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T-28 PARTICIPATION IN THE 1989 PRECIPITATION AUGMENTATION FOR CROPS EXPERIMENT IN ILLINOIS

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1. INTRODUCTION

This is the summary report of convective storm observations conducted with the armored T-28 aircraft facility operated by the Institute of Atmospheric Sciences (IAS) of the South Dakota School of Mines and Technology (SDSM&T) for the 1989 Precipitation Augmentation for Crops Experiment (PACE). The IAS used the aircraft to make penetrations of Illinois convective storms while participating in the PACE cloud seeding research experiments conducted by the Illinois State Water Survey (ISWS) during the spring of 1989. Funding for the T-28 operations was provided through the Federal/State Cooperative Program by the Desert Research Institute under Purchase Order BPO-190,423.

The purpose of the T-28 investigation was to obtain a data set from penetrations of cloud regions not normally accessible to conventional research aircraft. The emphasis was on microphysical observations, but supporting thermodynamic, kinematic, and electrification data were also obtained. These data will aid in the determination of possible seeding effects upon mature convective storms in the PACE region, as well as provide information about the precipitation mechanism applicable in Illinois thunderstorms.

The support for the T-28 in PACE provided for the flight operations and preliminary reduction of the data. This report is limited to a discussion of the field project activities and an overview and assessment of the quality of the data that were gathered. The actual data, including plots and other products, are being furnished directly to the ISWS for use in their PACE research studies.

2. DESCRIPTION OF THE T-28 SYSTEM

The T-28 system and its basic instrumentation complement are described by Johnson and Smith (1980) and IAS Bulletin 89-1 (1989). The aircraft is equipped for measurement of a variety of cloud microphysics and state variables, as well as navigation and aircraft performance variables (Table 1). Included in the instrumentation configuration for the first time were four electric field mills borrowed from the New Mexico Institute of Mining and Technology and the National Center for Atmospheric Research. After-the-fact determinations of numerous variables are possible, including such things as vertical winds, turbulence intensities, and equivalent potential temperature.

A new data acquisition system was installed early in 1989. The system is based on an IBM PC-AT-compatible industrial grade microcomputer, with 32 analog input channels, and uses 16-bit analog-to-digital converters. There are interfaces to accept digital data from the hail spectrometer, one PMS FSSP or 1-D probe, and one PMS 2-D imaging probe. Data are stored on a 40-MB streaming tape cartridge. The basic recording rate is once per second, but the option exists to sample selected variables at higher frequencies. The pilot can enter event codes and has the capability to re-boot the data system in flight should a failure occur.

Armoring of critical parts of the aircraft permits routine penetrations into regions of thunderstorms where the equivalent radar reflectivity factor is at or below 55 dBz. For safety and accuracy, the T-28 storm penetrations are directed from the ground, which requires real time knowledge of the aircraft location in relation to the storm echoes. Access to a quantitative weather radar with aircraft flight track information incorporated into the display provides the means to meet these needs. This was accomplished in the PACE work by using the CHILL radar with flight track data transmitted over telephone lines from the FAA Air Route Surveillance Radar located at Hanna City (~10 n mi west of Peoria).

T-28 PACE project personnel are as follows:

Paul L. Smith -- Facility Manager.

Dennis J. Musil -- Project Meteorologist.

Andy Detwiler -- T-28 Facility Scientist.

Ken Hartman -- Computer Programmer.

Jon Leigh -- Aircraft Mechanic.

Gary Johnson -- Electrical Engineer.

Daniel Custis -- T-28 Pilot.

TABLE 1

T-28 Equipment Used in PACE

VARIABLE	INSTRUMENT	RANGE	ACCURACY	RESOLUTION (as recorded)	NOTES
STATIC PRESSURE	ROSEMOUNT 1301-A-4B	0-15 psi (0-103 kPa)	±.015 psi (±0.1 kPa)	0.0002 psi (0.002 kPa)	• Bench calibration, 3/89
	ROSEMOUNT 1301-A-4B	5-15 psi (35-105 kPa)	±.015 psi (±0.1 kPa)	0.0002 psi (0.002 kPa)	• Bench calibration, 3/89
TOTAL TEMPERATURE	ROSEMOUNT 102AU2AP	-30 - +30°C	±0.5°C	0.001°C	• Platinum wire • ~2 sec time constant
	NCAR REVERSE FLOW	-30 - +30°C	±0.5°C	0.001°C	• Diode • Several sec time constant • Bench calibration, 3/89 • Recovery factor adjusted, 5/89
CLOUD WATER AND CLOUD DROPLETS	JOHNSON-WILLIAMS LIQUID WATER CONTENT	0 - 6 g/m³	±10%	0.0001 g/m³	• Accurate if all droplets have d <30 μm
	PARTICLE MEASURING SYSTEMS, INC. FORWARD SCATTERING SPECTROMETER PROBE	Size ~1 < 57 μm Concentration 0 - ~2000 droplets/cm³	±1 size channel in size and ±1% in concentrations at ~50/cm³	1 size channel	• 15 discrete size channels spread over an adjustable range • Sampling rate 300 cm³/km • Accuracy of computed liquid water contents ~±20%. Depends on processing.
PRECIPITATION PARTICLE SIZES AND CONCENTRATIONS	WILLIAMSON FOIL IMPACTOR	1 - 20 mm	0.2 mm	0.2 mm	• Sampling rate 1.4 m³/km
	PARTICLE MEASURING SYSTEMS, INC. 2-D Cloud Probe	Size 30 - 1000 μm	±30 μm	30 μm	• Computed ice and water contents can vary ±50% with processing technique • Sampling rate: 0.1 m³/km; DAS can accept ~250 particles/sec (2500/km)
AIRCRAFT MOTION	NCAR TRUE AIRSPEED COMPUTER	0 - 250 kts (0 - 130 m/s)	±3 kts (±1.5 m/s)	0.125 kt (0.07 m/s)	• True airspeed
	HUMPHREY SA09-D0101-1 VERTICALLY STABLILIZED ACCELEROMETER	-1 to +3 g's pitch -50° to +50° roll -50° to +50°	0.004 g 0.2° 0.2°	0.00006 g 0.002° 0.002°	
	ROSEMOUNT 1301-0-1B DYNAMIC PRESSURE	-3 to +3 psi (-20 to +20 kPa)	±0.1%	0.0001 psi (0.0006 kPa)	• Indicated airspeed • Bench calibration, 3/89
	ROSEMOUNT 1221-F-2A DYNAMIC PRESSURE	-2.5 to +2.5 psi (-18 to +18 kPa)	±0.1%	0.0001 psi (0.0006 kPa)	• Indicated airspeed • Bench calibration, 3/89
	GIANNINI 45218YE MANIFOLD PRESSURE	0 to 50 in Hg (0 to 169 kPa)	±2%	0.0008 in Hg (0.003 kPa)	• Used in one vertical velocity calculation • Bench calibration, 3/89
	BALL ENGINEERING 101A VARIOMETER	-6000 to +6000 ft/min (-30 to +30 m/sec)	±200 ft/min (±1 m/sec)	0.2 ft/min (0.001 m/sec)	
AIRCRAFT LOCATION	NARCO NAV-122 VOR	0 - 360°	±2°	0.005°	
	CESSNA 400 DME	0 - 100 nmi (0 - 185 km)	0.1 nmi (185 m)	0.002 nmi (3 m)	• Maximum 2 sec to lock on and acquire range

NOTE: Many of these instruments do not behave as ideal instruments. The use of one measure of accuracy over the entire range of measurement is, in many cases, questionable. An accuracy representative of the most useful part of the range is given here.

3. DESCRIPTION OF PACE

The Precipitation Augmentation for Crops Experiment (PACE) is a meteorological experiment designed to test the hypothesis that cloud seeding can make rain clouds grow bigger and/or last longer, in order to process more water, thereby producing more rain. The study area for the project includes approximately a 100-mile radius from Willard Airport at Champaign, Illinois (Fig. 1). The primary goal of the project is to determine if a scientifically sound way exists to enhance summer rainfall amounts, primarily for the benefit of agriculture in the region.

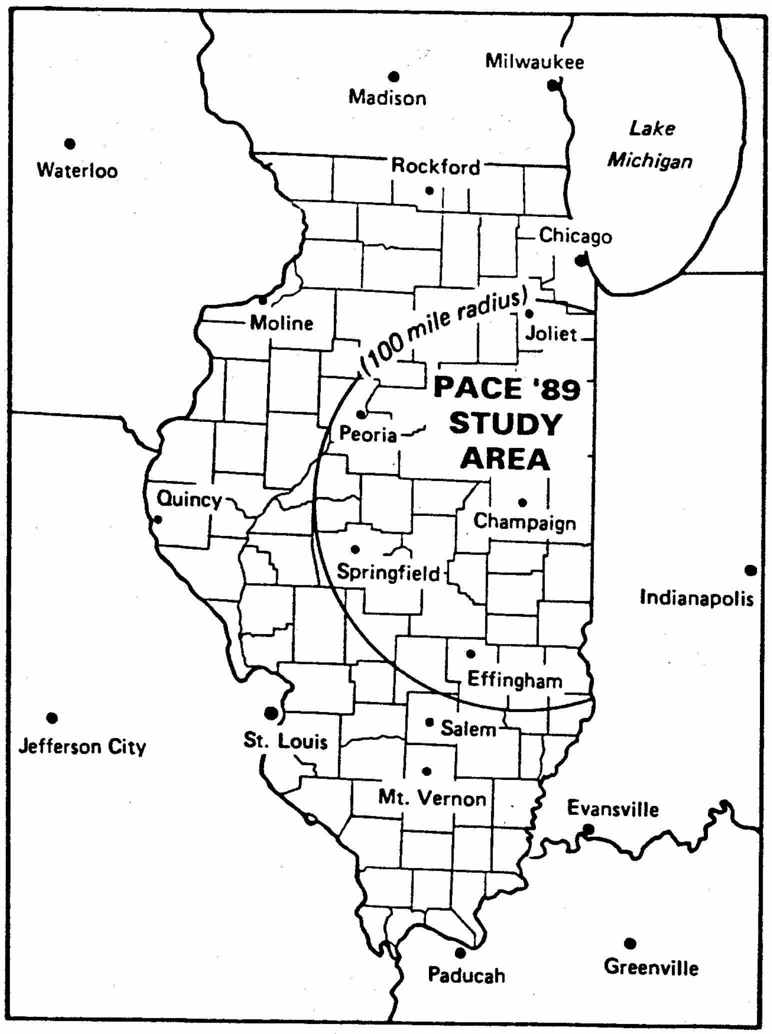

Fig. 1: Project study area for PACE.

