Report 78-13 December 1978

SUMMARY OF T-28 FIELD OPERATIONS - 1978

By: John Prodan, Dennis J. Musil,
Gary N. Johnson and Paul L. Smith, Jr.

Prepared for:

Convective Storms Division
NCAR
P. O. Box 3000
Boulder, CO 80307

Subcontract No. 182-71

and

Atmospheric Research Section
National Science Foundation
1800 G Street N.W.
Washington, DC 20550

Grant No. ATM78-17326

Institute of Atmospheric Sciences

South Dakota School of Mines and Technology

Rapid City, South Dakota 57701

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The Institute of Atmospheric Sciences (IAS) of the South Dakota School of Mines and Technology (SDSM&T) participated with its armored and instrumented T-28 research aircraft in two field programs during 1978. The first was conducted in northeast Colorado for the Convective Storms Division (CSD) of the National Center for Atmospheric Research (NCAR) from 19 June through 31 July 1978. Participation in the 1978 CSD field experiment was a continuation effort under Subcontract No. NCAR 182-71; the overall CSD program is sponsored by the National Science Foundation and is under the direction of NCAR. The second program was the Thunderstorm Research International Program (TRIP-78) conducted from NASA's Kennedy Space Center (KSC), with IAS participation during 6-15 August 1978. Participation in TRIP-78 was a cooperative effort between the SDSM&T and NCAR and was sponsored by a grant from the National Science Foundation to the SDSM&T (Grant No. ATM78-17326).

1.1 The CSD Program in Colorado

The 1978 CSD field experiment emphasized the gathering of data from convective clouds around the time of first radar echo development. The T-28's role in this coordinated experiment was to be the mid-altitude cloud penetrating aircraft of three assigned to the in-cloud data gathering task. The high-altitude aircraft was a NOAA/NCAR sailplane which was to circle in the cloud as it climbed, and the low-altitude aircraft was a University of Wyoming Queen Air with a task similar to the T-28's. The desired altitude separation was 2000 ft or more while in-cloud, for safety reasons.

The specific IAS objectives for the 1978 CSD program were:

1. Investigation of hydrometeor characteristics and size distributions in convective clouds at the time of first radar echo development and during the formation and growth of precipitation.

2. Identification of the location and microphysical structure of hail embryo growth regions.

Field personnel participating on a full-time basis included the pilot, a research engineer, an aircraft mechanic/technician, and a research assistant from the IAS, plus an electronics technician from CSD, all based at Laramie. The T-28 project meteorologist was located at Grover, Colorado.

1.2 The TRIP Program in Florida

By the time the T-28 arrived in Florida, aircraft operations for the other TRIP aircraft (a NASA Beech D-18, an Air Force T-39, and a Naval Research Laboratory S2D) had been completed. Thus the TRIP-78 investigations were not conducted as a coordinated "in-flight" program. However, most of the ground based experiments were still operational during the T-28 research flights and coordination was effected with those experiments. The T-28's main role was in collecting observations which could be reduced and organized in a way useful in complementing the extensive set of electric field, lightning, radar, and other observations collected during TRIP-78.

The specific IAS objective for TRIP-78 flight operations was to:

> Obtain measurements of hydrometeors and vertical air motions inside Florida thunderstorms for use in the determination of cloud electrification processes. These measurements will characterize the number and mass concentrations, size distributions, and types (crystal habits, degree of riming, etc.) of the hydrometeors and also locate them with respect to storm updraft areas.

The field personnel included the pilot, a research engineer, and an aircraft mechanic/technician from the IAS plus an electronics technician from CSD, based at Patrick AFB. The project meteorologist was stationed at KSC.

2. FLIGHT OPERATIONS SUMMARY

2.1 1978 CSD Field Experiment

The T-28 was flown to Laramie, Wyoming, airport on 16 June in preparation for the field season which was to begin on 1 July 1978. Prior to this, seven flights were conducted in the Rapid City area -- four for pilot checkout and aircraft familiarization for the new research pilot (John Prodan), one for tower fly-by practice, and two for checkout of the instrumentation system.

As in 1976, the T-28 was based in the University of Wyoming's hangar at Laramie. Again, this was an outstanding arrangement. The IAS is very appreciative of the cooperation of the Department of Atmospheric Science at the University of Wyoming for their support during this field season.

Seven more flights were made in the Laramie/Cheyenne area before the season started. Three flights were devoted to instrumentation flight checks, one was a tower fly-by calibration flight, and three were ferry flights. Fourteen flights were made during the official field experiment (1-31 July 1978), of which nine were research flights on which a total of 63 cloud penetrations were made. Two were ferry flights for aircraft radio work at Cheyenne. Of the three remaining flights, one was for in-flight data comparison with Wyoming's Queen Air, one was a flight test to get data for sensor temperature coefficient determination, and one was an instrumentation check flight. No flights were missed because of aircraft or instrumentation problems. A summary of the 1978 Colorado flight operations is included as Table 1.

To assure a T-28 fuel supply of 100/130 octane regular grade aviation gasoline required special arrangements with the local fixed base operator (Laramie Aviation, Inc.). As the initial supply of fuel approached zero, flight requirements were carefully monitored to insure that no research flight opportunities were lost; none were lost or delayed. The IAS is presently corresponding with the aircraft engine manufacturer to determine any possible deleterious effects on the engine from using 100/130 octane low lead gasoline, since it appears that this is going to be the only grade available in the future.

A base radio link was maintained from the Laramie hangar to the CSD control center at Grover, Colorado, for the entire season. After an initial interference problem with a local FM radio station was eliminated, this proved to be of great benefit.

TABLE 1

Summary of T-28 Colorado Flight Operations
16 June - 31 July 1978

Flight No.	Date	Time (hrs)	Approximate Research Time Block - MDT	Penetrations	Data Recorded* PI Tape	Pertec Tape	Voice Tape	Remarks
218	6/16	1.8						Ferry flight to Laramie, WY
219	6/23	1.6						Instrumentation check flight
220	6/28	1.5						Ferry to Cheyenne - radio work
221	6/28	1.4						Ferry to Laramie - Instrumentation check flight
222	6/29	2.2						Tower fly-by; recover Cheyenne
223	6/29	0.5						Ferry to Laramie
224	6/30	1.4						Instrumentation check flight
225	7/5	2.1	1809-1834	5	Yes	Yes	Yes	Research: Sailplane and T-28 only
226	7/9	1.5						Intercomparison in flight
227	7/10	2.3	1535-1648	6	Yes	Yes	Yes	Research: all aircraft
228	7/11	2.1	1421-1543	6	Yes	Yes	Yes	Research
229	7/13	2.2	1700-1754	9	Yes	Yes	Yes	Research
230	7/17	2.0						Instrumentation check flight
231	7/18	2.1	1616-1718	8	Yes	Yes	Yes	Research
232	7/19	2.1	1626-1727	6	Yes	Yes	Yes	Research
233	7/21	0.7						Ferry to Cheyenne - radio work
234	7/21	0.6						Ferry to Laramie
235	7/27	1.6						Temperature coefficient determination

TABLE 1 (Continued)

Flight No.	Date	Time (hrs)	Approximate Research Time Block - MDT	Penetrations	Data Recorded* PI Tape	Pertec Tape	Voice Tape	Remarks
236	7/28	2.0	1522-1630 (est)	4	Yes	Yes	Yes	Research - mature storms
237	7/30	2.3	1310-1353	10	Yes	Yes	Yes	Research
238	7/30	2.2	1612-1716	9	Yes	Yes	Yes	Research

Totals

Total number of flights	21
Total number of research flights	9
Total aircraft flight hours	36.2
Total number of cloud penetrations	63

*1. Cannon camera carried on all research flights except Flight 236 (7/28) when the hail spectrometer was used.
2. PI Tape: Basic aircraft instrumentation data.
3. Pertec Tape: PMS probe data.

