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LIGHTNING ELECTRIC FIELD MEASUREMENTS WHICH CORRELATE WITH STRIKES TO THE NASA F-106B AIRCRAFT (JULY 22, 1980)

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Abstract

On July 22, 1980 the NASA F-106B designed to collect data on lightning strikes to aircraft worked a storm cell within range of ground-based lightning monitoring equipment operated by the Goddard Space Flight Center at Wallops Island, Virginia. Several times during this storm the lightning monitoring instrumentation aboard the aircraft was triggered. The purpose of this report is to present data, in the form of slow electric field changes and RF radiation, recorded on the ground at these times. The data are presented so that they may be of help in the interpretation of the signals recorded by the F-106B. The ground based events correlate well with events recorded on the aircraft and provide an indication of the type of flash with which the aircraft was involved.

Background

Lightning is among the most damaging of weather related hazards (White and Hass, 1975) causing more than 100 deaths in a typical year, being a major source of forest fires and disrupting radio communications. Lightning is also a hazard to aircraft (Fisher and Plumer, 1977), and recent trends in aircraft design have raised concern about this hazard. For example, the light weight composite materials being developed for structural elements are poorer shields of electromagnetic fields than the metals they replace. This raises the prospect of larger electrical transients in the interior of an aircraft during a lightning strike. In addition, the computers being used for guidance and control are more susceptible to electrical transients than the older generation equipment they replace. All of this raises the concern over system "upset" due to electrical transients induced during a lightning strike.

The potential for lightning induced problems in aircraft is quite real (Fisher and Plumer, 1977; Corn, 1979; and e.g. NTSB Report #AAR-78-12) and criteria are needed to help the engineer design for safe operation in the presence of lightning strikes. Unfortunately, not enough is known about lightning that strikes aircraft and laboratory simulations have in the past been a questionable imitation of the real discharge. Information about real lightning strikes to aircraft is needed both to establish design criteria and to help develop laboratory techniques which adequately test for safety under conditions likely to be encountered in a real storm.

Experiments to collect this information are being conducted by NASA/LaRc using an airplane (NASA F-106B) instrumented to fly through thunderstorms and be struck by lightning. The aircraft is instrumented to measure such characteristics of the discharge as current and electric and magnetic fields on the surface of the plane. To aid in the interpretation of this data ground based observations of lightning are also made during the flights. Observations of lightning from aircraft are from a new perspective and by combining the new perspective with a traditional ground-based perspective more information is obtained to help in the interpretation of the aircraft data.

During the 1980 Storm Hazards experiments the Goddard Space Flight Center made simultaneous measurements of radio frequency (RF) radiation and slow electric field changes from the ground during several flights. In addition, development was begun on a system to make measurements of fast electric field changes in a manner which will permit correlation with field changes measured aboard the aircraft. The Wallops Flight Center has also undertaken the task of operating a lightning locating device (LDAR, See Uman, et al., 1978 and Rustan, et al., 1980) which will help identify the location of the aircraft within the discharge. Ultimately, these systems will provide fast and slow electric field changes and three dimensional mapping of the discharge in space to support the aircraft measurements.

The purpose of this report is to document the measurements of RF radiation and slow electric field changes made on July 22, 1980 during the flight mission that afternoon. The aircraft reported five "strikes" on this mission. The slow electric field changes provide an indication of flash type (cloud-to-ground or intra-cloud) and the RF radiation has been used to obtain an estimate of flashing rate. It is hoped that this information will be of help in interpreting the electric field measurements obtained by the aircraft.

Instrumentation

During the summer, 1980, the Goddard Space Flight Center measured slow electric field changes and RF radiation from lightning during flights in the vicinity of the Wallops Flight Center. The instrumentation was housed in the Spandar Radar Facility at the Wallops Flight Center. Fast electric field changes were also monitored but on a selected basis and not in a mode which permitted correlating with measurements aboard the F-106.

The RF system consisted of several channels covering the frequency range from about 3 MHz to 300 MHz. Measurements were made near 3 MHz and 30 MHz using fixed tuned receivers developed by the Georgia Institute of Technology (Le Vine, et. al., 1976). These receivers were driven by base loaded "monopole" antennas (i.e. whips) located on the ground. Measurements in the range from about 50 MHz to 300 MHz were made using commercially available Watkins Johnson receivers (WJ model 977 and WJ model 8730) which were modified to provide DC coupled video output. During the summer of 1980 these receivers were connected to disk-cone antennas also mounted on the ground. The system was designed to have a bandwidth of 300 kHz for each RF channel, a limit set by the recording instrumentation.

The electric field change systems were similar to those described by Krider et. al. (1977), Krider (1977), and Uman, (1969). Both fast and slow electric field change systems consisted of a flat plate antenna mounted on the roof of the Spandar Radar Facility (an all metal, shielded building) and connected to an integrating circuit at the recording instrumentation. The time constant for the slow antenna was about two seconds and the time constant for the fast antenna was on the order of one millisecond. One of the problems encountered in the past in recording slow electric field changes had been the variability of signal levels. Large electric field changes are often followed by small field changes. Many factors contribute to this effect including the motion of the storm and the natural variability of lightning. This uncertainty in the signal level makes it difficult to keep the gain of the system adjusted to obtain optimum resolution. To help overcome this problem the slow electric field changes were recorded on three parallel channels, each with a different gain. This was accomplished by using one integrator followed by three amplifers with different gain.

Data from the RF and slow electric field change systems were recorded simultaneously on an analogue tape recorder and a strip chart recorder. The strip chart recorder (an 8 channel Brush recorder model Mark 200-1707) was intended primarily for real time monitoring and to check signal levels. The tape recorder provided the permanent record for data analysis. An Ampex model PR-2200 recorder was used with both direct and FM (redundant) recording and an Ampex Model FR-1300 was available as a back-up recorder, but with only FM recording.

The fast electric field change system and recording mode were as described in Le Vine and Krider (1977). This system was not intended for support of the aircraft missions in 1980, although a system for this purpose is currently being developed.

The effective monitoring range of the electronics is limited by the slow electric field change system. This system, which measures quasi-static electric field changes (Uman, 1969) has a bandwidth from about 100 Hz to 1 kHz and is very susceptible to background noise at 60 Hz. It is the noise at 60 Hz which ultimately limits the effective range of the slow electric field change system. An estimate of the effective range on the most sensitive (highest gain) channel based on storms observed in 1980 is about 60 km (approximately 30 nautical miles).

Data

On the afternoon of July 22, 1980 the F-106 worked a storm over the Cheaspeake Bay just east of the confluence of the bay and the Potomac River. Figure 1 is a tracing of the cell as seen by the Spandar Radar at WFC. The open areas near the storm center were the location of the largest echos (maximum echos were on the order of 45 dbz). Figure 2 is a tracing of the Patuxant River radar display for this area at about 20:35:00 GMT (4:35 p.m. local time). The range circles in both figures are 25 nautical miles (46 km) and the central shaded area around the Patuxant River radar (at P) is ground clutter. The cell being worked is on the western edge of the clutter.

The F-106 left Langley Research Center at about 20:13:00 GMT and worked this cell from about 20:30:00 to about 21:00:00. The lightning strike monitoring instrumentation on the aircraft was triggered at 20:34:28, 20:34:40, 20:35:00 and also at 20:54:22, 20:54:48. The event at 20:34:28 triggered the magnetic field sensor on the top of the fuselage just forward of the tail and the other events triggered the electric field sensor on the fuselage under the nose. (See NASA TM-81946 for details.) The current probe on the nose of the aircraft was not triggered during this mission. The last trigger, at 20:54:48 resulted in a blank data record.

