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NASA Thunderstorm Overflight Program

Atmospheric Electricity Research: An Overview Report on the Optical Lightning Detection Experiment for Spring and Summer 1983

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and Space Administration

**Scientific and Technical
Information Branch**

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ACKNOWLEDGMENTS

The successful accomplishment of any research program requires the efforts and cooperation of the many individuals and groups who contribute so much to the operational aspects of the aircraft and data collection instrumentation and analysis of the data during the program. Foremost among those to whom we are indebted during the spring and summer 1983 flights were the U-2 pilots Jim Barnes, Bob Erickson, Ron Williams, and Jerry Houte. Also, we appreciate the dedicated efforts of Dr. John Arvesen and James Cherbonneaux, NASA, Bob Ekstrand of Analytical Technologies Applications Corp., and Norm Lefleur, Bob Danielson, and the many other support personnel of the Lockheed U-2 support group at Ames Research Center.

In addition I would like to acknowledge the efforts of the MSFC "OLDE" team members, Dr. P. H. Gillaspy (USRA), Mr. S. Goodman (USRA), Mr. R. A. Garst (EAI), Mr. L. Frost, and Dr. H. Christian, and to the atmospheric electricity research personnel from NOAA/SSL, Dr. David Rust, and D. MacGorman and also from the University atmospheric electricity researchers, Dr. B. Vonnegut of SUNYA and Dr. M. Brook, NMIT, and Dr. Roy Arnold and his team from University of Mississippi who provided various types of data for inclusion in this report.

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NASA THUNDERSTORM OVERFLIGHT PROGRAM — ATMOSPHERIC ELECTRICITY RESEARCH

An Overview Report on the Optical Lightning Detection
Experiment for Spring and Summer 1983

I. BACKGROUND

The Thunderstorm Overflight Program (TOP) is being conducted by NASA, NOAA, and Universities to provide various atmospheric physic researchers with an instrumented U-2 high altitude research platform for conducting atmospheric research. The objectives of the research program are (1) to determine the feasibility of making various measurements of lightning from above thunderstorms to provide design criteria data for a proposed lightning mapper satellite [5] which could be developed for use in monitoring the evolution of severe storms, and (2) to study lightning physics and correlate lightning activity with storm characteristics as cloud top heights, temperature, updraft velocity, etc. Previous reports on the results of TOP can be found in References 1 through 4 and 6 through 11.

Support of the U-2 operations and the lightning research program has been provided by the NASA Office of Space Sciences and Applications (OSSA), Mesoscale Atmospheric Processes Research Program.

II. INTRODUCTION

This report presents an overview of the NASA U-2/TOP Atmospheric Electricity Research Program as of June 1984. During the spring and summer of 1983 a number of U-2 (Fig. 1) research flights were conducted to collect data for the Optical Lightning Detection Experiment (OLDE). Preliminary analysis of some of the data collected during this experiment will be presented. A more detailed analysis of the 1983 OLDE data will be summarized in a number of research papers which have been submitted for publication. Figure 2 shows the management plan for the OLDE "83" experiment.

Figure 3 shows some of the in-house hardware which is used in the analysis of the data tapes produced by the OLDE sensors.

III. EXPERIMENT OBJECTIVES

The objectives of the OLDE are to establish the following characteristics:

A) The reflectivity, intensity, and variability of the cloud top background.

B) The absolute intensity of lightning-generated optical emissions radiating from the cloud tops.

C) The temporal and spatial variability of lightning-generated emissions.

D) The spectral characteristics of lightning-generated emissions:

1) Absolute intensities as a function of wavelength, lambda (λ).

2) Emission line widths and variability with particular emphasis at $\lambda =$ 7774 Å and λ=8683 Å .

IV. INSTRUMENTATION

A. Spring and Summer 1983 Program

The instrumentation pallet (Figs. 5 and 6) for the U-2 1983 flights consisted of nine sensors, two magnetic tape instrumentation recorders, a video tape recorder, a time code generator, and a power supply module. A block diagram is shown in Figures 4A and 4B. The sensors and responsible investigators are as follows:

1) Wide Angle Optical Pulse Detector - Extended Sensitivity (WADE) (Brook)

2) Electrical Field Change Meter (ΔE) - (Brook)

3) Optical Pulse Detector (OPD) - (Christian, Frost, Goodman)

4) Optical Array Sensor (OAS) - (Christian, Frost, Goodman)

5) 1/8 Meter Ebert Spectrometer (BBS) - (Christian, Frost, Goodman)

6) High RES Spectrometer (HRS) - (Christian, Frost, Goodman)

7) Potential Gradient Meter or Radio Active Probe (RAP) - (Vonnegut and Moore)

8) CCD TV Camera - (Vaughan)

9) Photography Time Lapse Cameras (2 each) - (Vaughan)

Other support instrumentation was:

1) 14 Channel Sangamo Sabre 80 Instrumentation Recorder (2)

2) A Panasonic Video Recorder.

3) A CAMAC data processor was again flown as was done in the summer 1982 program to process the data from the two spectrometers and the OAS.

In the following paragraphs each of the sensors are described:

1) Wide Angle Optical Pulse Detector-Extended Sensitivity (WADE). The new WADE (Fig. 7) was used to measure the optical pulses generated by the lightning. The WADE has a field of view (FOV) of 120 deg and has increased sensitivity due to

a larger detector size. Placed in front of the detector was a wide pass near infrared filter [1] having 85 percent maximum transmission at λ = 6560 Å.

2) The Electric Field Change Meter (ΔE). This instrument (Fig. 8) senses the changes in the electric field caused by the lightning [1]. The electric field change meter (ΔE) consisted of a circular flat plate with a geometric area of 75.43 cm^2 and associated electronics. This meter was mounted on the bottom hatch window of the U-2.

3) Optical Pulse Detector (OPD). This instrument (Fig. 9), developed earlier by UAOSC and modified by MSFC is a narrow angle, ac coupled photo diode with an interference filter (either 777.4 or 868.3 nanometers) selected prior to flight, and mounted in front of the detector. It has a 2 ms time resolution and a FOV of 1 radian. It is mounted in the same instrumentation container with the Optical Array Sensor. Its purpose is to detect lightning flashes (optical) and provide wave form information from the flashes. More details on this instrument can be found in Reference 7.

4) Optical Array Sensor (OAS). The Optical Array Sensor (Fig. 9) is a 50 x 50 element photo diode array manufactured by Reticon with a FOV of 1 radian. The array sensor observes the lightning flash through a narrow band interference filter which is selectable prior to flight. Since the OPD and the OAS are used together, the interference filters are the same for each flight. This sensor is a scene imaging system with a 150-m resolution at cloud top and has a 5-msec frame integration time. It is a dc coupled detector and measures the intensity of the lightning and the background.

5) Broad-Band Ebert Spectrometer (BBS). This spectrometer (Fig. 10) (one-eighth meter) is used to observe the lightning spectra (12 Å wavelength resolution) primarily in the near infrared. It has a 5-msec frame integration time, a FOV of 15 deg, and is stepper motor controlled. For the spring and summer 1983 flight program the BBS used a fiber optic plug to couple light to a micro channel plate image intensifier between the 50 μm wide entrance slit of the spectrometer and a 512 element S-series linear Reticon photo diode array. This technique provides an effective optical gain by a factor of nearly 20,000 to 1 over the 1981 system. More details on this instrument can be found in Reference 7.

6) High-Resolution Ebert Spectrometer (HRS). This spectrometer (one-half meter) (Fig. 11) was also used to observe the lightning spectra at 0.5 Å wavelength resolution primarily in the near infrared. This instrument was first flown in the summer 1982 flight program. It has a 4 msec frame time resolution, FOV of 3 deg, and is stepper motor controlled over a range of 3000 Å to 9000 Å. The sensitivity of this instrument was also increased through the use of an intensifier as was done on the broad band spectrometer.

7) Potential Gradient Meter or Radio-Active Probe (RAP). This type probe, developed by Vonnegut and Moore, is being flown to obtain data for determining the potential gradient of the electric field in the atmosphere, both when the aircraft is flying away from an electrified cloud and when directly over it. During the spring and summer 1983 flights only one probe and electronic package was flown as shown in Figures 12 and 13 and the data was recorded on the instrumentation recorders.

8) Charge Coupled Device (CCD) TV Camera. A Fairchild CCD MB 301AB TV System (Fig. 14) on loan from the USAF, Wright Aeronautical Laboratory, Wright Patterson AFB, Ohio, was installed in the U-2 to collect real time TV images of the cloud top structure and lightning discharges. This video data and IRIG-B time were recorded on a VTR. The TV camera had a 8 mm lens (FOV of 60 deg) and selectable interference filter (777.4 or 868.3 nanometer) for flight and looked through a window in the bottom hatch of the U-2. The filter used on the TV camera is identical to those on the OPD and OAS. The sensor of the TV camera is a CCD silicon array (488 lines x 380 pixels/line). The frame integration time was 33 msec (16 msec/380 x 244 fields). The frame rate was 30 frames per second and the sync was 1:1 standard interlace.

9) Video Tape Recorder. The video recorder (Fig. 14) was a Panasonic Omnivision II VHS, NV-8400 Portable video tape recorder with one audio channel. Video horizontal resolution in B&W is more than 300 lines. The video record system is a two rotary head, helical scanning system recording at 1-5/16 in. per second. Maximum record time for best resolution is 2 hr. IRIG-B time is inserted on the audio track of the recorder during the operation of the CCD TV camera.

10) Instrumentation Tape Recorders. The instrumentation rack in the upper bay of the U-2 aircraft had provisions for carrying two Sangamo Sabre 80 instrumentation recorders (Fig. 15). These standard tape recorders have 14 tracks for recording. Sangamo modified our two Sabre 80 recorders as per Christian's design to have an auto-reverse feature which enables each machine to record at 60 in. per second in both directions during the U-2 flight. The data can be recorded in the FM and direct wide band II record modes. For the spring 1983 and summer 1983 flight program two Sabre 80 recorders were used. To record 14 channels and achieve 1 hr of record time the auto-reverse feature was not used for this year and the data from the sensors were recorded (parallel and sequential) at 30 in. per second in one direction only thus providing a limited recorded frequency response of 125 KHz. In the future we are planning to operate the two recorders in the auto-reverse operational mode.

11) Photography Cameras. Two 70 mm Vinten Cameras were used to obtain high quality pictures of the thundercloud tops and associated lightning in both nighttime and daytime operations. Various filters are used to optimize photography based on the selected film for the particular flight period. These cameras (Fig. 16) are flown with shutters during the day operations and without shutters during the nighttime operations. For day photography f stops were 9.5 for the black and white film and 5.6 for the color film with shutter speeds of 1/250, while night photography was taken open shutter at 9 sec intervals. The cameras each have a 1-3/4 in. diameter Leitz lens with a FOV of 60°30'.

Based on the aircraft speed and the 9 sec time interval, 92.8 percent overlap occurs on the photos which provides stereo imagery for both night and daytime photography. For both the spring and summer flight programs one camera used Panatonic X B&W film with a Wratten 12 filter, and the other camera used Ektachrome EF Aerographic color SO 397 film.

12) CAMAC Crate. This equipment (Fig. 17) consists of one 8 bit transient and one 10 bit transient digitizer (each with 128 K buffer memory), a pulse code modulation (PCM) encoder, stepper motor drive, and 8085 single board microcomputer and controller. The outputs from both spectrometers and the Optical Array Sensor were digitized. The digitization rates are the same for the OAS and the spectrometers

and the digitization rate provides one sample per pixel for each of the instruments. The microcomputer controls the transfer of data from the transient digitizers to the PCM encoder and then transfers the data to the magnetic tape instrumentation recorders in parallel or sequential data flow.

V. DISCUSSION

A. Spring Program

The TOP 1983 spring research program began operation on May 19, 1983, and the U-2 aircraft, deployed from Ames Research Center (ARC) to Forbes Field, Topeka, Kansas, flew a total of five flights during the period of May 20, 1982 through June 5, 1983. During the research flights the aircraft is operating at a nominal altitude of 65,000 ft (19.8 km) and is vectored by ground control to fly over the more active areas of the storm. Instrumentation personnel from MSFC and U-2 operational support personnel from ARC supported the program from Forbes Field, Topeka, Kansas. In addition to the MSFC and ARC personnel, research teams from NOAA Severe Storms Laboratory (NSSL) Normal, Oklahoma and the University of Mississippi, Oxford, Mississippi also collected data during this period using fixed-ground and mobile instrumentation. Analysis of this ground truth data will be reported in university and government reports now in preparation. Figure 18 shows some of the ground instrumentation at the Norman, Oklahoma site. Figures 19 and 20 show the NSSL lightning ground strike detection and location network and a typical LLP ground strike map. Figures 21A and 21B show the instrumented storm chase van, typical daytime storm system, and a block diagram of the instrumentation in the storm chase van. Both day and night flights were conducted over a number of thunderstorms in Oklahoma and Texas and during each of the flights a considerable amount of data were collected. Figure 22 shows a composite map of three flight lines (4, 5, and 6) as flown during Flight No. 7 on Day 83/155. Figures 23 through 25 show some of the more spectacular type photographs of the storm cloud and lightning as seen by the U-2 from above the storm cells located near Paris, Texas. Figure 26 shows another spectacular photo taken of lightning during flight line No. 6 approximately 80 km NNW from Paris, Texas. A typical sample of U-2 magnetic tape data readout showing fast antenna, slow antenna, wide angle optical pulse detector-extended, and the optical pulse detector signatures for a cloud to ground flash on June 4, 1983 (83155-04:52:51 GMT) is shown in Figure 27.

From a preliminary analsyis of the data from two flight days (day 143 and day 155) in the spring program, a total of 4051 optical pulses was detected. The largest number of optical pulses in a single flash event was 60 on day 155 at 024122 GMT. Preliminary analysis of the slow antenna data for day 155 shows a total of 34 cloud to ground flashes (279 pulses) and 232 intracloud flashes (3123 pulses) that have been identified. The cloud to ground flashes were correlated by studying the E-field wave forms taken by instrumentation at NSSL and the wave forms obtained by the U-2 sensors and instrumentation and visual observations from the chase vehicle. The CG strike system at NSSL detected and located 20 of the 27 CG flashes as seen by the mobile laboratory at a nominal range of 210 km from NSSL. Figures 28A and B show a typical intra cloud flash as seen by the TV and the Vinten cameras. This photo illustrates the kind of data which can be sampled by the TV and film camera systems. The film and TV data after being digitized is useful for determining cloud top brightness, percent area illuminated by the lightning flash and flash rate. Figure 29 shows typical NSSL Doppler reflectivity data for day 83155. Shown also is the approximate flight path of the U-2 from 03:01:11 to 03:03:01 GMT. Goodman, et al. [12] has compiled a set of optical pulse statistics for day 83155 and these data are shown in Table 1. Figures 30 through 32 show a sequence of TV images of an interesting intra cloud flash. Figure 33 shows a sequence of cloud to ground flashes as seen by the NSSL chase vehicle on 83155 at 043855 GMT during the early part of the storm development.

B. Summer Program

The TOP 1983 summer research program began operation on August 19, 1983, and the U-2 aircraft flew a total of three flights during the period of August 22, 1983, through August 28, 1983. Instrumentation personnel from MSFC supported the operation at Ames Research Center, Moffett Field, California where the U-2 is normally based for the summer program.

Only night flights were conducted over Arizona and Nevada and again during these flights a considerable amount of data was collected. Ground truth data were obtained whenever possible using the Bureau of Land Management lightning location instrumentation. Figure 34 shows the present location in the Southwest of this instrumentation. This instrumentation has been used mainly by the Bureau of Land Management, Boise Interagency Fire Center, to help locate potential areas which have been struck by lightning and where forest fires could be occurring. We are continuing to use this system since it is readily available for ground truth data collection during our research program operation times. Photographs of some of the more interesting Summer 1983 lightning are shown in Figures 35 through 37.

During day 236 and day 239 a total of 81 flashes were recorded and have been identified by slow antenna and optical sensor data. One flash which occurred on day 236 at 034409 GMT consisted of 48 optical pulses.

The Broad Band Spectrometer data taken during the Summer 1983 flight program is being analyzed in more detail by H. Christian and associates at MSFC. From this type data the lightning versus background signal strength values can be determined for use in design criteria for the lightning mapper. Figures 38 through 42 illustrate a sequence of TV photos of lightning as seen by the spectrometer. Some preliminary results are presented in Reference 7.

VI. CONCLUSIONS AND FUTURE PLANS

Figure 43 summarizes the results of the atmospheric electricity research over the past few years. For future flight programs in 1984, it is planned to use an inertial navigation system on the U-2 to provide very accurate time and position data during the flights. Also planned is the use of an improved CAMAC system and a new pulse code modulation system to handle the data. If feasible, it is planned to conduct research flights in parallel with the Goddard ER-2 aircraft which has been instrumented for another atmospheric research program. Other sensors planned for 1984 are a second potential gradient probe and a modified BBS spectrometer instrument having two spectrometers each looking at a spectral band width of approximately 300 nanometers. The data from each spectrometer will be multiplexed using the CAMAC system. This will allow a wide range of spectral coverage and a higher resolution per spectral range to be sampled.

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APPENDIX

SUPPORTING ORGANIZATIONS AND PERSONNEL FOR THE "83" TOP/OLDE

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University of Mississippi
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Roy Arnold, FTS 601-232-5402

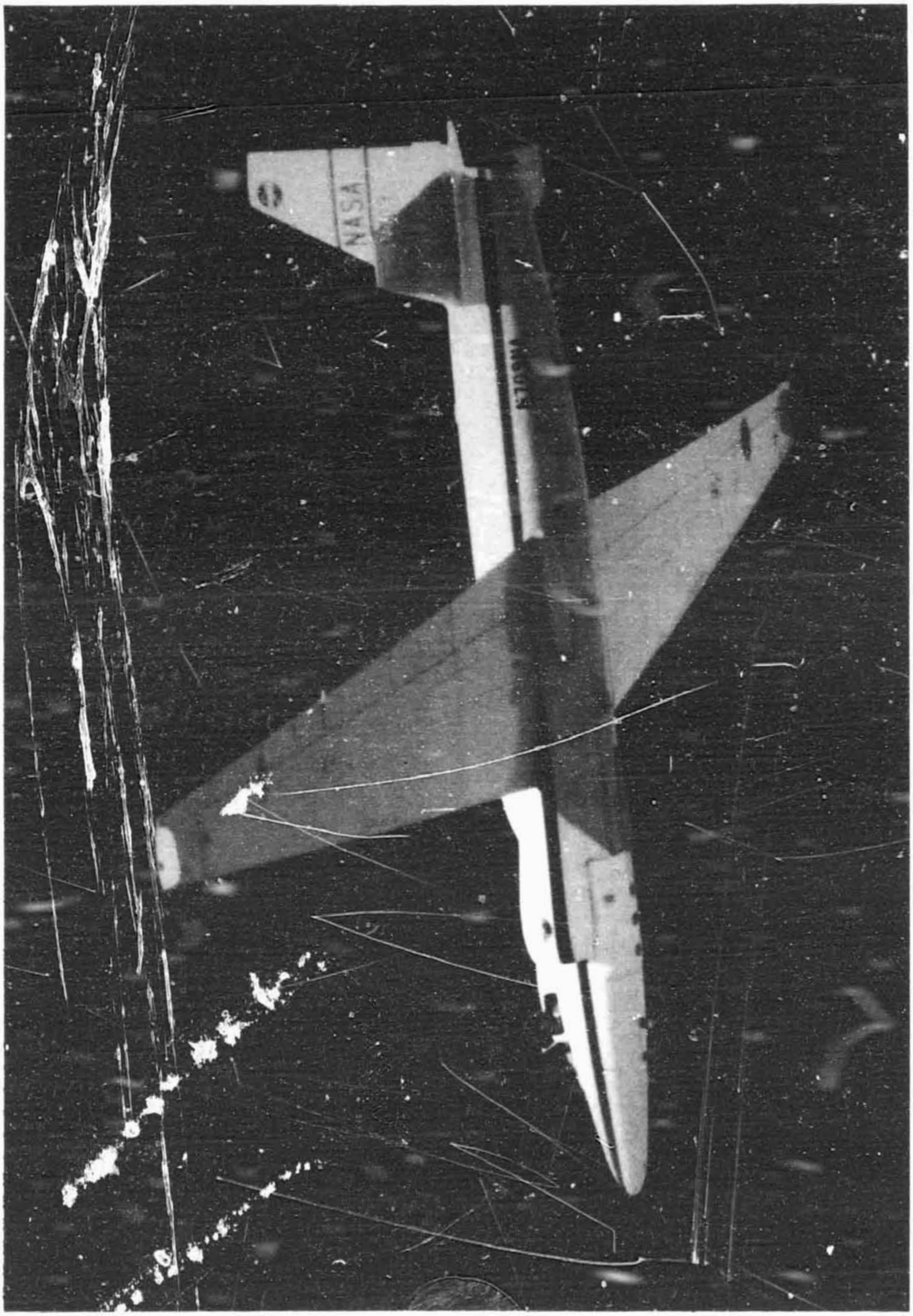


Figure 1. NASA U-2 High Altitude Research Aircraft.