No radar tracking of the T-28 was available because the new CSD tracking system was not operational. Coarse real-time aircraft position information was available to the meteorologist at Grover from an IFF-equipped weather surveillance radar. Position information for post-analysis had to be determined from FAA radar coverage and the on-board navigation equipment.

Because of the cooperative nature of this experiment and the need for the three penetrating aircraft to fly through the same cloud, airborne determination of the position of the cloud of interest was necessary. That task fell to the University of Wyoming's Queen Air crew. Without active and positive aircraft tracking from the ground, this was the only way that a semblance of control over the operations could be maintained. On several occasions, however, the T-28 either could not penetrate or aborted a penetration because of the lack of knowledge of the current position of the sailplane after it had released and was in-cloud but not climbing. Positive vectoring from the ground would have eliminated this problem.

The FAA support in supplying desired Instrument Flight Rules (IFR) clearance during the field program was outstanding. No trouble or delays were encountered in T-28 operations as a result of air traffic control and clearance requirements. Just the opposite occurred -- the T-28 operations were expedited as a result of the FAA cooperation.

2.2 TRIP-78 Operations

After completion of the CSD program, the T-28 was flown to Florida, leaving Laramie on 1 August 1978 and arriving at Patrick Air Force Base (PAFB) on 2 August. The rest of the team, together with the ground support equipment, arrived on 4 August 1978. The T-28 was based at Patrick AFB, about 20 miles south of KSC, and hangared in the NASA Flight Operations Facility. This arrangement proved adequate.

A communications and tracking check flight was made on 8 August. There were five subsequent research flights, with four resulting in 45 storm penetrations; the fifth research flight produced no data because of extremely rapid cloud dissipation. The T-28 departed for Rapid City late on 15 August after research opportunities had been exhausted and arrived on 17 August. A summary of the Florida flight operations is included as Table 2.

No difficulties were encountered with either the aircraft or the instrumentation. One intended quick turnaround research flight was cancelled on 12 August because of electrical activity in the vicinity of PAFB. It is Air Force policy not to refuel aircraft if an electrical storm is within five miles, as was the case on this day.

TABLE 2

Summary of T-28 Florida Flight Operations
1 - 17 August 1978

Flight No.	Date	Time (hrs)	Approximate Research Time Block - EDT	Penetrations	Data Recorded* PI Tape	Pertec Tape	Voice Tape	Remarks
239	8/1	2.6						Ferry flight to Wichita, KS
240	8/1	2.6						Ferry flight to Memphis, TN
241	8/1	1.9						Ferry flight to Atlanta, GA
242	8/2	3.0						Ferry to Patrick AFB, FL
243	8/8	1.6						Communications and tracking check
244	8/9	2.1	1523-1616	9	Yes	No	Yes	Research
245	8/10	1.5	1205-1237	10	Yes	Yes	Yes	Research
246	8/10	0.8			Yes	Yes	Yes	Research - clouds dissipated
247	8/12	2.3	1122-1224	18	Yes	Yes	Yes	Research
248	8/13	1.7	1516-1605	8	Yes	Yes	Yes	Research
249	8/15	2.5						Ferry flight to Atlanta, GA
250	8/16	2.4						Ferry flight to Greenville, MS
251	8/16	2.2						Ferry flight to Dallas, TX
252	8/17	2.0						Ferry flight to Wichita, KS
253	8/17	2.7						Ferry flight to Cheyenne, WY
254	8/17	1.4						Ferry flight to Rapid City, SD

Totals

Total number of flights	16
Total number of research flights	5
Total aircraft flight hours	33.3
Total number of cloud penetrations	45

*1. Cannon camera carried on all flights.
2. PI Tape: Basic aircraft instrumentation data.
3. Pertec Tape: PMS probe data.

A capability for radar tracking of the aircraft existed. Kennedy Space Center provided a C-band radar transponder that was compatible with the Eastern Test Range tracking net, and the system was checked out on the 8 August flight. Unfortunately, schedule conflicts with three spacecraft launches resulted in no tracking of the T-28 during the research flights.

Initial contact with the FAA in Miami to request their recorded aircraft tracking data (similar to that used for Colorado) indicated that the data would be available. However, the FAA subsequently advised us of their policy decision not to provide this information. As a result, no external tracking data are available for the T-28 TRIP operations. Data recorded on the aircraft -- VOR radial and DME distance readouts -- are therefore being used to generate the track information.

Operationally, the FAA gave outstanding service in providing IFR clearances. No delays or restrictions were encountered during T-28 operations, in spite of the fact that the areas worked included heavily traveled airways.

One unforeseen operational problem came up because of the T-28's limited defogging system. After the airplane was cold soaked at altitude during a research mission, descent to the warm and humid lower levels (below about 4000 ft) resulted in heavy condensation (beyond the T-28 defogging capability) inside the canopy and windscreen with no outside visibility. This necessitated about 15 minutes of circling at 1500-2000 ft until the aircraft warmed sufficiently to evaporate the condensation enough to make a landing possible. As a result, 15 minutes less on-station time was available for the research mission.

3. INSTRUMENTATION PERFORMANCE

The T-28 instrumentation performed well throughout the 1978 season. A summary of the performance of major system components follows. Comments regarding the quality of data gathered are subject to revision after more thorough analysis.

3.1 Data Recording Systems

Both the Monitor Labs 9100 and Particle Measurement Systems (PMS) digital data recording systems experienced minor problems but were fixed fairly quickly. The 9100 data exhibited some irregularity on the high resolution static pressure and the reverse flow temperature channels. This was solved by replacing multiplexer components. The problems associated with the 9100 are apparently due to the age of the unit and indicate that it should be replaced within the next year or so. The PMS system, which records all digital and some analog data from other instruments on the T-28 as well as the PMS probe data, had a calibration problem on some channels early in July. On two occasions the recorder shut down early, but this was later traced to operational error rather than a true hardware failure.

3.2 Particle Measurements

The system carried on the T-28 for measuring sizes, numbers, and composition of hydrometeors consists of a PMS forward scattering spectrometer probe (FSSP) and a PMS two-dimensional optical array spectrometer probe (2-D), the IAS hail spectrometer, the Cannon camera, and a foil impactor. A Johnson-Williams cloud liquid water concentration (LWC) sensor also provides data for the cloud droplets. Data quality from the PMS probes appears to be quite good, although the 2-D data contain some contamination. The source of this contamination is still not entirely known, but some shedding of liquid water from the probe tips did occur. The FSSP data now appear to correlate well with the J-W LWC sensor aboard the aircraft, at least in Colorado.

The hail spectrometer was carried only once this year, but the data from this flight appear to be good. This was the first use of the instrument since revamping the size categories and adding the "slow particle" sensor to the unit. No slow-particle indications appeared, which is the desired behavior because any such indications would suggest contamination of the hail spectrometer data by fragments of ice breaking off the aircraft structure. Only a few hail-sized particles, the largest being nominally 1.1 cm in diameter, were encountered on the flight. However, for mature storm studies, the hail spectrometer appears to be fully operational.