This storm was within range of the slow electric field change system operated by the Goddard Space Flight Center at Wallops Island and records of slow electric field changes (Slow E) and RF radiation were obtained for this storm. Figures 3-5 are representative of data collected during this storm. Figure 3 is a copy of a portion of the real time strip chart record made during this storm. The strip chart normally includes records of RF radiation at several frequencies, a time code, and three channels of slow electric field changes. The three channels of slow E record the same data but with different gain to help insure a readible record in face of the variable nature of radiation from lightning. Figure 3 shows a representative example of radiation at 139 MHz and two channels of slow electric field change. The electric field change at 20:53:13 is representative of an intracloud flash and the change at 20:53:20 is representative of a cloud-to-ground flash (Uman, 1969, Golde, 1977). Figures 4 and 5 show these events on an expanded time scale. This data was obtained from the tape recorder by playing it back at a reduced speed and recording on the strip chart recorder. Figure 4 is the intracloud flash at 20:53:13 and Figure 5 is the cloud-to-ground flash at 20:53:20. Notice, in Figure 5, the step-like changes of the electric field record typical of changes which occur during return strokes. Notice also the radiation at 139 MHz coincident with these steps. RF radiation in the HF-VHF range tends to have a pattern indicative of flash type (Le Vine, 1978). The vertical scale of the slow E record is linear (volts/meter) but has not been labelled because a proper calibration of the system is not yet complete.

Data such as is shown in Figure 3 was used to compute a flashing rate for this storm. To do this the number of identifiable lightning events in a one minute interval were counted and plotted as a function of time. The result for this storm is shown in Figure 6. Figure 6 shows a flashing rate with peaks near 20:25:00 and 20:35:00 followed by a rapid decay after 20:40:00. (Time in this figure begins at 20:00:00.) The airplane worked this cell from about 20:30:00 to 21:00:00 GMT and experienced "strikes" near 20:34:00 and 20:54:00 as indicated on the figure. The first "strikes" were clearly during a peak in the activity and the second group occurred after the peak, probably during the decaying phase of this particular cell. (The instrumentation used to record RF radiation and electric field changes is omni-directional. The instrumentation has no directional capability, and consequently there is no absolute way to distinquish flashes associated with the particular cell the aircraft worked from flashes in other cells active at the same time. However, the signals from lightning are distance dependent and by adjusting the gain to reject signals radiated from distant lightning one can obtain a record which reflects the activity in a nearby, active cell. This procedure is reasonable in cases where one nearby cell is dominant, but obviously is misleading if several strong cells are active within range of the equipment at the same time.)

Examples of electric field changes recorded on the ground at same time that events triggered the recording system aboard the aircraft are shown in Figures 7-13. Figures 7-9 are examples of field changes recorded at the time of the two events at 20:54:22 and 20:54:48. Figure 7 is a portion of the real-time strip chart record for this interval, showing radiation at 139 MHz and two channels of the slow electric field change recording. The two events on this record correlate well with the events monitored on the aircraft. The event at 20:54:22 is shown in expanded form in Figure 8 and the event at 20:54:48 is shown with an expanded time scale in Figure 9. Both records are suggestive of intra-cloud lightning discharges. Figures 10-13 are portions of the real-time strip chart record at the time of the events at 20:34:28, 20:34:40 and 20:35:00. The four figures show a continuous section of strip chart record from just before the events (20:33:40) to just after the events (20:35:30). Only one level of slow electric field change is shown but three were recorded. The events observed by the aircraft at 20:34:40 and 20:35:00 (Figure 12) correspond closely with events seen on the ground. (The relative timing accuracy for comparing ground and aircraft observations is estimated to be about one second.) The flash near 20:35:00 appears to be a cloud-to-ground flash and that at 20:34:40 to be an intra-cloud flash. The pilot reported seeing lightning at both of these times. He also reported seeing lightning at 20:34:33 (Figure 11) a time which corresponds to a field change observed on the ground (probably an intra-cloud flash) but for which there was no signal recorded at the aircraft. The event at 20:34:28 (Figure 11) is unusual in that it shows the poorest correlation of all events with an electric field change on the ground. Assuming the time to be off by one second would put this event in the tail of what appears to be an intra-cloud flash with an unusually long tail. This record is also the only event in this flight which triggered a B-dot (fast magnetic field change) sensor. The D-dot sensor which recorded the other events during this mission did not trigger at this time. No expanded time scale reproductions of data on this section of tape was possible because of noise on the tape recorder.

In all but one instance events recorded on the aircraft correlate well with electric field changes measured on the ground supporting the supposition that the events seen on the aircraft were associated with lightning. However, whether the aircraft was struck by lightning in the sense that it was part of the overall discharge between positive and negative charge centers, or whether it was experiencing secondary effects such as corona or transients induced by a nearby discharge is not clear from this data. More extensive measurements are required to address questions such as these.

Conclusions

The observations on July 22, 1980 demonstrate the potential for correlated ground and airborne measurements of lightning. The data offer confirmation that the events recorded by the aircraft are associated with lightning and provide an indication of the type of flash involved. However, additional information is required to determine how the aircraft was involved with the discharge.

To interpret the data recorded by the aircraft a clearer understanding is needed of how the aircraft is involved with the lightning flash. For example, it would be helpful to determine if the aircraft was "struck" in the sense of being part of an independent streamer (e.g. leader, return stroke, etc.) which would have occurred even if the aircraft hadn't been there or if it was experiencing a secondary effect such as corona induced by locally high electric fields but otherwise independent of the lightning discharge. To address questions such as these, records of fast electric field changes and improved timing accuracy between the aircraft and the ground would be very helpful. The shape of fast electric field changes radiated by many events (e.g. stepped leaders and return strokes) are characteristic of the event (Weidman and Krider, 1978, 1979, Krider, et. al., 1977) and such records could be used to determine which part of the discharge involved the aircraft. Recording sequences of fast field changes, ideally together with slow electric field changes, would provide a more complete picture of the discharges, and locating the event seen by the aircraft in such a pattern would help greatly to identify the part of the flash with which the aircraft was involved. Finally a capability to map the discharge in space and time (as is potentially inherent in the LDAR and has been demonstrated by Rustan et. al., 1980) would be helpful, especially if the aircraft could be accurately located on the same coordinate system. Work is underway to provide much of this additional monitoring capability for future experiments.