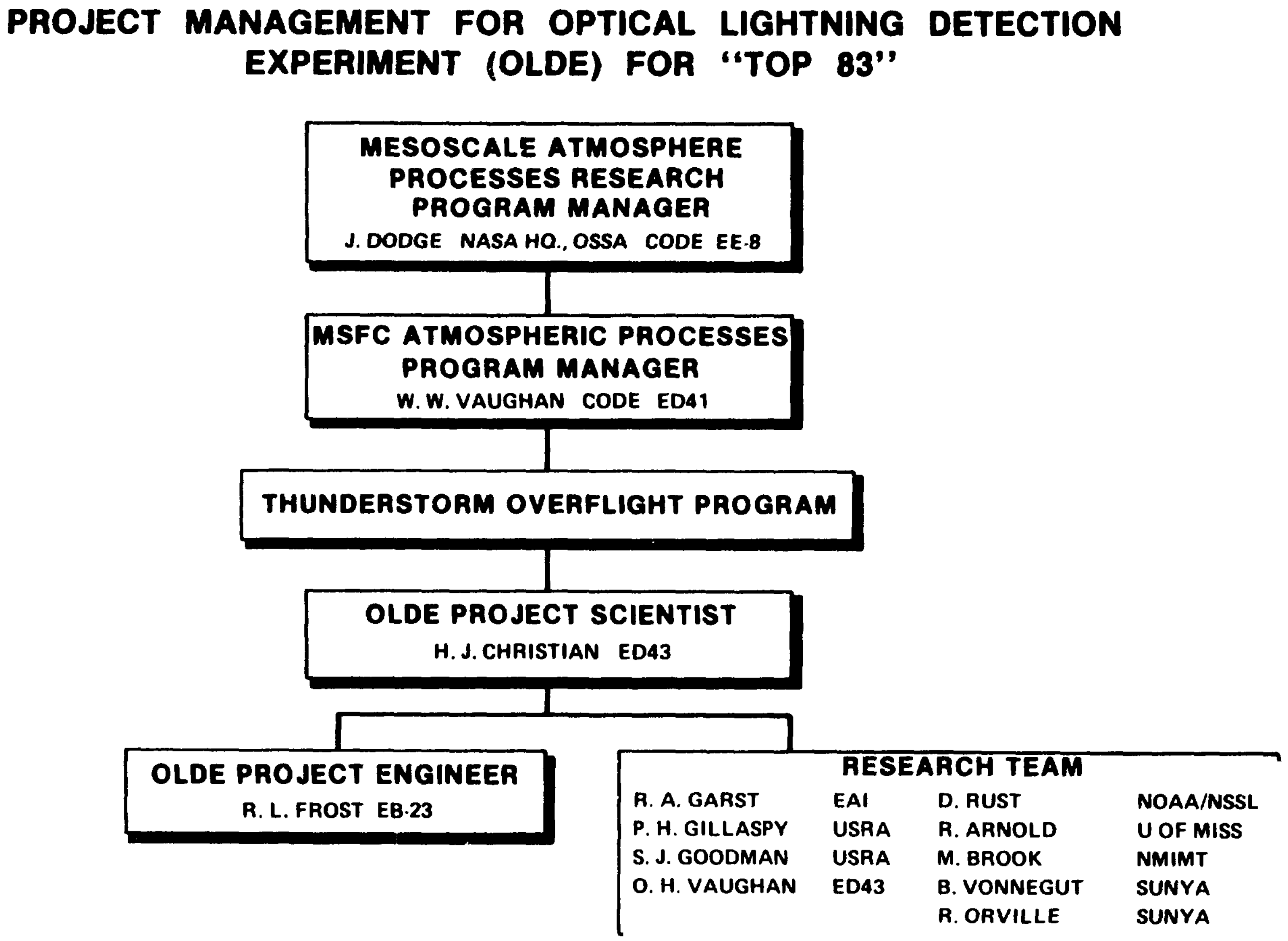


Figure 2. Project management for OLDE for "TOP 1983".

U-2 MSFC/OLDE DATA REDUCTION AND ANALYSIS SYSTEMS


VIDEO TAPE DIGITIZER SYSTEM


ANALOG/DIGITAL DATA
CONVERSION SYSTEM


McIDAS


HP 1000-L COMPUTER SYSTEM


APPLE III COMPUTER SYSTEM

Figure 3. Data reduction and analysis hardware for U-2/MSFC CLDE.

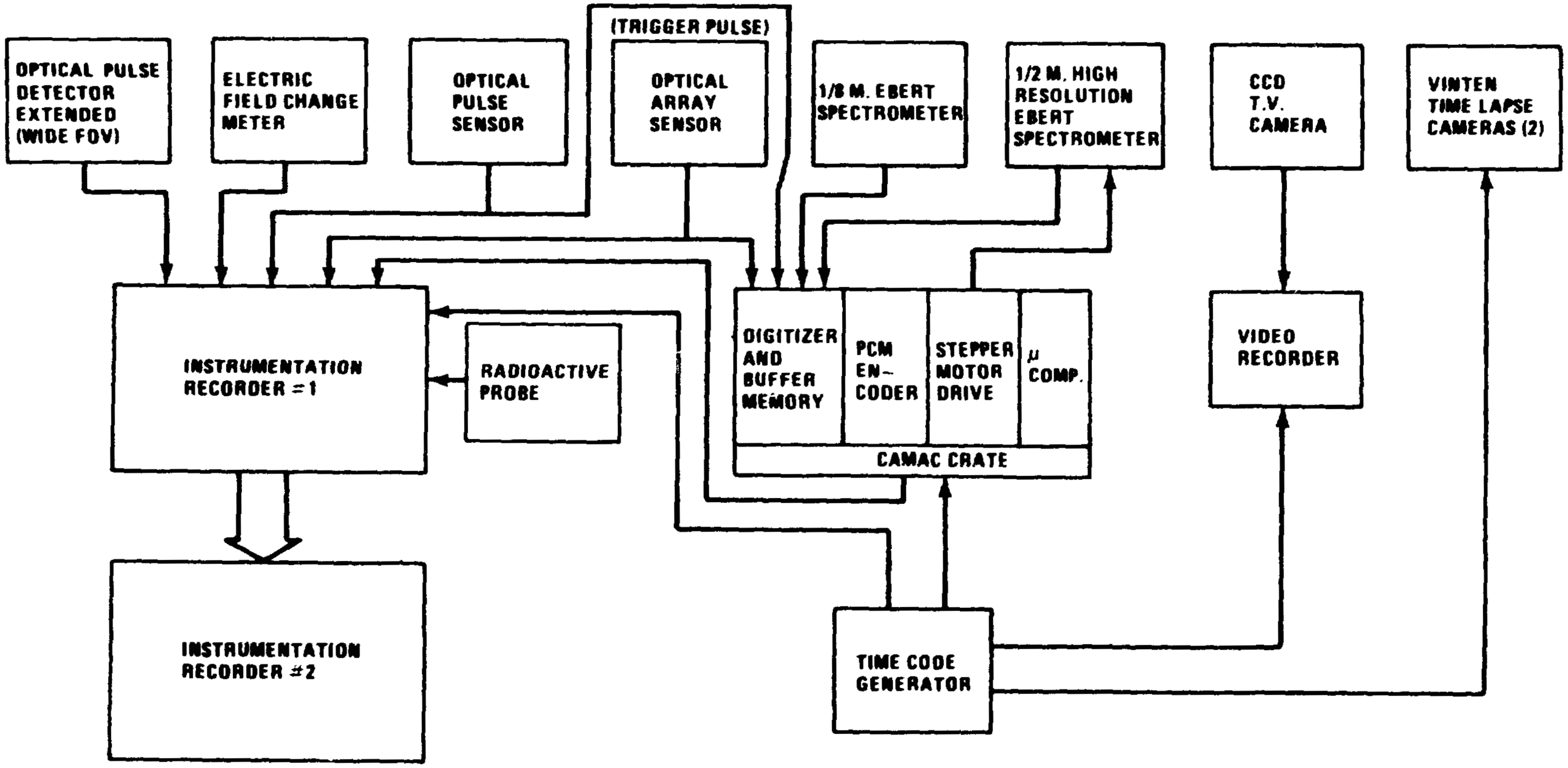


Figure 4A. Block diagram of U-2 aircraft lightning instrumentation for Spring and Summer 1983.

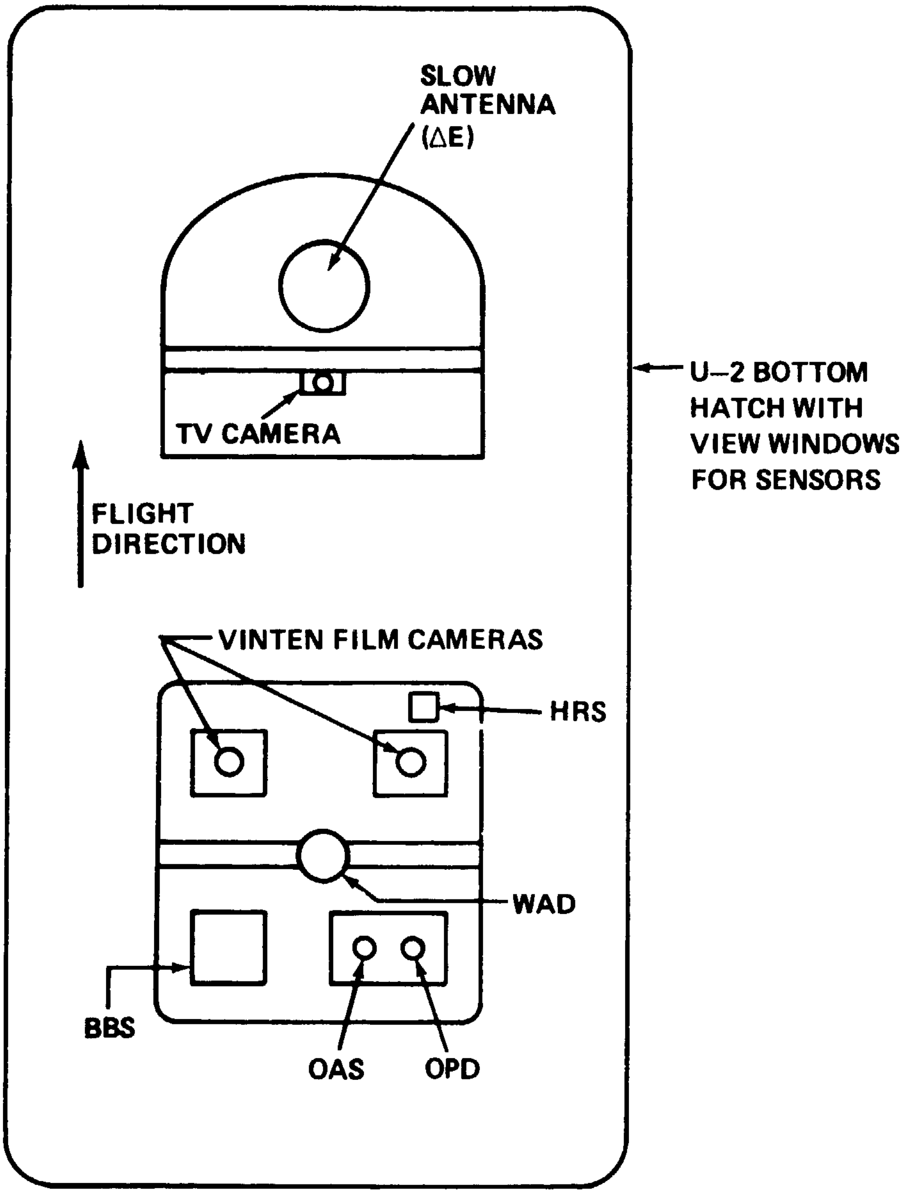


Figure 4B. Schematic layout of various sensors for atmospheric electricity research program/"OLD 1983" Spring and Summer program.

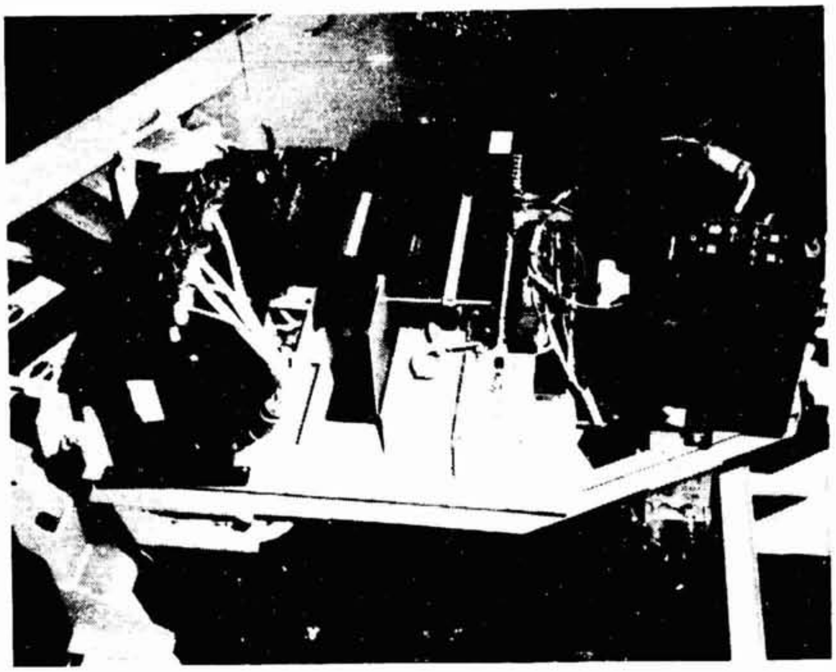


Figure 5. Top view of pallet mounted instrumentation for Spring and Summer 1983.

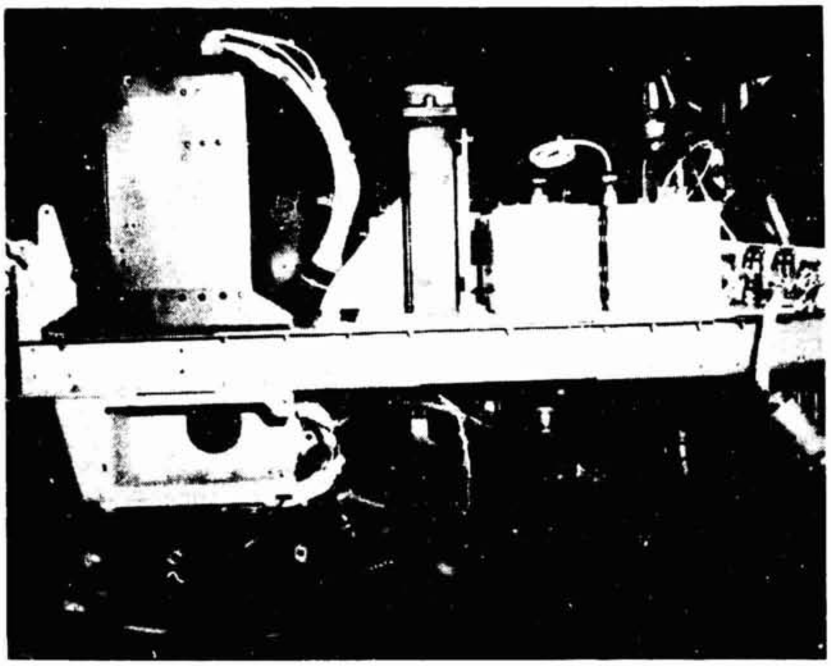
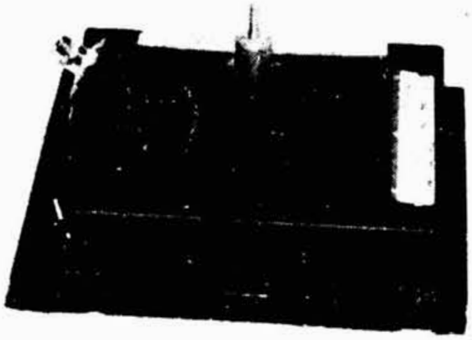
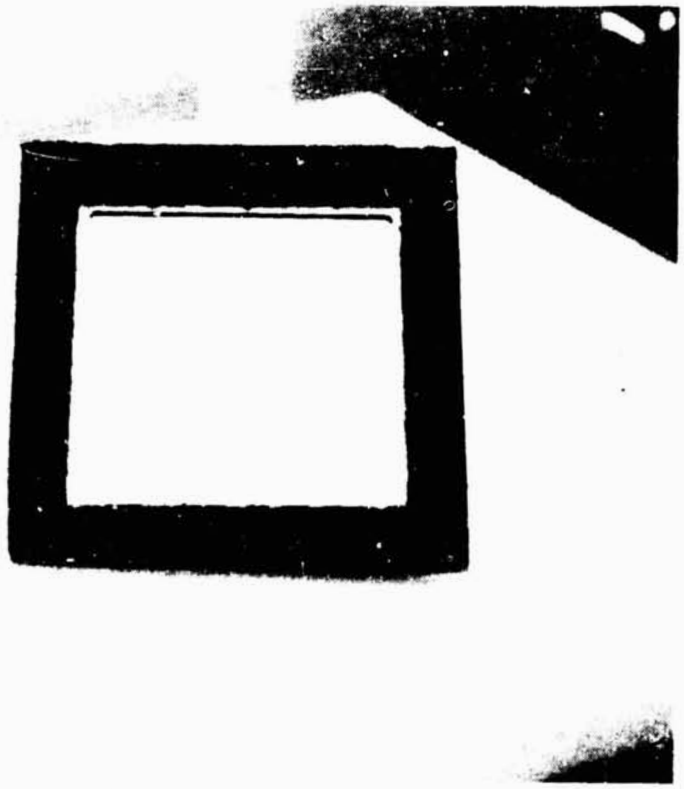


Figure 6. Side view of pallet mounted instrumentation for Spring and Summer 1983.