The Cannon particle camera performed well during its second operational season and has provided much good data. Some data were lost due to incorrect airspeed compensation and optical alignment problems but, in general, good performance was achieved. Large numbers of liquid raindrops were encountered on one of the Florida flights, providing the first extensive demonstration of the capability of this instrument to identify liquid drops.

Foil data were rather sparse in Colorado due to the nature of the clouds penetrated, but no problems were encountered with the impactor itself. The foil data from Florida revealed the presence of large concentrations of rather uniformly shaped and sized particles.

3.3 Cloud Liquid Water Concentrations

The Johnson-Williams (J-W) cloud liquid water concentration indicator was plagued with problems throughout the season due to poor electrical contacts within the sensing head and its connector. We found that meticulous cleaning of the connector improved the performance of the J-W unit considerably. However, it was apparent that a ground test facility for this unit should be built so that problems of this nature can be fixed more readily in the future.

3.4 Pressure Instruments

The T-28 pressure measuring devices include Rosemount absolute (altitude) and differential (indicated airspeed) pressure transducers, a "times 5" amplifier for the Rosemount absolute pressure signal, a Ball altimeter, and a Giannini manifold pressure transducer. No problems were encountered with the pressure devices. The Ball altimeter showed some discontinuities in its output voltage throughout the season; however, this has appeared to be a normal condition. This transducer is considered to be a secondary measurement device so no effort was made to fix it.

3.5 Temperature Instruments

The NCAR reverse flow and Rosemount temperature probes worked well throughout the season and no problems were encountered. No conspicuous evidence of wetting of the reverse flow probe appeared, although the cloud liquid water concentrations encountered were generally low.

3.6 Angle-of-Attack Vane

Data from the angle-of-attack vane have proved to be questionable due to apparent airflow turbulence around the instrument. Test flights have shown that sideslip of the aircraft is the most significant cause of this turbulence. Various smoothing techniques are currently being investigated to make the angle-of-attack data more usable for updraft calculations.

3.7 Acceleration, Pitch, and Roll Data

The Humphrey vertically stabilized accelerometer appeared to work normally throughout the season. Some problem may have been experienced with the roll transducer, which is integral to the Humphrey accelerometer. This only became apparent at small roll angles where the data plots suggest that the transducer may be "hanging up" at zero output. Further analysis will be required to clear up this potential problem. The peak-reading accelerometer units, designed to supplant the twice-per-second "instantaneous" recordings, appeared to function properly for the first time.

3.8 Vertical Air Motions

The procedure for determining vertical air motions with the T-28 involves first measuring the rate-of-climb of the aircraft. Then the measurement is corrected for the influence of aircraft-induced effects to determine the air motion. Past studies have indicated that the rate-of-climb can be best determined by differentiating the altitude (essentially static pressure). Because of the irregularities in the 1978 static pressure data noted in Section 3.4, some erratic values result from this technique. Separate variometer indications of rate-of-climb are available and can be substituted in those instances.

Previous corrections were based on airspeed and engine manifold pressure data. Implicit in that approach was the assumption that the attitude of the aircraft would be fairly steady during storm penetrations. Experience has shown that not to be the case. An alternate approach has been developed in which the corrections are based on pitch, roll, and angle-of-attack data. As noted in Section 3.6, however, the present angle-of-attack data are not satisfactory. Consequently, a reliable procedure for determining vertical air motions does not presently exist. Work is in progress to solve this important problem.

3.9 True Airspeed

The NCAR true airspeed (TAS) computer performed within specifications all season. The T-28 telemetry transmitter interference problem experienced during the 1976 field season has been eliminated.

3.10 Heading Indicator

The IAS heading indicator did not work at all during the season. No use of the data, which are useful only in connection with good ground tracks to estimate horizontal wind speeds, was anticipated so repair of this unit was given a low priority.

3.11 Radio Navigation

New VOR and DME units were used for the first time this season and both worked well. The data are essential in circumstances where no other source of track data is available. The No. 2 DME suffered from low sensitivity, even after an overhaul, and during most flights the data from this radio are unusable. Another new DME should be purchased to replace this older unit, because tracks derived from dual DME's are more accurate than ones based on the VOR-DME combination.

3.12 Telemetry System

The T-28 telemetry system was expanded for the 1978 season to provide more operational utility. Additional subcarrier oscillators were incorporated in the system so that the project meteorologist could get real-time data from the rate-of-climb and altitude transducers in addition to hearing the pilot's voice comments. This turned out to be quite useful. No problems were encountered after the initial calibration. This unit was used only during the Colorado operations.

4. SYNOPSIS OF OPERATIONAL DAYS

4.1 CSD Field Experiment

A total of 63 cloud penetrations were made on nine research flights in northeast Colorado during the 1978 CSD field experiment. The following ranking of the operational days, given in descending order of importance, should be taken as preliminary. However, it presents a first estimate of the most promising candidates for detailed study, from the viewpoint of T-28 operations. The ranking is based on such things as data quality and visual evaluations of the storms penetrated.

30 July (Flight 237)
13 July
18 July
19 July
30 July (Flight 238)

11 July
28 July
10 July
5 July

Brief descriptions of the best six days ranked above follow. The missions of 5 and 10 July were plagued by early season coordination problems and are not likely to become case study candidates. The storm of 28 July was a weak mature storm and was penetrated only by the T-28 to test the modified hail spectrometer. Therefore it will be analyzed by IAS personnel and should not be included in the first-echo study category.

30 July (Flight 237) - Ten penetrations were accomplished by the T-28 as part of a well coordinated multiple aircraft mission. Good updrafts were encountered in what appeared to be new towers prior to the time radar echoes formed.

13 July - Nine penetrations were made in clouds that developed just north of Grover, presumably along a convergence zone on the higher ground there. Penetrations were made in new growth which seemed to form in about the same spot at successive times, with the clouds subsequently moving off to the east or southeast. Some penetrations were in non-echoing clouds while others were in clouds with echoes approaching 50 dBz.

18 July - Several good penetrations were made by the T-28 and Wyoming Queen Air through clouds which had quite strong updrafts,

especially on some of the early penetrations. Penetrations were made in the vicinity of Cheyenne because the weather did not develop over the as had been expected.

19 July - Penetrations were characterized by severe turbulence in spots on this day. The first two penetrations were apparently in non-echoing clouds to the southwest of the main echo, but the third may have been partly in the echo associated with a weak echo notch on the south side of the storm.

30 July (Flight 238) - This was the second flight accomplished on 30 July. Some of the early penetrations appeared to be quite good, but the storms generally seemed to be in a diminishing stage throughout the flight. The clouds were definitely not as good as on Flight 237 earlier in the day.

11 July - This was a coordinated mission on rather weak clouds, in which six T-28 penetrations were accomplished. The clouds were not very well organized and radio malfunctions near the end of the mission caused some coordination problems.

4.2 TRIP Experiment

A total of 45 penetrations were made on four research flights in Florida during the latter part of the 1978 TRIP field season. No attempt will be made here to classify the storms in order of importance; instead, a brief description of the activities on each day will be given.

9 August - Nine penetrations were made between about 1520-1620 EDT on two different clouds, one northeast and the other southeast of the Orlando VORTAC, both at approximately 20 miles distance. The northern storm had quite strong updrafts, and the radar reflectivities in the storms were generally about 40 dBz. The penetrations began around 17,000 ft at relatively warm temperatures, and the particle sensors show clear evidence of millimeter-sized raindrops.

