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(NASA-CR-154629) A PRELIMINARY TEST OF THE APPLICATION OF THE LIGHTNING DETECTION AND RANGING SYSTEM (LDAR) AS A THUNDERSTORM WARNING AND LOCATION DEVICE FOR THE FHA INCLUDING A (RCA Service Co., John F. N79-12655

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A Preliminary Test of the Application of the Lightning Detection and Ranging System (LDAR) as a Thunderstorm Warning and Location Device for the FAA

including a Correlation with Updrafts, Turbulence, and Radar Precipitation Echoes

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A PRELIMINARY TEST OF THE APPLICATION OF THE LIGHTNING DETECTION AND RANGING SYSTEM (LDAR) AS A THUNDERSTORM WARNING AND LOCATION DEVICE FOR THE FAA INCLUDING A CORRELATION WITH UPDRAFTS, TURBULENCE, AND RADAR PRECIPITATION ECHOES

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SUMMARY

Results of a test of the use of a Lightning Detection and Ranging (LDAR) remote display in the Patrick AFB RAPCON facility are presented. Agreement between LDAR and radar precipitation echoes of the RAPCON radar was observed, as well as agreement between LDAR and pilot's visual observations of lightning flashes. A more precise comparison between LDAR and KSC based radars is achieved by the superposition of LDAR with radar precipitation echoes. Airborne measurements of updrafts and turbulence by an armored T-28 aircraft flying through the thunderclouds are correlated with LDAR along the flight path. Calibration and measurements of the accuracy of the LDAR System are discussed, and the extended range of the system is illustrated.

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ACKNOWLEDGEMENT

The author wishes to express his acknowledgement to the following who have contributed data that was used in this report.

Mr. Dennis J. Musil, Research Scientist of the Institute of Atmospheric Science of the South Dakota School of Mines and Technology.

Mr. Laurence Jones, Air Traffic Representative, FAA

Dr. Roger Lhermitte of the Division of Atmospheric Science, University of Miami Rosenthiel School of Marine and Atmospheric Science.

Mr. James Nicholson, of the NOAA National Weather Service.

I. INTRODUCTION

An interagency agreement (Ref. 1) dated April 28, 1978, provided for the installation of an LDAR display unit at the Patrick AFB RAPCON. A Department of the Air Force Memo (Ref. 2) from Major Peppler (FFNR) to SCA/FFN dated April 24, 1978, provides concurrence for "using the Patrick AFB RAPCON for application testing of the Lightning Detection and Ranging System (LDAR) display for control purposes". An FFA/NASA Test Plan for "Evaluating the Use of a Remote Display of the Lightning Detection and Ranging System (LDAR) in the Patrick AFB RAPCON" (Ref. 3) was issued June 29, 1978, spelling out the scope, test objective, method of accomplishment, and the test schedules.

This report will discuss the LDAR data that was provided, the comparison of LDAR with RAPCON radar data as entered in the log by Laurence Jones, Air Traffic Representative, FAA, as well as a correlation of LDAR data with updraft wind velocity and turbulence as provided by Mr. Dennis J. Musil, Research Scientist of the Institute of Atmospheric Science of the South Dakota School of Mines and Technology, and will discuss a more precise comparison of LDAR with radar precipitation echo data, and finally will discuss the range and the accuracy of the LDAR System. The data presented places emphasis on those capabilities of the LDAR System that are expected to be of interest to the FAA. In conclusion, experience gained on this preliminary test is used to draw up recommendations for an improved utilization of LDAR by FAA.

II. DISCUSSION

In order to provide for a remote display of the Lightning Detection and Ranging (LDAR) System's output, changes in the LDAR System data processing and the data display terminal were required. Specifically it was necessary to replace the Tektronix Model 4010 terminal with a Tektronix Model 4025 terminal, which provides a TV-compatible second output suitable for transmission along a wideband cable. The $5,000 provided by the FAA and the $5,000 provided by NASA for making the necessary changes were used to purchase the required Tektronix Model 4025 terminal, to program the LDAR operating program to be compatible with the Tektronix Model 4025 terminal, and for rental of the required wideband line.

A 25 inch TV monitor was set up at the PAFB RAPCON facility in a position near the controllers. The LDAR display was intended to assist the controllers in locating thunderstorm activity in the area

LDAR display data was furnished to RAPCON over the period July 27 to August 25, 1978. A log of the correlation of LDAR displays with RAPCON radar precipitation echoes was prepared by Laurence Jones. An abbreviated version of this log, giving the pertinent data, is presented in Appendix B. The activity is further summarized in the table below.

	Sun	M	T	W	T	F	Sat
JULY		17 TH	-	TH	C	21 C	
1978		24 C	C	L	TH	28 C	
		31 C	1 C	C	C	4 C	
AUG		7 L	L	L	L	11 L	
		14 C	C	-	-	18 -	
		21 -	-	C	C	25 C	

TH-Thunderstorm, C-clear or light precipitation, L-launch, - no data

Over the observation period, active thunderstorms occurred on three days, clear weather or light precipitation was noted on fifteen days, the video cable was preempted by a scheduled launch for six days, and no data was available for six days. For our comparison, we therefore have three thunderstorm and fifteen clear (or light precipitation) days.

Reference to the log given in the Appendix shows close correspondence between the LDAR and the RAPCON radar data. A small sample of this data, reproduced below illustrates the point:

		AZIMUTH,DEG		RANGE,NM	
Day	Time,Z	LDAR	Radar	LDAR	Radar
7-27-78	1840	260-265	265	15	15
7-27-78	1845	300-330	310-340	10-20	10-25
7-27-78	1855	325	320-330	10-15	8-15

A more precise identification of the precipitation echo than was possible by the visual comparison of the LDAR and RADAR displays shown above will be presented later in this report by means of overlays of the LDAR and radar data. This will show that, in general, the precipitation echo is much larger than the LDAR area, showing that only selected portions of the precipitation echo are electrified, as indicated by the LDAR response.

Data for the fifteen clear (or light precipitation) days showed no cloud electrification (LDAR response) is present on clear or light precipitation days. In fact, other more detailed data (Ref. 4) indicated that LDAR activity does not appear until cloud tops exceed approximately 30,000 feet elevation.

The test plan (Ref. 3) specified that "Aircraft within RAPCON's delegated airspace may be asked by USAF controllers to verify LDAR information by visual observations". Laurence Jones reported that this was done on at least a dozen occasions, when planes were at a distance at some 5 to 15 n. miles from the activity indicated by the LDAR. Mr. Jones reports that in all cases the pilots verified the presence of lightning flashes in the region indicated by LDAR.

III. CORRELATION OF LDAR WITH RADAR PRECIPITATION ECHOES, UPDRAFT/DOWNDRAFT WIND VELOCITIES, AND TURBULENCE DURING A TYPICAL THUNDERSTORM

Discussion

In addition to the visual comparison of LDAR and RAPCON radar displays, we had available to us updraft/downdraft wind velocities and turbulence data measured on Sunday August 13 by an armored T-28 aircraft flying through thunderclouds some 45 km NW of the LDAR site at an elevation of 6500 meters. Because August 13 was a Sunday, no comparison data from the RAPCON facility is available.

To illustrate the correlation between LDAR and updraft/downdraft wind velocity and turbulence measured by the T-28 aircraft, we will present LDAR plots for appropriate time periods within the interval 1920 to 2004 GMT, keyed to the flight times of the armored aircraft through the clouds. This data is a first since no comparison of LDAR with updraft/downdraft wind velocity or with turbulence has previously been presented.