Rear View of Sensor



Front View of Sensor

Figure 7. Wide angle optical pulse detector - Extended Sensitivity (WADE).

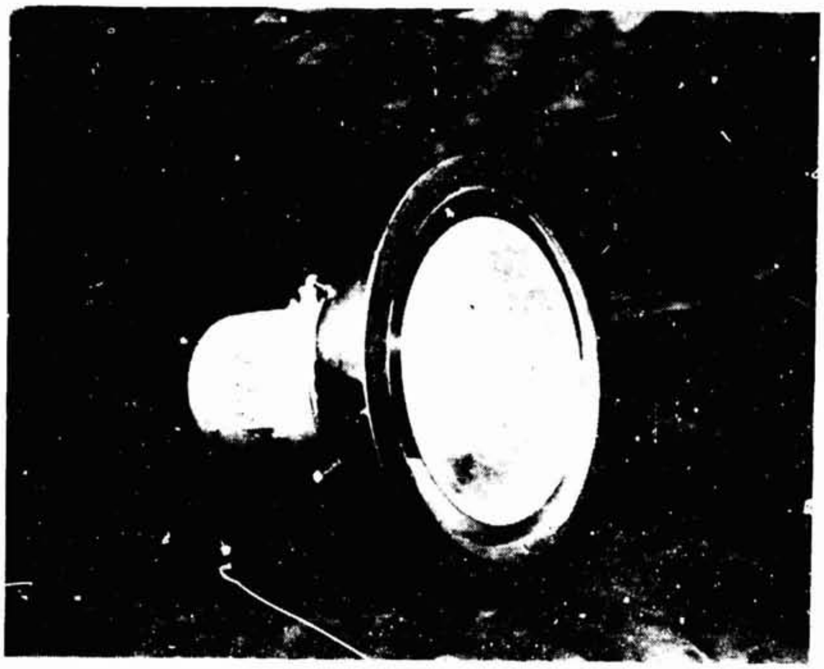


Figure 8. Electric field change meter (ΔE).

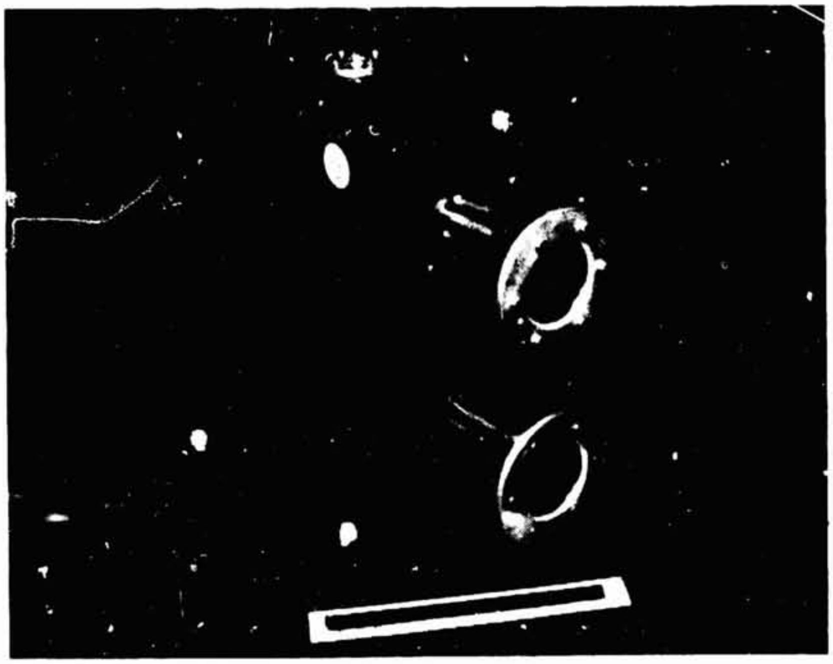


Figure 9. Optical pulse detector (OPD) and optical array sensor (OAS).

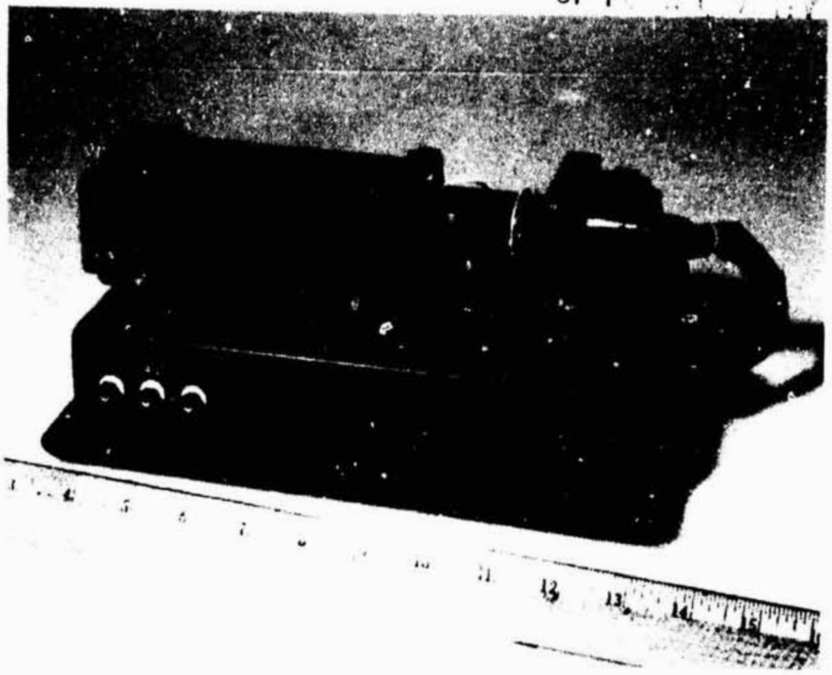


Figure 10. Broad band Ebert spectrometer (BBS).

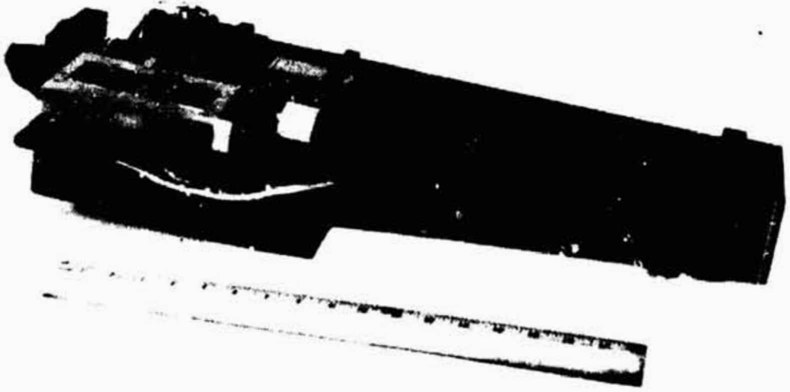


Figure 11. High resolution Ebert spectrometer (HRS).

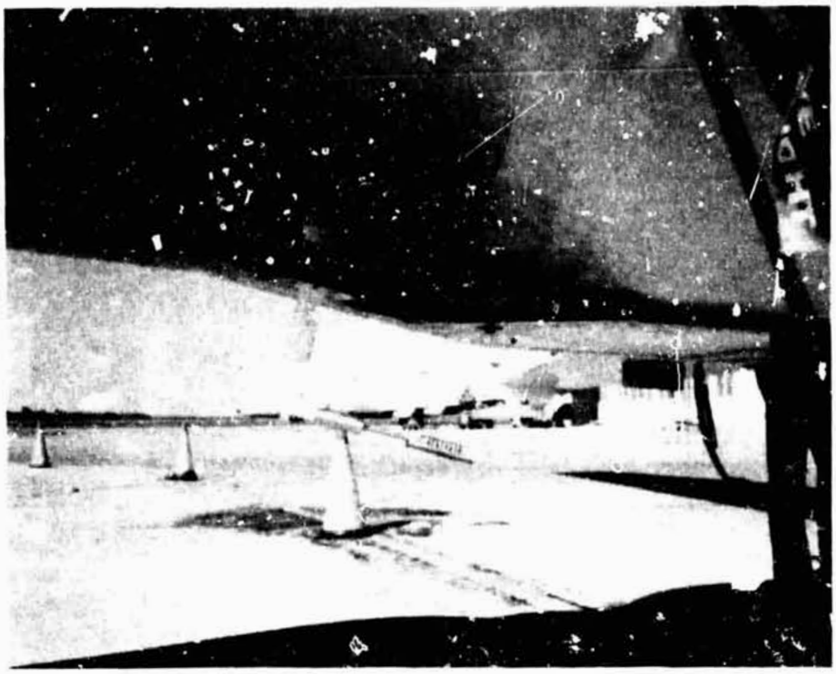


Figure 12. Potential gradient meter or radio-active probe (RAP).

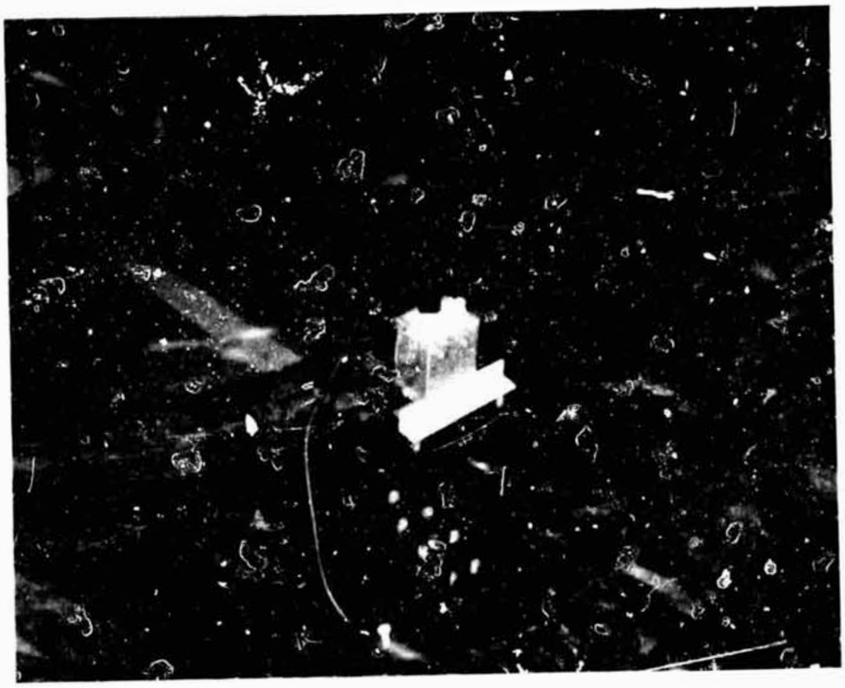


Figure 13. Potential gradient meter electronics package as mounted on bottom hatch of U-2 aircraft.

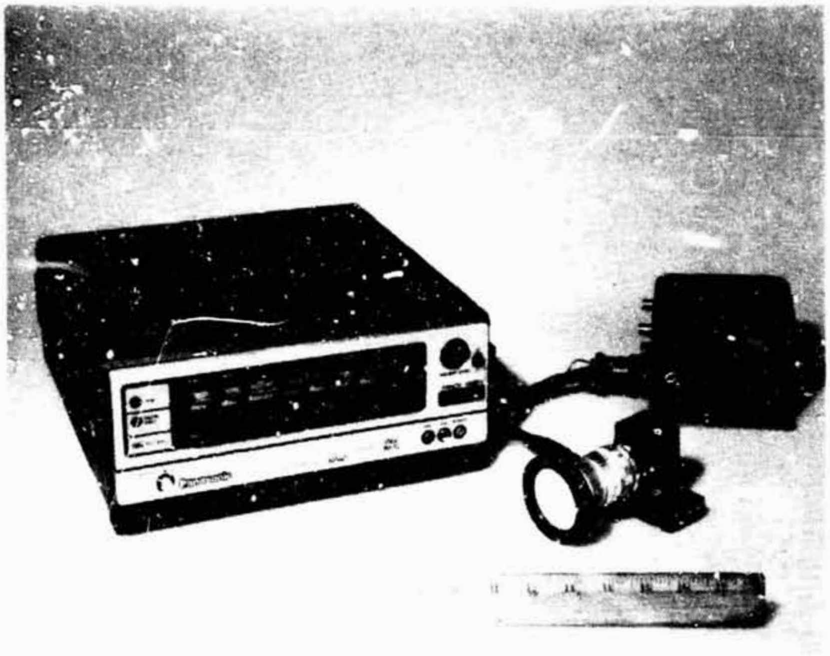


Figure 14. CCD Camera, recorder, and power supply.

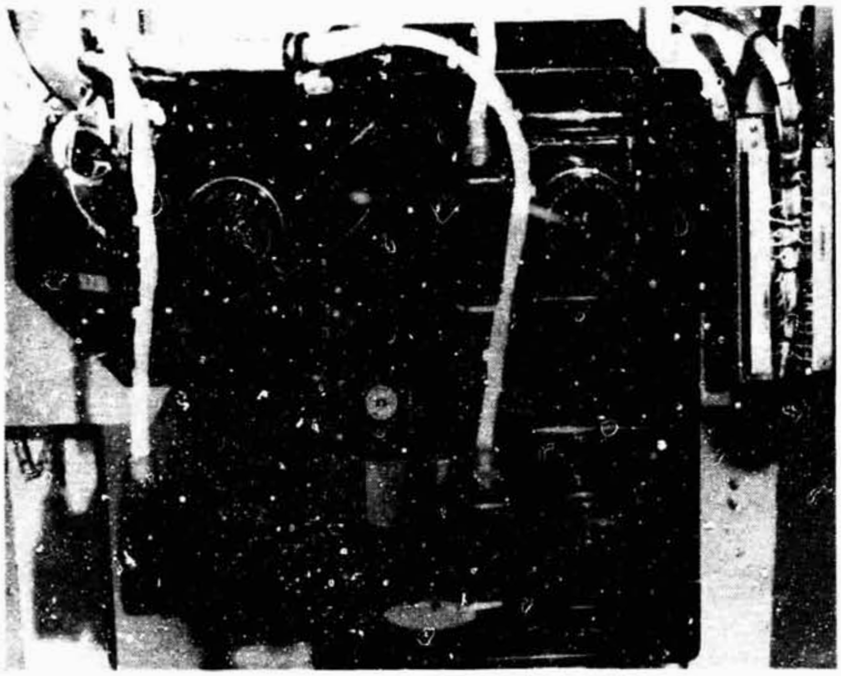


Figure 15. Vinten camera—four mode operational configuration.

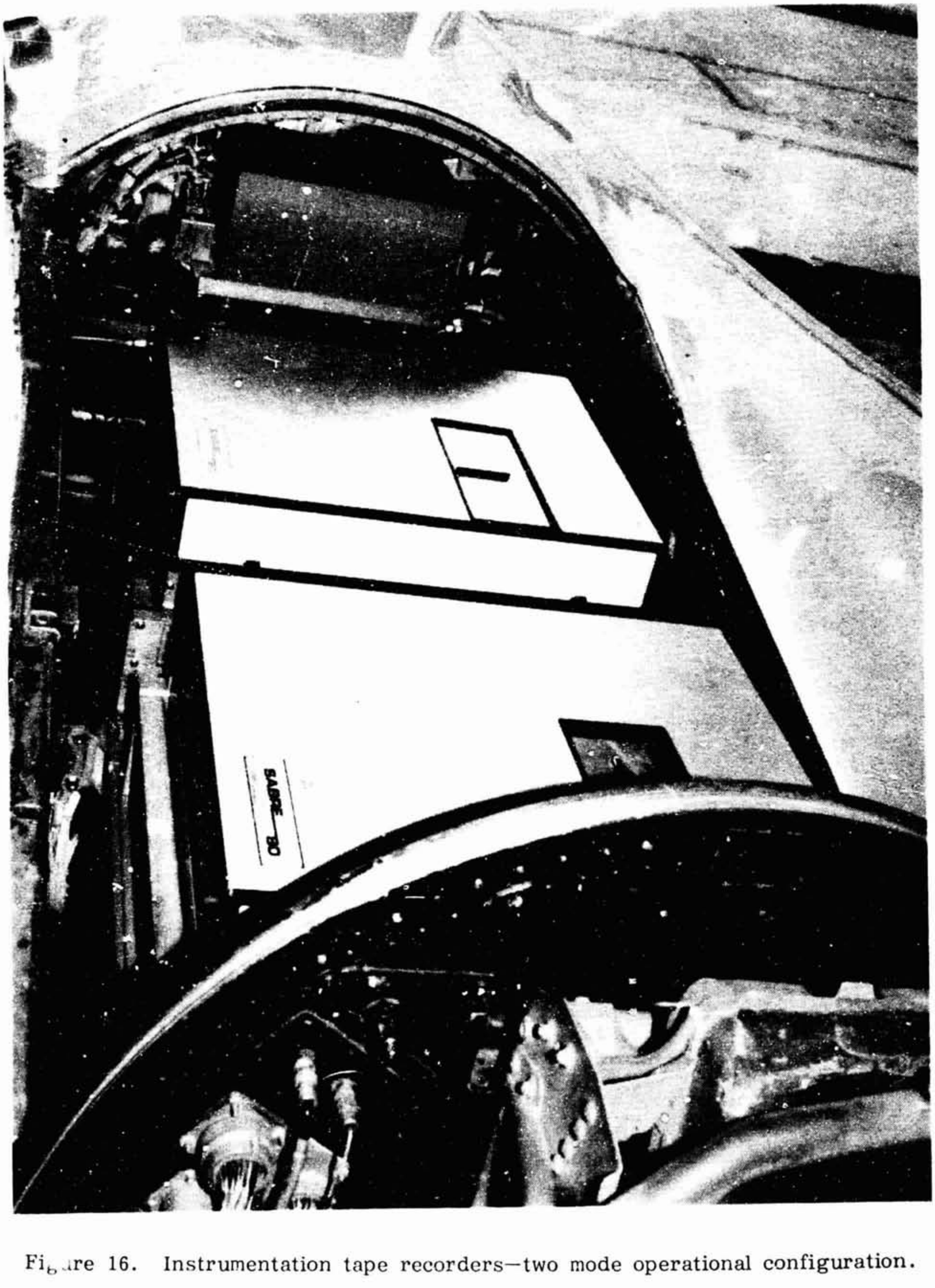


Figure 16. Instrumentation tape recorders—two mode operational configuration.

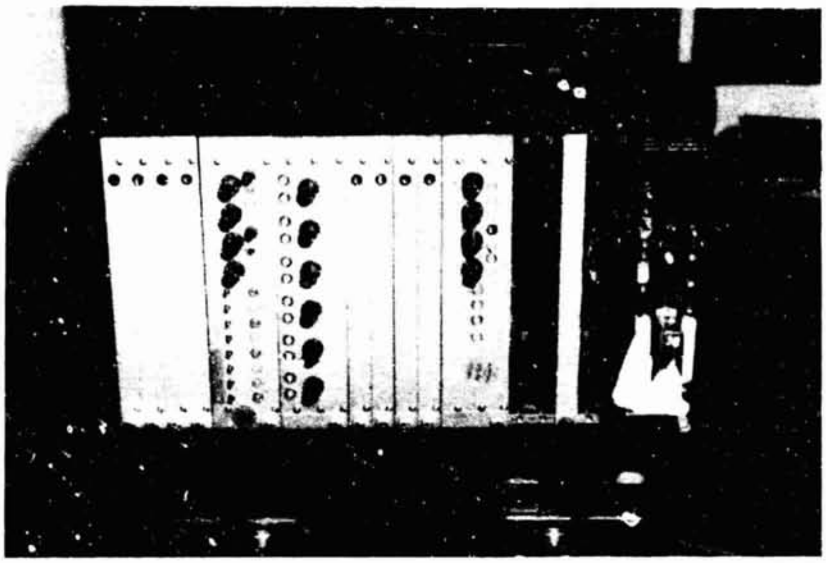


Figure 17. CAMAC crate configuration.