10 August - Ten penetrations were made on small clouds with weak echoes just west of Kennedy Space Center. The echoes were arranged in lines oriented approximately north-south. The penetrations were made between about 1205-1240 EDT at about 18,000 ft, and the tops of the clouds tended to be around 21,000 ft. Updrafts were generally weak and there were no thunderstorms present during these penetrations.

12 August - Eighteen penetrations were accomplished on three different storms in the TRIP operational area and just outside of the area on the northeast and northwest sides. This should have been a good case because the storms went through a towering cumulus

stage to light thundershower stage while the penetrations were being made between 1115-1230 EDT.

13 August - Eight penetrations were made on light thundershowers which developed around the Indian River in the early afternooon and then developed further to the west about 10 n mi from Orlando in north-south lines. These penetrations should also be good despite the fact that the storms were outside the TRIP operational area. The penetrations were made between about 1515-1615 EDT.

4.3 Data Samples

Preliminary investigation of the T-28 data gathered during the 1978 CSD and TRIP field seasons indicates that there are some marked differences, as well as many similarities, between Florida and Colorado clouds. Some of these differences and similarities are illustrated by the data samples presented below.

Figures 1 and 2 show segments of the standard T-28 data plot for 11 July (Colorado) and 13 August (Florida), respectively. The main difference illustrated here is that even though the penetrations were of roughly similar length (about 18 km), the updrafts in Florida seemed to occupy a larger proportion of the cloud than in Colorado. Cloud liquid water concentrations indicated by the Johnson-Williams liquid water concentration sensor were quite similar in spite of the higher adiabatic values found in Florida. The Colorado clouds studied were generally weaker than those in Florida; therefore, one should expect lesser amounts of cloud water in the former.

Samples of the cloud droplet spectra measured by a PMS FSSP probe are shown for Colorado (Fig. 3) and Florida (Fig. 4). There is a marked difference in that the spectra in Florida tend to be quite broad with droplets occurring all the way to the maximum size measured (45 μm diameter). In Colorado clouds, there appears to be an abrupt cutoff at droplet diameters of about 20 μm. The difference in these spectra may account in part for the low cloud liquid water concentrations observed in Florida, because the J-W instrument is insensitive to particles larger than about 30 μm in diameter and the spectra are somewhat similar below that limit. In support of this argument, LWC values computed from the Florida FSSP droplet spectra are frequently much higher than the J-W indications. The total droplet concentrations observed in Florida tend to be lower than those found in Colorado. These observations are consistent with the well known differences between continental and maritime clouds.

Figure 5 shows a sample of the PMS 2-D probe output from Colorado, while Fig. 6 shows similar output for a Florida cloud. The differences are remarkable in that the Colorado clouds tend to be characterized

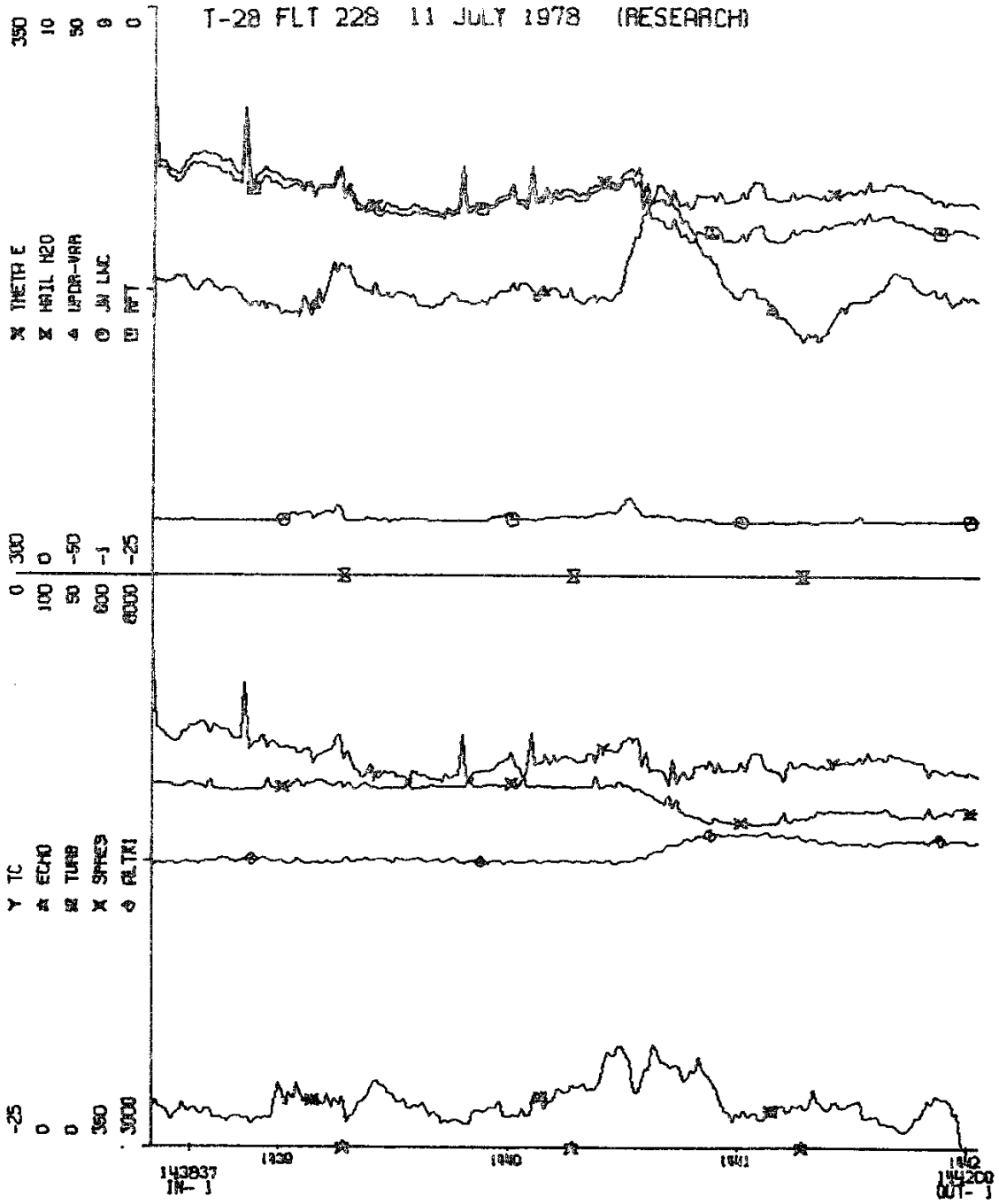

Fig. 1: Plot of data for a 4-min segment of the T-28 flight on 11 July 1978 in Colorado. Points of cloud entry and exit are indicated by the IN-1 and OUT-1 marks on the abscissa; the time scale (MDT) can be converted to an approximate distance scale using the nominal flight speed of 6 km/min. Variables plotted are indicated along the ordinate, with the scale range and plotting symbol indicated for each curve.