The Institute of Atmospheric Sciences of the South Dakota School of Mines and Technology participated in the TRIP International Thunderstorm Research Program at the Kennedy Space Center in the Summer of 1978, with Dr. Paul L. Smith as Principal Investigator. Their measurements on the updraft/downdraft wind velocity and turbulence on a storm that occurred some 45 km NW of the Kennedy Space Center and that was tracked by KSC's LDAR System was made available to us by Mr. Dennis T. Musil, Research Scientist. These data are included in this report together with correlated LDAR data because of their revalence.

Also participating in the TRIP-78 thunderstorm project, were Dr. Roger Lhermitte of the Division of Atmospheric Science, University of Miami Rosenthiel School of Marine and Atmospheric Science, and Mr. James Nicholson of the NOAA National Weather Service. Both investigators have contributed their X-band radar data for use in this report.

LDAR is a time-of-arrival system that determines the location was well as the elevation of an electrical discharge in the atmosphere from the times of arrival of the emitted electromagnetic signals in the band 60-80 MHz at four stations positioned in a Y-configuration with a baseline of approximately 10 km. A minicomputer, using the times of arrival as input, solves the hyperbolic equations and plots the position of the electrical discharges on a PPI plot, as shown in Figure 1. The elevation of the discharges is indicated in the boxes at the left, as a function of range. Two boxes are shown. The upper box contains the height data for all the discharges north of the central LDAR site, that is in the azimuth range 270 to 90 degrees. The lower box contains the height data for all the data points that occur south of the central LDAR site, located at X= 613,593.0 Feet East and Y= 1,528,943.5 Feet North in the Florida East coordinate system. For each data point in the PPI plot, a corresponding point appears on the height-range plot. Positive identification is best made in real time, since the two dots appear simultaneously. However the range scale will in some cases help to identify corresponding points. It should be noted that each LDAR dot on the LDAR plot is often many (as many as 10-30) separate data points so close together that they appear as one on the plot. Additional data on the LDAR System can be found in References 4 and 5.

The T-28 armored aircraft made eight passes through the clouds associated with the thunderstorm 45 km NW of the Kennedy Space Center between the hours 1916 to 2043 on August 13, 1978. We will present typical data for five of these passes.

Data Analysis

Pass 1

Figure 1 shows a composite LDAR, updraft/downdraft wind velocity, turbulence parameter $\varepsilon^{1/3}$, radar precipitation echo plot for Pass 1 on which the aircraft entered the cloud at 1916 GMT and exited from the cloud at 1920 GMT. The altitude on this and on the other passes was approximately 6500 meters.

Updraft/downdraft wind velocity data was derived from variometer readings, and according to Mr. Dennis J. Musil have an estimated error of 10% or 3 meters/sec, whichever is larger.

Values of the turbulence parameter were derived from recordings of dynamic pressure. The aircraft was flown with primary reference to attitude with little attention to altitude, in order to keep the airspeed relatively constant. The dynamic pressure was recorded two times per second in order to provide adequate resolution for calculating turbulence. The dynamic pressure measurements were processed to give values of the turbulent energy dissipation rate ε, which was derived from the fluctuation in the true air speed. For a further discussion of the derivation of the turbulent energy dissipation rate ε see Appendix C.

The radar precipitation echo was derived from the University of Miami radar data for an altitude of 1.0 km. Comparison with the KSC weather radar precipitation echo at 3 degrees elevation, showed close agreement.

The LDAR plot is a composite plot of all the LDAR activity that occurred during the transit of the aircraft through the thunderstorm.

Figure 1 shows that the LDAR activity occupies only a portion of the area enclosed by the radar precipitation echo. This is in accord with past observations (see Ref. 4). In general the precipitation echo is much larger than the LDAR area, showing that only selected portions of the clouds represented by the precipitation echo are electrified, as indicated by the LDAR response.

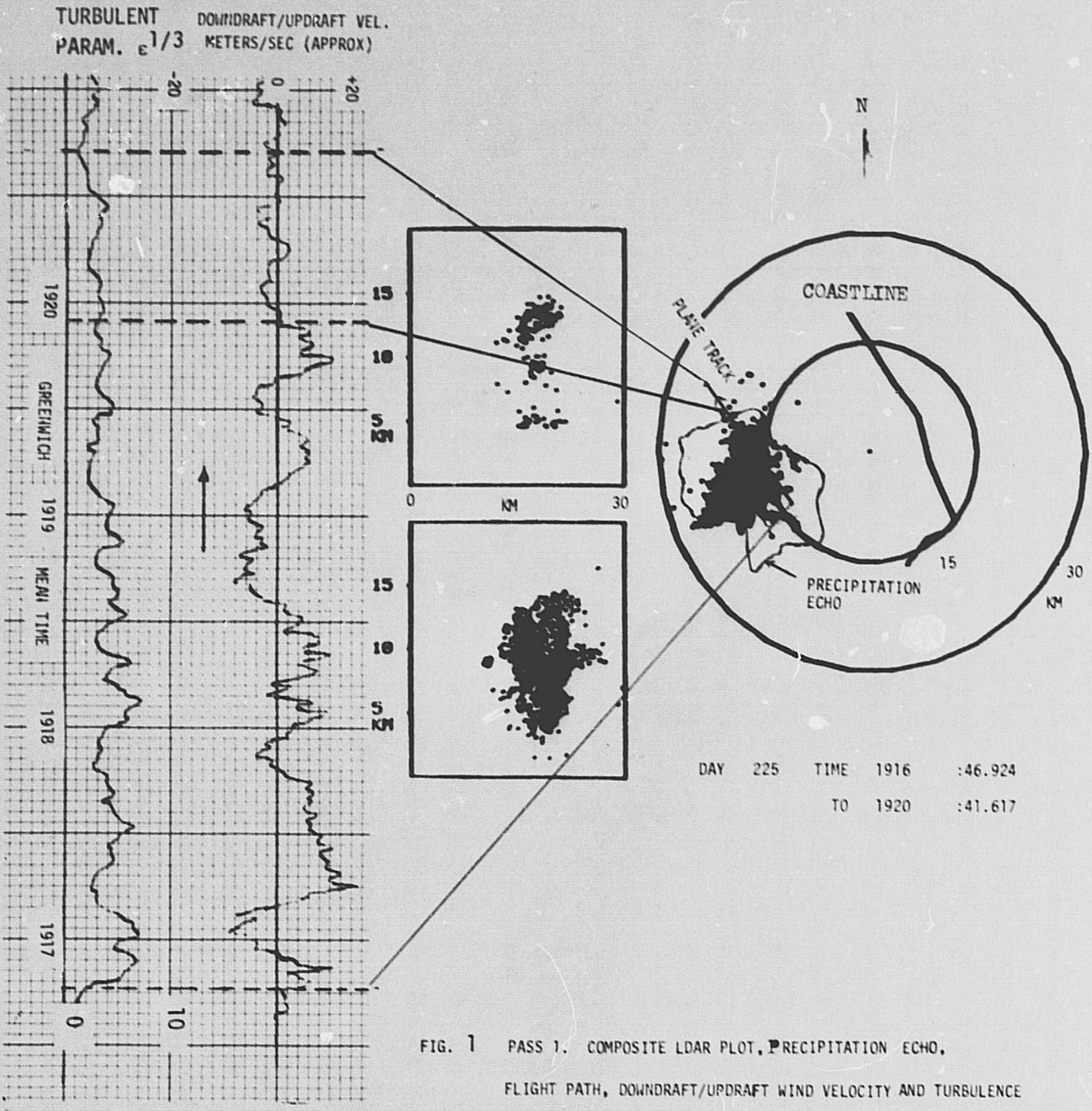

FIG. 1 PASS 1. COMPOSITE LDAR PLOT, PRECIPITATION ECHO, FLIGHT PATH, DOWNDRAFT/UPDRAFT WIND VELOCITY AND TURBULENCE

As the aircraft flies NW along its 21 km path through the region of LDAR activity, strong updrafts (up to 18 m/s, i.e. 40 mi/hr) are seen to alternate with downdrafts. The updrafts, separated by downdrafts, are interpreted as individual cells of the thunderstorm. In this, and in subsequent flights through the cloud on Day 225 the downdrafts are of lesser magnitude than the updrafts.