Acknowledgements

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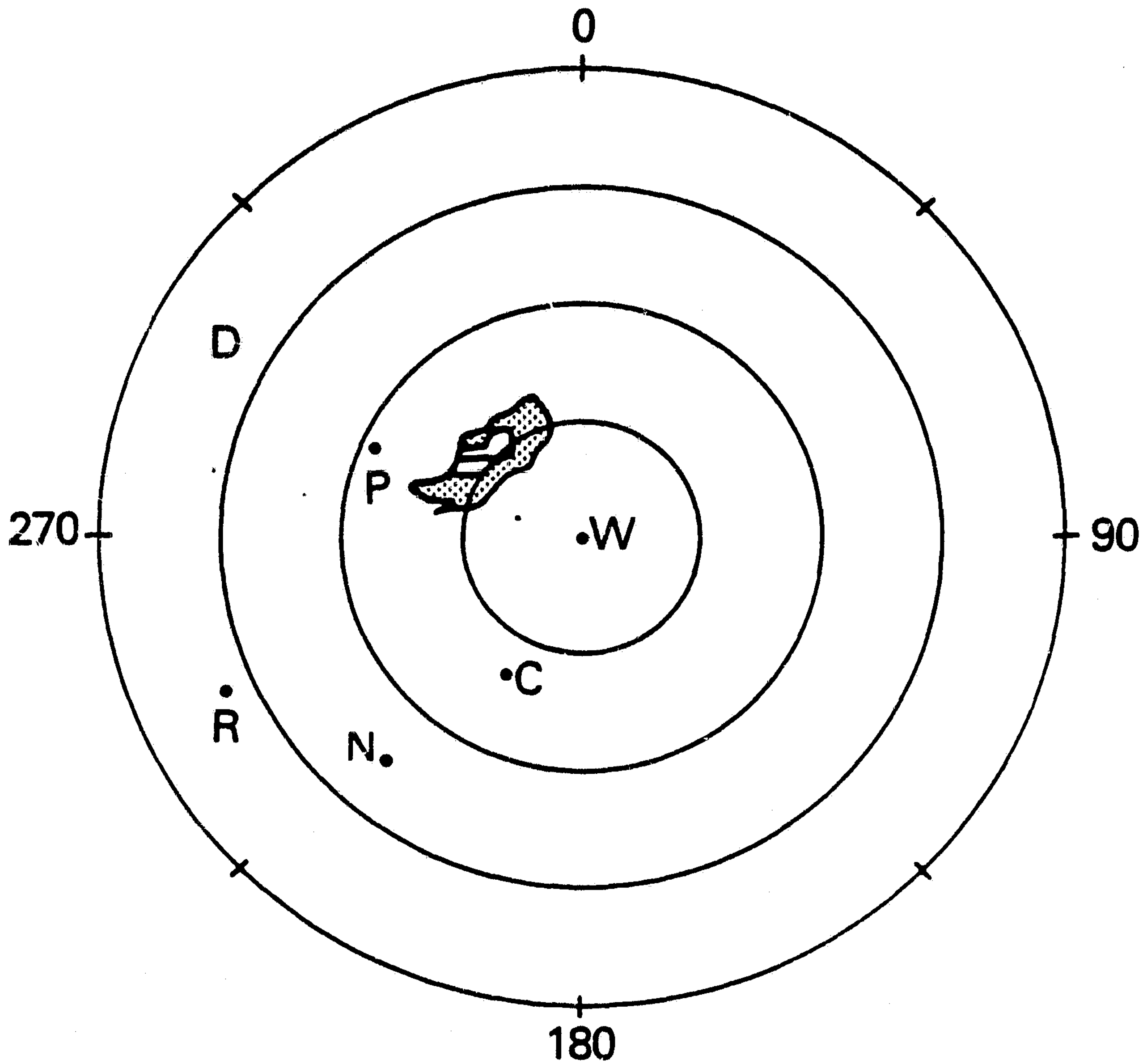

Figure 1. Tracing of the Spandar Radar display at about 20:38:00 GMT on July 22, 1980. The range circles are 25 nm (46 km). W indicates the radar location at the Wallops Flight Center, Wallops Island, VA, P is the location of the Patuxant River radar, D is Dulles airport and C is Cape Charles, VA.

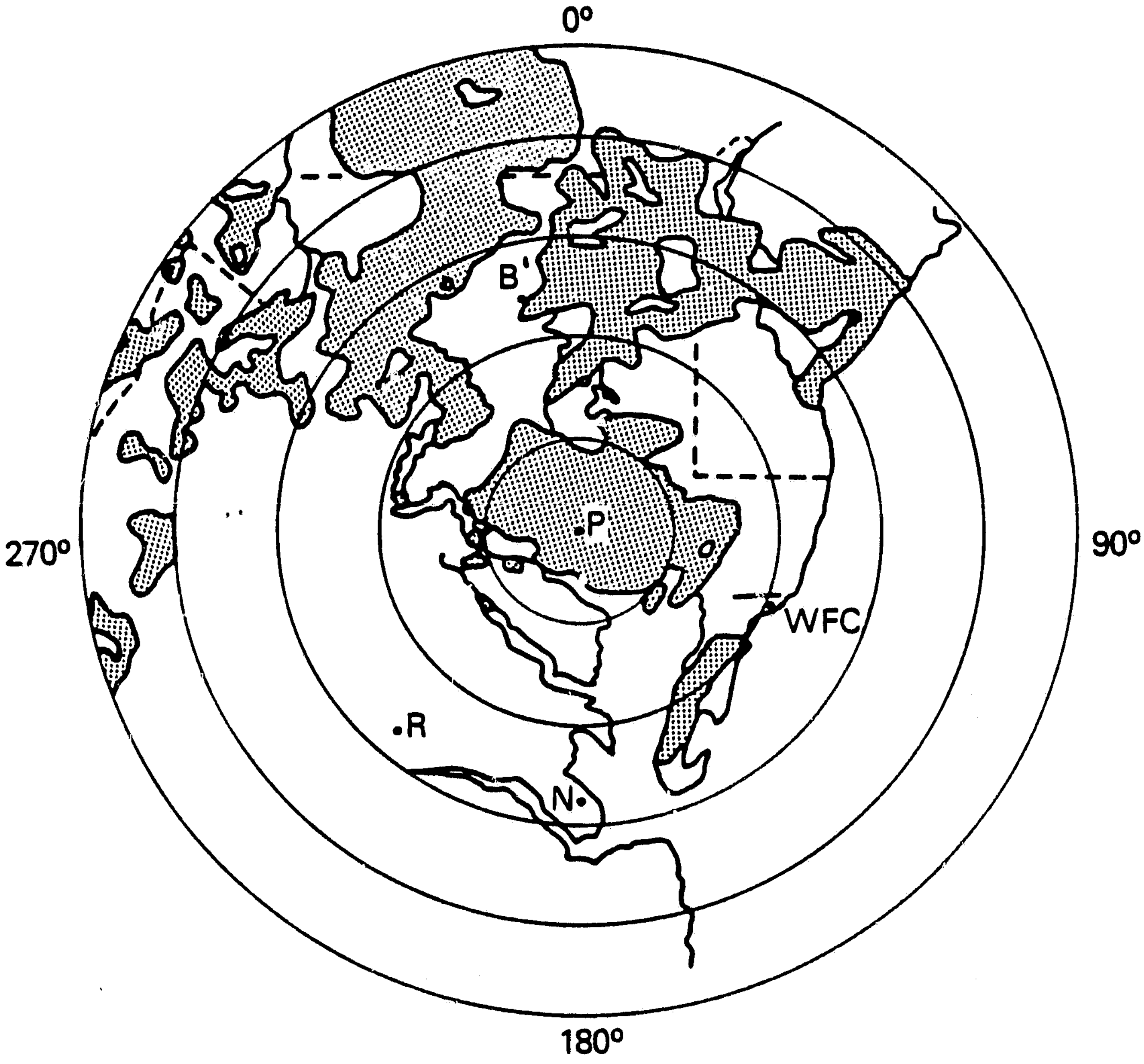

Figure 2. Tracing of the Patuxant River radar (WSR-57) display at 20:35:00 GMT on July 22, 1980. P indicates the location of the radar and WFC indicates the Wallops Flight Center and location of the ground based lightning monitoring equipment. B is Baltimore, MD and N is Norfolk, VA. The range circles are 25 nm (46 km). The central shaded area around P is ground clutter.