A twin engine Beechcraft Baron was available for the delivery of seeding materials and research measurements for the duration of the 1989 PACE operations. The armored T-28 aircraft was used for the penetration of mature storms and was available for a three-week period in May 1989. Both aircraft had similar instrumentation packages, except that the Baron could measure dewpoint, had a PMS 2D-P probe (in addition to a 2D-C), and had an angle-of-attack device in a nose boom.

In addition to the aircraft, a forecasting/nowcasting service was provided by personnel of the Illinois State Water Survey. This included the basic weather data provided from Zephyr Weather Service, satellite imagery obtained by a telephone link to the Man-Computer Interactive Data Access System (MCIDAS) at the University of Wisconsin, and a Cross-chain Loran Atmospheric Sounding System (CLASS) at the airport.

Various flight plans were developed for the two aircraft (some in coordination with each other) and are outlined in the PACE Operations Manual (Changnon et al., 1989a) and the PACE Final Report (Changnon et al., 1989b). Basically, the aircraft filed to some predetermined way point, after which penetrations were carried out singly by the T-28 or as a coordinated effort with the Beechcraft Baron. In the coordinated missions, the Baron first made a treatment penetration of a suitable cloud. This was followed by T-28 penetrations, while the Baron flew a safe distance away from that region, while searching for a second case. When the system could no longer be penetrated, a new candidate was to be selected, time permitting. On other occasions, the T-28 was to make solo penetrations of clouds and thunderstorms to collect additional data to help characterize the basic precipitation processes in them. Other flight plans called for the Baron to operate alone.

4. SUMMARY OF FLIGHT OPERATIONS

A summary of T-28 flight activity is given in Table 2. Suitable flying weather was infrequent, and only 3 research flights occurred during the short three-week period of T-28 participation in PACE. There were several additional instrumentation and procedural test flights.

The storms penetrated by the T-28 in PACE were characterized by cells with relatively weak dynamics and embedded in generally overcast conditions. However, Flight 503 on 25 May had numerous hailstones of the order of 1 cm diameter or larger and relatively large amounts of cloud liquid water over several kilometers of flight path during the second penetration. A synopsis of each day's research flight operation is given as follows:

<u>24 May</u>

Takeoff: 1632[1]
Landing: 1821

Twelve penetrations were accomplished in three separate clouds approximately 40-60 nautical miles west of Champaign. The convective cells were embedded in an overcast condition and were consequently very difficult to work. The first two clouds were penetrated at temperatures of about -10°C; the last at 0°C. The clouds were weak and lacked organization, although they did exhibit a short life cycle. Subsequent examination of the data confirmed the weak updrafts and a scarcity of precipitation-sized hydrometeors. A visual inspection of 2D-C particle images shows that they tended to come in clusters of the same general shape and size, lasting for several seconds or more. This suggests that the coherent volumes present in the cloud had similar evolutionary history, separated from other volumes with different histories. Some penetrations indicated maximum updrafts near 10 m s^{-1}. There was no seeding on this flight as the Baron was down for equipment repairs on this day.

<u>25 May</u>

Takeoff: 1519

Landing: 1605

This flight provided some of the best data of the project for the T-28, even though only two penetrations were made in a developing storm about 40 nautical miles southwest of Champaign. Cells on this day were again embedded and visibility in the region at flight level was very bad. Development of the storm after the T-28 penetrations included an overhang, very high reflectivities (up to about 70 dBz), and large hail.

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[1]All times are given as Central Daylight Time.

TABLE 2

T-28 Flight Summary Precipitation Augmentation
Crops Experiment, Champaign, Illinois -- 1989

DATE	FLIGHT	---TIMES (CDT)---- TAKE OFF	LANDING	(HRS) FLIGHT DURATION*	REMARKS
5 May	493			1.0	Equipment Test at RAP.
8 May	494			0.5	Abort - Communications probs.
8 May	495			2.5	Ferry RAP to DSM.
8 May	496			1.5	Ferry DSM to CMI.
10 May	497			1.4	Equipment test flight.
12 May	498			1.3	Intercomparison with Baron.
17 May	499			1.9	Tracking test.
18 May	500			0.7	Equipment Repair at Bloomington, Illinois.
20 May	501			0.7	Return from Bloomington.
24 May	502	16:32	18:21	2.2	Research.
25 May	503	15:19	16:05	1.0	Research.
30 May	504	09:08	10:55	2.5	Research.
31 May	505			1.5	Ferry CMI to IRK (generator failure).
1 Jun	506			1.1	Ferry IRK to Clarinda, Iowa (engine problems).
3 Jun	507			1.6	Ferry Clarinda, Iowa, to MHE.
3 June	508			1.6	Ferry MHE to RAP.
Total				23.0	

*"Flight duration" includes taxi time, engine run up, etc.

The high reflectivities were just beginning during the second penetration and had reached the T-28 limit of 55 dBz as the aircraft passed through or near the eastern edge of the organizing mass while traveling northeast in a southwest-northeast oriented line. Moderate updrafts of approximately 10 m s^{-1}, high concentrations of large hydrometeors on the foil impactor, numerous smaller particles imaged by the 2D-C, as well as ample amounts of cloud liquid, were encountered on the second penetration. The measured values of cloud liquid water concentration probably represent about 40-50% of adiabatic values, but more detailed analysis is needed to determine a more exact ratio. This was a vigorous storm and it is possible that the strongest draft regions were not penetrated, although distinct features in the radar reflectivity that might indicate stronger updrafts were not visible at the time of the operation.

The first penetration was accomplished about 3 n mi east of the second penetration track in a southwesterly direction in advance of the storm, and exhibited relatively weaker conditions. Both penetrations were made near the 0°C level.

Equipment problems developed during the second penetration, including questionable position keeping, and a decision was made to return to base for safety reasons. This was just barely accomplished before heavy rain from the system reached the airport at Champaign. The Baron was not involved in this mission because of the strength of the storms.

30 May

Takeoff: 0908
Landing: 1055

Seven penetrations were accomplished in two separate clouds in a coordinated mission between the T-28 and the Baron. The clouds were relatively weak and again difficult to work because of the general overcast conditions. This made it difficult to identify discrete towers for a long period of time. Nevertheless, two clouds were treated, followed by post-treatment penetrations by the T-28; the first set was made near -10°C and the second near -7°C. Updrafts were generally < 5 m s^{-1} and cloud liquid mostly $\leqslant 0.5$ g m^{-3}. Very high concentrations of particles between about 50 μm and a few mm in size were found in the first cloud penetrated. The concentrations were the highest observed by the T-28 during its participation in PACE. These data should provide a preliminary look at possible seeding effects.

5. DATA SUMMARY

An overview of the data collected on the three research flights is given by cloud penetration in Table 3. The table is organized by date and penetration, giving times, locations, and values for selected variables characterizing each penetration.

The cloud penetration times were established according to the following priority:

(1) Pilot-activated in/out marker switch;

(2) Pilot notes;

(3) Ground controller notes; and

(4) FSSP droplet concentrations.

The values for azimuth, range, and heading are based upon FAA position information from each penetration. Equivalent potential temperature (Theta E) was computed from static pressure and reverse flow temperature observations assuming saturation with respect to liquid water. The values for pressure altitude, temperature, vertical wind velocity, and the hydrometeors are all maximum 1-sec averages from each penetration, unless indicated as a minimum (1 sec) in the table. The hydrometeor types from the 2D-C images represent a rough characterization of the predominant particle type sampled during each penetration. That characterization is given by:

g: graupel;

rs: rimed snow (not quite graupel);

sd: shed drops (artifacts);

tiny: too small to characterize; and

d: drops.

The last two columns give the maximum positive and strongest negative potential gradients observed during each penetration. Positive values indicate a positive charge overhead and/or a negative charge underneath the aircraft.

The static pressure sensor was somewhat noisy during the T-28 participation in PACE. This results in rather erratic vertical velocity values, but, in general, the data are usable for vertical wind velocity computations. In Flight 502 (24 May), the pressure noise tended to be minimized during the cloud penetrations. The Forward Scattering Spectrometer Probe (FSSP) liquid water concentration (LWC) values tend to be greater than the Johnson-Williams (JW) values for LWC ≤ 1 g m^{-3}, while at LWC > 1 g m^{-3}, the JW tends to give larger values than the FSSP. It is not known with certainty which is more correct.