The turbulence parameter $\varepsilon^{1/3}$ also shows increased values for regions of marked LDAR activity. The changes in the turbulence parameter, however are less marked.

As the aircraft enters the LDAR-free area at 1919:50 GMT the updraft/downdraft activity subsides. The turbulent parameter values also become smaller.

The height plots at the left show electrical discharges occurring at heights of 2-14 km in the lower box (90-270 azimuth region, in this instance approximately the first half of the flight), and occurring at heights from 4 to 15 km in the upper box (270 to 90 degree region, or approximately the second half of the flight).

Note the difference in the height distribution of the LDAR activity on the two portions of the flight.

Each LDAR dot represents an electrical discharge in the atmosphere produced by the electrical breakdown of the air preceding and accompanying lightning activity. LDAR does not register the instantaneous ground strike, since the electromagnetic radiation during the ground strike occurs at much lower frequency (<10 MHz) than the 60-80 MHz input frequency range of the LDAR System. This, however, is a fine point of limited practical importance to lightning activity detection and warning since each ground strike is accompanied by 50 to 100 LDAR discharges within milliseconds of the ground strike.

The Ground Strike Location System (GSLS) (Ref. 4) makes use of the difference in the frequency of the radiated electromagnetic energy during ground strikes to detect and locate ground strikes. Using the same configuration of ground stations the Ground Strike Location System detects and processes the time of arrival of electromagnetic signals below 1 MHz to determine the location of ground strikes to a high degree of accuracy (better than 1%). See Ref. 4.

The vertical extent of the thunderstorm is illustrated in Figure 2 by the 1911 GMT, 213° Azimuth RHI plot recorded by the KSC radar, located at X= 600,572 Feet East and Y= 1,559,707 Feet North in the Florida East System, some 10 km NW of the LDAR. The indicated radar tops of 45 kft give an indication of the intensity of the storm, and, from reference to Figure 1, can be seen in excellent agreement with the 15 km height indicated by the LDAR.

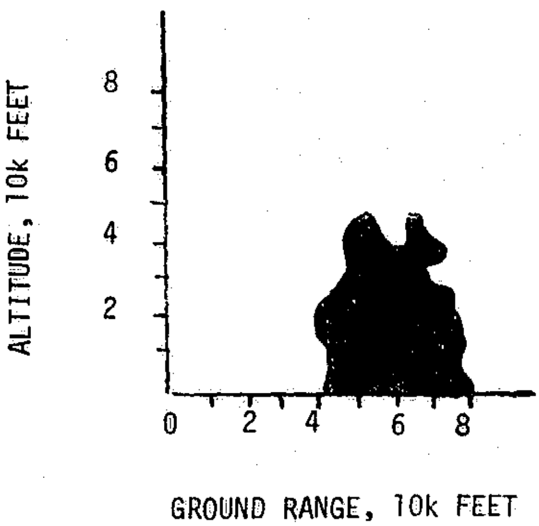

FIG. 2 RADAR RHI PLOT OF 1911 GMT
AZIMUTH 213°

Pass 5

Figure 3 shows the composite LDAR, flight path, updraft/downdraft, turbulent parameter plot for Pass 5. According to the pilot's log, he penetrated the cloud at 1949:50 and exited the cloud at 1953:09 GMT. The flight path is indicated on the LDAR plot, with an arrow showing the direction of flight.

Of particular interest is the absence of LDAR activity in the cloud traversed. This is further evidenced in the very small level of updraft/downdraft activity, and in the decrease in the turbulent parameter along the flight path.

Pass 6

Figure 4 shows the composite LDAR, flight path, updraft/downdraft, turbulent parameter plot for Pass 6. The flight track is from right to left, along the line indicated. The end points are keyed to the updraft/downdraft, turbulent parameter plots.

The distribution of LDAR dots show that the flight path is along the southern portion of a large, well-developed thunderstorm. The two peaks in the updraft velocity indicate presence of two thunderstorm cells in the flight path.

An increased updraft/downdraft activity and the turbulent parameter are evident in the passage through the storm. Comparison of Figure 4 with Figure 3 shows how well LDAR correlates with updraft/downdraft and turbulent parameter activity.