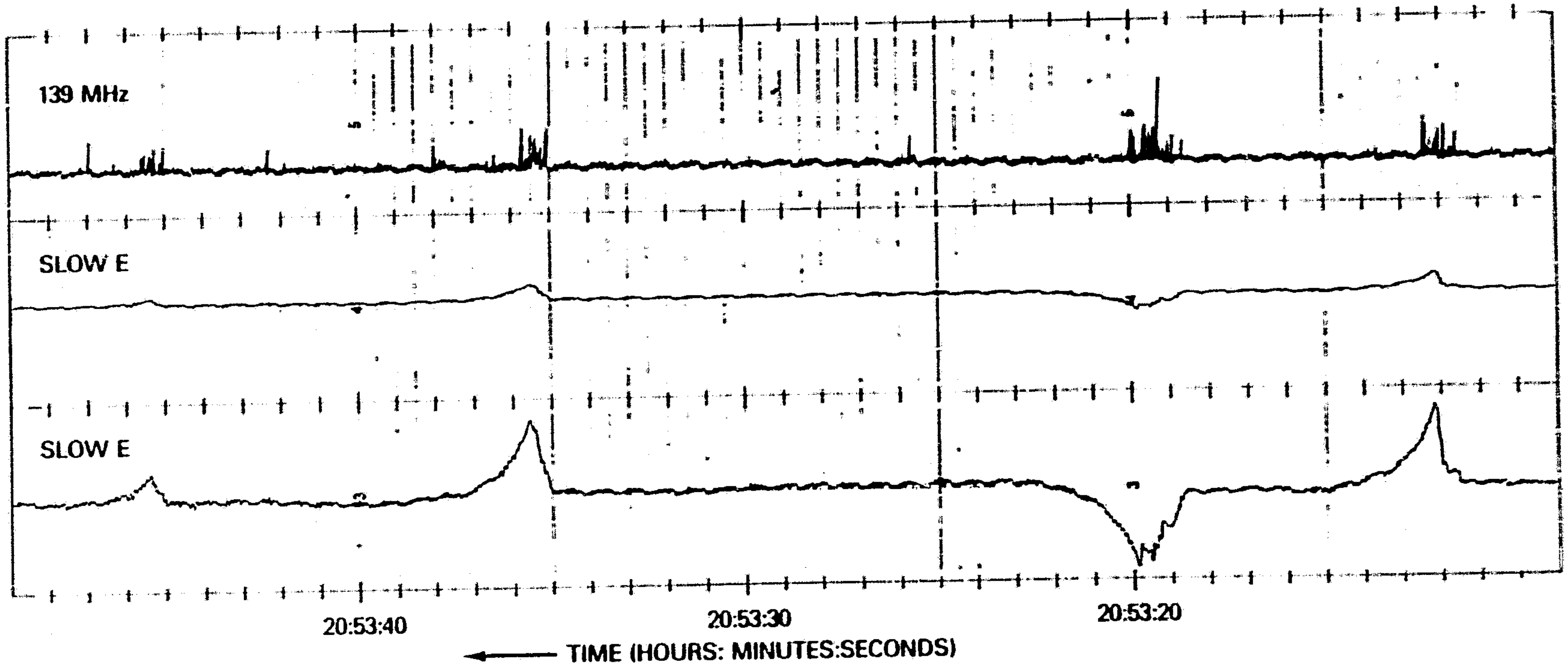

Figure 3. A representative section of strip chart showing data recorded on the ground on July 22, 1980 at Wallops Island, VA.

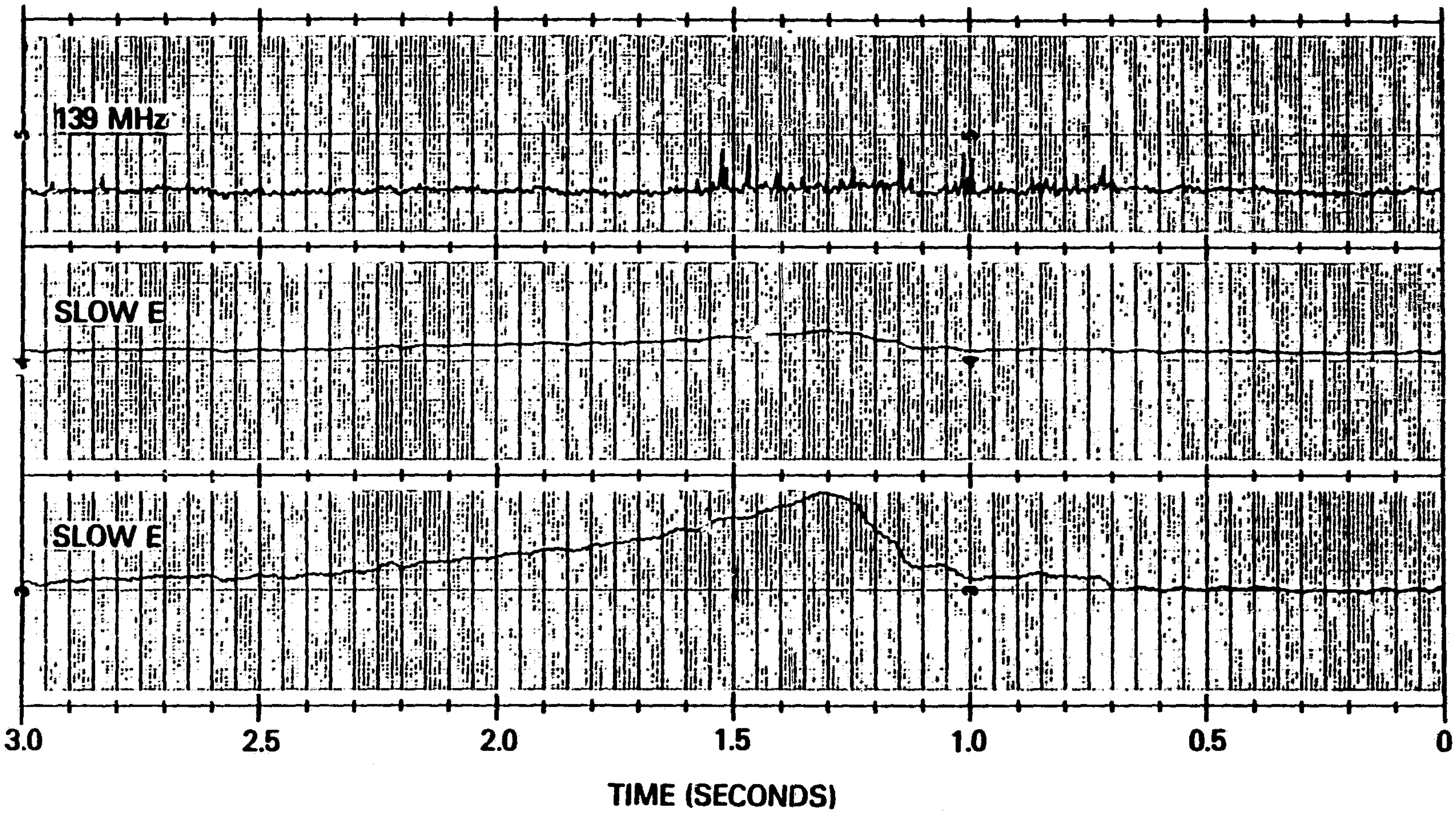

Figure 4. The event occurring at 20:53:13 (Figure 3) shown in with an expanded time base. The RF radiation and slow electric field changes are typical of an intra-cloud flash.