TABLE 3

Summary of T-28 Cloud Penetration Data

Date	Flt	Pen	TIMES Beg	TIMES End	INITIAL POSITION az (true)	INITIAL POSITION rng (km)	hdg (true)	length (km)	altitude (m MSL)	TEMPERATURE env (C)	TEMPERATURE max (C)	TEMPERATURE min (C)
24 May	502											
		1	170330	170600	280.6	104.9	335	12.5	5513	-11.3	-10.2	-11.5
		2	170810	170951	283.8	121.6	266	9.0	5528	-10.7	-8.5	-12.3
		3	171144	171351	283.5	125.1	47	16.0	5563	-11.0	-9.0	-11.8
		4	171524	171737	289.2	118.0	194	12.5	5580	-11.3	-10.6	-12.5
		5	171950	172251	284.1	114.0	19	20.2	5535	-10.5	-8.6	-13.2
		6	172555	172823	295.8	113.8	185	16.0	5480	-11.0	-9.3	-12.5
		7	173118	173435	286.3	103.0	20	22.3	5445	-10.0	-8.5	-13.5
		8	173700	173910	298.2	105.9	184	14.1	5490	-10.5	-7.0	-12.0
		9	174730	174921	291.0	95.9	29	13.7	4350	*	*	*
		10	175400	175500	299.5	88.3	107	10.6	4143	1.2	2.1	0.0
		11	175631	180003	301.4	79.6	321	18.3	4328	-0.5	0.3	-1.5
		12	180234	180442	303.5	88.0	107	15.4	4343	-2.0	0.8	-2.0
25 May	503											
		1	154344	154530	229.7	80.2	265	7.6	4095	0.8	2	-0.4
		2	154735	155457	235.1	83.5	57	56.0	4120	0.3	1	-1.7
30 May	504											
		1	93929	94402	285.3	96.5	329	24.3	5530	-8.7	-7.8	-10.1
		2	94510	94717	294.4	110.2	145	13.0	5740	-9.4	-9.2	-10.5
		3	95148	95528	290.3	99.5	21	20.9	5725	-9.5	-8.9	-11.1
		4	95853	100141	299.1	98.9	197	14.2	6093	*	*	*
		5	100339	100523	293.2	91.6	29	14.5	6315	-14.5	-13.8	-15.4
		6	101949	102049	299.0	92.0	347	8.0	5205	-6.2	-6.0	-7.7
		7	102315	102404	304.8	94.9	230	4.4	5315	-6.9	-6.3	-8.5

*Penetration made in ascending/descending mode.

TABLE 3 (continued)

Theta E max (K)	VERTICAL VELOCITY max (m/s)	VERTICAL VELOCITY min (m/s)	JW max (g/m³)	FSSP max (g/m³)	FSSP conc (cm⁻³)	2D-C conc (l⁻¹)	2D-C d max (μm)	2D-C type	POTENTIAL GRADIENT max (kV/m)	POTENTIAL GRADIENT min (kV/m)
330	10	-6	<0.1	<0.1	125	34	3000	g,rs	46	-3
334	6	-10	0.5	0.7	520	24	2400	g	0	0
334	6	-6	0.4	0.7	475	64	3100	g	0	-45
331	10	-12	0.2	0.6	360	40	3500	g	0	-87
335	10	-10	0.4	0.8	545	53	4700	g,rs	0	-132
332	7	-8	0.7	0.7	435	46	5000	g	0	-97
331	6	-7	0.6	0.7	495	50	3700	g,rs	57	-120
338	14	-15	0.9	0.7	540	153	2700	g	72	-15
338	10	-10	0.2	0.3	570	24	5100	g,sd	10	-80
338	6	-7	0.2	<0.1	M	33	5100	g,sd	0	-65
337	12	-10	0.2	0.3	540	31	4300	g,sd	0	-100
338	10	-9	<0.1	<0.1	M	26	4500	g,sd	20	-40
338	3	-7	0.8	0.8	520	4	1800	g,d	8	2
339	9	-3	1.9	1.4	520	69	4700	g,d	69	-140
336	5	-9	0.4	0.9	400	180	3100	g,rs	90	-60
336	1	-8	<0.1	0.1	6	82	2800	g,rs	70	0
336	3	-7	0.7	1.4	470	235	2600	g,rs	10	-30
335	6	-8	0.2	0.4	170	340	1800	g,rs	95	0
336	3	-3	<0.1	0.1	50	96	3300	g,rs	32	0
335	2	-8	0.5	1.0	420	11	700	tiny	0	0
335	2	-8	0.4	0.9	420	9	350	tiny	0	0

Figure 2 shows a sample plot for a portion of the second penetration during Flight 503 (25 May) showing vertical wind velocity and LWC from the FSSP. The JW device was damaged (probably due to a hailstone impact) at a point when it was indicating its peak LWC during this penetration. The erratic nature of the computed vertical velocities is apparent in the middle of the updraft (~1550), but the nature of the static pressure noise that caused it appears to be correctable. There appear to be numerous small scale updrafts, superimposed upon the larger scale updraft between 1848-1850, that are somewhat coincident with peaks in LWC. This indicates the presence of numerous buoyant updraft elements during the penetration.

Another example (Fig. 3) from a portion of a penetration during Flight 502 (24 May) shows numerous narrow updrafts. Note the close correspondence between vertical wind velocity and temperature near 172030, indicating a strong buoyant updraft. Temperatures were measured by a reverse flow temperature device (RFT) and a Rosemount device (ROSE) that generally agreed within a few tenths of a degree in clear air, but often differed by more than 1°C in-cloud. Sometimes the Rosemount value was higher. Suspected wetting of the RFT can account for some of this type of disparity when T is about 0°C, but the reasons for differences in other circumstances are not clearly established. A sample of the differences between the two temperature devices during the second penetration during Flight 503 (25 May) is shown in Fig. 4. The differences are generally less than 0.5°C, but a separation of about 1°C appears around 155020 for about 10 sec. This is about the same time where the JW device becomes erratic (probably due to a hailstone) and within 20 sec is not working at all. The temperatures shown in Table 3 represent a "best estimate" for the particular penetration.

Only a cursory visual check of the 2D data was made. One buffer on the PMS 2D-C probe was not dumping to tape properly. Consequently, the 2D data analysis summarized in Table 3 results from data from the buffer that did work properly. Good probe data were accumulated for a specified duration, so that the data represent a specified fixed sample volume. However, the location of a given sample in time can be no better than the time interval it took to accumulate the specified sample volume. Thus, the locations of the 2D-C observations are subject to some time and aircraft position uncertainties. Table 3 also includes values based on an automated analysis procedure developed at the IAS (Hartman and Detwiler, 1989).

The vertical potential gradient from the electric field mills is not yet absolutely calibrated to take into account the distortion of the field due to the presence of the aircraft itself. The tabulated values are probably two to three times too high in absolute magnitude. Nevertheless, interesting results can be seen in Table 3, especially for Flight 502 (24 May). During the penetration of the second cloud (170810-173910), the vertical potential gradient shifts from negative to positive as the cloud builds and decays during the penetrations.

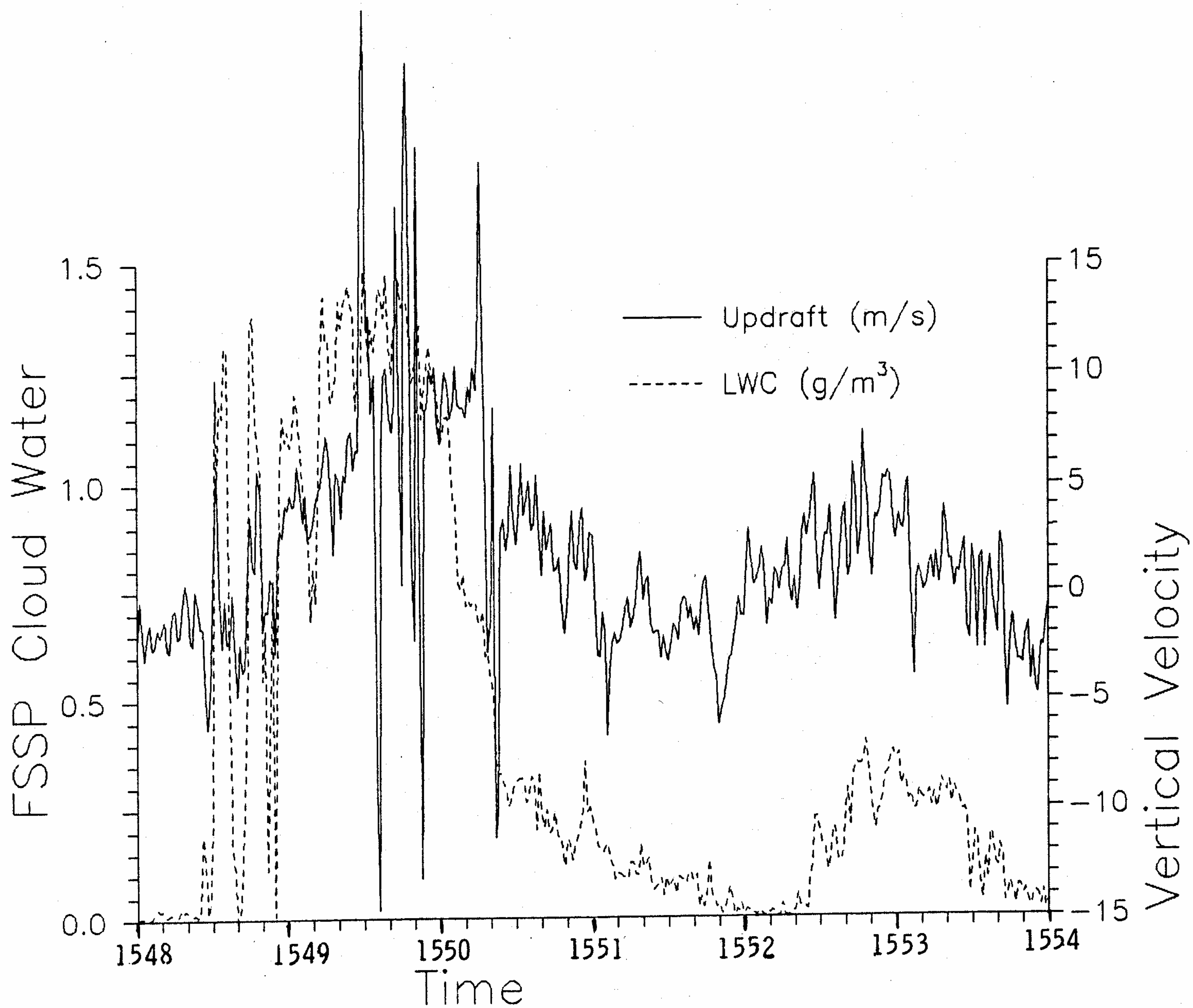

Fig. 2: Plot of FSSP LWC and vertical winds for Penetration 2 on 25 May 1989.