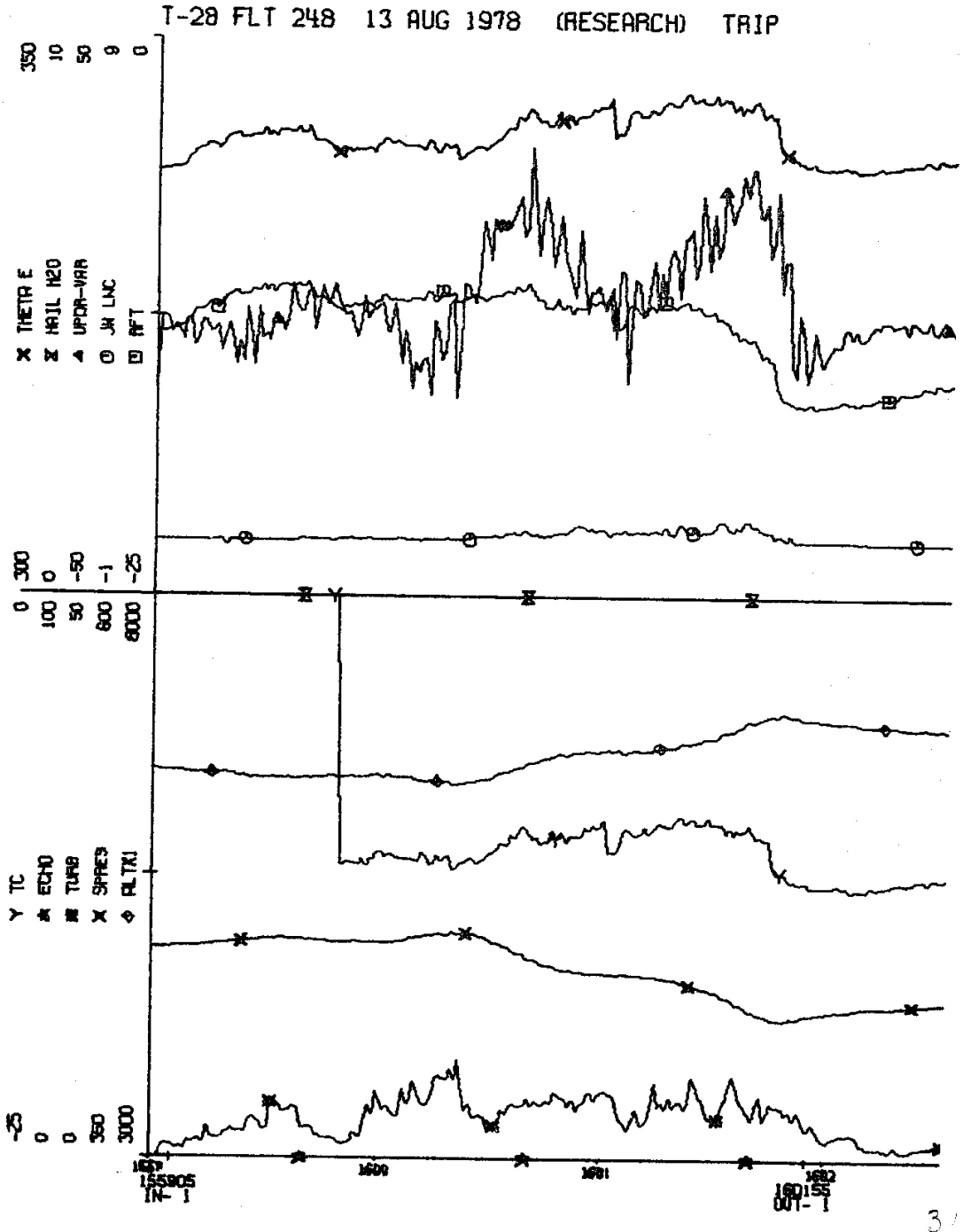

Fig. 2: Same as Fig. 1, except for a 4-min segment of the T-28 flight on 13 August 1978 in Florida.

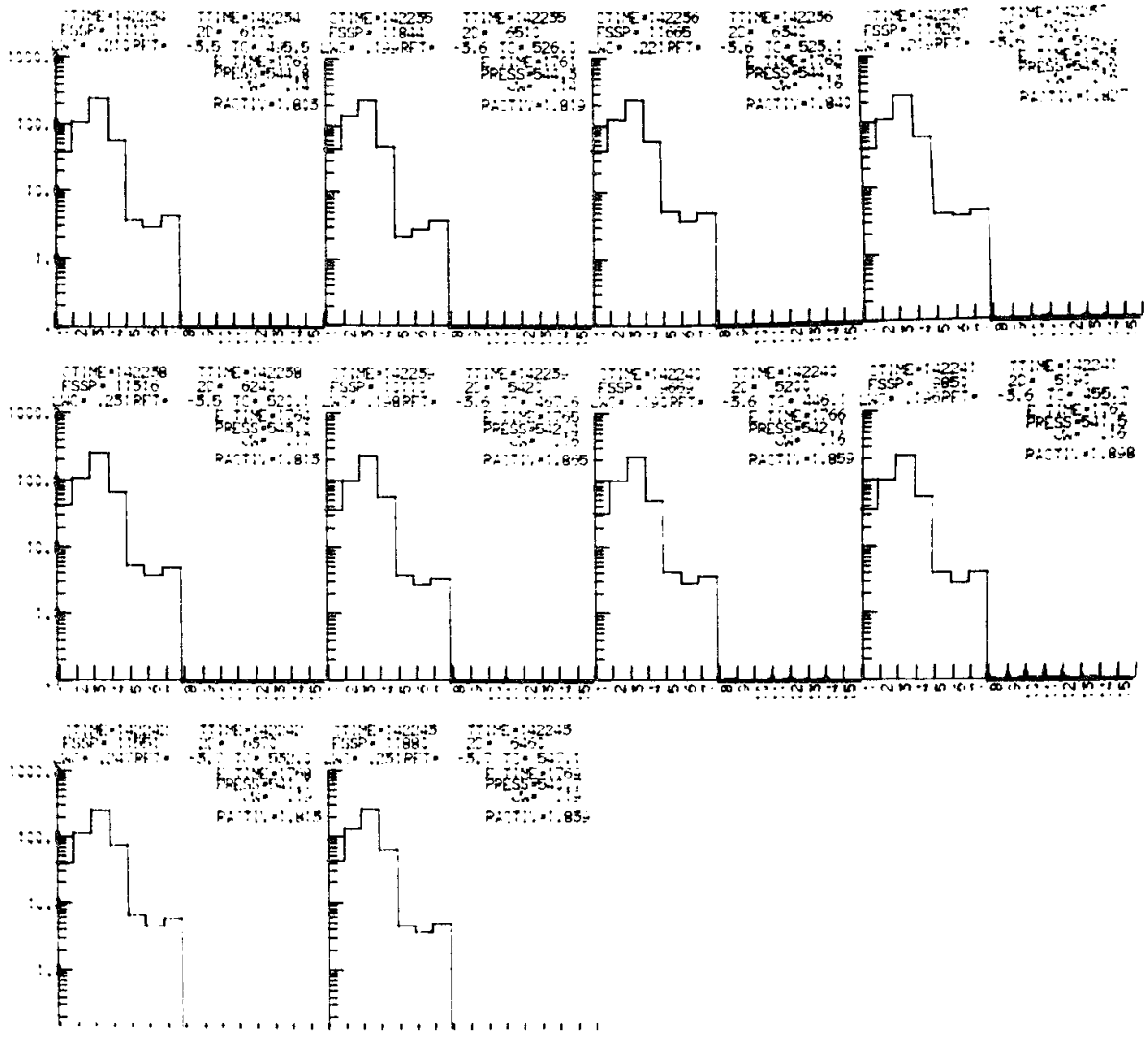

Fig. 3: Sample of FSSP cloud droplet spectra for a portion of a T-28 cloud penetration in Colorado on 11 July 1978. Each histogram represents the spectrum observed during a 1-sec sampling period. The abscissa represents droplet size channels in 3-μm diameter increments beginning with 3 μm. The ordinate represents number concentration (log scale) for each channel, in cm^{-3}. The legend with each histogram contains a variety of related information.