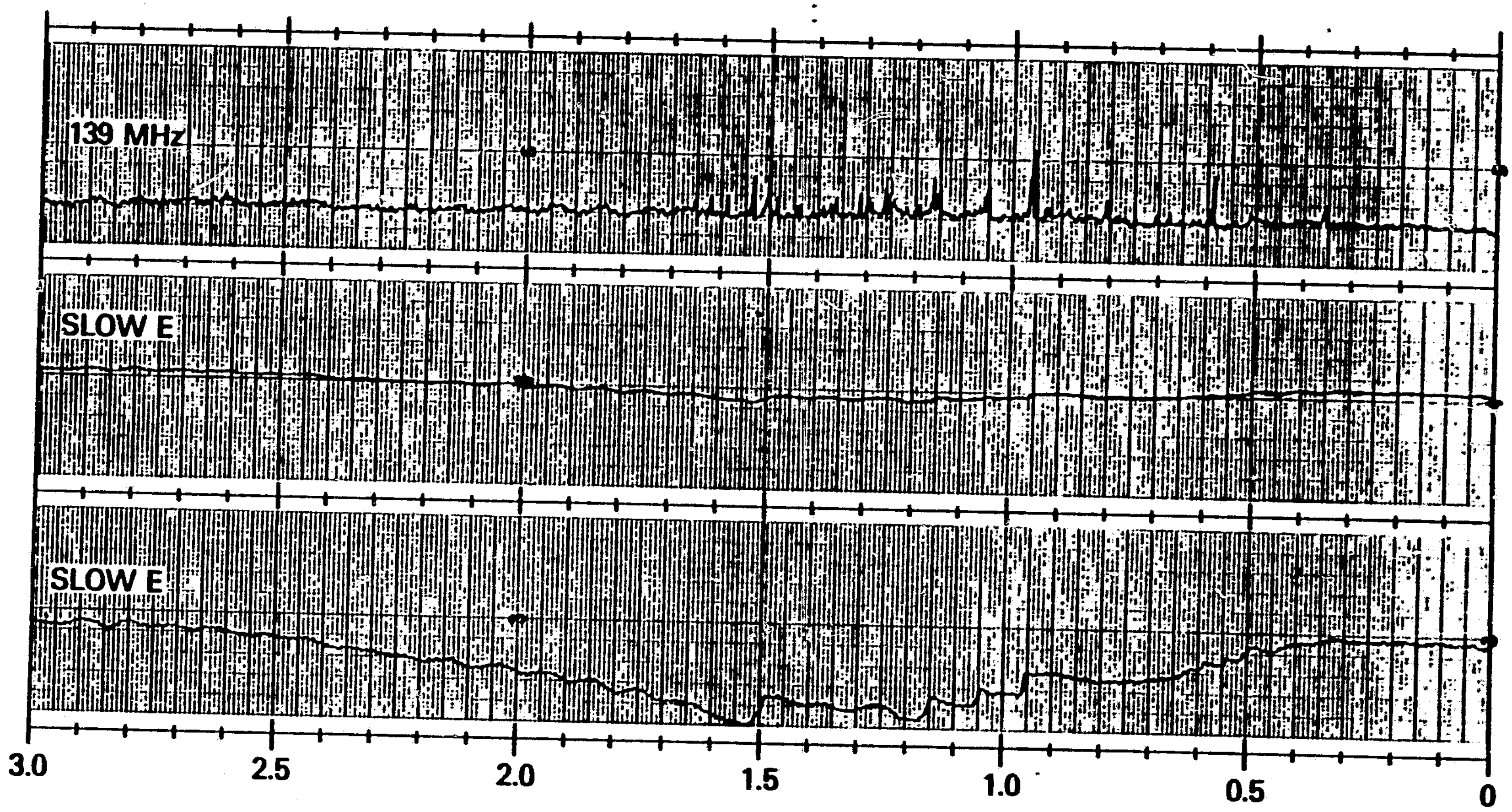

Figure 5. The event occurring at 20:53:20 (Figure 3) seen with an expanded time base. The slow electric field change is typical of a cloud-to-ground flash.

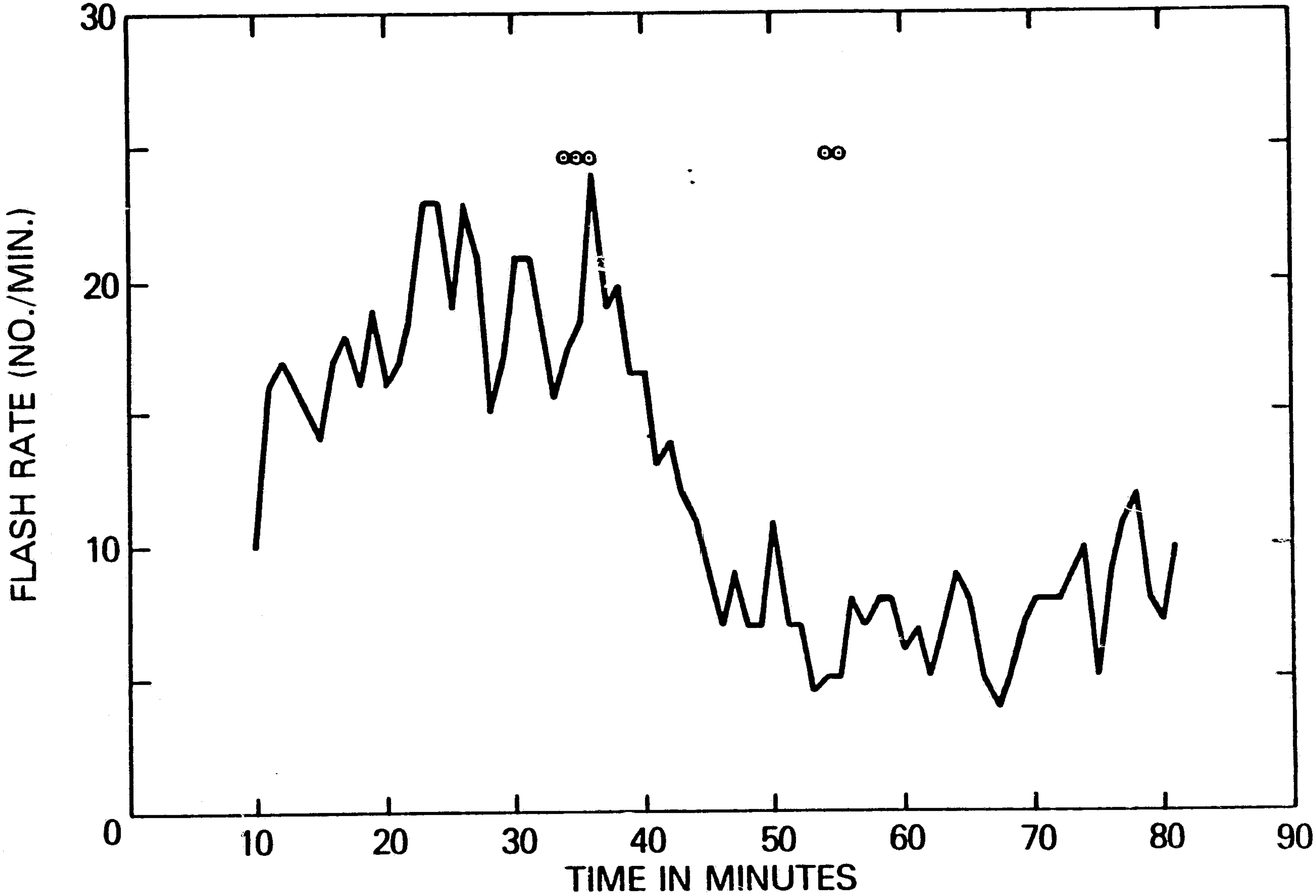

Figure 6. Flashing rate history for the storm on July 22, 1980. The dotted circles (⊙) indicate times at which instrumentation aboard the aircraft was triggered. The time scale begins (t = 0) at 20:00:00 GMT.