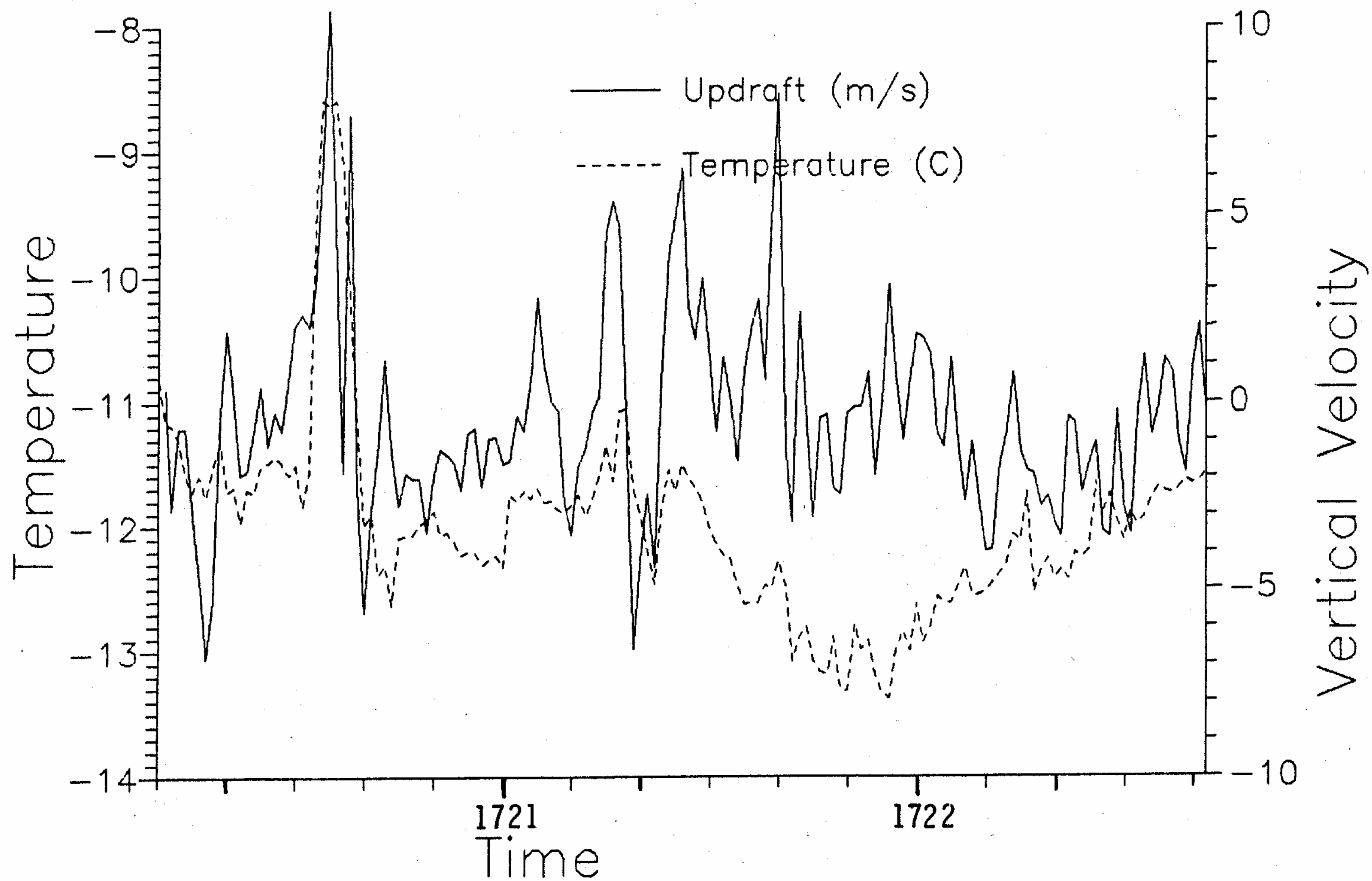

Fig. 3: Plot of temperature and vertical winds for Penetration 5 on 24 May 1989.

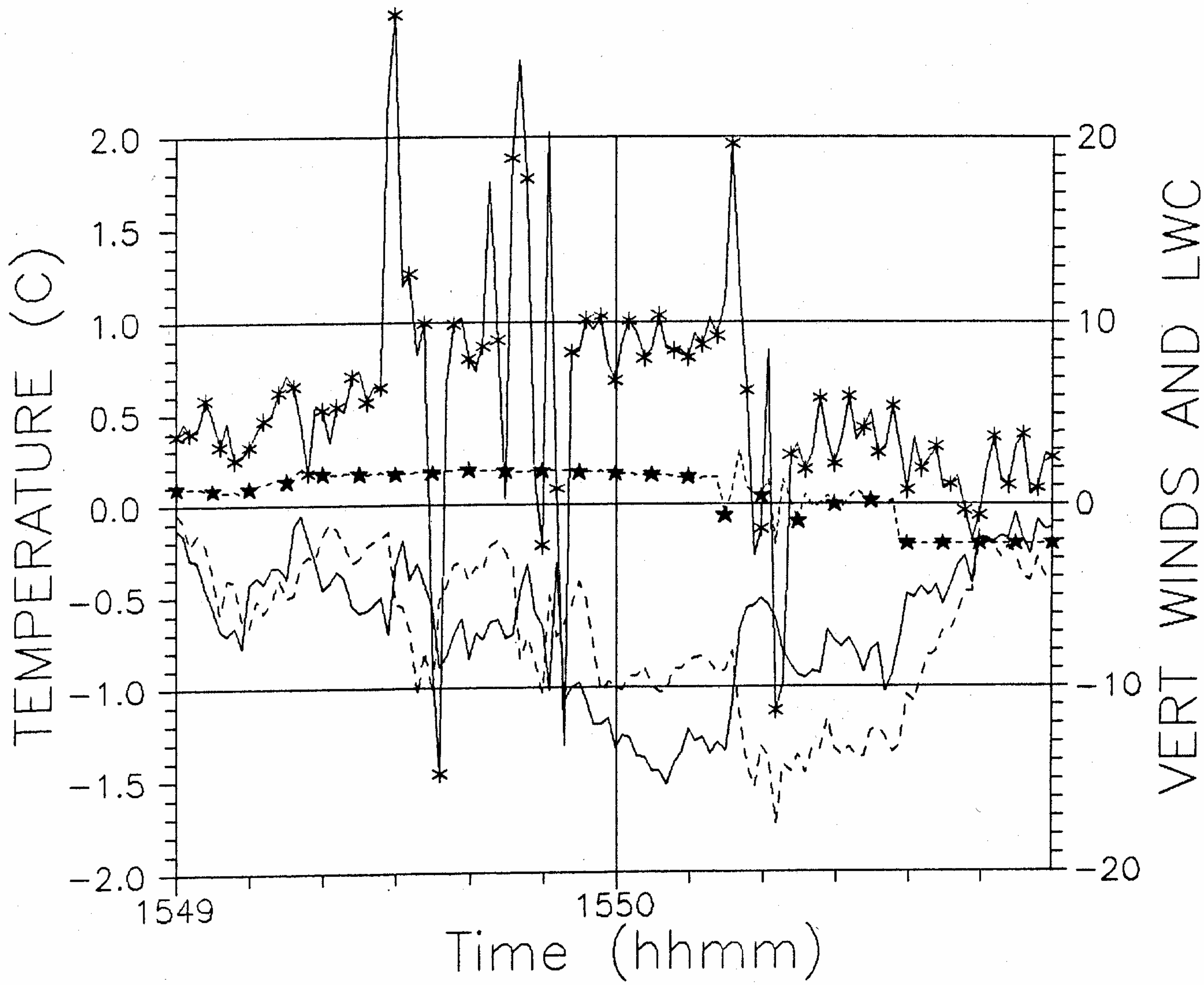

Fig. 4: Comparison of temperatures from the reverse flow (solid) and Rosemount (dashed) devices. Also shown are vertical winds in m s^{-1} (solid with ✱) and Johnson-Williams LWC in g m^{-3} (dashed with ★).

The concentration of particles from the 2D-C probe also increases throughout the penetrations of that cloud, and cloud LWC shows a tendency to increase and then stays relatively high. It is possible that these data will present an interesting case study for natural precipitation development and electrification.

Preliminary reduction of part of the foil impactor data from Flight 503 (25 May) resulted in the frequency distributions shown in Figs. 5 and 6. Hydrometeors were obviously larger during the second penetration, which should be expected because it was made in a more intense part of the storm. This can also be seen in Figs. 7 and 8, which show substantially higher number and mass concentrations during Penetration 2. In fact, the numbers are quite similar to results presented by Musil and Smith (1989) for data obtained during intense storms penetrated during the Cooperative Huntsville Meteorological Experiment (COHMEX) in the southeastern part of the United States. The two penetrations on 25 May were made around the 0°C level, which can provide important clues about some of the possible precipitation processes.

Further summary data are contained in two appendices. Flight tracks for the three research flights are given in Appendix A. Voice notes recorded by the pilot during each research flight have been transcribed and are presented in Appendix B.