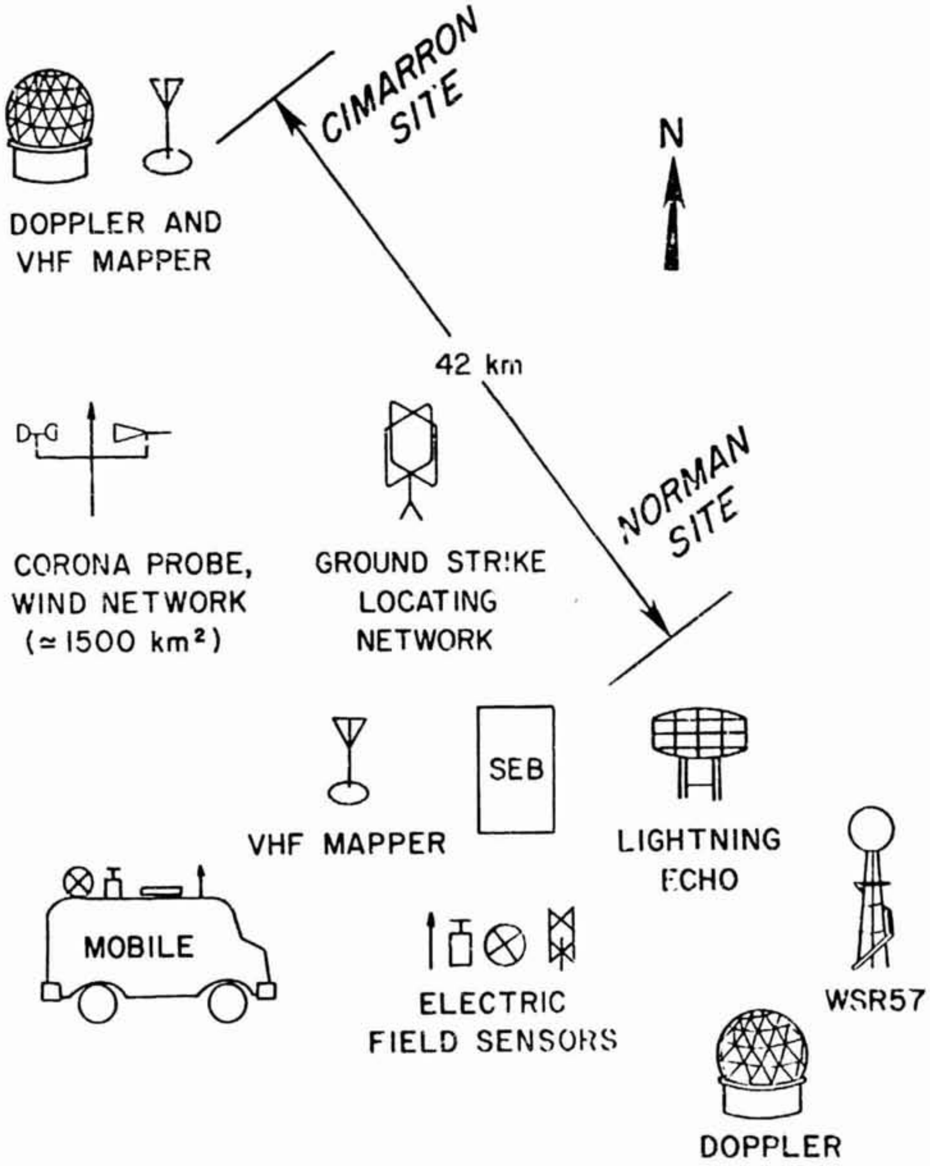


Figure 18. Storm electrical research facilities at Norman, Oklahoma, severe storms research laboratory, NOAA.

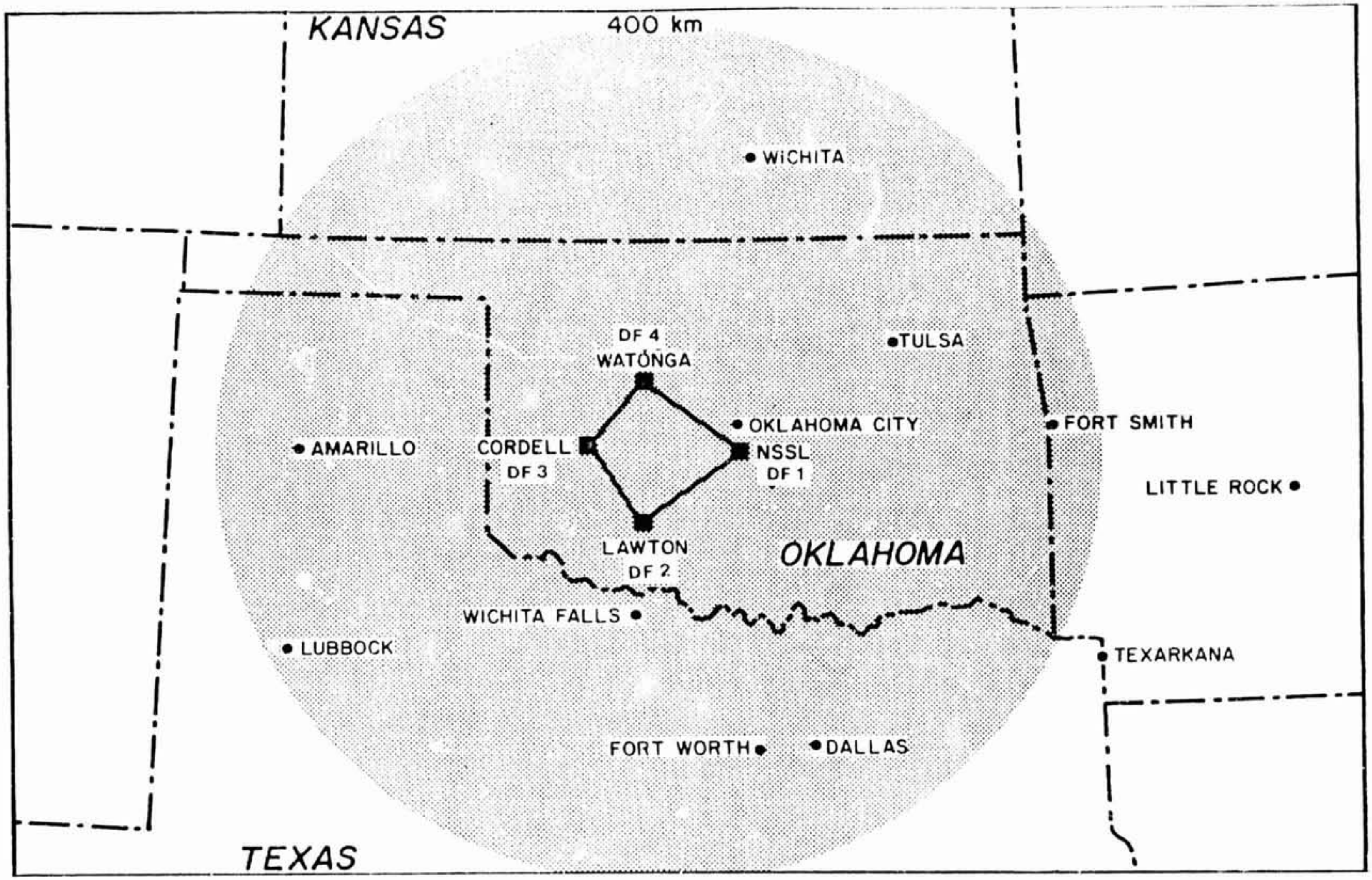


Figure 19. Lightning locating ground instrumentation netwerk in Oklahoma.

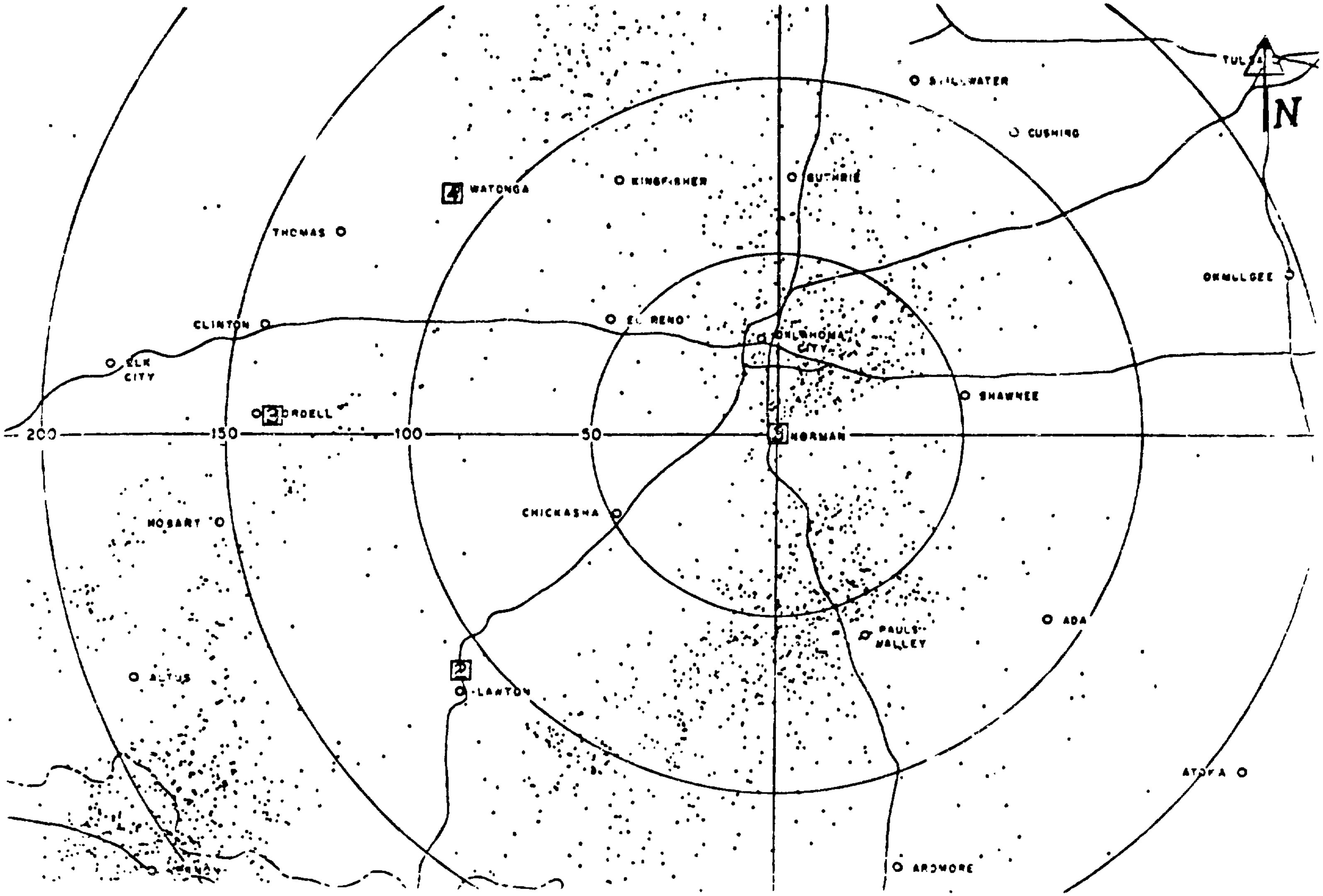


Figure 20. Typical cloud to ground lightning strike map as produced by ground strike lightning network.

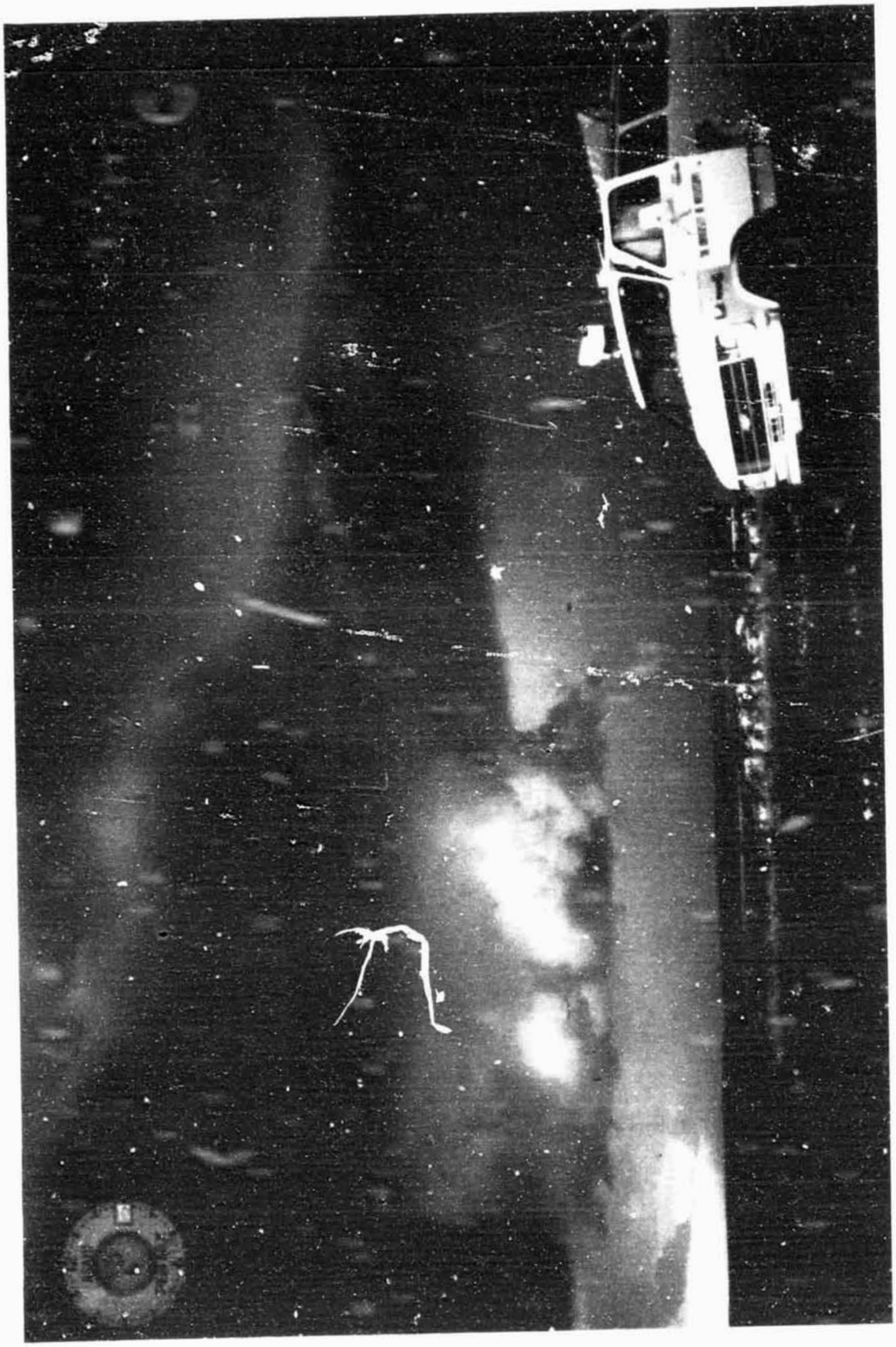


Figure 21A. NSSL storm chase vehicle, typical storm cloud.

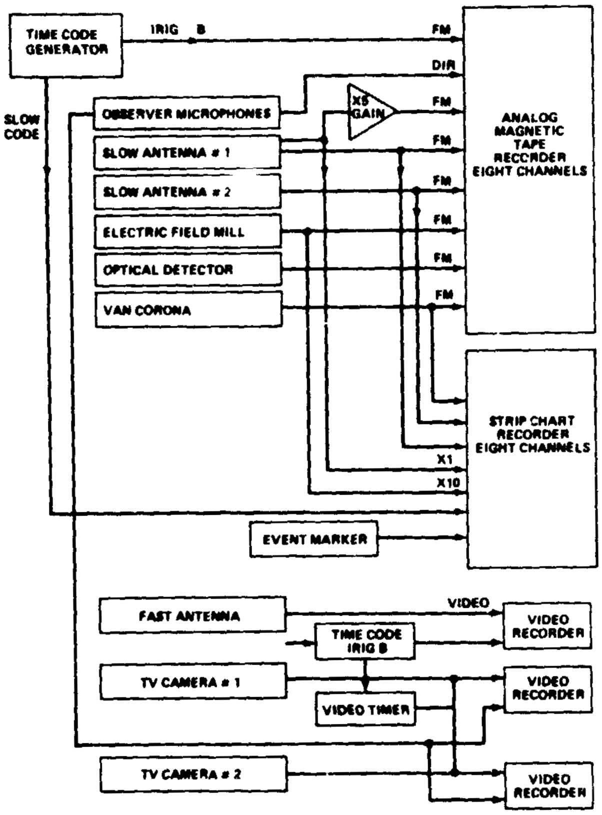


Figure 21B. Storm chase vehicle instrumentation.

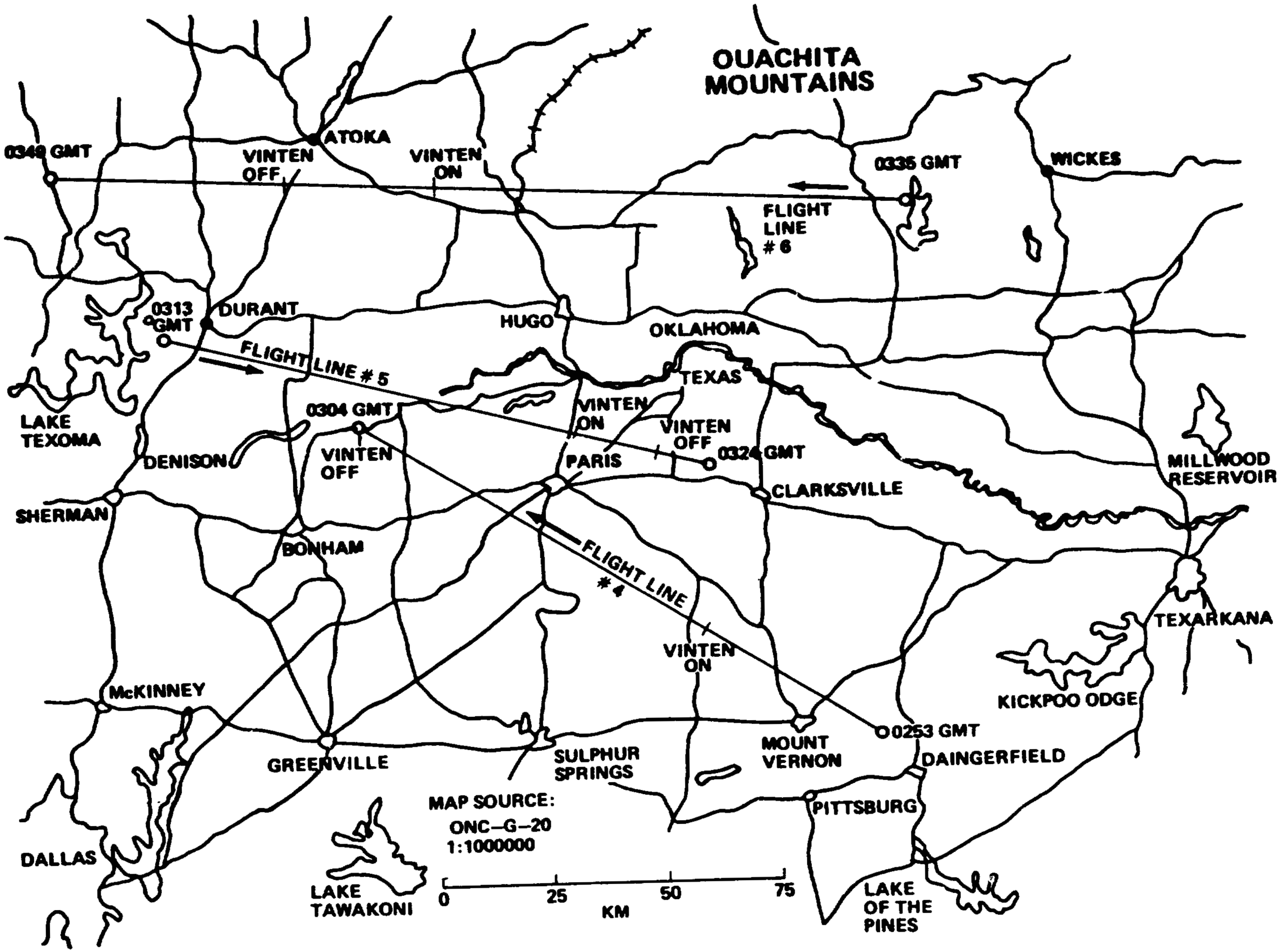


Figure 22. Composite map showing flight lines 4, 5, and 6 for flight No. 7, flown 83/155.