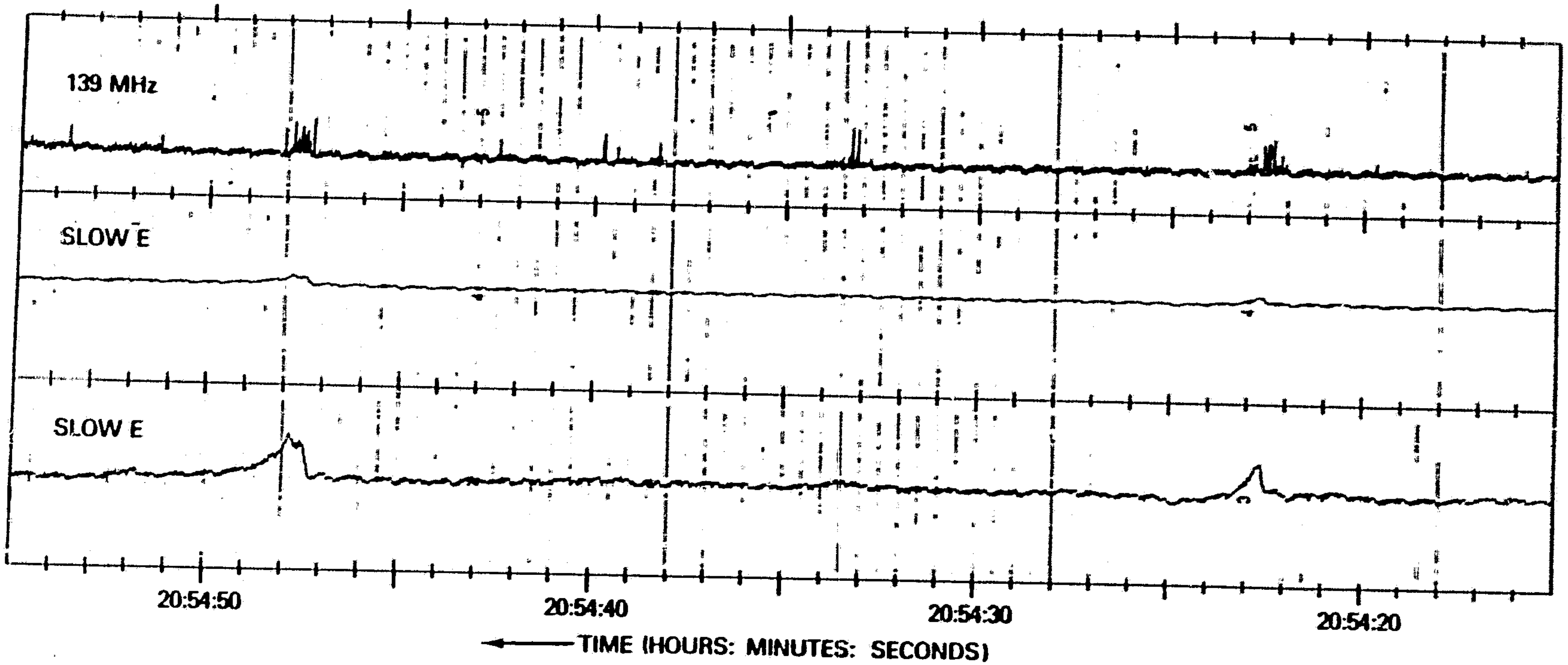

Figure 7. Electrical field changes and RF radiation recorded at the time of the "strikes" to the aircraft at 20:54:22 and 20:54:48 on July 22, 1980.

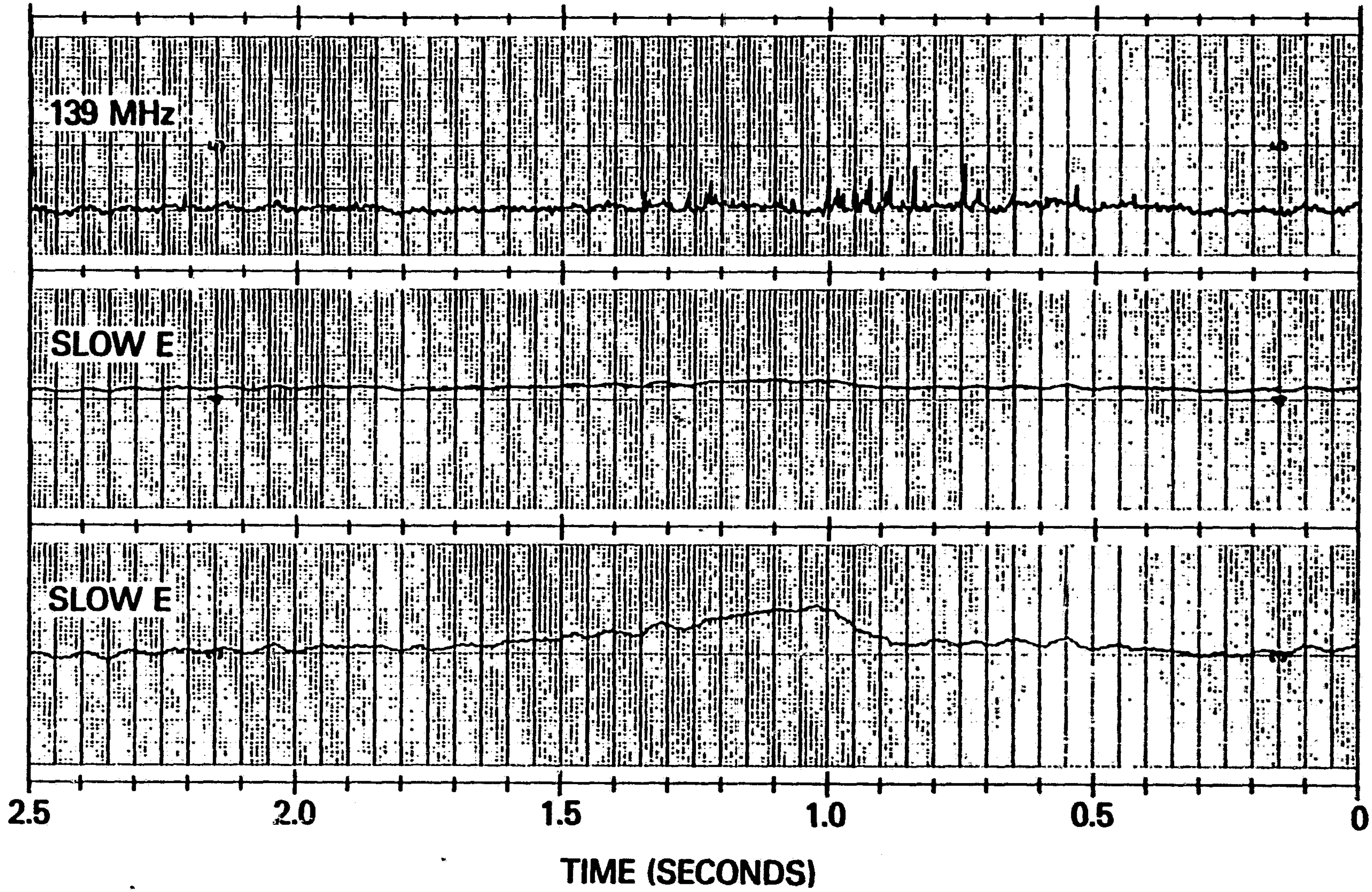

Figure 8. The event at 20:54:22 (Figure 7) with an expanded time base. This field change is representative of an intra-cloud flash.