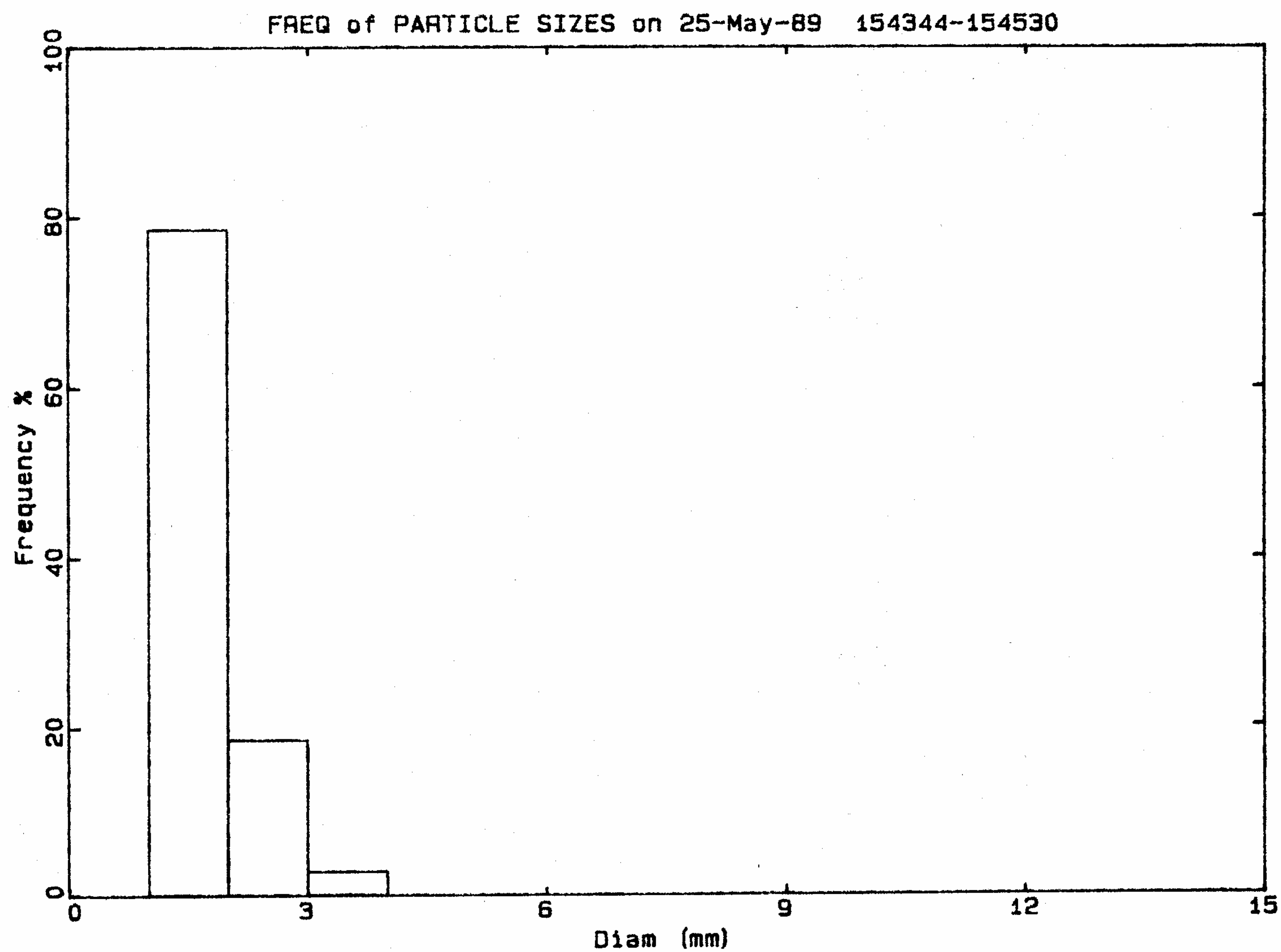

Fig. 5: Frequency distribution of particle sizes from the foil impactor for Penetration 1 on 25 May 1989.

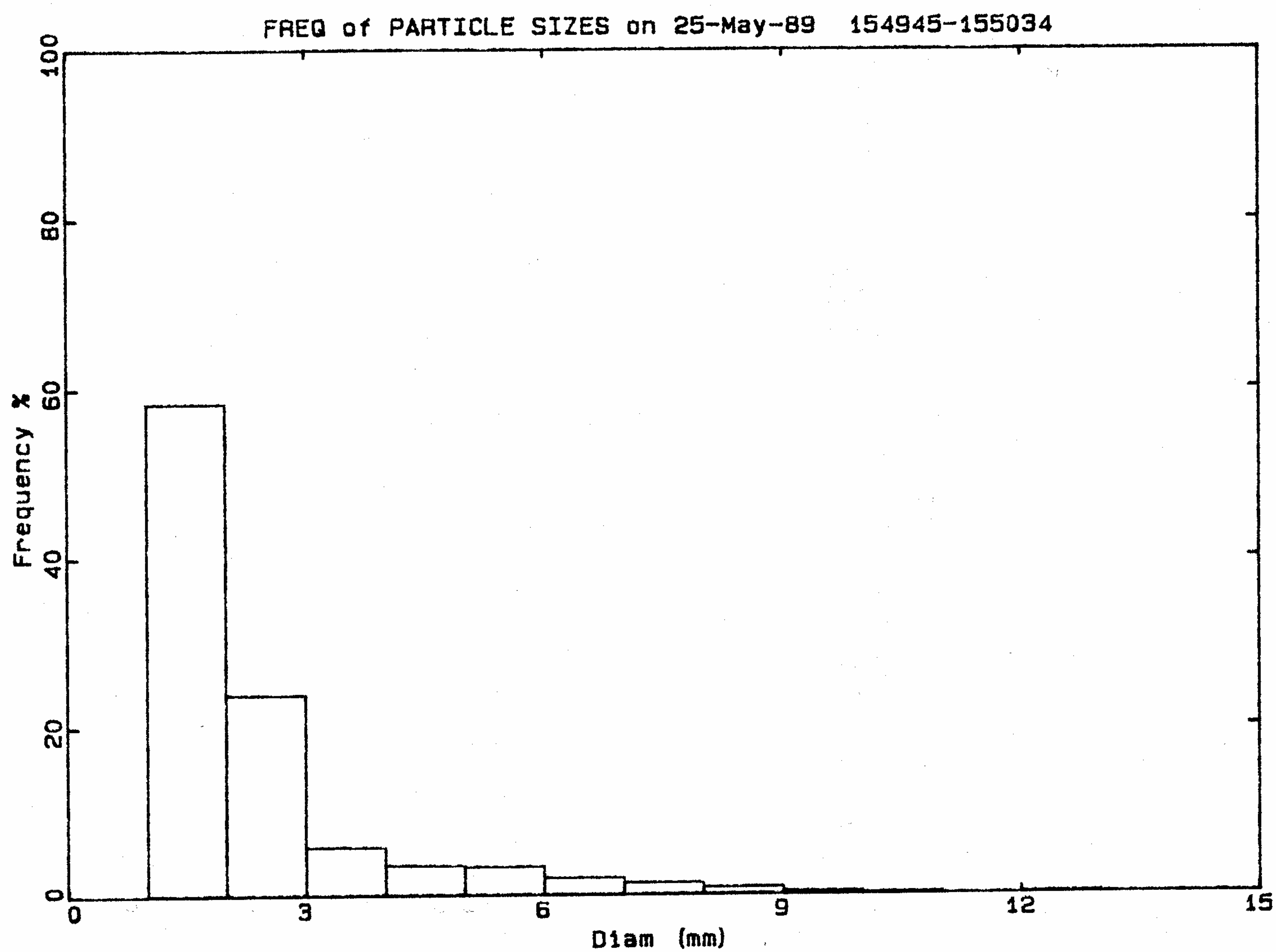

Fig. 6: Frequency distribution of particle sizes from the foil impactor for Penetration 2 on 25 May 1989.