Figure 23. Vinten image of lightning at 02:56:57 GMT 83 Day 155 (4 June 1983).

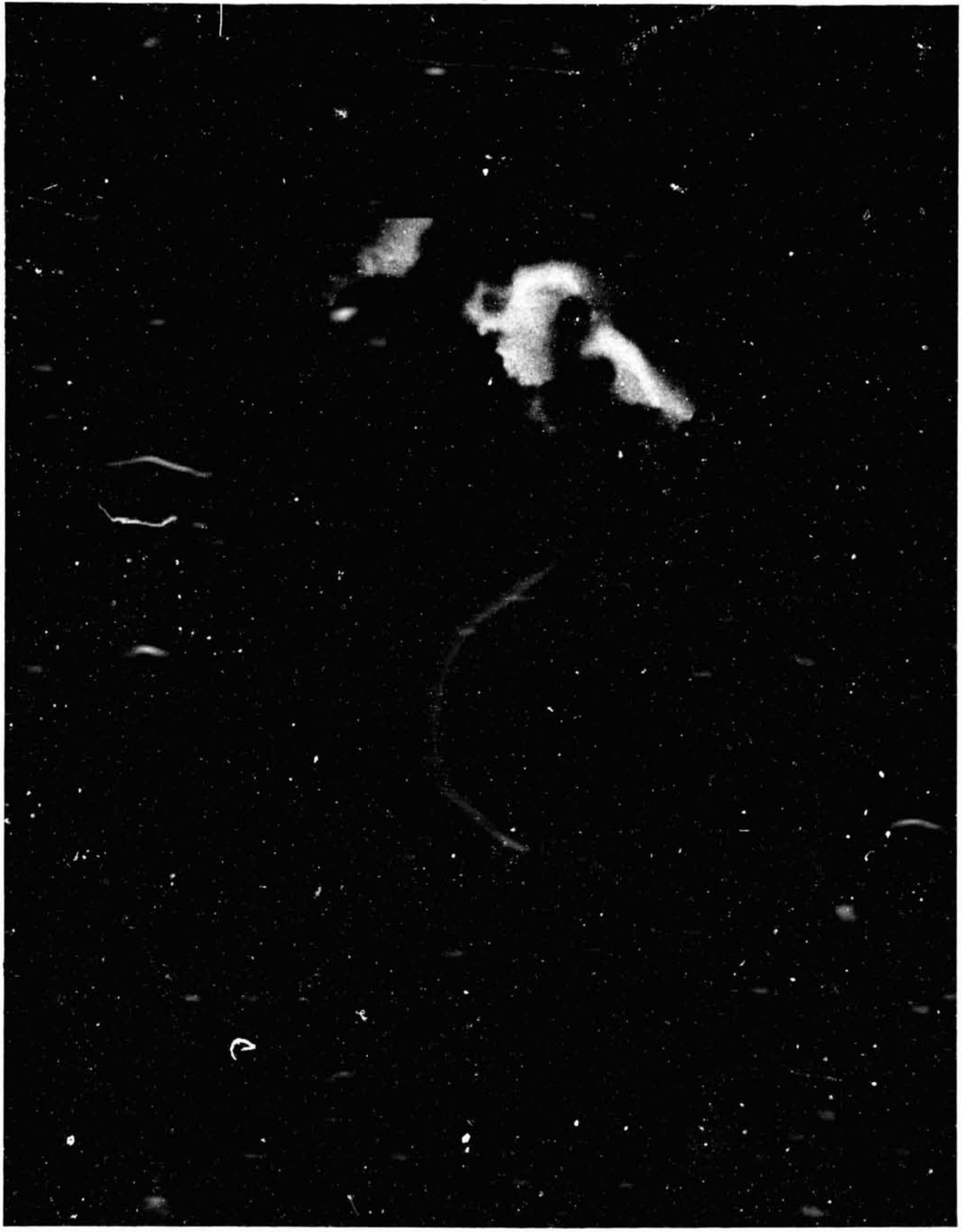


Figure 24. Vinten image of lightning at 03:02:03 GMT 83 Day 155 (4 June 1983).

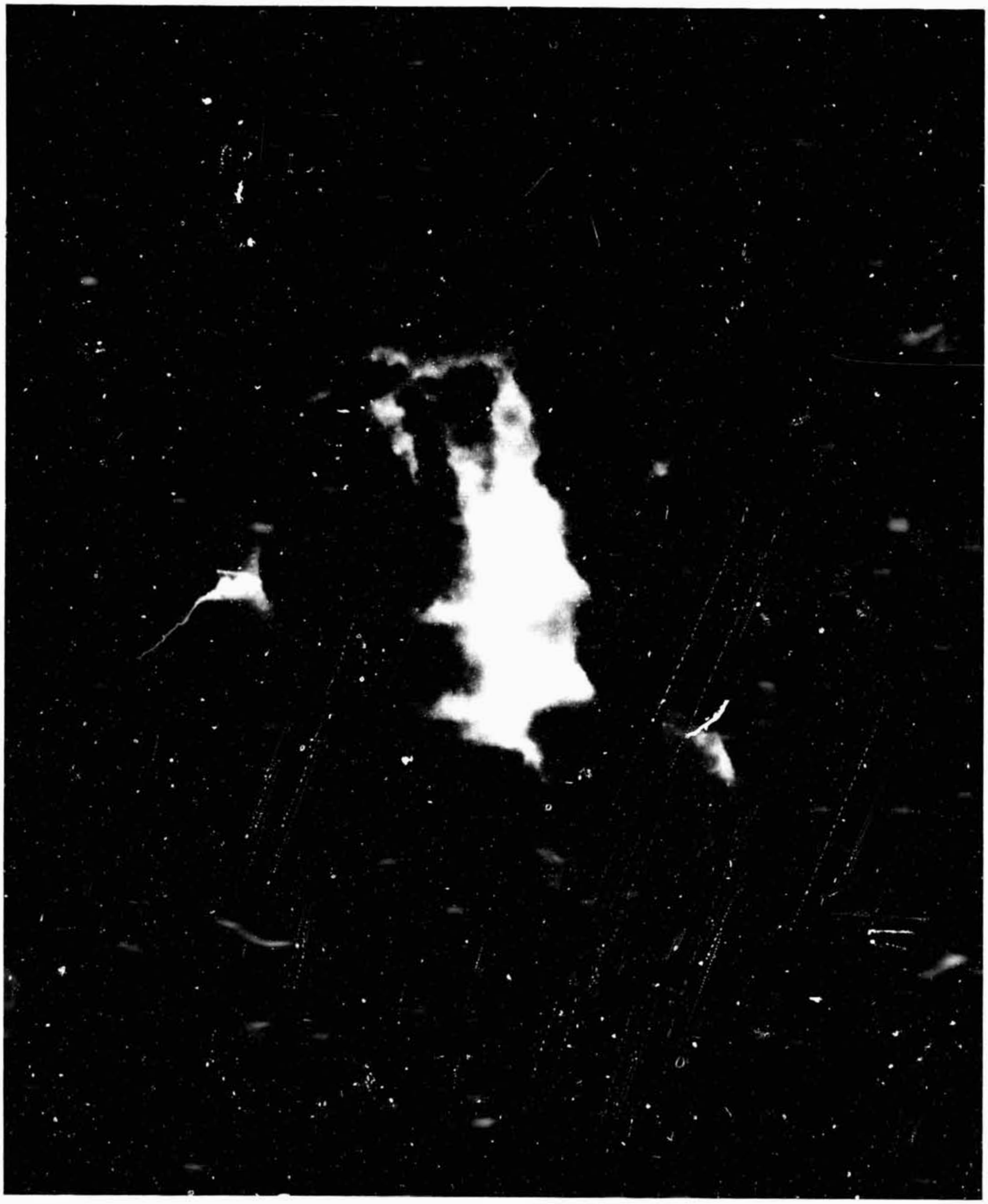


Figure 25. Vinten image of lightning at 03:02:48 GMT 83 Day 155 (4 June 1983).

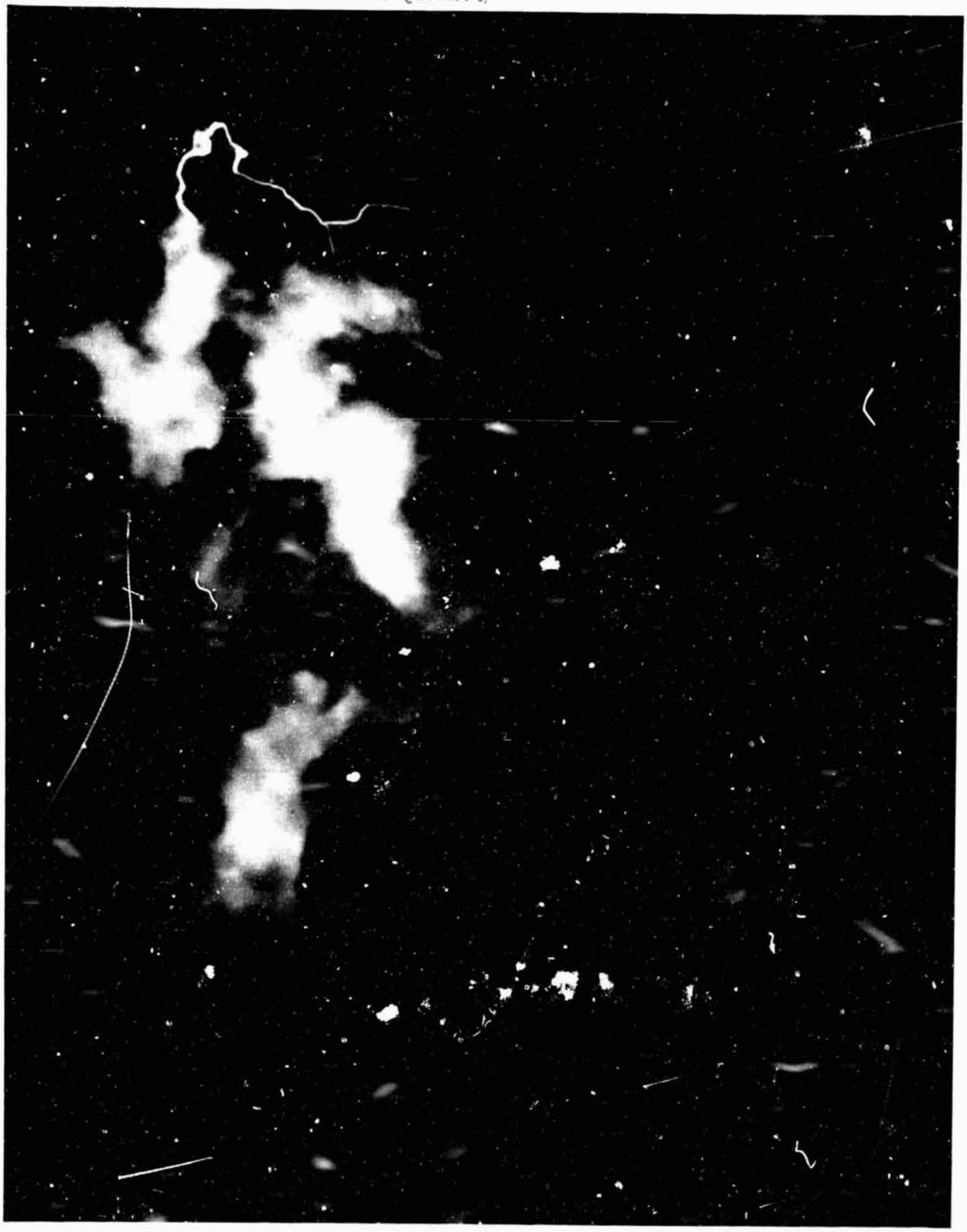
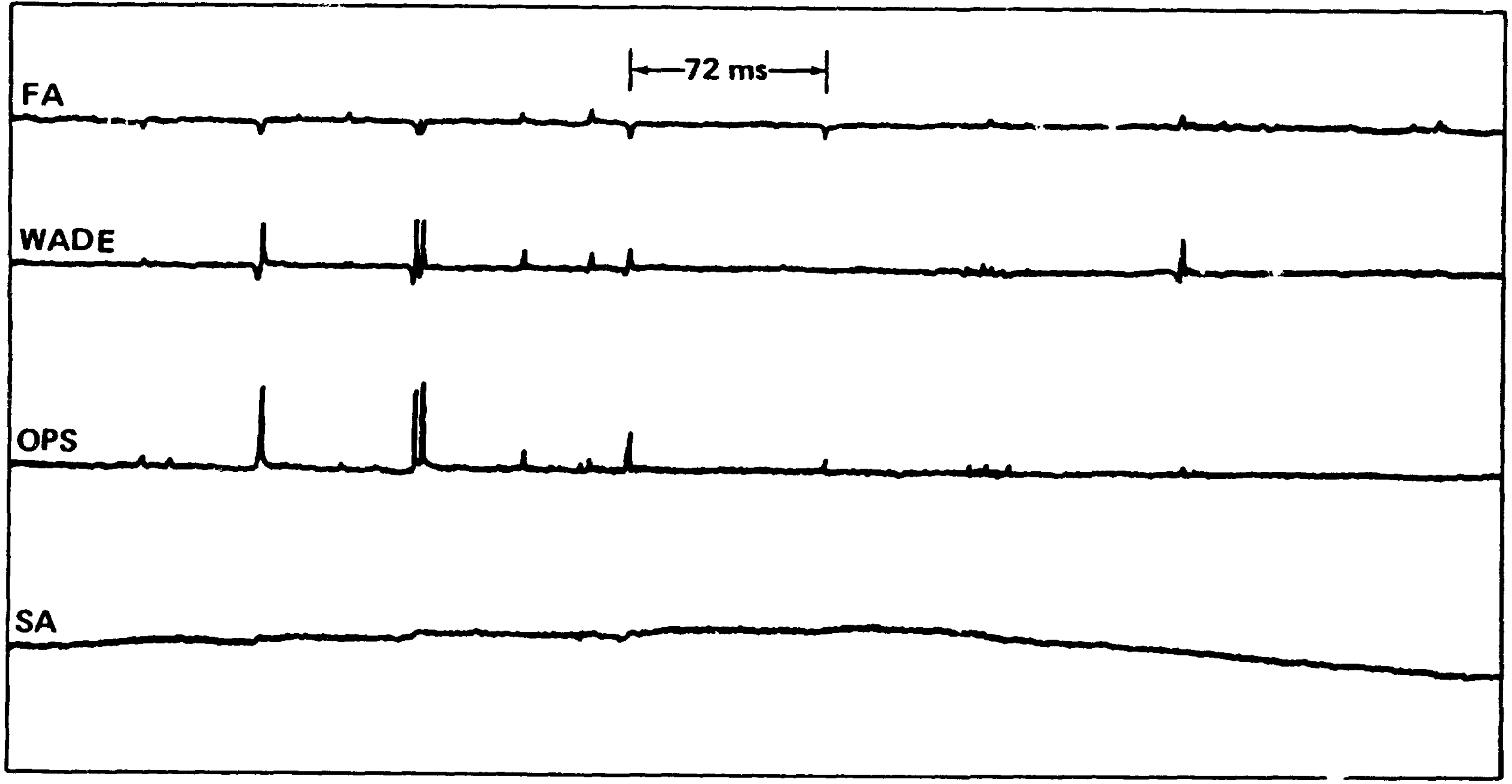


Figure 26. Vinten image of lightning at 03:45:01 GMT 83 Day 155 (4 June 1983).



DATE: 83155 TIME: 04:52:51

CG FLASH

Figure 27. Typical sample of U-2/magnetic tape data readout for 4 June 1984 (83 Day 155) 04:52:51 GMT) showing slow antenna, optical pulse sensor, wide angle pulse detector, and fast antenna.

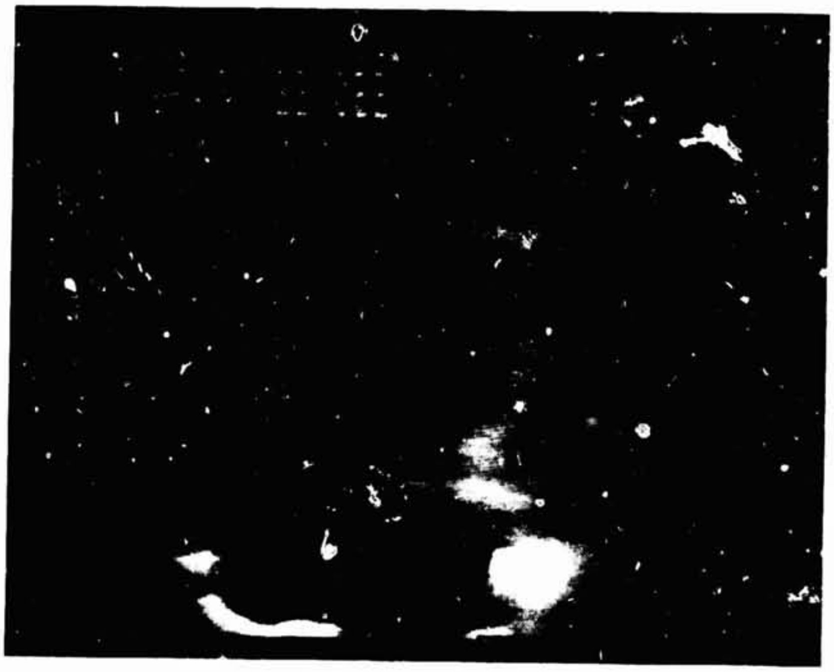


Figure 28A. TV image of intra cloud flash at 03:20:22 GMT 83 Day 155 (4 June 1983).