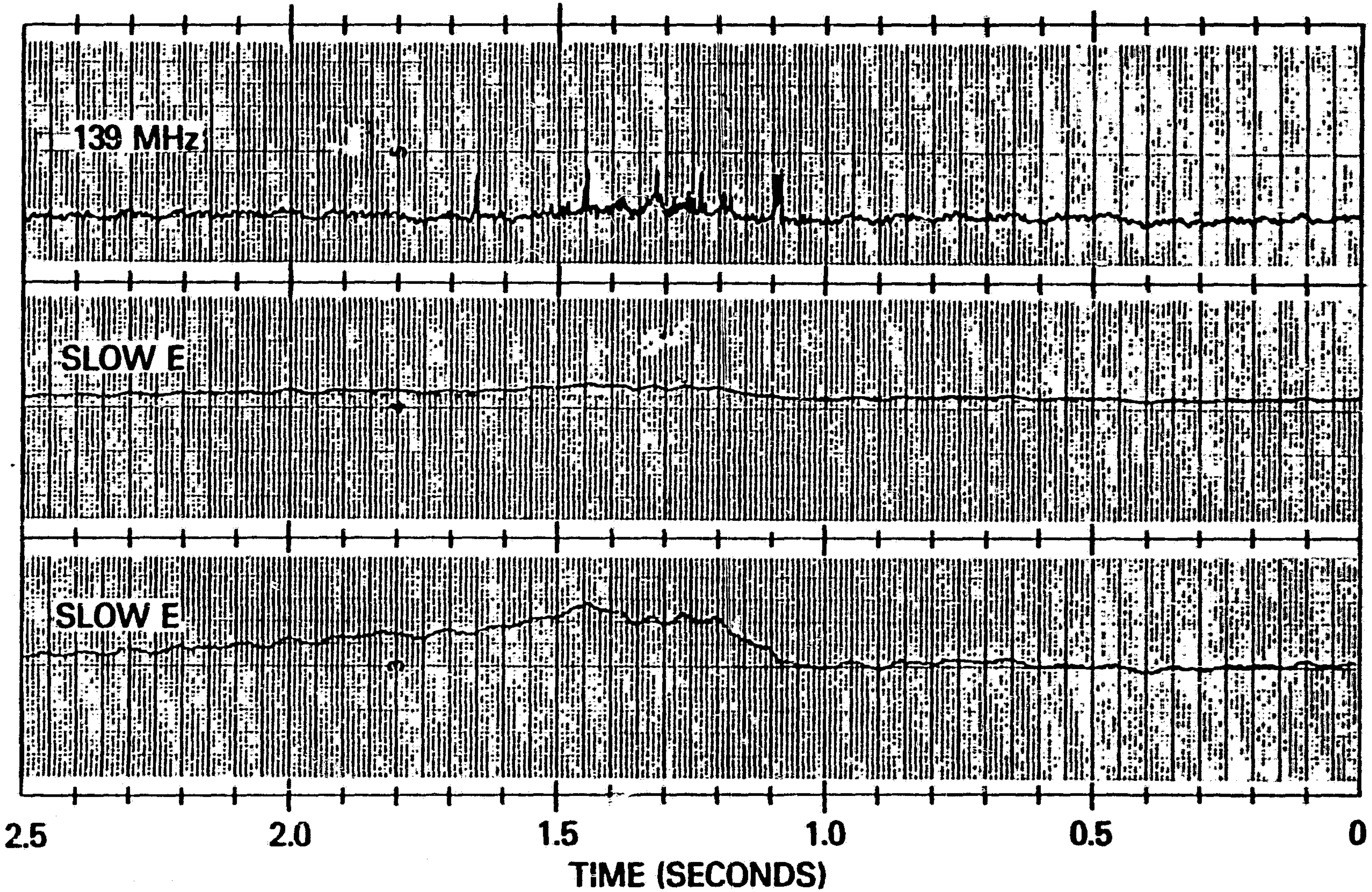

Figure 9. The event at 20:54:48 (Figure 7) with an expanded time base. This field change is representative of an intra-cloud flash.

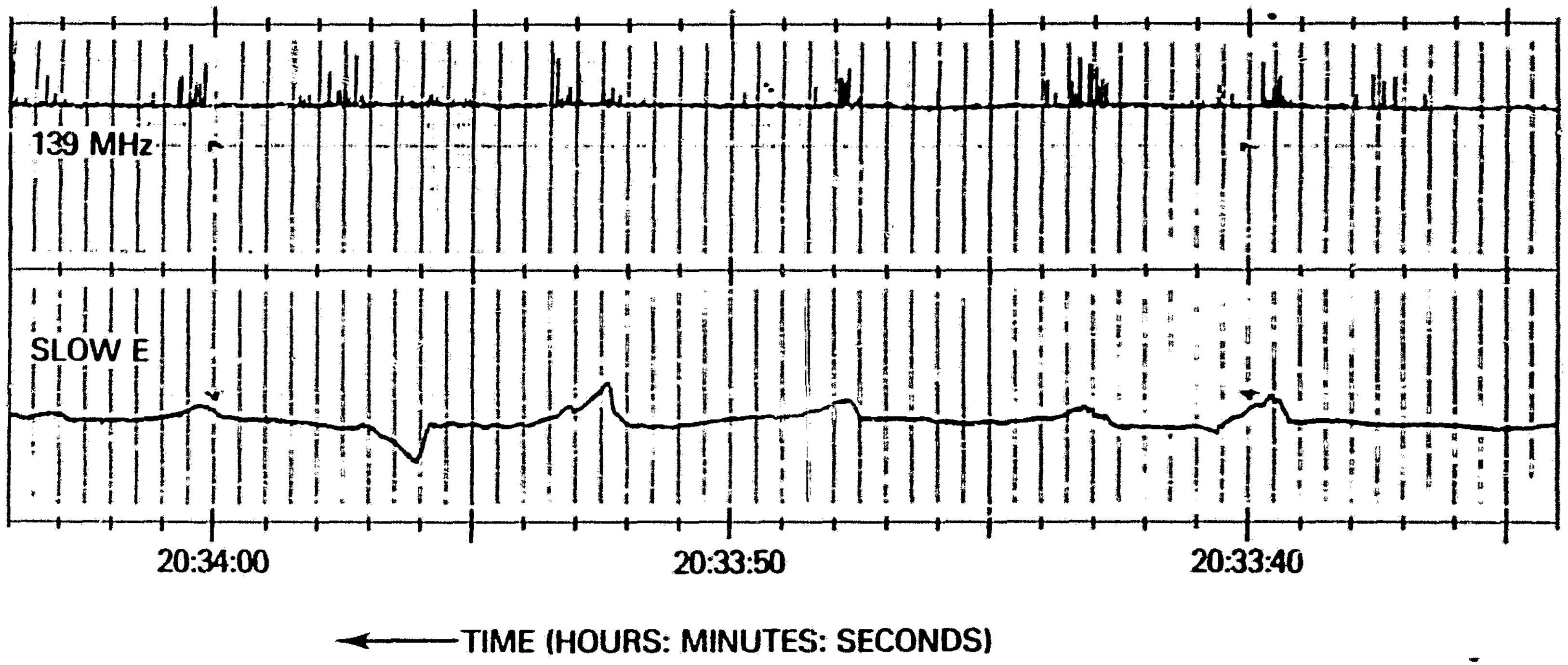

Figure 10. The first in a sequence of strip chart records showing data recorded on July 22, 1980. The record is just prior to the first of three "strikes" to the aircraft.

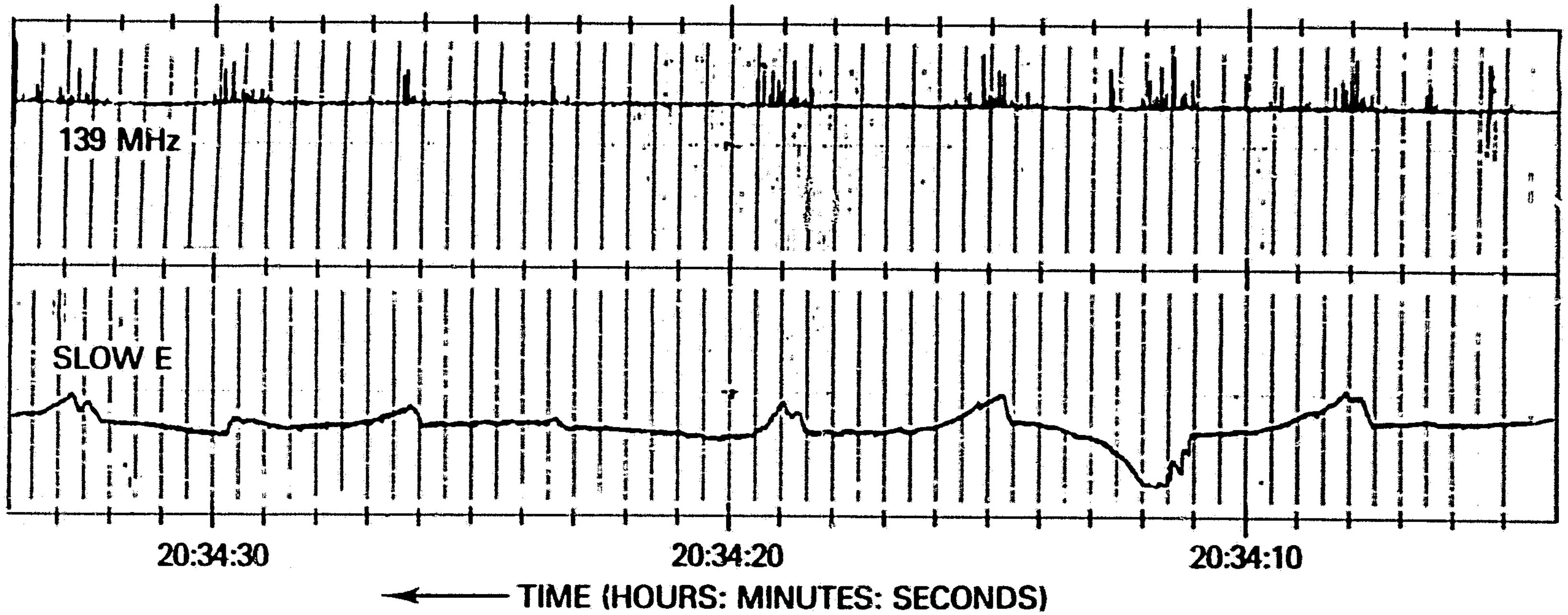

Figure 11. The second of in a sequence of strip chart records showing data recorded on the ground on July 22, 1980. The aircraft instrumentation recorded an event at 20:34:28 and the pilot reported seeing lightning at 20:34:33.