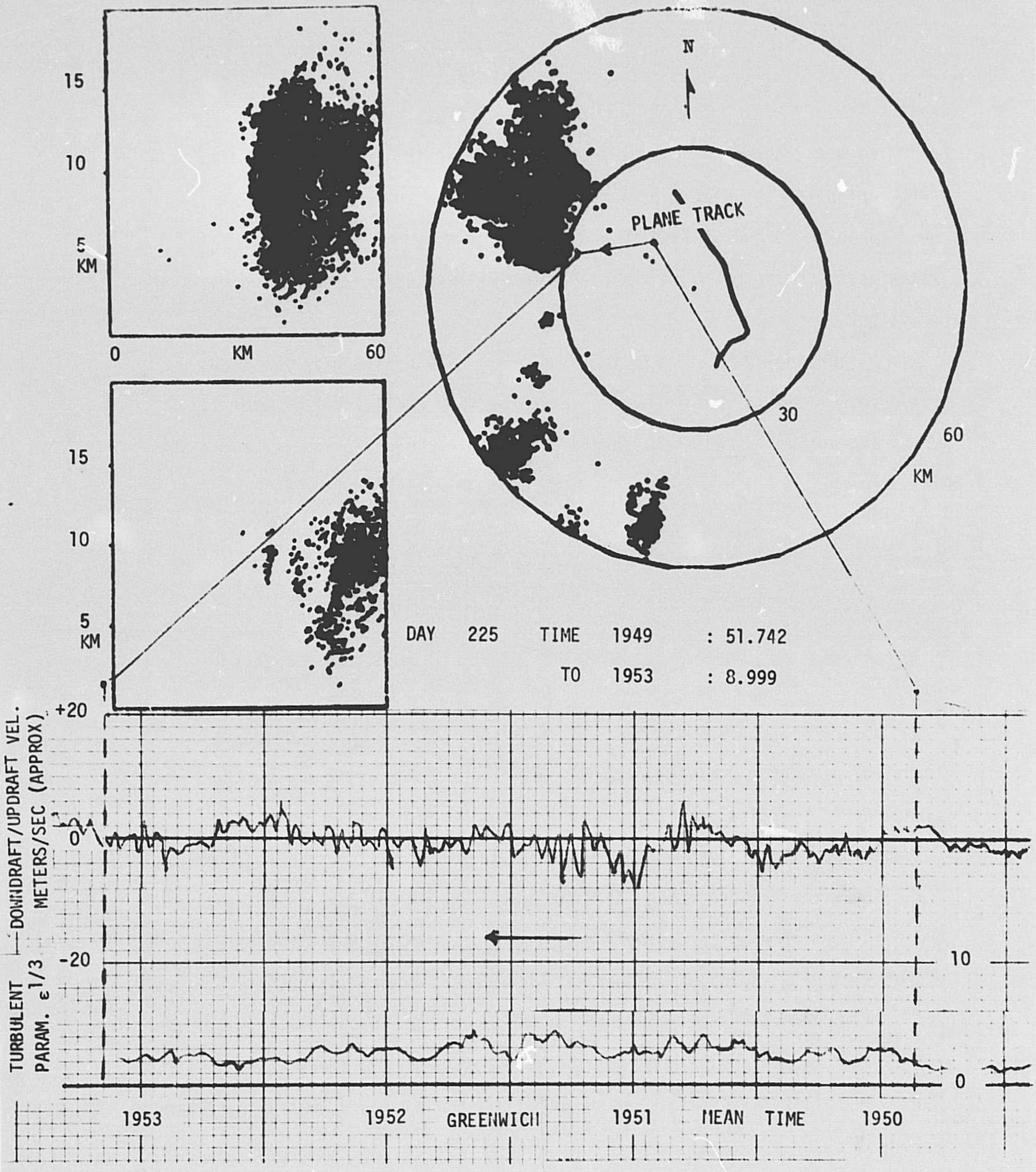

FIG. 3 PASS 5. COMPOSITE LDAR PLOT, FLIGHT PATH, DOWNDRAFT/UPDRAFT WIND VELOCITY, AND TURBULENCE

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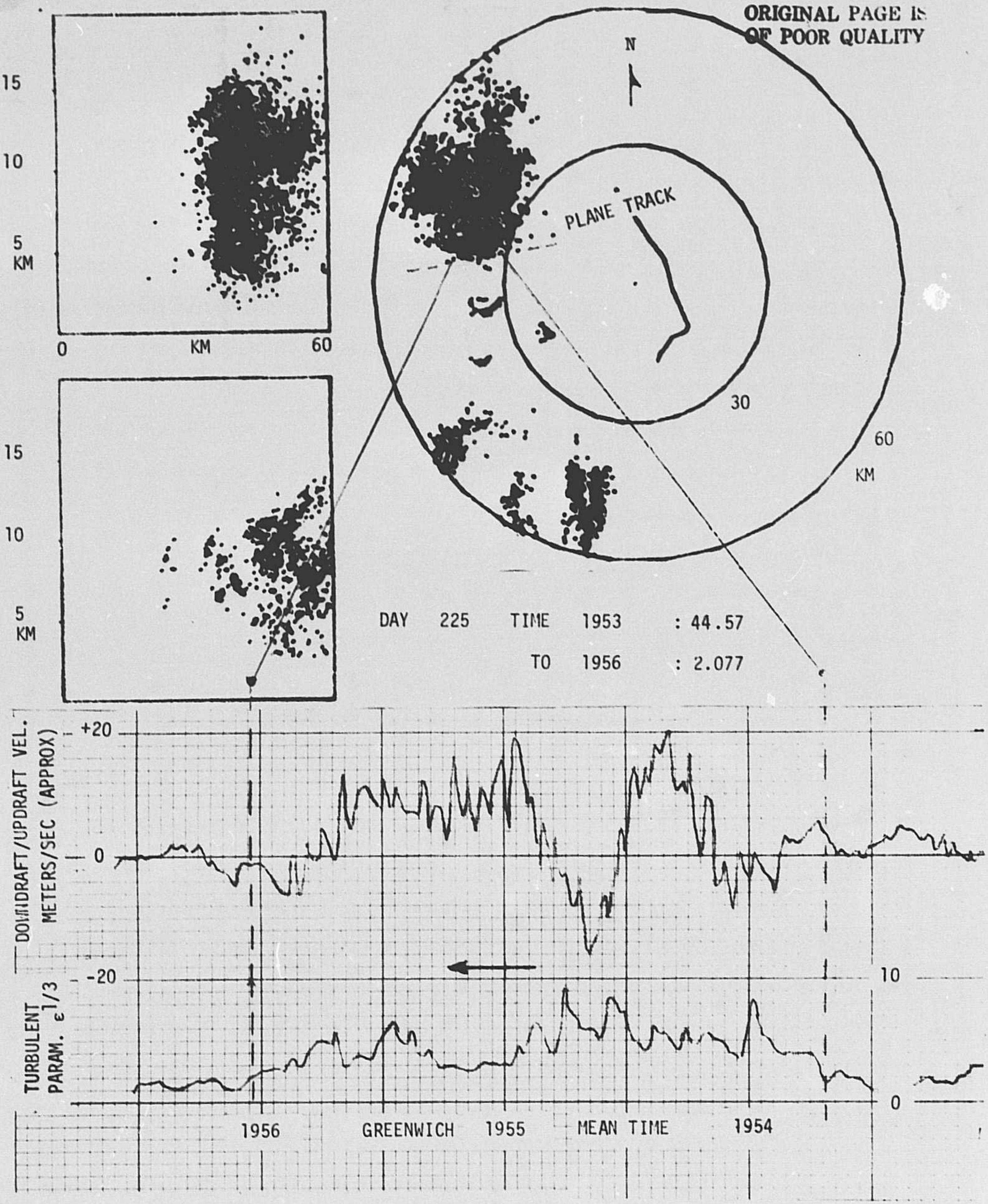

FIG. 4 PASS 6. COMPOSITE LDAR PLOT, FLIGHT PATH, DOWNDRAFT/UPDRAFT WIND VELOCITY, AND TURBULENCE

Pass 7

Figure 5 shows the composite LDAR,flight path, updraft/downdraft, turbulent parameter plot for Pass 7.

The aircraft has now reversed its flight path, flying through the cloud from west to east. The flight path is through the large thunderstorm indicated by LDAR, flying easterly through the bottom portion of the thunderstorm, somewhat further into the storm than on Pass 6. The increased updraft/downdraft activity and turbulent parameter reflect the deeper penetration.

The two peaks in the updraft are indicative of two cells of the thunderstorm. The highest value of updraft (29 meters/sec) indicated on any pass is registered on this pass, as one would expect from the increased penetration into the storm.

Voice tape recordings of the pilot's comments during Pass 7 were made available to us by Dennis J. Musil. The following exerpts are particularly appropriate:

1959:07 GMT Enter Cloud	2000:45 Updraft 2000 ft/min*
59:37 Going through moderate turbulence	:55 Lots of lightning
59:56 Flash	2001:00 Updraft 2000 ft/min*
2000:08 Flash	:09 Static burst
:29 Moderate turbulence; static	:37 Light flashes
:33 Flash	:38 Updraft 2000 ft/sec*
:37 Lots of lightning	:44 Updraft 3000 ft/sec*
:39 Updraft 1700 ft/min*	:56 Break out of cloud

The lightning flashes noted in the voice recordings have been entered in Fig. 5.

Pass 8

Figure 6 shows the composite LDAR, flight path, updraft/downdraft, turbulent parameter plot for Pass 8. According to the pilot's log, the cloud was penetrated 2002:39 and was exited at 2004:29 GMT. No voice comments on updrafts or flashes.

Clearly the cloud was not electrified and did not register any thunderstorm activity. The lack of updraft/downdraft activity coupled with the lack of LDAR activity shows how LDAR can be used to determine areas free of thunderstorm, updraft/downdraft and turbulent activity.

Data from this test indicates that "no LDAR response indicates lack of thunderstorm and updraft/downdraft activity as clearly as the presence of LDAR activity serves as a warning of thunderstorm and high updraft/downdraft activity."