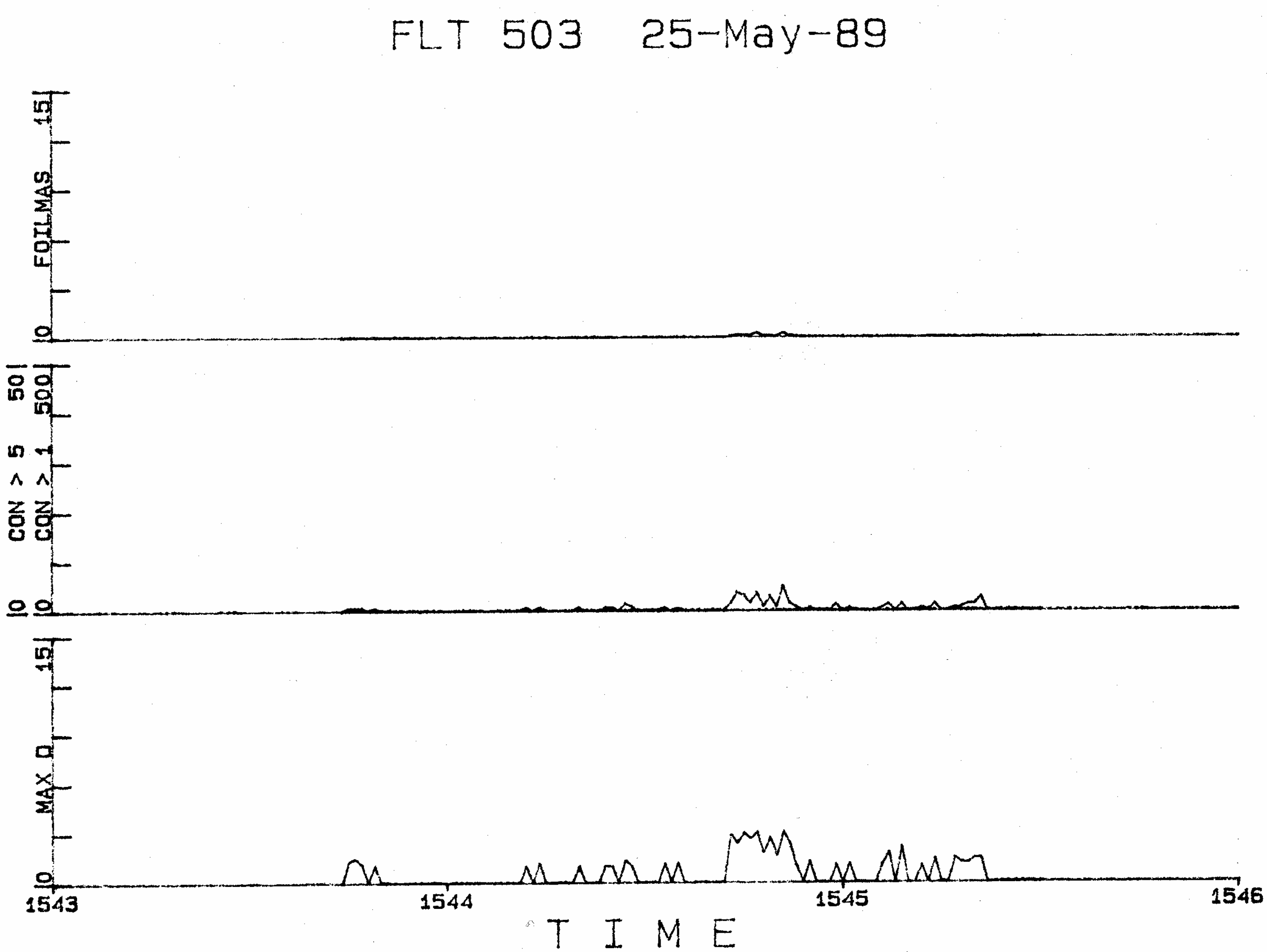

Fig. 7: Time history of precipitation characteristics observed with the foil impactor during Penetration 1 on 25 May 1989. Max D (lower) is given in mm, concentrations (middle) are given in m^{-3}, and mass (upper) is given in $g\ m^{-3}$.

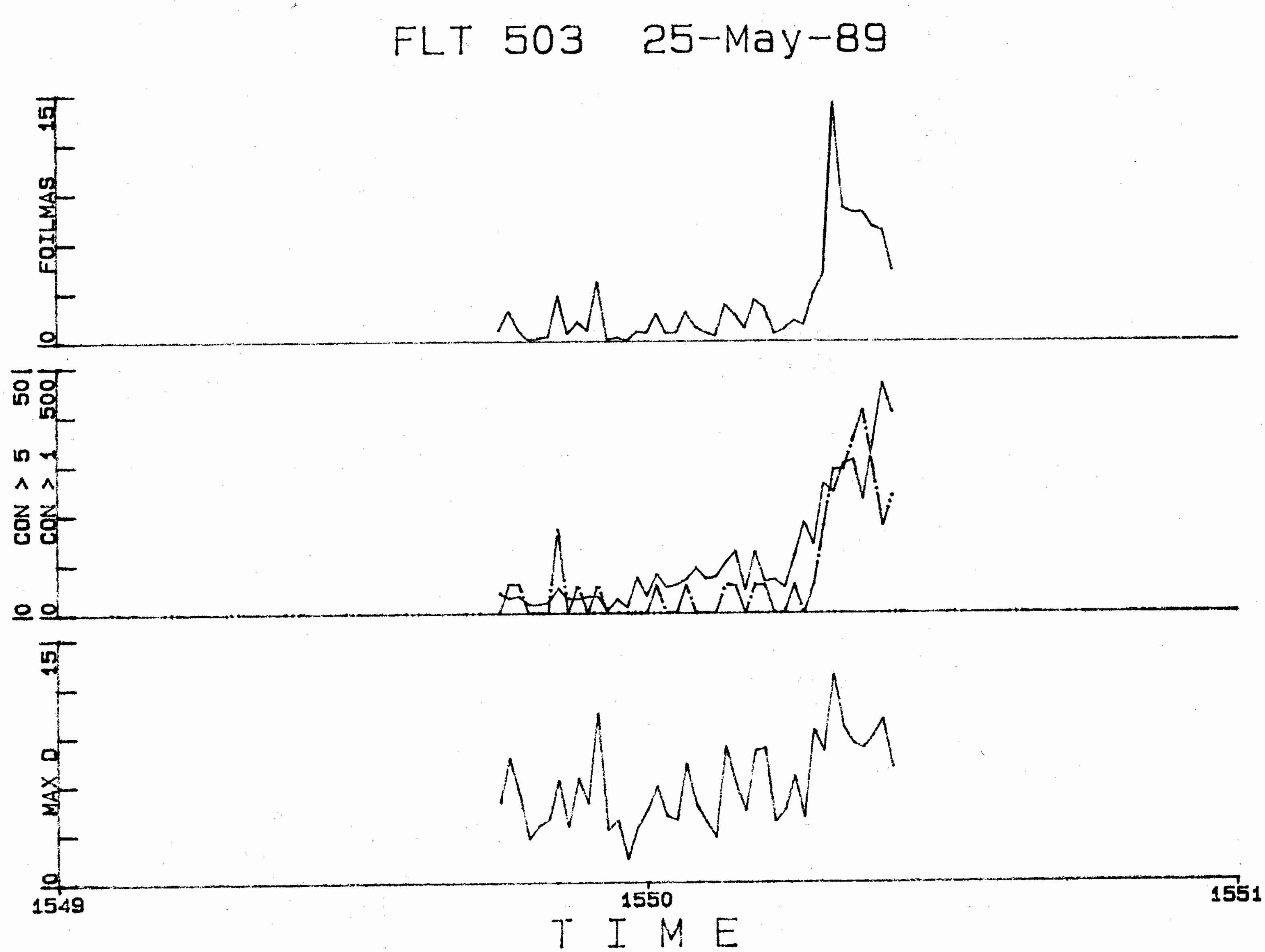

Fig. 8: Time history of precipitation characteristics observed with the foil impactor during Penetration 2 on 25 May 1989. Max D (lower) is given in mm, concentrations (middle) are given in m^{-3}, and mass (upper) is given in $g\ m^{-3}$.

6. SCIENTIFIC ANALYSIS

No formal data analysis is planned at the IAS because funds were not included for analysis in this project. Only a preliminary reduction and examination of the data has been accomplished at this time. The data from 25 May will likely receive some emphasis in conjunction with analysis of data from other projects. The data gathered on 25 May are of particular interest because the penetrations were made in a hailstorm; a phenomenon not unknown in Illinois, but certainly a rather rare event, especially one this large.

The electrical and hydrometeor data from the Flight 502 (24 May), although from a much smaller cloud, contain interesting material for a possible case study of natural precipitation development and electrification. Four cloud-to-ground strokes were recorded by the SUNY Albany national lightning network in the vicinity of the second cloud penetrated. The fact that the cloud was electrified but produced little lightning makes it an excellent candidate for comparing observations to a simulation using the IAS 2D cloud electrification model (Helsdon and Farley, 1987). It is possible such a simulation could be carried out under another program active at SDSM&T.

The flight data from Flight 504 (30 May) provides a good case study of possible seeding effects. The large concentrations of small hydrometeors encountered in the first treated cloud suggest that this cloud was treated with an active seeding agent and not a placebo, or that secondary ice production processes were unusually active.

Personnel at the Illinois State Water Survey plan more extensive analysis of data from the entire PACE season, especially pertaining to the search for effects due to seeding in those experiments.

ACKNOWLEDGMENTS

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APPENDIX A

Figures A1 - A3 show the flight tracks of the T-28 for Research Flights 502 - 504 from PACE. The plots are centered on the CHILL radar at Willard Airport and the range rings are labeled in n mi. The numbers along the tracks are at 1-min intervals and represent the least significant minutes digit.