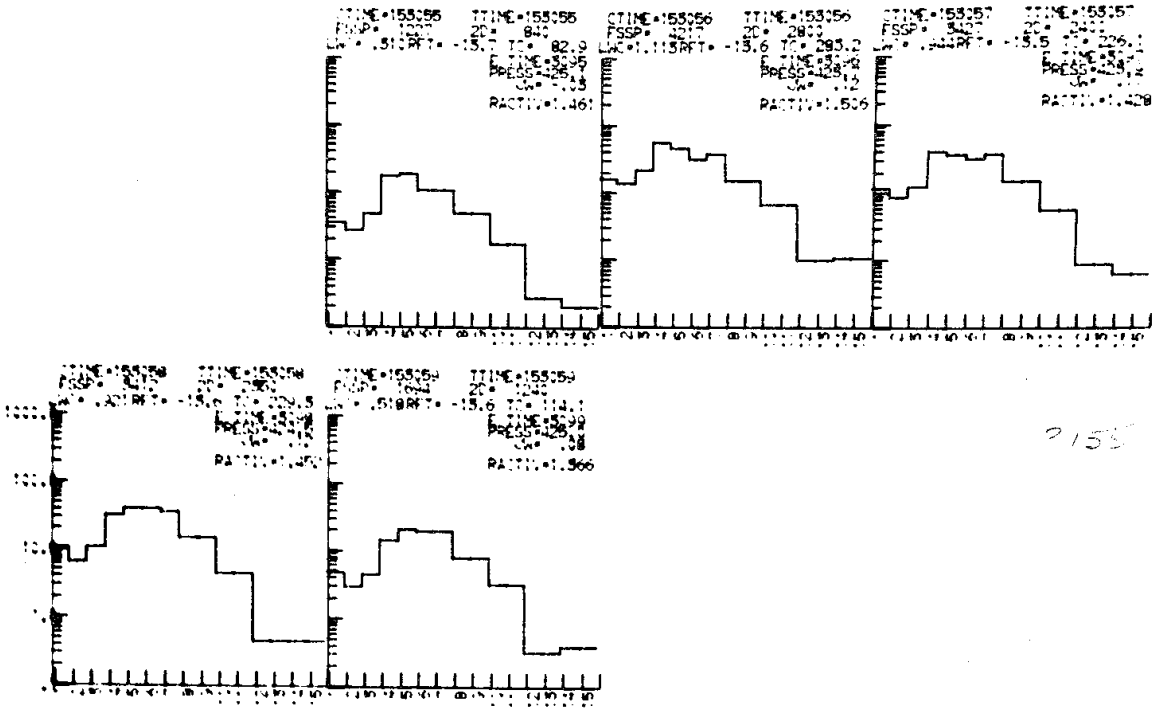

Fig. 4: Same as Fig. 3, except for a portion of a T-28 cloud penetration in Florida on 13 August 1978.

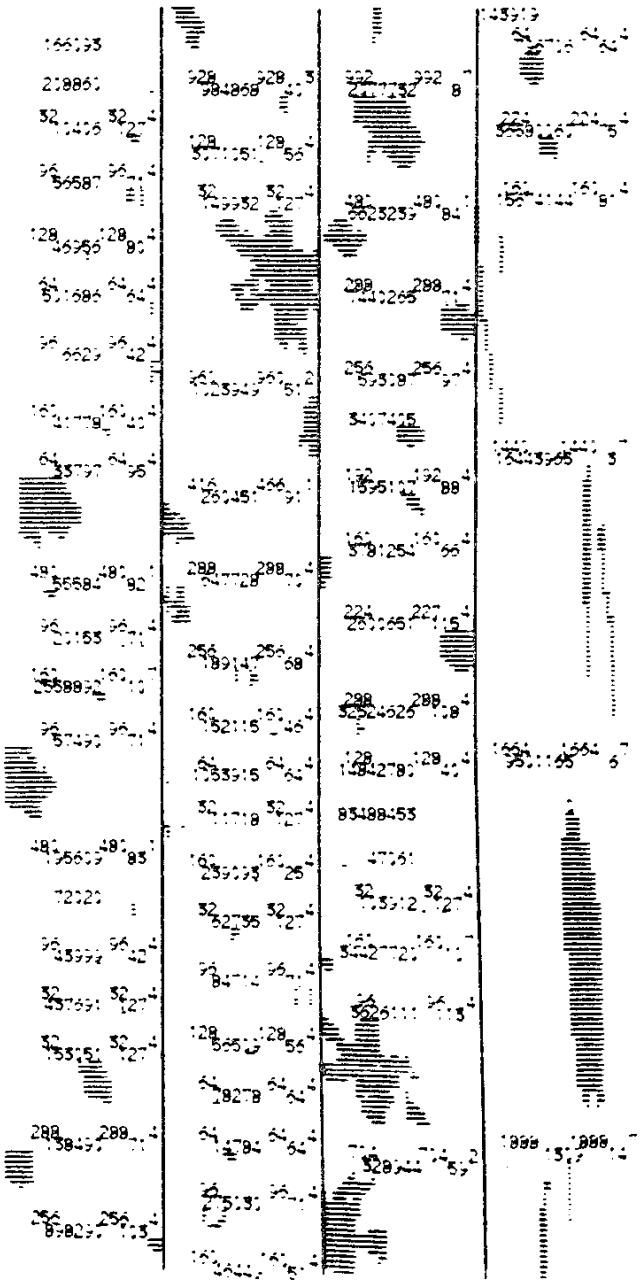

Fig. 5: Sample of the particle images obtained by the PMS 2-D probe during a T-28 penetration in Colorado on 11 July 1978. Distance between the heavy bars represents approximately 1 mm, giving an idea of the particle sizes represented. Numbers represent information about particle characteristics, distance between particles, etc.