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* Approximate

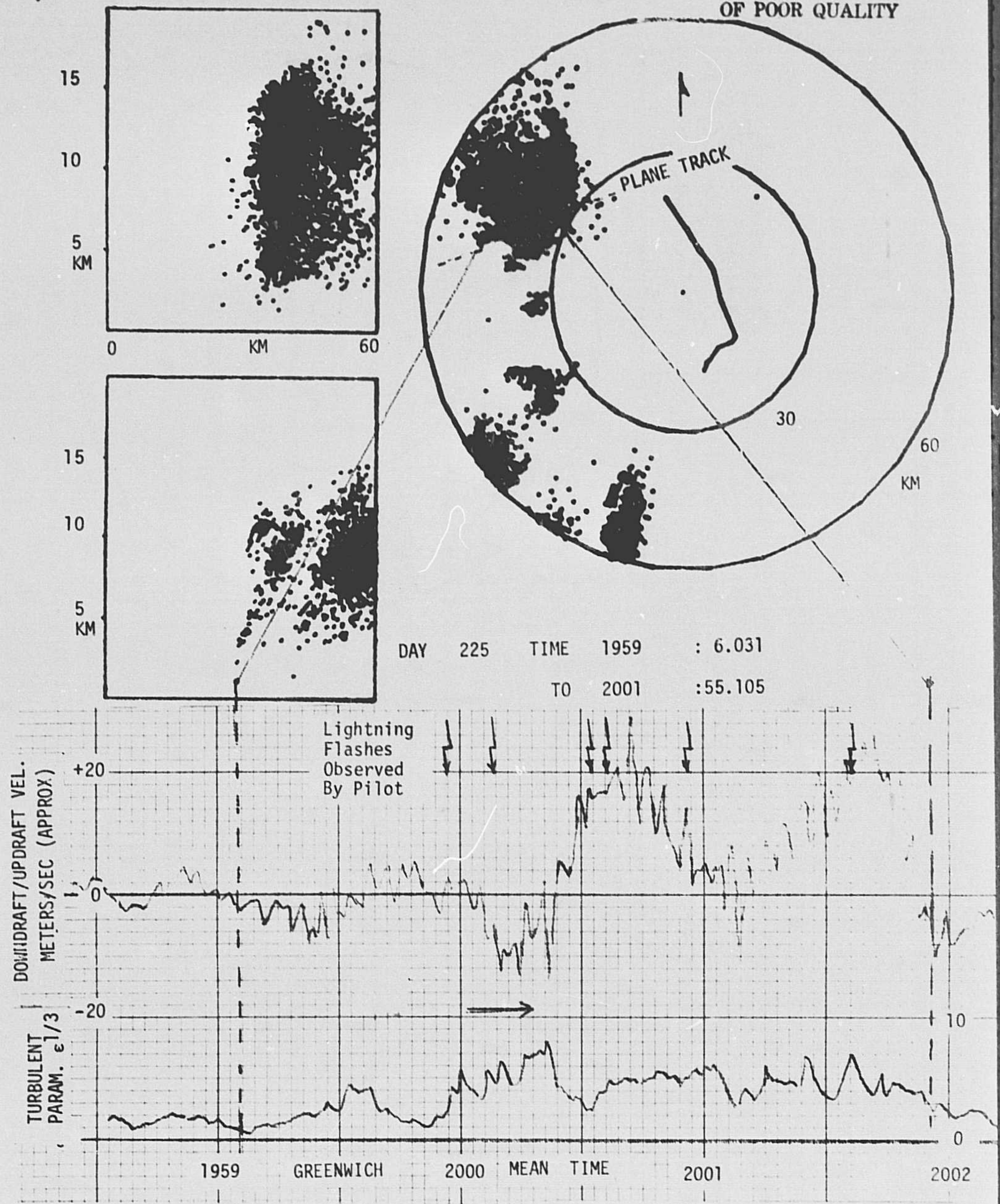

FIG. 5 PASS 7. COMPOSITE LDAR PLOT, FLIGHT PATH, DOWNDRAFT/UPDRAFT WIND VELOCITY AND TURBULEN

IV. CONCLUSIONS

1. Visual comparison of RAPCON radar echoes with LDAR plots of electrical activity gave excellent agreement. LDAR agreed in azimuth and range with the precipitation echo indicated on the RAPCON radar. In the absence of LDAR activity, the weather was observed to be either fair or consisting only of light precipitation.

2. Pilot's visual observations of lightning flashes at distances of 5 to 25 miles were in agreement with the areas of electrical activity indicated by the LDAR.

3. Detailed comparison of LDAR with KSC radars showed LDAR activity was present only over a portion of the precipitation echo. In general, only a portion of the precipitation echo corresponds to an electrified, thunderstorm cloud.

4. Airborne measurements of updraft and turbulent parameter by an armored T-28 aircraft penetrating thunderclouds near KSC established close agreement between the presence of LDAR and high updraft/downdraft activity and increased values of the turbulent parameter.

5. No LDAR response indicates a lack of thunderstorm and updraft/downdraft activity as clearly as the presence of LDAR activity serves as a warning of thunderstorm and high updraft/downdraft activity.

6. The excellent correlation of LDAR with thunderstorm and high updrafts reported herein, indicates that LDAR could serve as a useful adjunct to the FAA for air traffic control in the thunderstorm environment.

V. RECOMMENDATIONS

1. Improve display. Modify LDAR display so as to continuously update lightning events to always present a current display. New events will be presented in real-time as before. However, points older than five minutes will be removed, keeping the display updated. Removal of older data points will be controlled by the computer, and will be adjustable about the nominal 5 minutes. Current practice is to display all LDAR points until a fixed number (say 500) has been reached, at which point the data points are erased, and the cycle is repeated.

2. Develop a data interface so as to make it possible to present the LDAR lightning events on the same display currently used to display the targets (aircraft), thus reducing operator work load.

3. Dedicate a quality telephone line communications system to assure uninterrupted data flow from the central LDAR site to the desired FAA station. Modify the output data transmission to be compatible with telephone lines.

4. Continue the investigation of the correlation of LDAR with air motion fields inside developing thunderstorms as determined by the triple Doppler radar system operated by Dr. Roger M. Lhermitte of the University of Miami. Results of preliminary correlation are described in Ref. 9.

5. Continue operating the LDAR System to further explore its usefulness to FAA aircraft control problems.

VI. REFERENCES

1. Department of Transportation, Federal Aviation Administration, Washington, D.C., Interagency Agreement No. DOT-FA78WAT-900, April 28, 1978.

2. Department of the Air Force, Headquarters Air Force Communications Service Scott Air Force Base, Illinois, 62225, Memo of 24 April 1978 from FFNR (Major Peppler, 5436) to SCA/FFN, Subject: "Proposal by NASA to Install Remote Display Unit in Patrick RAPCON Facility (Yours Ltrs. 6 April 1978 and 13 April 1978".

3. FAA/NASA Test Plan, 29 June 1978, "FAA/NASA Test Plan Evaluating the Use of Remote Display of the Lightning Detection and Ranging (LDAR) System in the Patrick RAPCON".

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APPENDIX A

LDAR ACCURACY

The basic principles underlying the accuracy of the LDAR System were spelled out in "An Accuracy Analysis of the LDAR System" (Ref. 6). In this report it was shown that the use of a symmetrical Y configuration produces a uniformly low measurement error in all four quadrants. The x,y position accuracy is high within the baseline (10 km) of the system, with an error of less than 1%. At distances greater than the baseline length, the accuracy decreases with distance.

Angular position (azimuth) is the parameter that the LDAR System measures most precisely, typically with an error of less than 0.1 degree.

Because of the planar orientation of the LDAR receiving stations, height is measured with a lesser accuracy than azimuth or range. Height is measured most accurately above 1000 feet. Below 1000 feet the accuracy of the height measurement decreases.