FIGURE A1

Flight 502 24-May-89 164354 - 181624

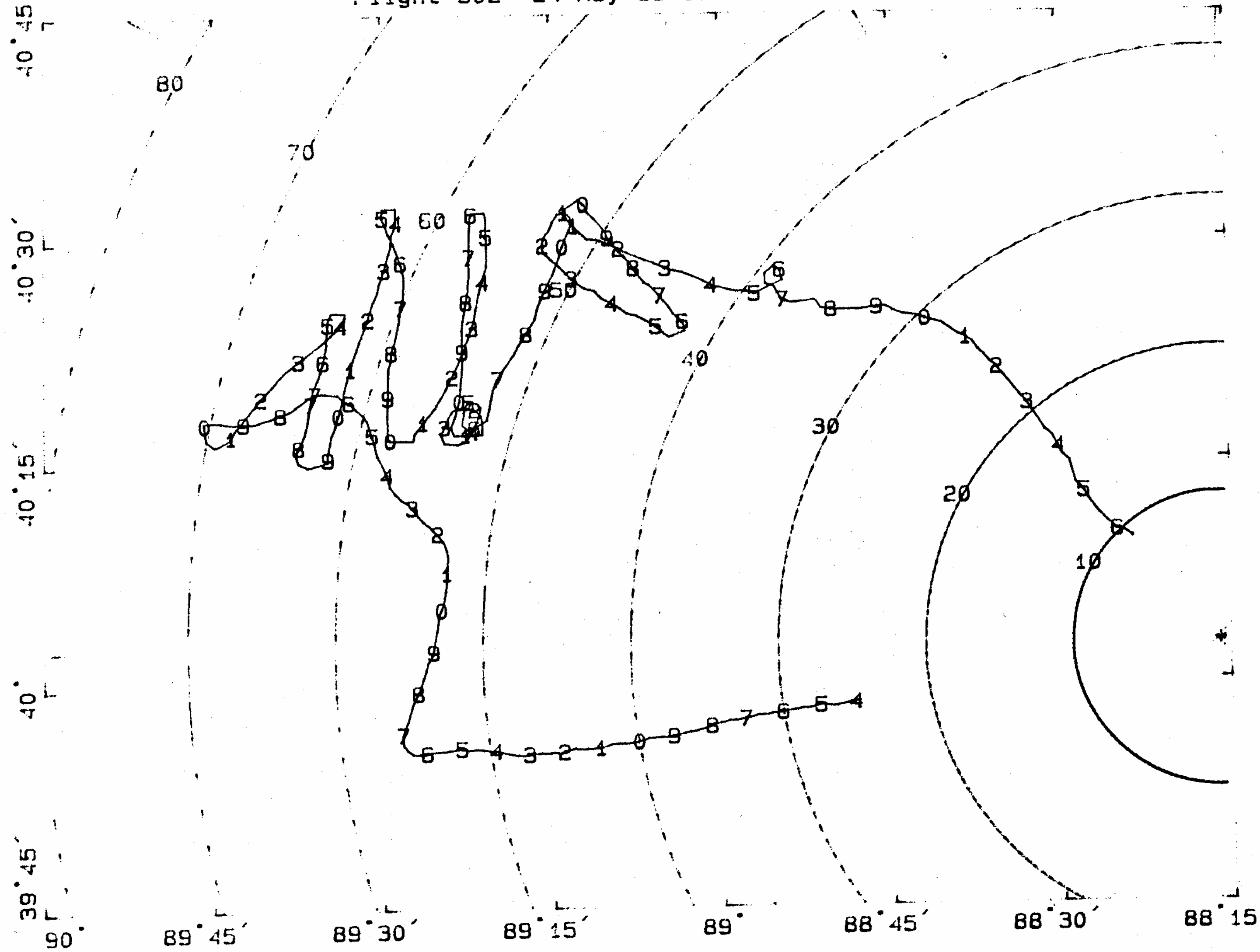


FIGURE A2

Flight 503 25-May-89 152235 - 160103

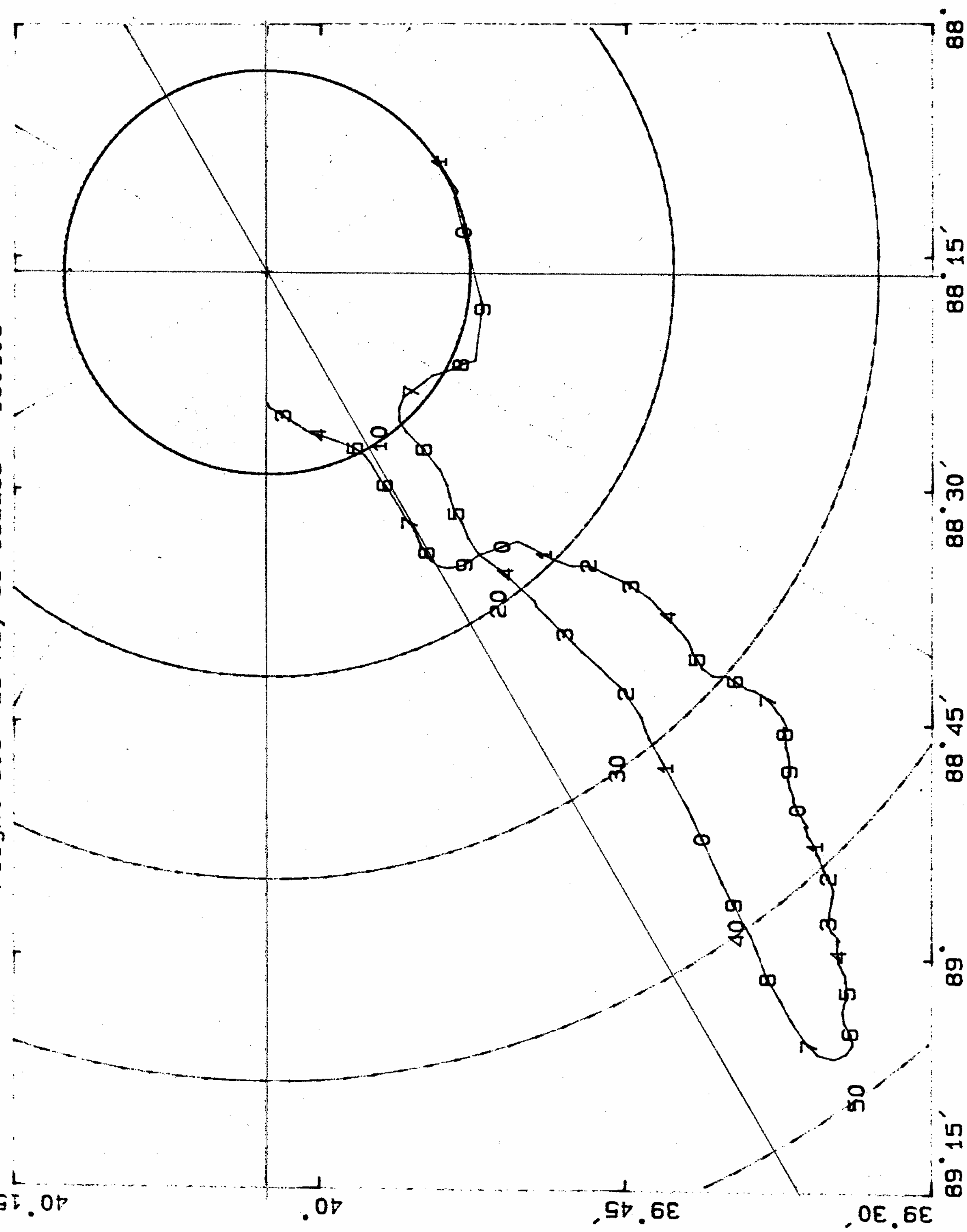
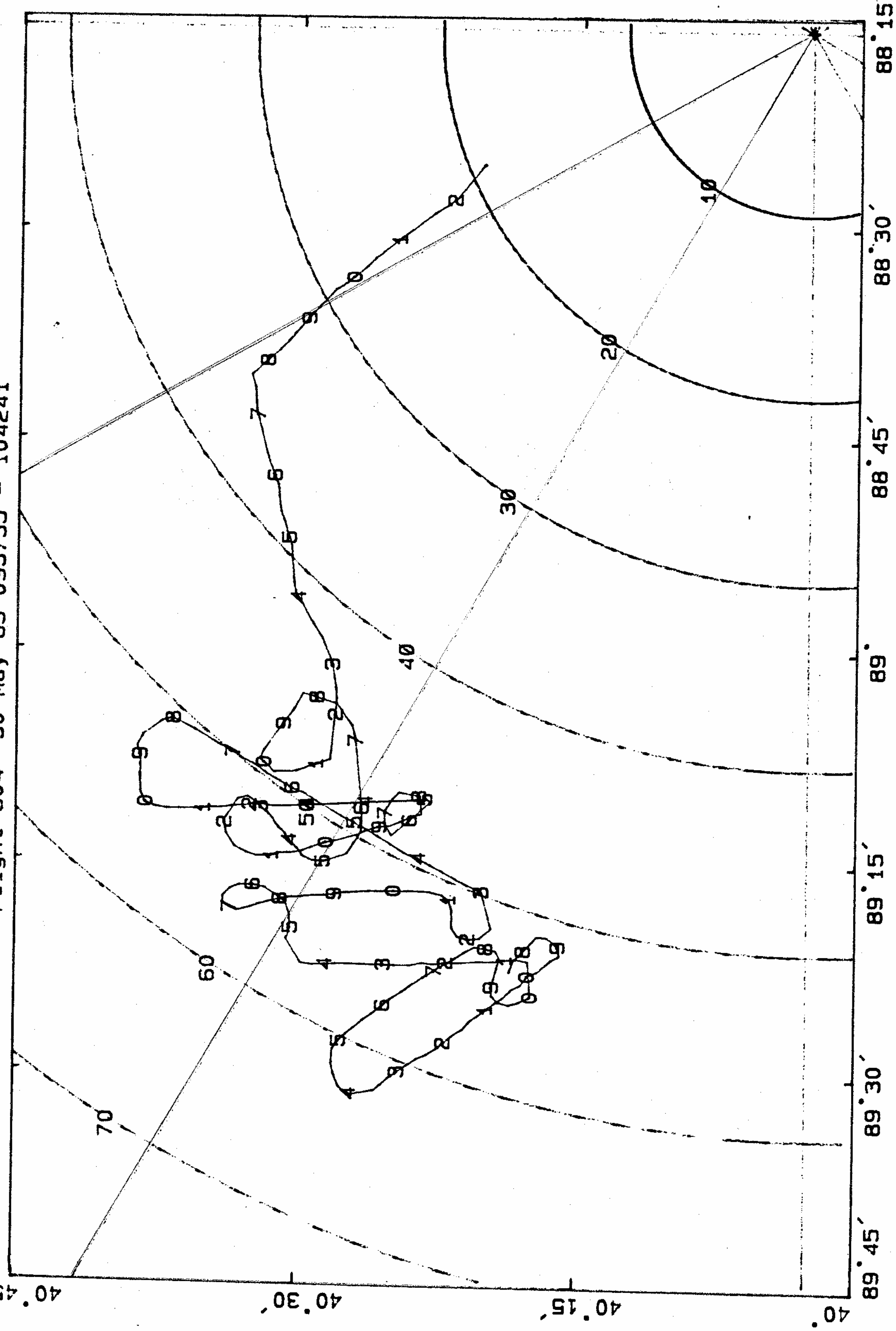


FIGURE A3

Flight 504 30-May-89 093735 - 104241



APPENDIX B

Flight: 502, 24 May 1989

Takeoff: 1632

Land: 1821

In-cloud switch not on for first penetration. All positions with respect to Champaign (CMI). JW and foil on at 1635. Field mill test 1635 to 1636 and 1655 to 1656.