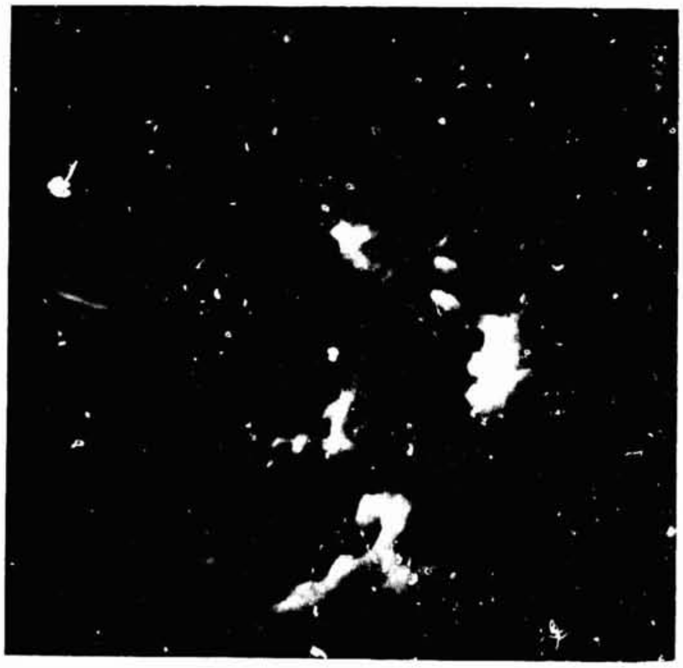


Figure 28B. Vinten image of same flash on 83 day 155 (4 June 1983).

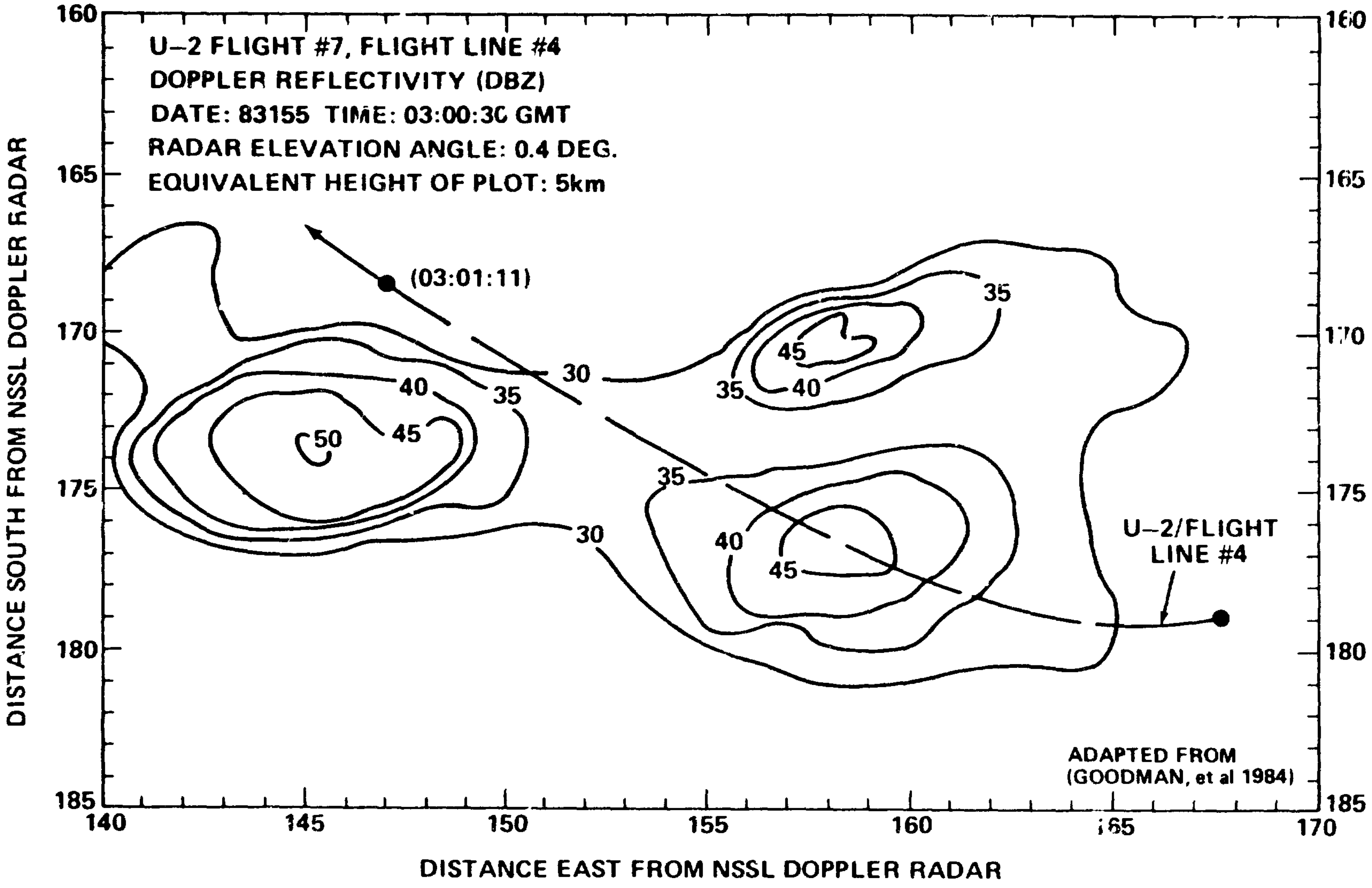


Figure 29. NSSL doppler radar reflectivity map of the storm cells producing the lightning as seen by the U-2 aircraft at 03:00:30 GMT to 03:03:01 GMT.

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TABLE 1. OPTICAL PULSE STATISTICS

TYPE	PARAMETERS	MEAN	MEDIAN	MAXIMUM	MINIMUM	RANGE	VARIANCE	STANDARD DEVIATION	NUMBER OF PULSES
CG FLASHES (N=25)	Power ($W \cdot m^{-2} \cdot sr^{-1}$)	.128E-01	.651E-02	.207E+00	.217E-02	.205E+00	.365E-03	.191E-01	229
	Power Model (log W)	.829E+01	.822E+01	.972E+01	.774E+01	.198E+01	.153E+01	.391E+00	229
	Peak Power ($W \cdot m^{-2} \cdot sr^{-1}$)	.384E-01	.197E-01	.207E+00	.455E-02	.202E+00	.173E-02	.416E-01	25
	Peak Power Model (log W)	.880E+01	.870E+01	.972E+01	.806E+01	.166E+00	.160E+00	.400E+00	25
	Energy ($J \cdot m^{-2} \cdot sr^{-1}$)	.607E-05	.328E-05	.534E-04	.474E-06	.529E-04	.628E-10	.729E-05	208
	Energy Model (log J)	.496E+01	.492E+01	.613E+01	.408E+01	.205E+01	.179E+00	.423E+00	208
	Peak Energy ($J \cdot m^{-2} \cdot sr^{-1}$)	.163E-04	.116E-04	.534E-04	.115E-05	.522E-04	.178E-09	.133E-04	25
	Peak Energy Model (log J)	.532E+01	.547E+01	.613E+01	.446E+01	.167E+01	.736E+00	.857E+00	25
	10%-10% Width (s)	.908E-03	.800E-03	.316E-02	.270E-03	.289E-02	.164E-06	.405E-03	214
	50%-50% Width (s)	.422E-03	.385E-03	.140E-02	.140E-03	.126E-02	.335E-07	.183E-03	229
	90%-90% Width (s)	.104E-03	.101E-03	.310E-03	.200E-04	.290E-03	.305E-08	.553E-04	229
	10%-50% Rise Time (s)	.180E-03	.120E-03	.173E-02	.200E-04	.171E-02	.403E-07	.201E-03	228
	10%-90% Rise Time (s)	.307E-03	.240E-03	.190E-02	.500E-04	.185E-02	.551E-07	.235E-03	228
	10%-Peak Rise Time (s)	.369E-03	.310E-03	.207E-02	.800E-04	.199E-02	.580E-07	.241E-03	228
	Interpulse Time (s)	.403E-01	.124E-01	.525E+00	.102E-02	.524E+00	.519E-02	.721E-01	209
FIRST RETURN STROKES	Power ($W \cdot m^{-2} \cdot sr^{-1}$)	.276E-01	.906E-02	.207E+00	.229E-02	.205E+00	.209E-02	.457E-01	23
	Power Model (log W)	.848E+01	.836E+01	.972E+01	.776E+01	.196E+01	.270E+00	.520E+00	23
	Energy ($J \cdot m^{-2} \cdot sr^{-1}$)	.103E-04	.448E-05	.534E-04	.101E-05	.524E-04	.180E-09	.134E-04	22
	Energy Model (log J)	.516E+01	.505E+01	.613E+01	.441E+01	.172E+01	.212E+00	.461E+00	22
	10%-10% Width (s)	.880E-03	.840E-03	.191E-02	.460E-03	.145E-02	.131E-06	.362E-03	22
	50%-50% Width (s)	.407E-03	.405E-03	.790E-03	.200E-03	.590E-03	.214E-07	.146E-03	23
	90%-90% Width (s)	.104E-03	.950E-04	.200E-03	.200E-04	.180E-03	.319E-08	.565E-04	23
	10%-50% Rise Time (s)	.112E-03	.700E-04	.440E-03	.300E-04	.410E-03	.887E-08	.941E-04	22
	10%-90% Rise Time (s)	.235E-03	.200E-03	.520E-03	.900E-04	.430E-03	.170E-08	.130E-03	22
	10%-Peak Rise Time (s)	.297E-03	.280E-03	.570E-03	.130E-03	.440E-03	.203E-08	.142E-03	22
SUBSEQUENT RETURN STROKES	Power ($W \cdot m^{-2} \cdot sr^{-1}$)	.164E-01	.850E-02	.640E-01	.229E-02	.617E-01	.218E-03	.168E-01	50
	Power Model (log W)	.842E+01	.833E+01	.921E+01	.776E+01	.145E+01	.169E+00	.410E+00	50
	Energy ($J \cdot m^{-2} \cdot sr^{-1}$)	.858E-05	.511E-05	.415E-04	.668E-06	.408E-04	.764E-10	.874E-05	46
	Energy Model (log J)	.515E+01	.511E+01	.602E+01	.423E+01	.179E+01	.169E+00	.411E+00	46
	10%-10% Width (s)	.103E-02	.935E-03	.219E-02	.440E-03	.175E-02	.190E-06	.436E-03	47
	50%-50% Width (s)	.494E-03	.470E-03	.112E-02	.170E-03	.950E-03	.474E-07	.213E-03	50
	90%-90% Width (s)	.111E-03	.120E-03	.240E-03	.200E-04	.220E-03	.325E-08	.570E-04	50
	10%-50% Rise Time (s)	.168E-03	.120E-03	.670E-03	.200E-04	.650E-03	.227E-07	.151E-03	50
	10%-90% Rise Time (s)	.311E-03	.240E-03	.820E-03	.600E-04	.760E-03	.347E-07	.186E-03	50
	10%-Peak Rise Time (s)	.375E-03	.320E-03	.960E-03	.120E-03	.840E-03	.361E-07	.190E-03	50
PULSES ASSOCIATED WITH CG FLASHES THAT ARE NOT RETURN STROKES	Power ($W \cdot m^{-2} \cdot sr^{-1}$)	.963E-02	.596E-02	.686E-01	.217E-02	.664E-01	.109E-03	.104E-01	156
	Power Model (log W)	.823E+01	.818E+01	.924E+01	.774E+01	.150E+01	.119E+00	.344E+00	156
	Energy ($J \cdot m^{-2} \cdot sr^{-1}$)	.458E-05	.261E-05	.363E-04	.474E-06	.358E-04	.346E-10	.588E-05	140
	Energy Model (log J)	.486E+01	.482E+01	.596E+01	.408E+01	.188E+01	.152E+01	.390E+00	140
	10%-10% Width (s)	.873E-03	.770E-03	.316E-02	.270E-03	.289E-02	.157E-06	.396E-03	145
	50%-50% Width (s)	.400E-03	.370E-03	.140E-02	.140E-03	.126E-02	.297E-07	.172E-03	156
	90%-90% Width (s)	.102E-03	.900E-04	.310E-03	.200E-04	.290E-03	.299E-08	.547E-04	156
	10%-50% Rise Time (s)	.185E-03	.130E-03	.173E-02	.200E-04	.171E-02	.391E-07	.198E-03	155
	10%-90% Rise Time (s)	.307E-03	.240E-03	.190E-02	.500E-04	.185E-02	.567E-07	.238E-03	155
	10%-Peak Rise Time (s)	.369E-03	.300E-03	.207E-02	.800E-04	.199E-02	.606E-07	.246E-03	155
INTRACLOUD FLASHES (N=232)	Power ($W \cdot m^{-2} \cdot sr^{-1}$)	.161E-01	.688E-02	.294E+00	.214E-02	.292E+00	.772E-03	.278E-01	3126
	Power Model (log W)	.833E+01	.824E+01	.987E+01	.773E+01	.214E+01	.188E+00	.434E+00	3126
	Energy ($J \cdot m^{-2} \cdot sr^{-1}$)	.655E-05	.264E-05	.181E-03	.277E-06	.181E-03	.163E-09	.128E-04	3016
	Energy Model (log J)	.489E+01	.482E+01	.666E+01	.385E+01	.282E+01	.233E+00	.483E+00	3016
	10%-10% Width (s)	.789E-03	.700E-03	.328E-02	.210E-03	.307E-02	.144E-06	.380E-03	3067
	50%-50% Width (s)	.346E-03	.300E-03	.172E-02	.800E-04	.164E-02	.295E-07	.172E-03	3126
	90%-90% Width (s)	.911E-04	.800E-04	.390E-03	.200E-04	.370E-03	.247E-08	.497E-04	3126
	10%-50% Rise Time (s)	.171E-03	.110E-03	.225E-02	.200E-04	.223E-02	.369E-07	.192E-03	3118
	10%-90% Rise Time (s)	.274E-03	.210E-03	.237E-02	.300E-04	.234E-02	.557E-07	.236E-03	3118
	10%-Peak Rise Time (s)	.327E-03	.260E-03	.247E-02	.500E-04	.242E-02	.592E-07	.243E-03	3118
	Interpulse Time (s)	.282E-01	.874E-02	.103E+01	.700E+00	.403E+01	.431E-02	.657E-01	2898

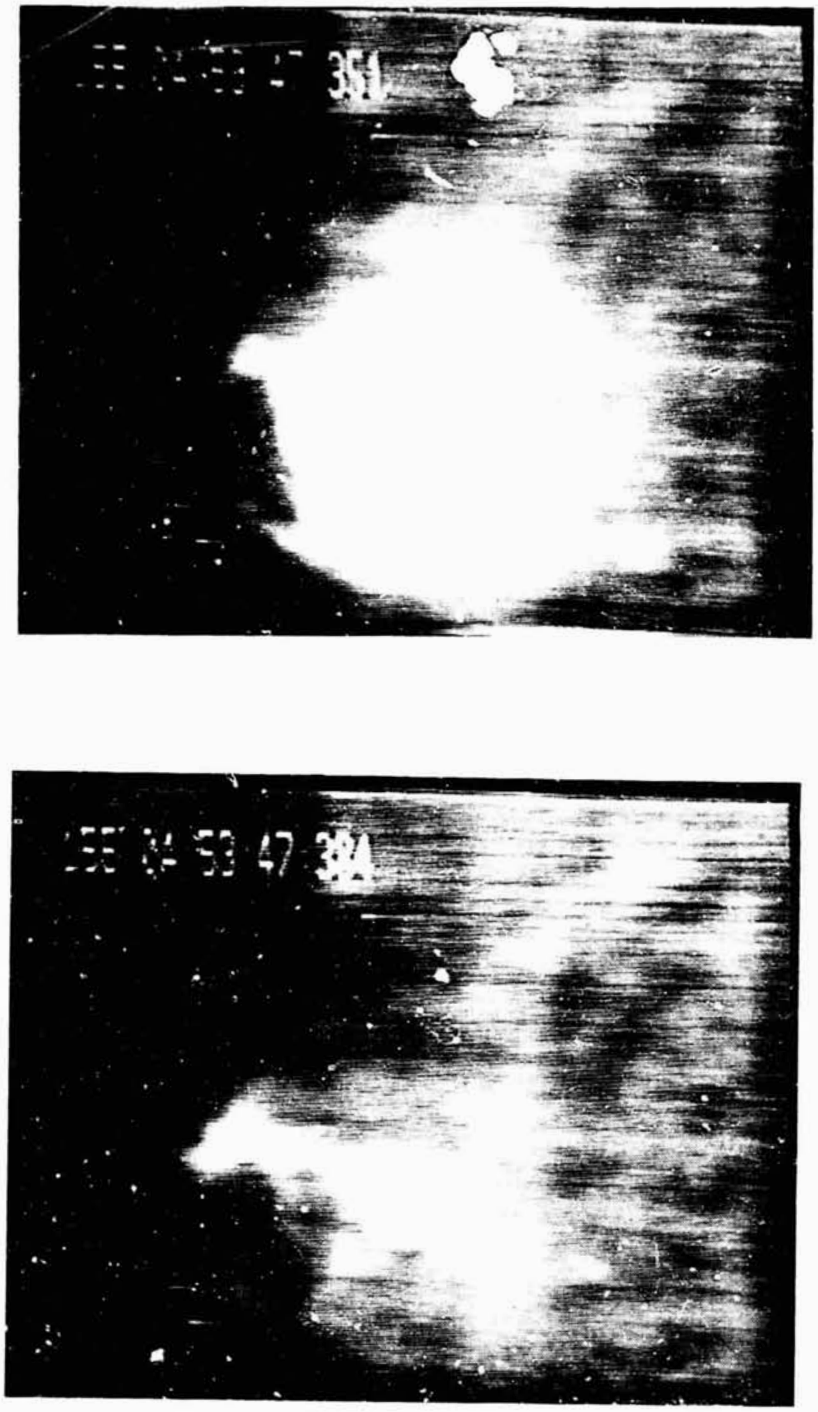

Figure 30. TV images of intra cloud flash on 83 day 155 at 04:53:47.351 GMT and 04:53:47.384 GMT.