A calibration of the LDAR System was conducted in 1978 by S-band radar beacon track of an airplane in all four quadrants of the LDAR System at 10,500 feet altitude, out to a range of 40 miles. The details of the calibration can be found in "S-Band Radar Calibration Test of the Lightning Detection and Ranging System (LDAR)" (Ref. 5). Calibration was made possible by mounting both an S-Band transponder and a lightning simulator on the airplane. Analysis of the data showed the error to be uniform in the four quadrants, and to be <0.5 degrees in azimuth, and <1% in range within the baseline (10 km) of the LDAR System. Outside the LDAR baseline, the range errors increased, as theory predicts. LDAR height calibration was not possible because of radar height instrumentation malfunction on this test. The pilots altitude log, however, showed the LDAR height error was less than 100 meters.

Recently the LDAR System was calibrated against a high precision Laser tracking system PLTS (Precision Laser Tracking System) that was at the Kennedy Space Center for calibration of the Space Shuttle's Microwave Scanning Beam Landing System, MSBLS. The PLTS system has a specification accuracy of better than 0.01 degree in azimuth, 0.01 degree in elevation, and ± 2 feet (0.003% at 65,000 feet) in range. An airplane, equipped with both a Laser retro-reflector and a lightning simulator, was simultaneously tracked by both the PLTS and the LDAR System, on flight through the four quadrants of the LDAR System, at elevations of 10,500 feet.

The Laser calibration tests showed that the LDAR System was indeed more accurate than had been indicated by the radar calibration tests. Comparison with the Laser Precision Tracking System showed the LDAR's azimuth to be within 0.1 degree, the range to be within 0.5%, and the height to be within 100 meters, for points within the 10 km baseline of the LDAR System.

APPENDIX B

EXCERPTS From RAPCON RADAR/LDAR LOG

		LDAR Lightning Location From COF n.m.		Radar Precipitation Area Location From COF n.m.		
Date	Time, Z	Degrees	Distance n.m.	Degrees	Distance n.m.	Remarks
7-17-78	1822	10-20	20-25	020	25-35	
7-17-78	1825	10-25	15-35	10-25	20-45	Altitude 8,000' +
7-17-78	1830	190-210	35-40	196-210	25-10	Altitude 8,000' +
7-17-78	1835	25-40	15-25	20-30	15-20	Altitude 9,000' +
7-17-78	1840	20-35	15-25	25-35	10-30	Altitude 8,000' + Very Intense
7-19-78	1729	300-360	10-25	280-360	10-25	Altitude 4,000' +
7-19-78	1735	290-360	10-25	290-360	10-25	Altitude 1,000' +
7-19-78	1738	210-345	8-30	220-360	5-30	Altitude 15,000' +
7-19-78	1752	250-350	5-25	245-355	5-25	Altitude 15,000' + Very Intense
7-19-78	1800	225-360	3-40	220-360	4-35	Altitude 15,000' +
7-19-78	1810	200-360	4-30	210-355	2-35	Altitude 10,000' + Very Intense
7-19-78	1820	195-360	3-35	220-360	4-35	Very Intense at KSC and MLB Extending SSW
7-19-78	1850	200-360	8-20	180-350	8-30	
7-19-78	1900	195-220	10-35	180-215	20-35	
7-19-78	1902	350-360	15-20	350-005	15-25	
7-19-78	1915	190-300	22-35	180-270	20-40	Very Intense SSW
7-27-78	1837	300-310	15	300-310	15	TSTMS Extending SW TO NW
7-27-78	1840	260-265	15	265	15	
7-27-78	1845	300-330	10-20	310-390	10-25	Discharges Extensive 220° to 330°, 15 to 400
7-27-78	1855	325	10-15	320-330	8-15	Cloud to Ground @ TICO Precipitations Extensive SW TO NE
7-27-78	1910	330-350	12-20	320-355	5-25	Mod. Intensity
7-27-78	1930	Lightning Disipitated				
7-28-78	1800	No Precipitation or Electrical Discharges Within 30 N.M.				
8-02-78		No LDAR Display, No Precipitation Areas				
8-03-78		No LDAR Display, No Isolated Precipitation Areas				
8-04-78		No LDAR Display, No Isolated Precipitation Areas				
8-14-78		No LDAR Display and Very Little Precipatation				

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APPENDIX C

CALCULATION OF TURBULENT ENERGY DISSIPATION RATE (From Ref. 7)

The turbulent energy dissipation rate ε is derived from fluctuations in true air speed, TAS. The TAS values within each sample are determined by correcting the indicated air speed with average temperature and pressure for the entire penetration. The TAS is then expressed as a Fourier series over a time period, T, of 8 seconds, with two samples of airspeed per second. The Fourier transform yields an average TAS, A_o, and the coefficients of the first eight frequencies, A_n and B_n. The spectral energy E, per gram of air of the airflow at wavenumber k for a unit wavenumber bandpass is expressed by

$$E_k = 1/2(A_n^2 + B_n^2) A_oT$$

where the wavenumber k is determined by the expression

$$k = n/A_oT$$

The equation relating the turbulent energy dissipation rate ε to spectral energy is given by

$$\varepsilon = ([E_k k^{5/3}]/0.15)^{3/2}$$

A point value of ε can then be determined by averaging the values of ε for the eight wavenumbers available.

APPENDIX D

EXTENDED RANGE OF THE LDAR SYSTEM

The intensity of the radiation plus the extreme height at which impulsive radiations originate in thunderstorms make possible operating ranges in excess of the 6 mile baseline of the LDAR System. At the same time, the line-of-sight propagation of the high frequencies at which the LDAR operates, eliminates over-the-horizon response which is not desired.

While the accuracy of the LDAR System decreases as we go out many multiples of the baseline, quite usable data can still be obtained at distances out as far as 110 nm, at least at the operating frequencies of 30-40 MHz at which the LDAR System was operated when the data of Figures 2A and 4A were taken.

The available GEOS satellite infrared photographs (Ref. 8) provide useful information for identifying thunderstorms, since the tops of the thunderstorms present the coolest temperatures, which show up as black centers in the photograph, surrounded by lighter (warmer) areas.

In Figure 1A we present an 1831 GMT GOES infra-red photograph of the state of Florida, taken on July 19, 1977. Three thunderstorms are visible in the center of the state, slightly NW, W, and slightly SW of the Kennedy Space Center. The tops of the thunderstorms appear as black areas, surrounded by white.

For comparison the LDAR plot of 1831 GMT is shown in Figure 2A. Remarkable agreement is evident.

A more distant thunderstorm, one just off the west coast of Florida at Tampa (some 110n.m. from the Kenndedy Space Center) at 2031 GMT July 19, 1977, is shown in Figure 3A. The corresponding LDAR plot of 2032 GMT, Figure 4A shows remarkable agreement, and illustrates the extended range capability of the LDAR System.

