discharge. In this case the background noise in the TV transmission partly obscures any details of the image. Shuttle STS-31 was over East Africa on orbital pass 37. A single vertical column was observed at 22:22:43 GMT on April 26, 1990.

DISCUSSION

Some features appear to be common among the various video observations of stratospheric lightning.

These flashes are clearly a part of series of thunderstorm discharge processes. The vertical event typically occurs about a half second after the cloud illuminates due to electrical discharge processes. The video imagery obtained from a viewpoint above the thunderstorm shows the clouds illuminated from within and does not present evidence to distinguish between intracloud events and cloud-to-ground strokes. The cloud remains illuminated after the vertical event, typically for a large fraction of a second.

The flash appears as a singular event which penetrates the stratosphere. Repeated vertical events have not been captured on video but several eyewitnesses have observed them.

In most cases the discharges appear to be aligned nearly with the vertical. The vertical extent of the flash is established within the time resolution of one video frame. The observations to date do not contain convincing evidence of the direction of propagation.

The width of the luminosity seems to vary considerably between events. Some examples show a very thin or even several thin vertical lines while others are much broader plumes. Several examples show some sort of darkened region below the top of the discharge.

The typical stratospheric flash accompanies a cloud flash in a cell that exhibits a low flash rate, about one flash per minute. The movement of the Shuttle limits the observation time of any location to several minutes at most. There is insufficient information to determine whether the observed low flash rate is a characteristic of the storm and its environment or an aspect of the individual storm life cycle.

The geographic distribution of events is biased by the limited opportunities to observe them. The major limitations are the number and duration of Shuttle missions, the inclination of the trajectory , and the inability to observe these phenomena during daylight. The examples do include Northern and Southern hemisphere cases, oceanic and continental storms. Thus it appears that the conditions for these stratospheric discharges may occur over most regions of the globe.

A rough estimate of the frequency of occurrence of stratospheric lightning can be made from the volume of MLE observations. This estimate is biased by the impression that the vertical discharge could not be identified against a bright background. Consequently all cases that have been observed appear near the horizon. We estimate that vertical flashes can occur with a frequency of the order of one in five thousand total lightning flashes. These vertical events are unusual but not rare.

These observations of stratospheric lightning raise additional questions. If these vertical events are not that rare, why are there so few reports of vertical lightning? Why did it take until 1990 to get images of vertical flashes? Some partial answers can be given. The phenomena is unusual. The visual impression is so fleeting that there is no clear recall of the event. Written reports emphasize repeated events when the attention of the observer was focussed on identifying the next unusual visual event. The video camera observations were discovered during replay. The luminance of vertical lightning is much less than the cloud flash it accompanies. Vertical events can not be identified against a bright background. If intervening clouds block the view of the sky above the cell in question, the event will not be observed. The video cameras that were used to document this phenomena were special low light level video cameras capable of recording events near the threshold of human vision; and were pointed in the right direction at the right time.

CONCLUSIONS

More measurements are needed to identify the physical processes producing the visible glow. Spectroscopic analysis of the optical emissions should yield information about the atomic processes. There is some hope that limb scanning type satellite instruments may observe some of these stratospheric events. We are now working with scientists who make observations in the radio frequency spectrum to help identify the radio signature of these events. We conjecture that the conditions for stratospheric lightning, some combination of thunderstorm electrical fields or electric field changes as well as some stratospheric conditions, may often exist before and return after the vertical event as well as at near by cells. It may necessary to necessary to postulate some external , possibly ionizing, event to explain the infrequent and localized occurrence of these phenomena.

We intend to continue to gather observations from further Shuttle flights and make quantitative analyses of selected video scenes.

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1 Vaughan, O.H., Jr. (1990). "Mesoscale Lightning Experiment (MLE): A View of Lightning as Seen From Space During the STS-26 Mission", NASA TM-103513, 61 p.

2 Boys, C.V. (1926). "Progressive Lightning", Nature, Vol. 118, pp. 749-750.

3 Vaughan, O.H., Jr. and Vonnegut, B. (1989). "Recent Observations of Lightning Discharges From the Top of a Thundercloud Into the Clear Air Above", Journal of Geophysical Research, Vol. 94, pp. 13179-13182.

4 Fisher, J.R. (1990). "Upward Discharges Above Thunderstorms", Weather, Vol. 45, pp. 451-452.

5 Everett, J.D. (1903). "Rocket Lightning", Nature, Vol. 68, p. 599.

6 Franz, R.C., Nemzek, R.J., Winckler, J.R. (1990). "Television Image of a Large Upward Electrical Discharge Above a Thunderstorm", Science, Vol. 249, pp. 48-51.

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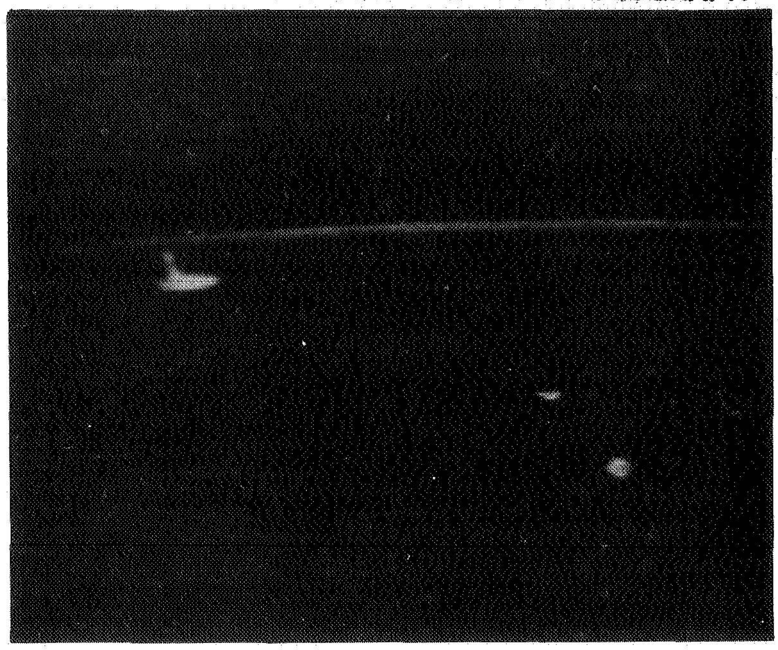
Figure 1

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Blow-up of
Vertical Discharge



Vertical Discharge from a Thunderstorm Cell Located At Limb Of Earth. Note Small Storm Cells Illuminated by Lightning in Foreground