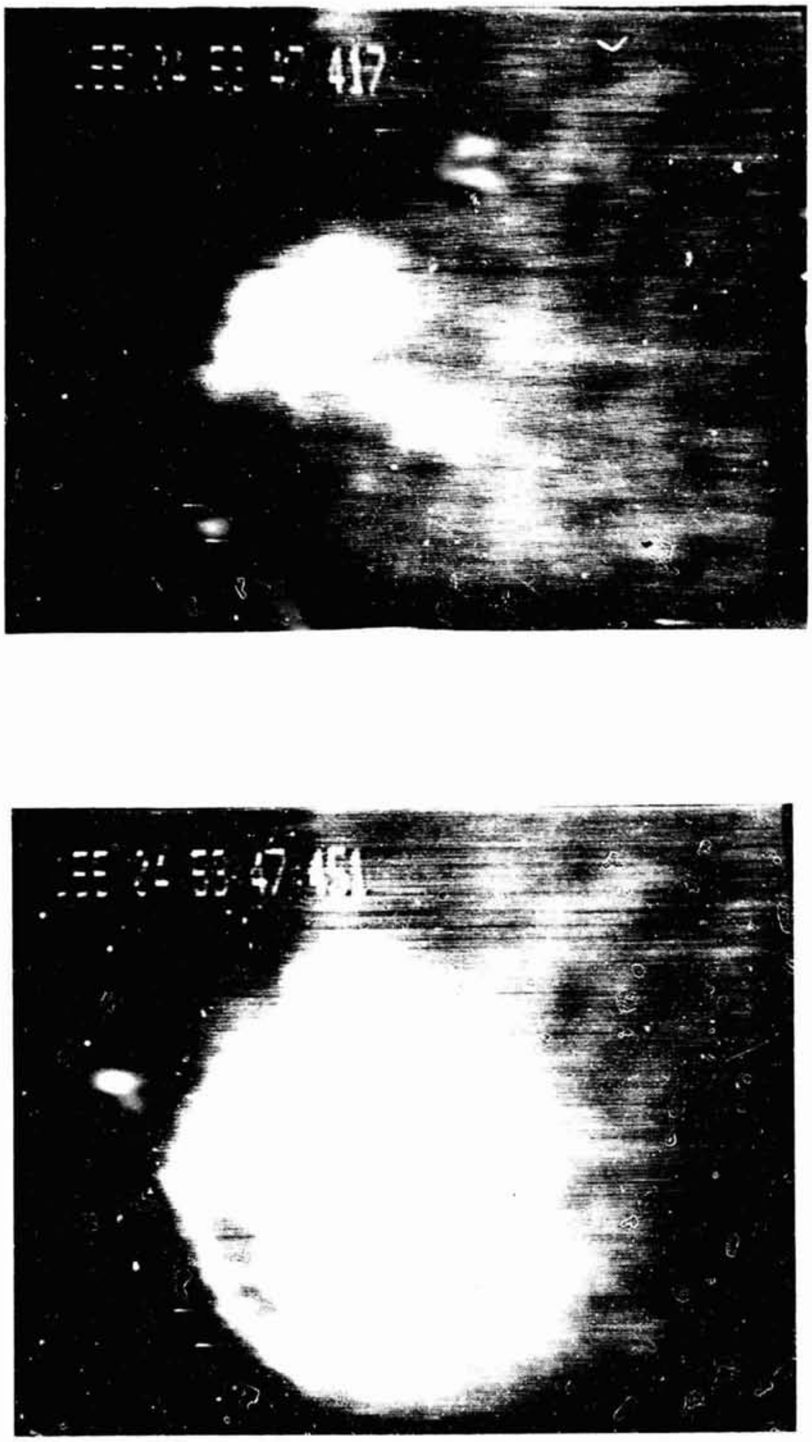

Figure 31. TV images of intra cloud flash on 83 Day 155 at 04:53:47.417 GMT and 04:53:47.451 GMT.

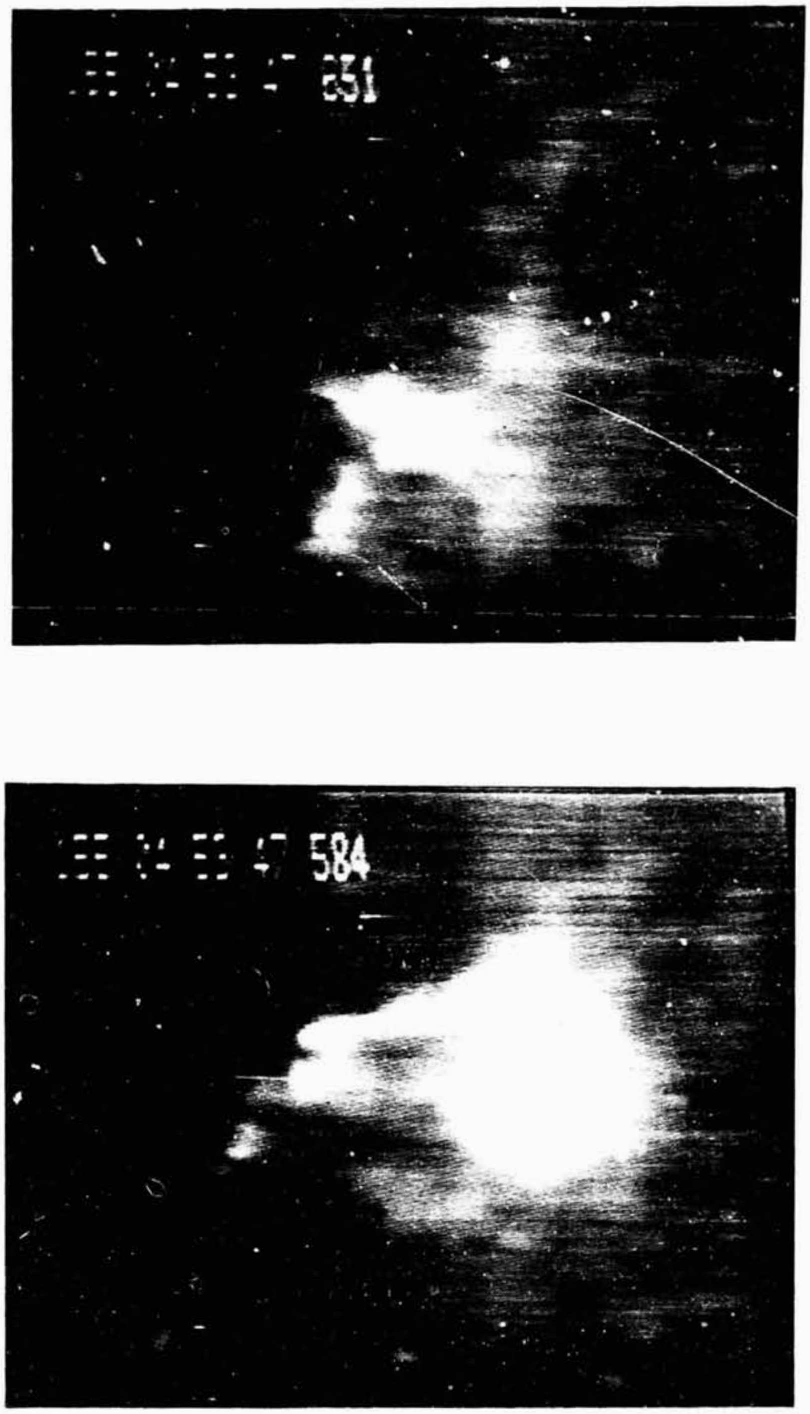

Figure 32. TV images of intra cloud flash on 83 Day 155 at 04:53:47.651 GMT and 04:53:47.584 GMT.

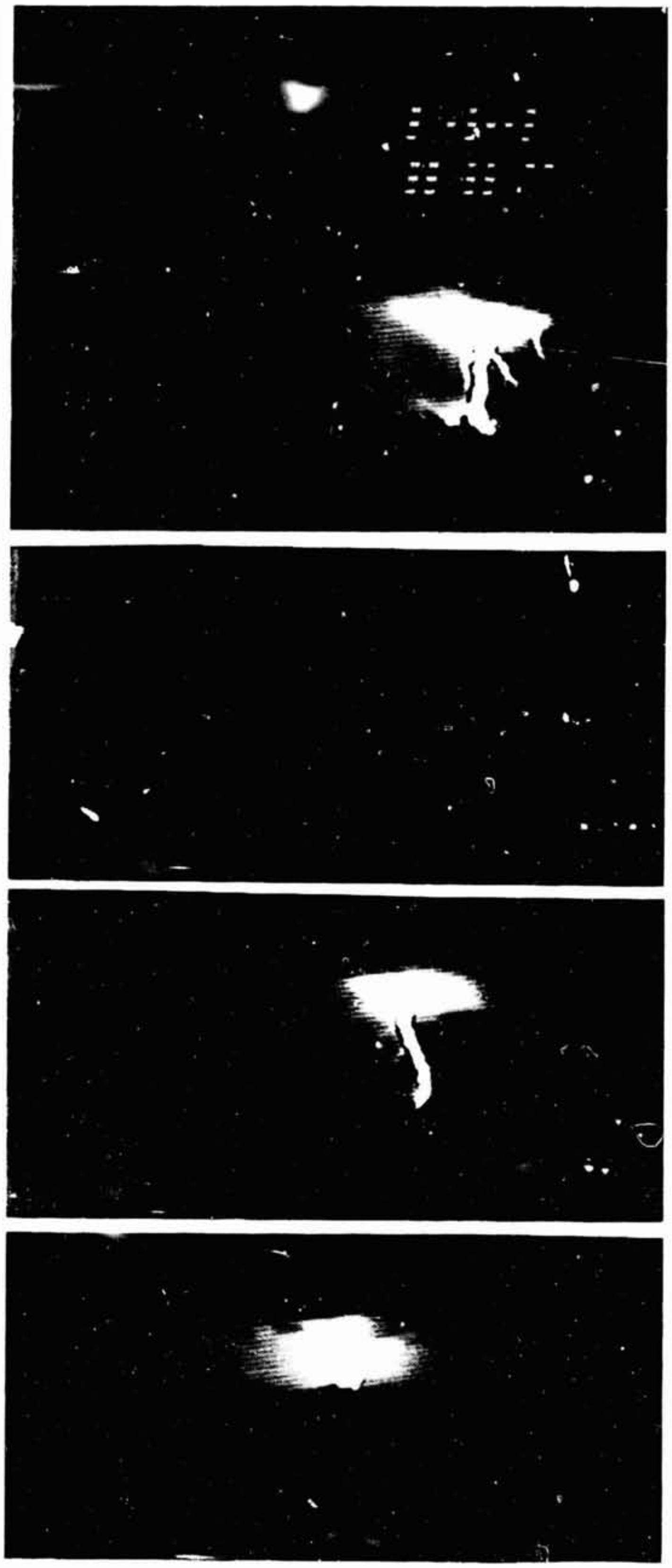

Figure 33. A sequence of TV images of cloud to ground flashes as seen by the storm chase vehicle at 83 Day 155 at 03:38:55 GMT (a total of 10 frames occurs between the first image and the last image shown here).

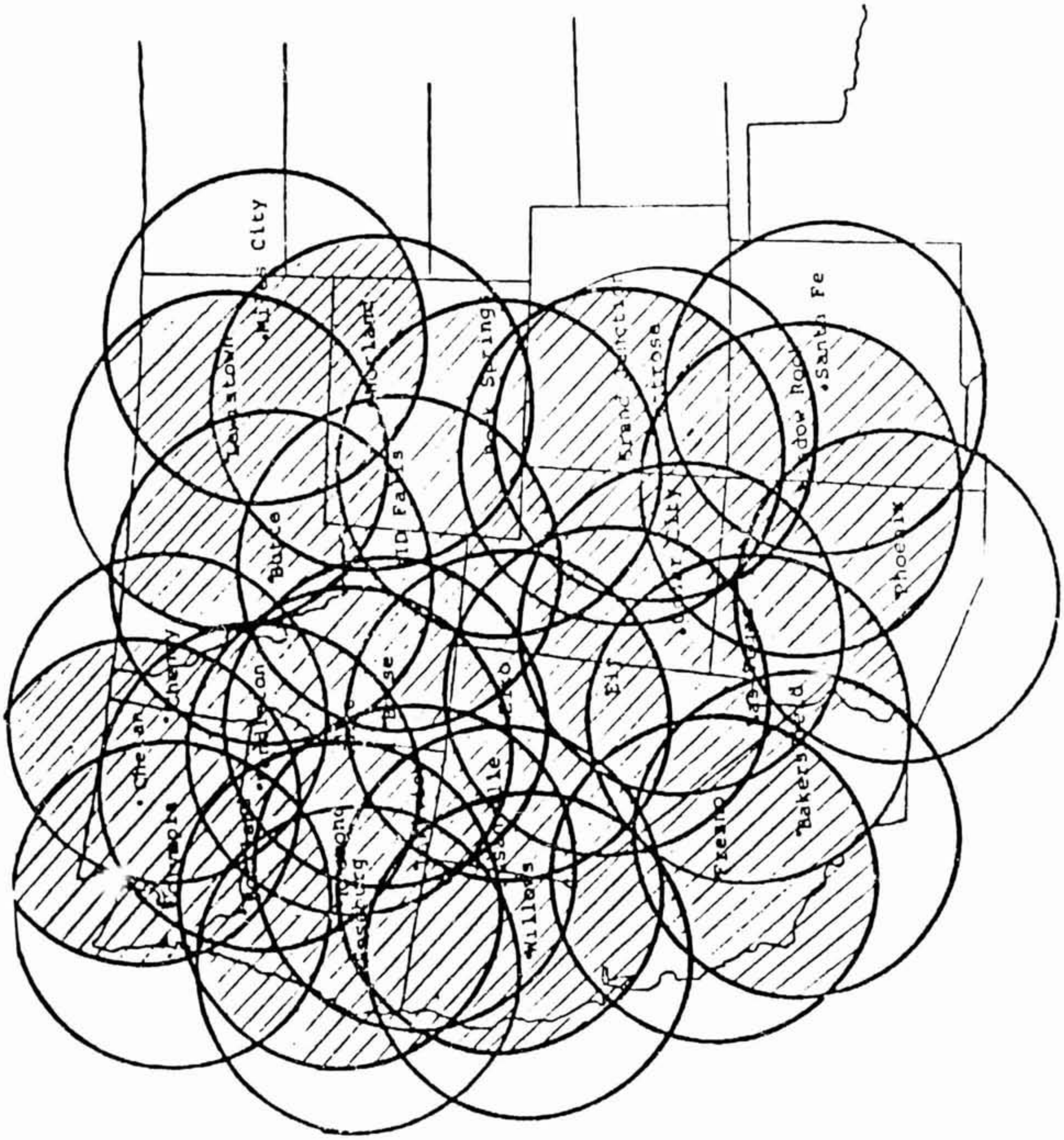

Figure 34. BLM lightning location network in the Southwest.

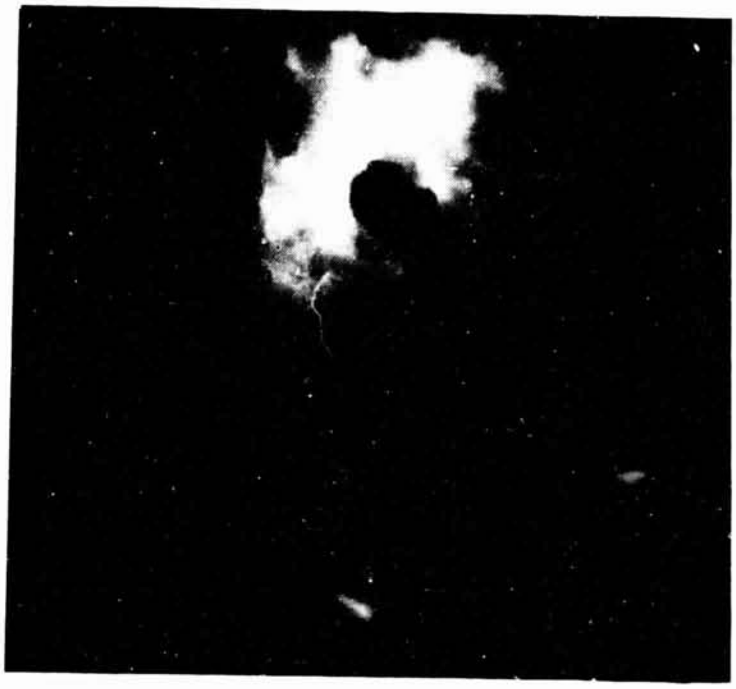

Figure 35. Vinten image of lightning bolt at 030024 GMT 83 Day 236 (24 August 1983).

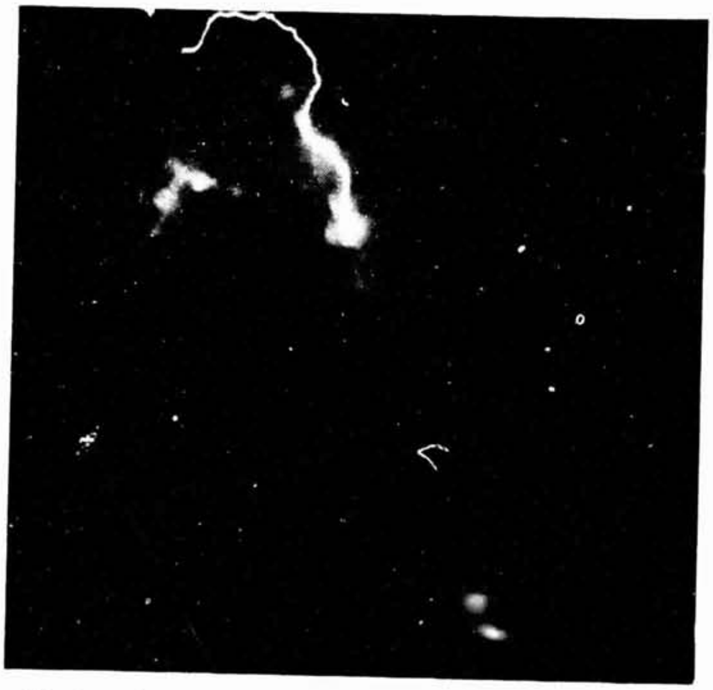

Figure 36. Vinten image of lightning bolt at 035911 GMT 83 Day 236 (24 August 1983).

Figure 37. Vinten image of lightning bolt at 043030 GMT 83 Day 236 (24 August 1983).

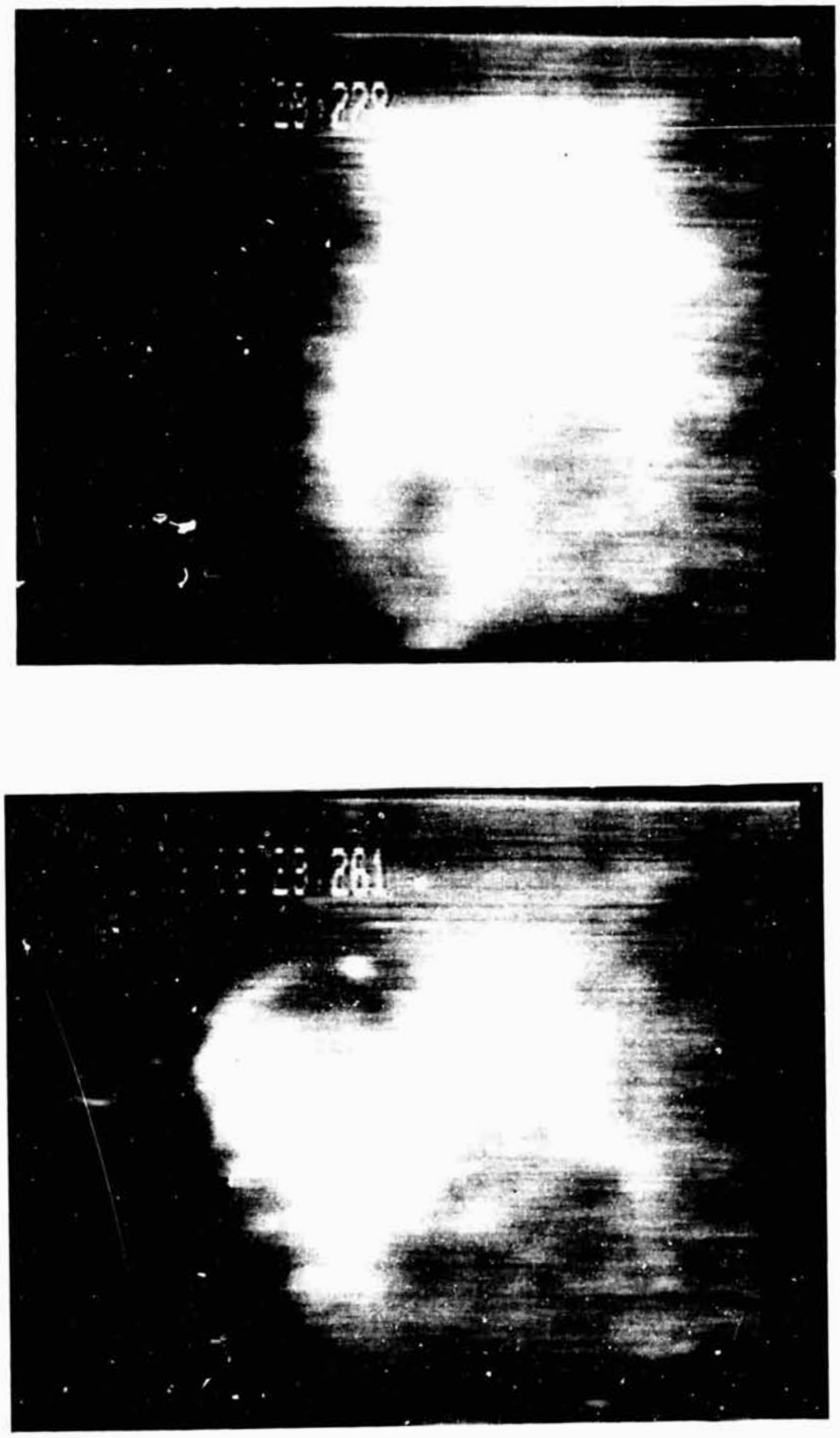

Figure 38. TV images of cloud flash 83 Day 236 at 03:06:29.228 GMT 03:06:29.261 GMT (24 August 1983).