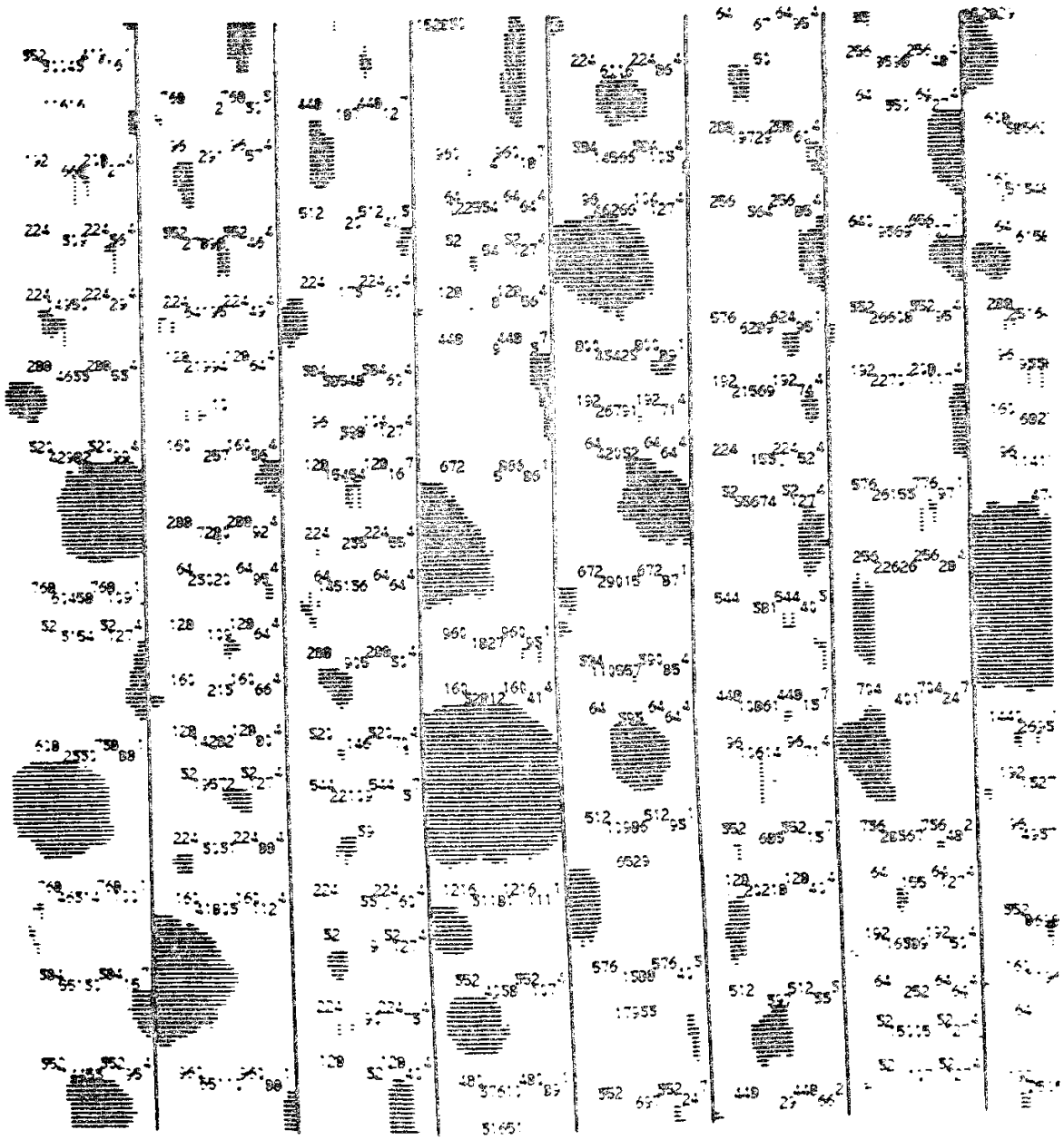

Fig. 6: Same as Fig. 5, except for a portion of a T-28 penetration in Florida on 13 August 1978.

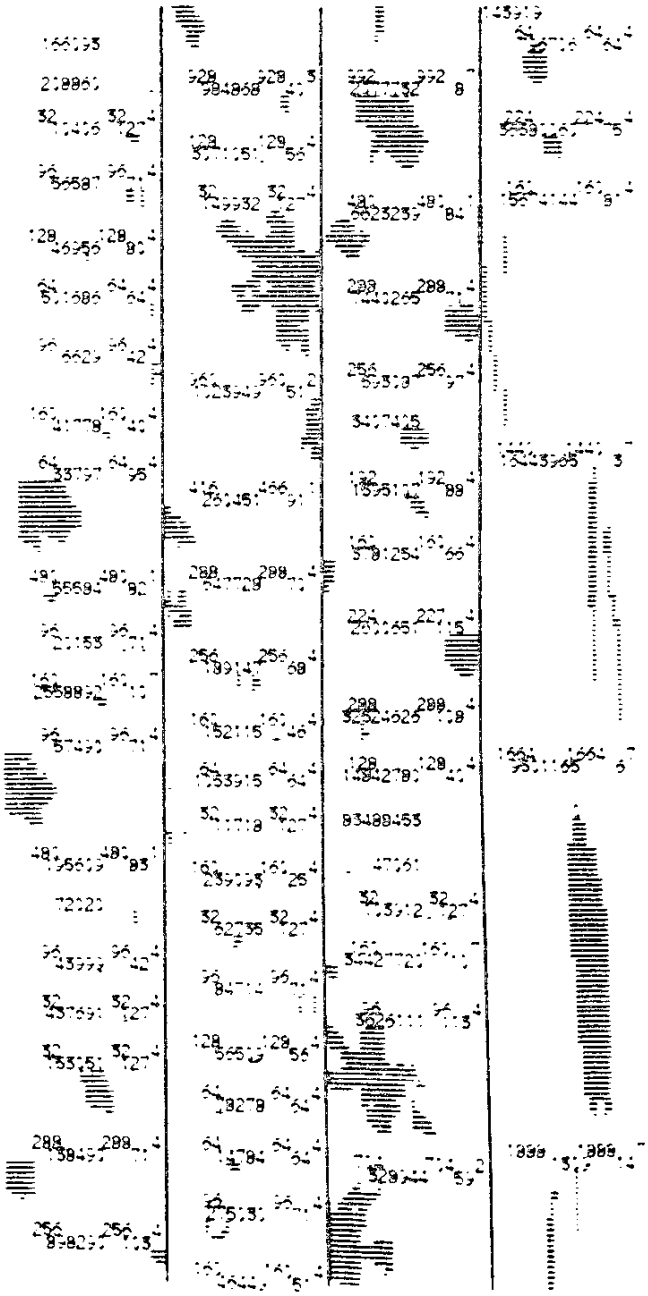

Fig. 5: Sample of the particle images obtained by the PMS 2-D probe during a T-28 penetration in Colorado on 11 July 1978. Distance between the heavy bars represents approximately 1 mm, giving an idea of the particle sizes represented. Numbers represent information about particle characteristics, distance between particles, etc.