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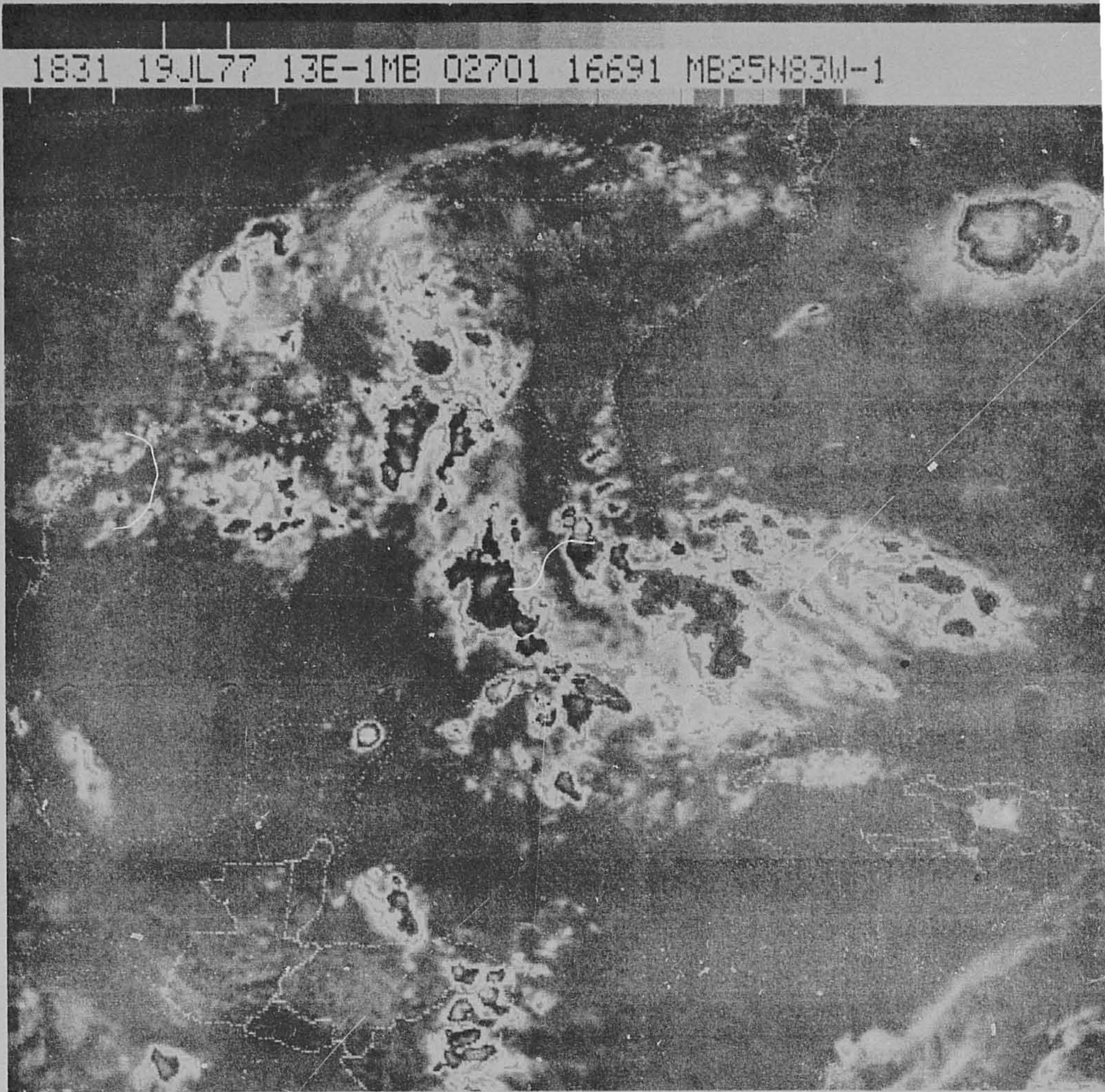

FIG. 1A INFRA RED, GOES SATELLITE PICTURE OF FLORIDA, SHOWING THUNDERSTORMS NEAR ORLANDO, JULY 19, 1977, Day 200 1831 GMT