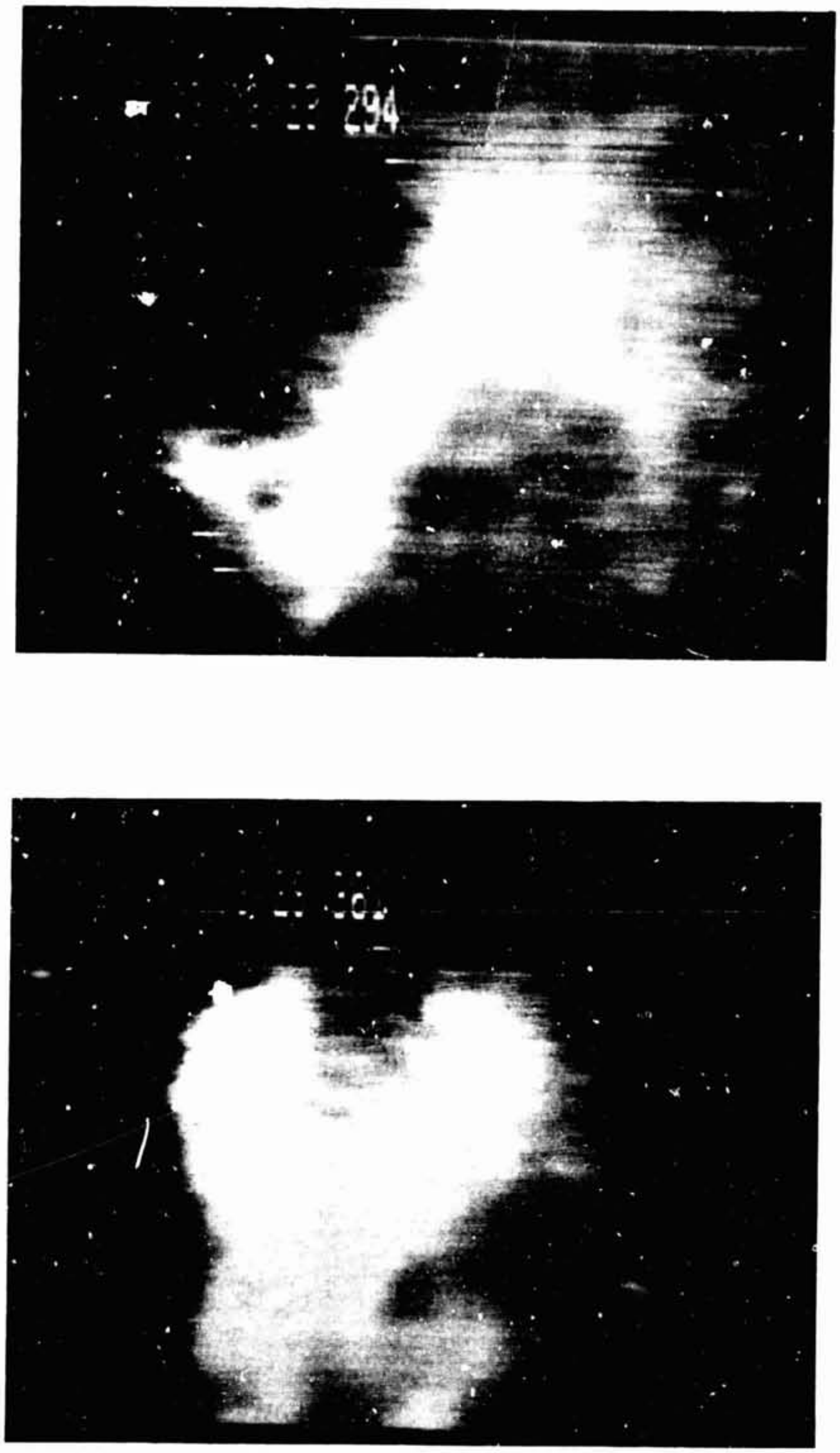

Figure 39. TV images of cloud flash on 83 Day 236 at 03:06:29.294 GMT and 03:06:29.361 GMT (24 August 1983).

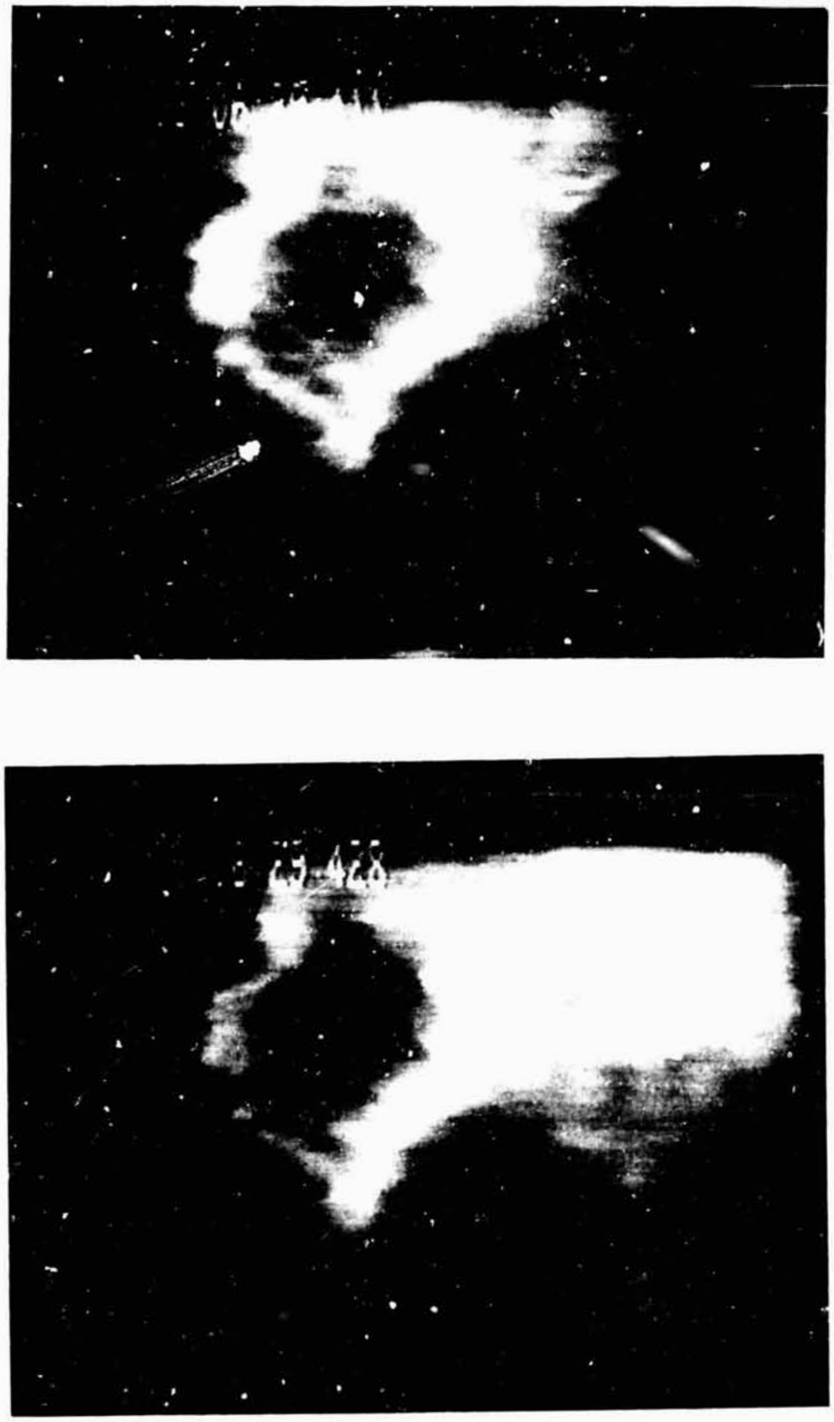

Figure 40. TV images of cloud flash on 83 Day 236 at 03:06:29.411 GMT and 03:06:29.428 GMT (24 August 1983).

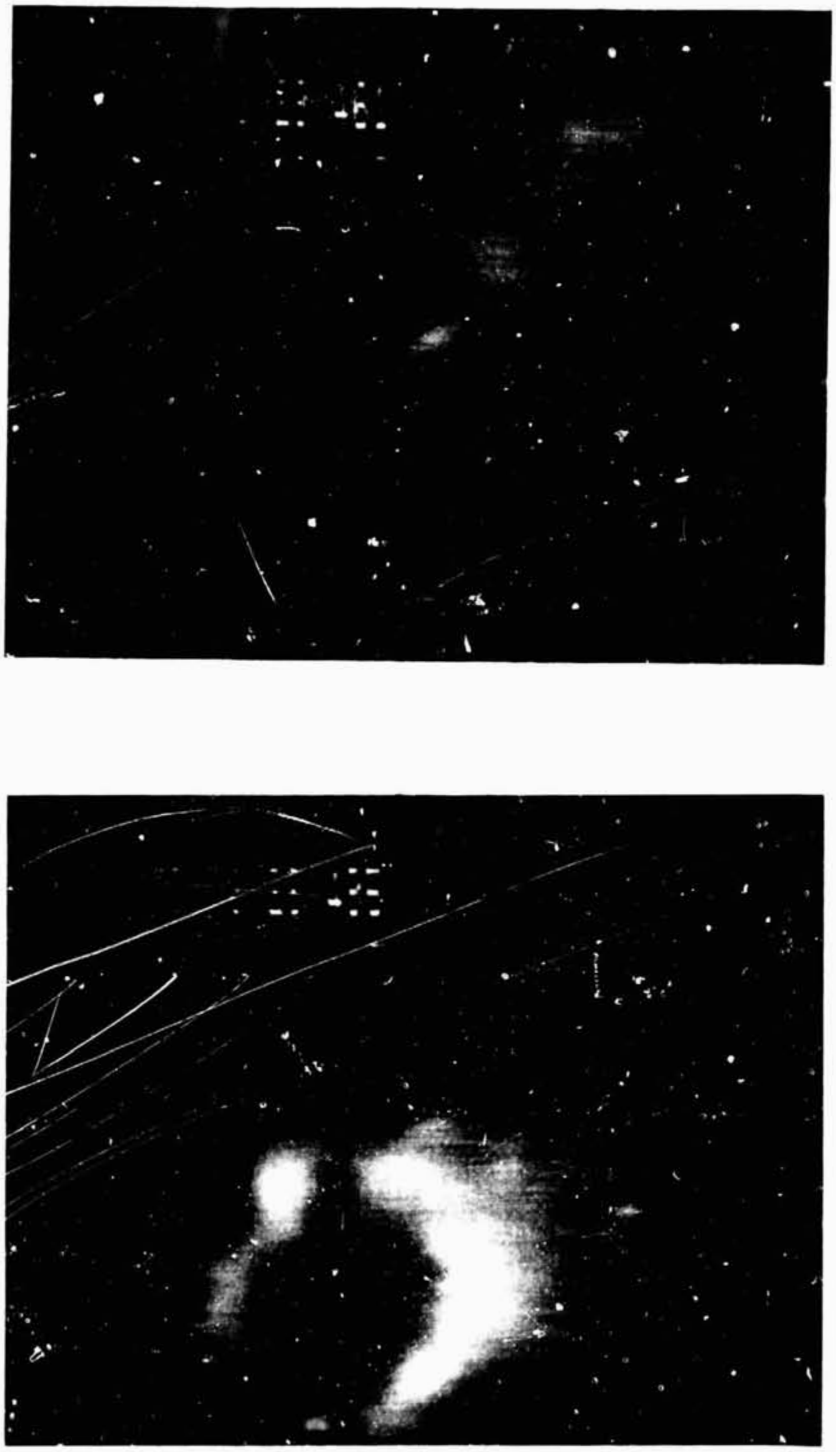

Figure 41. TV images of cloud flash on 83 Day 236 at 03:06:29.461 GMT and 03:06:29.495 GMT (24 August 1983).

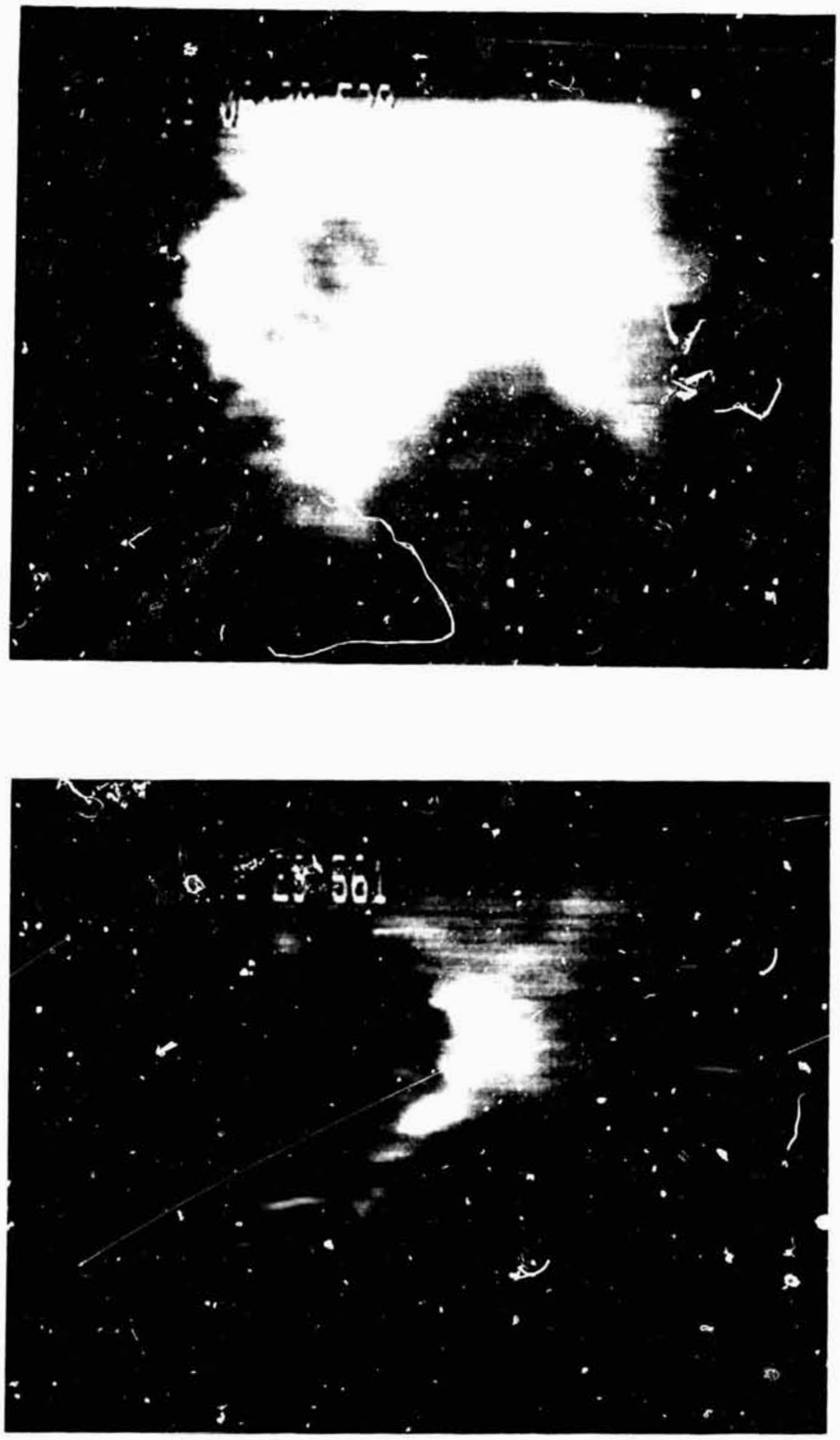

Figure 42. TV images of cloud flash on 83 Day 236 at 03:06:29.528 GMT and 03:06:29.561 GMT (24 August 1983).

SIGNIFICANT ACCOMPLISHMENTS FOR 81, 82 AND 83 U-2 "TOP"

- OPTICAL SIGNALS FROM DART LEADERS, RETURN STROKES, AND CONTINUING CURRENTS CAN BE RECOGNIZED ABOVE THE CLOUD.

- THE ANALYSIS OF THE U-2/OPTICAL SENSOR DATA WHICH HAD INTERFERENCE FILTERS (8683°A AND 7774°A), SHOW THAT THE LIGHTNING FLASH CREATES OPTICAL PULSES THAT HAVE A SLOWER RISE TIME AND A BROADER PULSE WIDTH THAN THE OPTICAL PULSE THAT HAS BEEN OBTAINED FROM GROUND BASED DETECTORS.

- SPECTRAL CHARACTERISTICS OF THE NEUTRAL EMMISSION LINES AS MEASURED BY AIRBORNE SENSORS ARE SIMILIAR TO THE GROUND BASED LIGHTNING DATA.

- THE OPTICAL ENERGY WHEN MEASURED ABOVE THE CLOUD TOP, USING INTERFERENCE FILTERS (8683°A AND 7774°A), APPEARS NOT TO BE SIGNIFICANTLY DIFFERENT THAN MEASUREMENTS MADE FROM BELOW ON CLOUD TO GROUND EVENTS.

- THE OPTICAL MEASUREMENTS FROM THE U-2 ABOVE THE CLOUD TOP INDICATE OPTICAL PULSE DETECTION IN DAYTIME IS NOT AS DIFFICULT AS ORIGINALLY ESTIMATED.

- MANY WEAK LIGHTNING CHANNELS HAVE BEEN OBSERVED TO EXIST IN THE CLEAR AIR ABOVE AND AROUND CLOUD TOPS INDICATING THAT LIGHTNING IS CAPABLE OF INTRODUCING CHEMICAL SPECIES, IONS, AND SPACE CHARGE DIRECTLY INTO THE UPPER TROPOSPHERE LOWER STRATOSPHERE.

- OBSERVATIONS AT NIGHT FROM AIRPLANE ABOVE CLOUD TOP SHOW MOST CLOUD LIGHTNING ACTIVITY ASSOCIATED WITH STRONGLY CONVECTIVE CLOUD FORMATIONS.

Figure 43. Significant accomplishments of 81, 82, and 83 atmospheric research program.