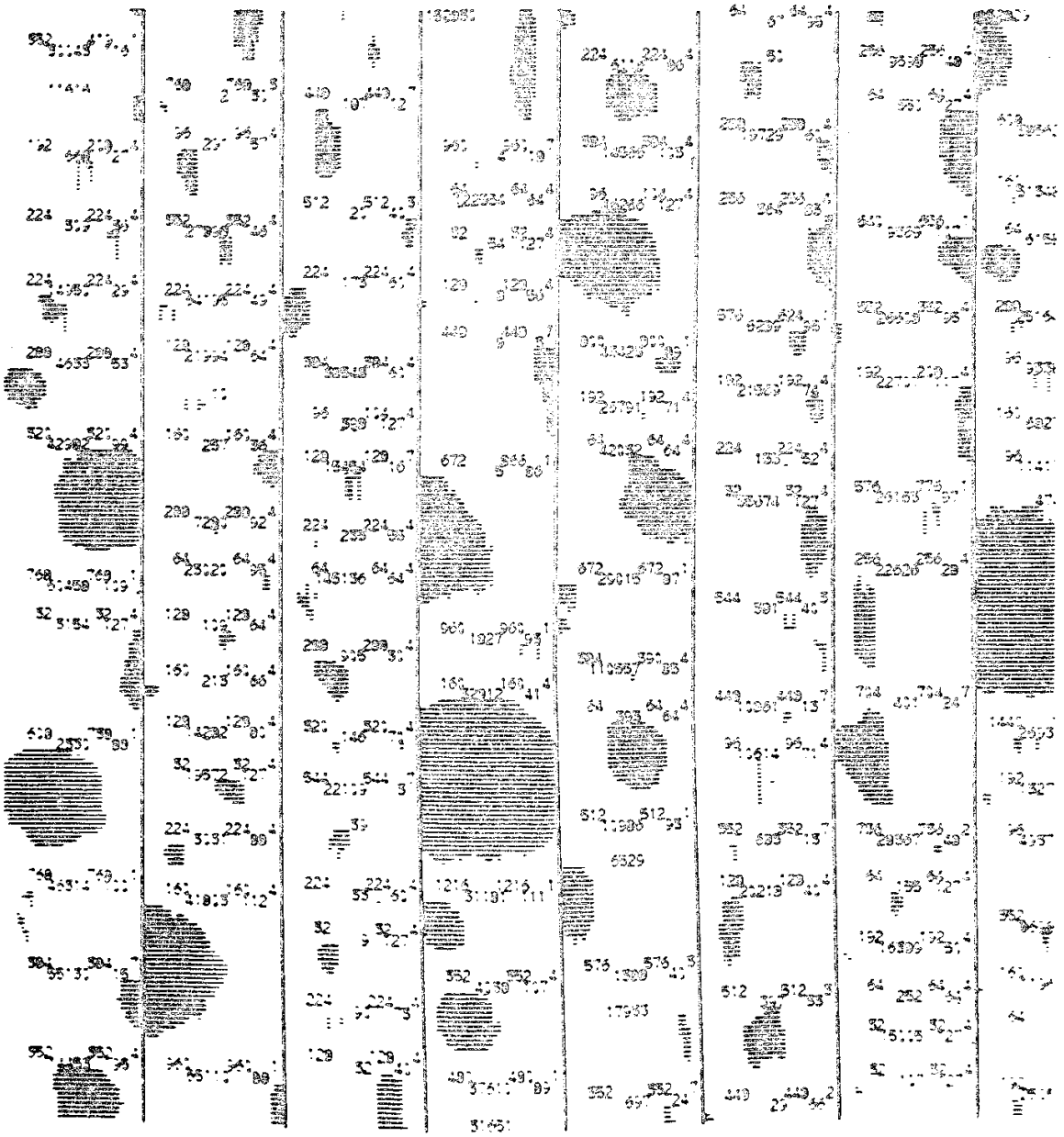

Fig. 6: Same as Fig. 5, except for a portion of a T-23 penetration in Florida on 13 August 1978.

by many dendritic crystal habits, while the Florida particles tend to be more uniform with roughly spherical shapes. Both the PMS 2-D probe and the foil impactor show that the number concentrations of precipitation-sized particles were generally much higher in Florida than in Colorado.

Observations from the Cannon camera (Figs. 7 and 8 for Colorado and Florida, respectively) support the 2-D PMS measurements. Furthermore, the uniform spherical particles from Florida show a strong tendency to be rimed frozen drops at colder temperatures (say, -10C or below), and liquid drops at warmer temperatures (around -5C). In Colorado clouds, any spherical particles found tend to be graupel, presumably having developed from the riming of the more irregular ice crystals.

The above data samples are preliminary and are presented for illustrative purposes only. More detailed analysis is necessary before drawing conclusions about the precipitation processes that might be involved.

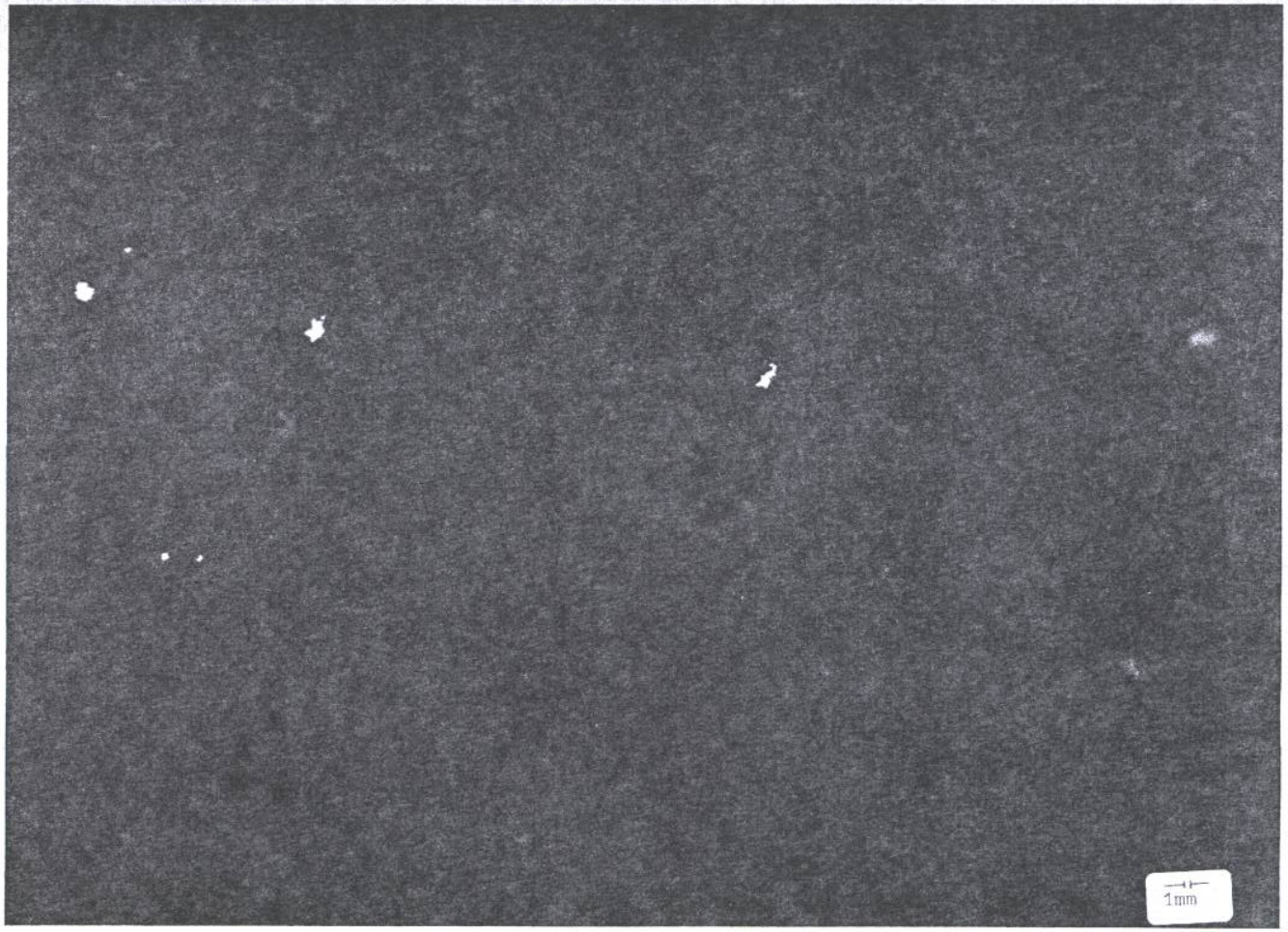

Fig. 7: Sample of Cannon camera photo from a T-28 penetration in Colorado on 30 July 1978. The volume in focus is about 10 liters and the largest particles represented are about 5 mm across.

Fig. 8: Same as Fig. 7, except for a T-28 penetration in Florida on 9 August 1978. Most of the particles visible are raindrops (as indicated by the dot pairs) 1 to 2 mm in diameter, and their concentration is about 9000/m^3.

ACKNOWLEDGMENTS

This research was supported by the National Center for Atmospheric Research under Prime Contract Number C460, Subcontract Number NCAR 182-71 and by the Atmospheric Research Section, National Science Foundation, under Grant Number ATM78-17326.