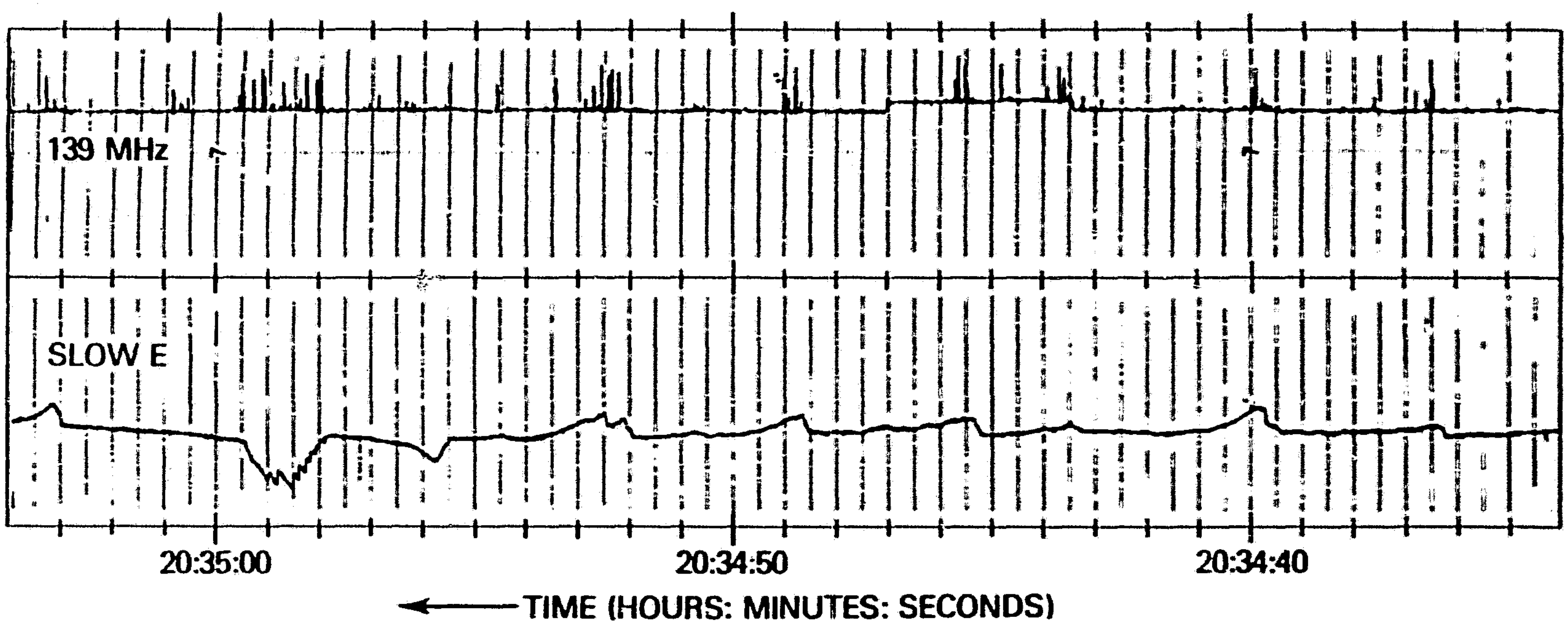

Figure 12. The third in a sequence of strip chart records showing data recorded on the ground on July 22, 1980. The aircraft recorded "strikes" at 20:34:40 and 20:35:00. The pilot reporting seeing lightning at both of these times.

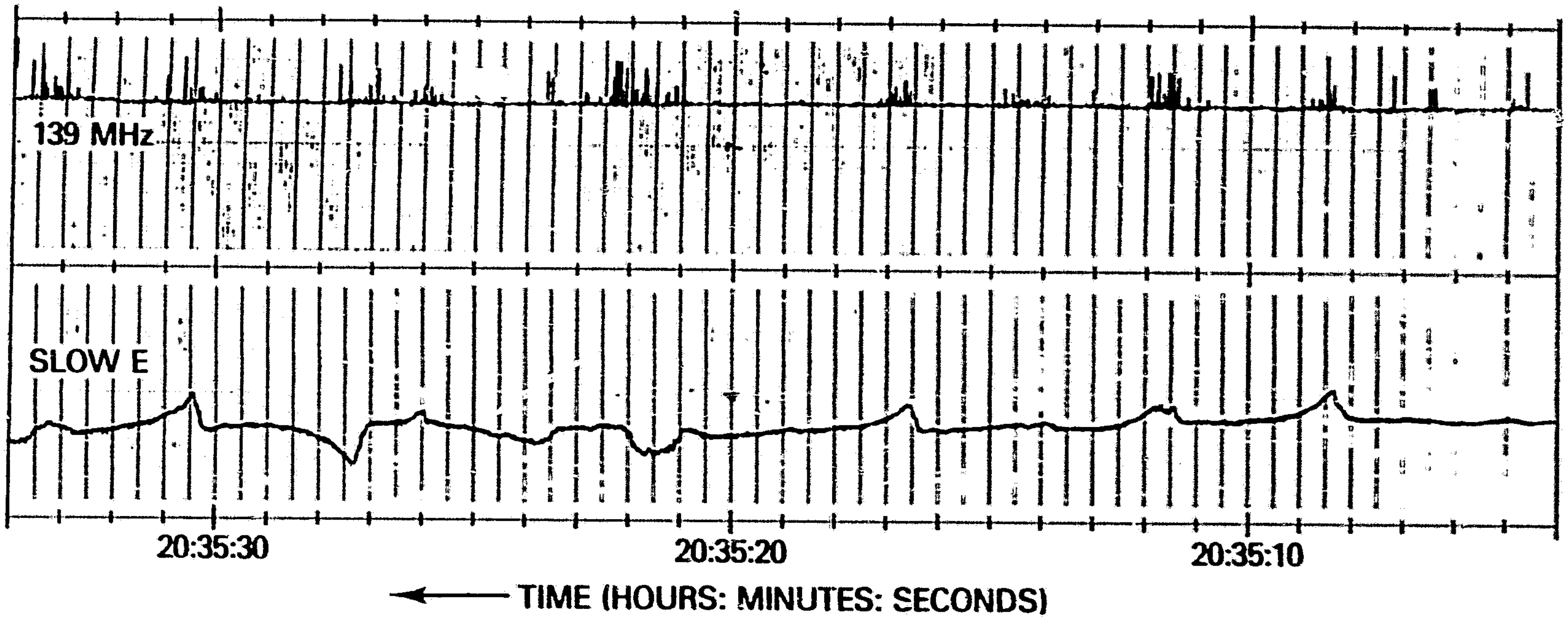

Figure 13. The fourth in as a sequence of strip chart records showing data recorded on July 22, 1980. None of these events triggered instrumentation aboard the aircraft and the pilot did not report seeing lightning.