TIMES	COMMENTS
	Center, CHILL-2, like to fly 55 nautical mile arc up to 300° radial CNI.
	Altitude 17,800, heading 230, entering cloud, turning to 320.
	Another cell, out of cloud.
	Second cloud at this time, heading 250, position 285/64, altitude 18,800, OAT -10C, light turbulence, air speed 140 knots.
	Light precip. on windshield, altitude 17,800,
	Position 285/66, light turbulence, up to 18,200, 400 feet per minute up.
17:09:39	Out of cloud.
	CHILL-2 out of cloud at this time, heading 015, altitude 18,000, position 285/66.6, OAT -8, ±600 feet per minute.
	Very light precip. on windshield.
	Very light jolts, ±500 feet per minute, up/down.
	Very light precip., negative icing.
	Still in-cloud at 17:13:37, position 290/63.2.
17:15:37	Back in-cloud, altitude 18,000, heading 195, position 290/63.
	Out of cloud, CHILL-2, 500 feet per minute, up/down.
	No icing, negative precip.

TIMES	COMMENTS
	Getting light icing on windshield.
	Another good one directly in front, penetrate on this heading.
	Momentarily out of cloud, will be back in shortly.
17:15:59	Heading 260, altitude 18,000, temp -10, 600 feet per minute up, 400 feet per minute down.
17:17:31	Out of cloud, in-cloud switch off.
17:20:16	In-cloud, position 280/61, altitude 17,800, heading 360, OAT -10C.
	500 feet per minute up and down, air speed 135.
	Light precip., 17,800 feet altitude, ±600 feet per minute up and down.
	Light icing.
	Exiting cloud at 292/61, altitude 17,700.
	Entering cloud 17,800 feet, heading 200, OAT -10C, air speed 140.
	Light precip.
	Light precip. on windshield, ±500 feet per minute.
	Rime ice, light turbulence, 550 feet per minute up/down, exiting cloud at position 288/59.
17:21:12	Altitude 17,500.
17:21:20	Altitude 17,500, air speed 150, 600 feet per minute up and down.
	OAT -8C, heading 350, precip.
	Rime ice (light), 17,500 foot altitude.
	700 feet per minute down, light precip. on windshield.
17:34:24	Precip. now very light, exiting cloud, air speed 140 knots, heading 345, altitude 17,500.

APPENDIX B (continued)

TIMES	COMMENTS
17:40:37	Last penetration pretty much like previous. penetration, altitude and air speed and temperature the same.
17:48:17	Entering cloud, 13,800 foot altitude, heading 020, temperature -3, position 295/54.6. Continue descent down to 13,000 feet.
17:49:22	Out of cloud, hardly any precip., believe at bottom at 13,000 feet.
17:54:00	Penetrating, 13,000 foot altitude, 0°C temperature, light precip., heading 130, want to go out and do 180, climb to 14,000, air speed 145, have 350 pounds of fuel, enough for 10 minutes more.
	Entering cloud at this time, heading 315, altitude 13,700, stand by for your heading, position 300/43, level at 13,900, air speed 125 and climbing, picking up little precip., not much turbulence.
	Level at 14,000.
	Heading 315, light precip., level at 14,000.
17:59:13	Exiting cloud at this time, altitude 14,000 feet.
	Doing 180 for another penetration.
	Position at cloud exit 300/50, 14,000 feet altitude.
18:02:35	CHILL-2 entered cloud at 18:02:41, heading 125, altitude 14,000, air speed 142, OAT 0.
	Entering cloud, heading 135, altitude 14,000.
	Pretty much at base of this one, 800 feet per minute up and down, light and occassionaly moderate turbulence, very little precip. on windshield, there was just one period of 800 feet per minute up.
18:04:41	Exit cloud at altitude 13,800.
18:15:04	Switches off.

Flight: 503, 25 May 1989

Takeoff: 1519

Land: 1605

All positions with respect to CMI.

TIMES	COMMENTS
15:43:41	Entering first cloud at 235/44.
	Can't see anything, no precip.
	Will do, altitude 13,000, air speed 140, 400-500 feet per minute up-and downdraft, light precip., OAT 0.
	Up to 1,000 feet per minute up and down.
15:45:26	Exiting cloud.
15:47:35	Logging another cloud entry at 15:47:48, position 235/43, altitude 13,100, air speed 140, OAT 0.
	Exit time 47, light precip. on windshield, negative icing, up and downdraft of 500 or less.
	Updraft 800 feet per minute, precip. more intense, moderate rain, heavy drops, presently 235/37.
	Time 49, more intense rain now. Can hear it on canopy. Very large drops, more updrafts, altitude up to 13,400, air speed 180, quite a bit of lift, power back at 180.
	Rain is intensifying, power back 25 inches, air speed 170, a bit of descent, decrease in intensity, still negative ice.
	Getting downdraft of 500 feet per minute or more. About out of rain now. Very light.
	When would you like the 180? That will be fine.
	I've lost my DME, it is inoperative in test.
	Say again?
	It is going to be difficult to maintain my position. I'll leave that up to you.

TIMES	COMMENTS
	I'm in another good cell at this time, getting lightning and updraft activity, I'm going to talk to Center and be off about a minute.
15:54:31	Exiting cloud, altitude 13,200, air speed 140, no position VOR and DME out.
	JW and foil off at 1603, be on ground at 1605.

Flight: 504, 3 May 1989

Takeoff: 0908

Land: 1055

#1 DME on CMI.
#2 DME on Capital.

TIMES	COMMENTS
9:15:17	Take off 0908 on 30 May, number two in flight of two.
	JW and foil on 0909, everything normal.
	Position 285/52.3, 25.9 off capital, altitude 18,000, OAT -10, air speed 140, heading 312, turning to 315
	CHILL Lead, CHILL-2 in-cloud.
	Altitude 18,000, stopping altitude.
	CHILL control, are you getting my transponder without altitude okay?
	I'm getting a lot of precip. static. CHILL Lead, say your heading. 330. Roger, 300, I'm going to 315, getting a good bit of activity. Getting a bit of ice. Updraft up to 700 feet per minute out of cloud. Entered cloud approximately 38, out at 42.
9:45:09	Roger, climbing up to 18,000, making my turn out to northeast, that's it. Out at 295/61. Exit 18,000, air speed 140, OAT still -10.
	Entered cloud on heading 155, position 290/58.5, altitude descend to 18,500, air speed 130 and climbing, time was 45:38 on entering.
9:50:53	Air speed 130, heading 155. Going into cloud at this time, altitude 18,500, going to be on left side. Picking up 300 feet per minute updrafts, light turbulence. Air speed 145.
?	Out of cloud at 46:59, altitude 18,000, position 29/53.7.

TIMES	COMMENTS
	Altitude 18,550. Okay, out of cloud. Not much going through there.
	Negative ice, 18,500.
	Position Norm penetrated on 350 at 18,500.
9:51:??	Altitude 18,500, air speed 130, position 285/53. Just entering cloud at this time at 51, heading 350.
9:58:25	Okay, are you going to come through.
	Roger. 500 feet per minute downdraft, 600 feet per minute down, 800 per feet per minute down, air speed 140. Picking up moderate rime ice.
	CHILL out of cloud at 53, altitude 18,600, got up to 800 feet per minute downdrafts, light to moderate turbulence, have a little cell in front, I'll go through that prior to doing a 180, out of cloud, be doing my 180 to left or east.
	Doing 180 at this time. Okay, what altitude for this penetration?
	Out of it at 53, roll out shortly and check back with you.
9:58:55	Be climbing up to 19,500, at heading 090, be climbing in left turn to 90 at this time. Rolling out.
	No. 4 penetration 58:30, position 300/53, altitude 19,600, air speed 130, OAT -12.
	Cloud switch on, air speed 140.
	Roger, 20.5.
	Starting to get 500 feet per minute downdrafts, 300 feet per minute up.
	Coming out of cloud at 10:00:05.
	CHILL control, not much activity on that pass, no more than 500 feet per minute downdrafts, 300 feet per minute updrafts.

TIMES	COMMENTS
	Roger, CHILL, I'm starting my climb at 20,500 feet.
10:03:02	CHILL control, did you copy my transmission on the cloud? Turning to right, back to a heading of 240, turn in to west, going out to 20,500, roger.
	Turning back to left, give me a better chance to get lined up here.
	Cloud switch off, foil off.
	Penetration 4, negative icing, not much activity.
10:04:05	Penetration No. 5, heading 025, altitude 20,500.
	Altitude 19,500, entering at 10:04, air speed 140, negative turbulence.
	Air speed up to 148, 500 feet per minute vertical.
	Exiting cloud at 10:05:20. Altitude 19,600, air speed 140, got one 500 feet per minute updraft, doesn't seem to be much activity in there.
10:18:27	Heading 150, slowing down.
	Say again, Norm.
	Okay.
	Exit position 300/49. What's your altitude?
	Okay, I'm still at 20,500, heading 025, air speed 140.
	CHILL control, CHILL-2, heading toward cloud, heading 330, 17,000, over.
	Position 292/48 for penetration No. 6, penetration No. 6 at 17,000, right in the tops of small cumulus cloud, heading 330, air speed 140.
10:19:51	Cloud switch on at 10:19:47. Heading 330, position 300/3.6.
	Going into the cloud. Air speed 140, altitude 17,050, light turbulence, 400 feet per minute down, light rime ice.

TIMES	COMMENTS
	Out of cloud at 10:20:45, cloud switch off.
	CHILL-2 out of cloud, start a right turn to the east.
	Are you still at 17?
	Okay, just hold 17, I only got about 300 feet per minute vertical activity in that. Very light rime icing.
	Okay, same altitude, 17 or a little below.
	Okay, I have you at 7 o'clock.
	Okay, going up to 17,250 to take a look.
10:22:39	Position 303/50.5.
10:22:46	Another penetration, air speed 140, heading 250, going into cloud at this time.
	Heading 240.
	Exit at 23:49, altitude 17,250, position 300/51.
	Okay, out of cloud, little more turbulence with that penetration so maybe it's starting to build.
	Roger, say heading again.
	Roger, 180 to left. 17,250, okay.
	Penetration No. 7 out about 24 past the hour.
10:24:51	Okay, down to 3,000.
	Okay, 350, CHILL-2 right to 360.
	Tower CHILL-3 wind check.
	CHILL-3.