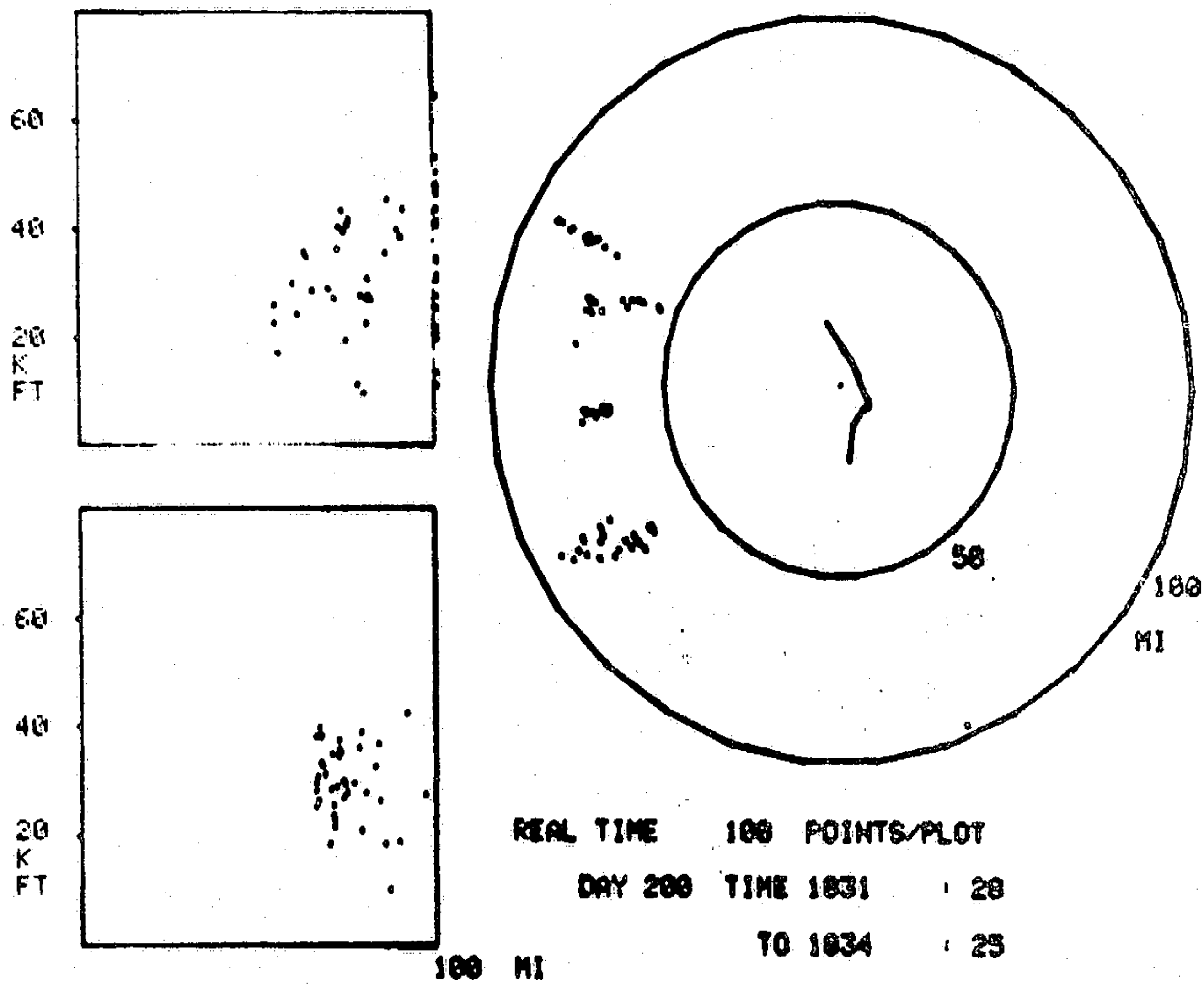

FIG. 2A MATCHING LDAR PLOT, INDICATING THUNDERSTORM ACTIVITY, DAY 200, 1831-1834 GMT

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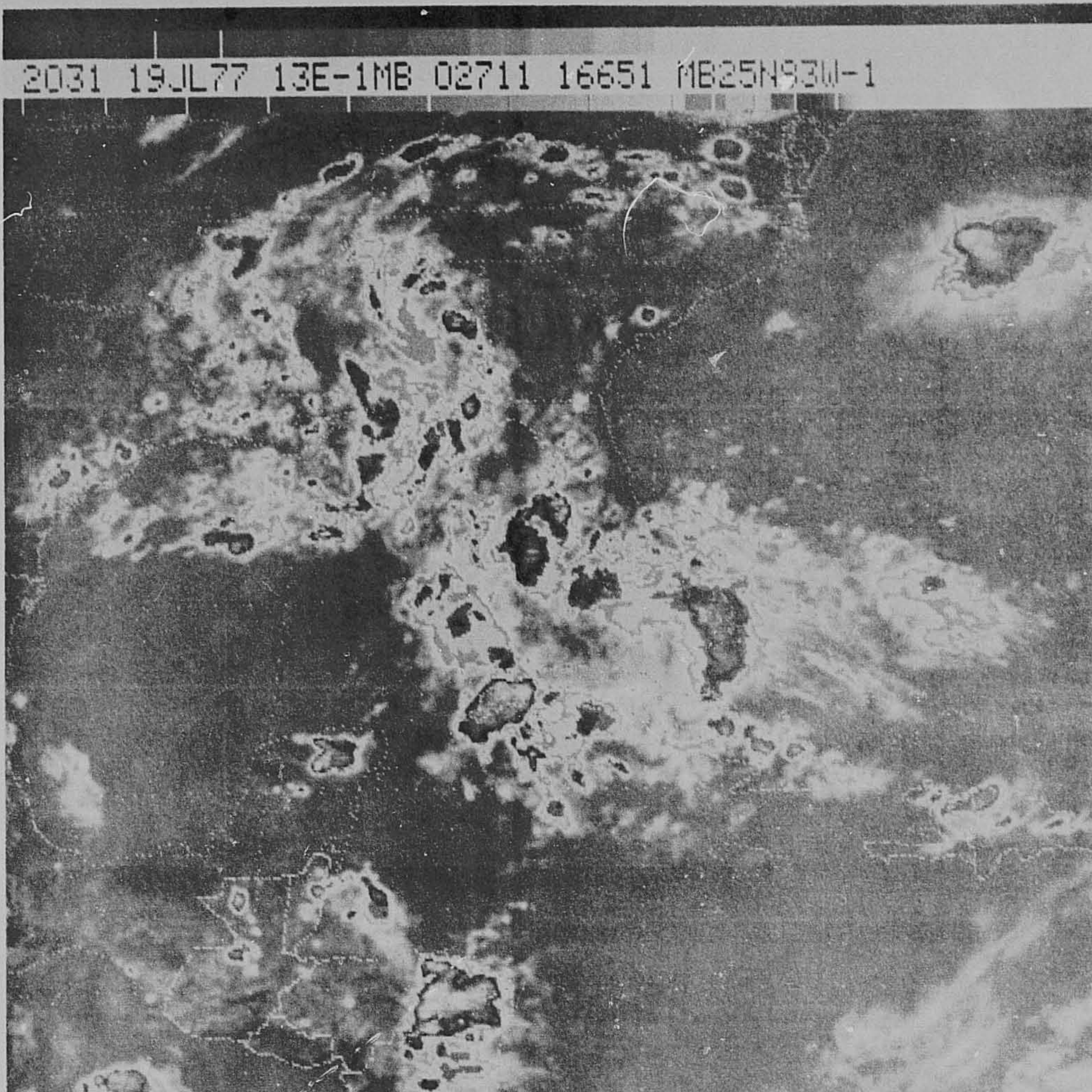

FIG. 3A INFRA RED, GOES SATELLITE PICTURE OF FLORIDA,
SHOWING THUNDERSTORMS NEAR TAMPA,
JULY 19, 1977, DAY 200, 2031 GMT

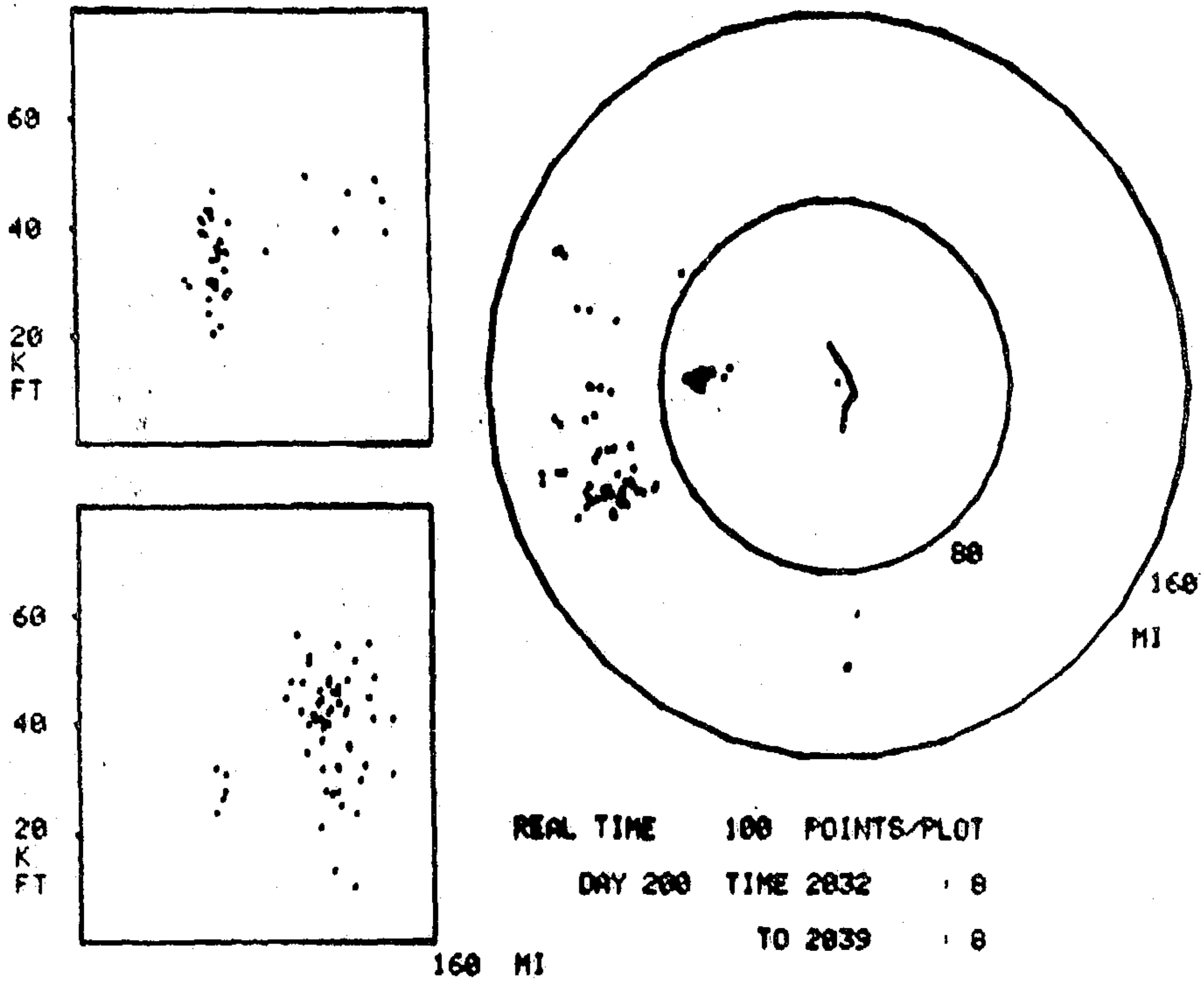

FIG. 4A MATCHING LDAR PLOT INDICATING THUNDERSTORM ACTIVITY, DAY 200, 2032-2039 GMT