Report SDSMT/IAS/R-90/05 May 1990

T-28 PARTICIPATION IN THE 1989 NORTH DAKOTA THUNDERSTORM PROJECT

By: Andrew G. Detwiler, Dennis J. Musil
and Paul L. Smith

Prepared for:

North Dakota Atmospheric Resource Board
P.O. Box 1833
Bismarck, North Dakota 58502

Contract No. ARB-IAS-89-1

Institute of Atmospheric Sciences

South Dakota School of Mines and Technology

501 East St. Joseph Street

Rapid City, South Dakota 57701-3995

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1. INTRODUCTION

This is the summary report of convective storm observations conducted with the armored T-28 aircraft operated by the Institute of Atmospheric Sciences (IAS) of the South Dakota School of Mines and Technology (SDSM&T) for the 1989 North Dakota Thunderstorm Project (NDTP). This field project was based in Bismarck, North Dakota, during June and July 1989. A general description of the NDTP is contained in the North Dakota Thunderstorm Project 1989 Field Program Data Inventory (Hirsch, 1989). Copies of this report may be obtained from the IAS or from the North Dakota Atmospheric Resource Board.

The NDTP rose from the ashes of the planned Hailswath II program. Planning efforts for this large study of High Plains convective storms began in the mid-1980's. After several years of planning, a determined effort was made to mount the experiment in central North Dakota during the summer of 1989. When it became apparent in late 1988 that funding would not be available to mount the full scale Hailswath II, some of the principal scientists involved reorganized and planned for a smaller-scale field experiment which became the North Dakota Thunderstorm Project. Primary funding sources for the project were the National Oceanic and Atmospheric Administration (NOAA) through the Federal/State Cooperative Program in Atmospheric Modification Research, the National Science Foundation (NSF), and the State of North Dakota. Additional funding and/or facilities were made available by the National Center for Atmospheric Research (NCAR), the U.S. Bureau of Reclamation, the NOAA National Severe Storms Laboratory, the U.S. Department of Agriculture, and the North Dakota Army National Guard.

T-28 participation was originally requested in the Hailswath II program by the Hailswath II Steering Committee. The NCAR Research Aviation Facility Advisory Panel recommended allocation of the T-28 to the Hailswath II program at their 1988 fall meeting. This allocation was subsequently transferred to the NDTP. Funding to support T-28 participation in the NDTP came from the North Dakota Atmospheric Resource Board under Contract No. ARB-IAS-89-1. Additional support for scientific participation and data analysis was provided by the NSF under Grant No. ATM-8720252.

Data collection in the NDTP began on 12 June and continued through 22 July 1989. Six aircraft, three ground-based Doppler weather radars, and a variety of other facilities were focused on thunderstorms and lesser convection during this period. There were 18 formal experimental protocols put together by NDTP investigators. Three operations directors determined which experiments would be performed on which days. Their decisions, and the accumulated number of experiments of the different types performed, were reviewed by a Steering Committee throughout the project in an effort to make sure all experiments were performed a satisfactory number of times.

The T-28 was involved in several of these experiments, including Experiment 1, Mid-Cloud Treatment of Feeder Clouds with SF_6; Experiment 2, Mid-Cloud Treatment of Feeder Clouds with Chaff; Experiment 3, Cloud-Base Treatment of Feeder Clouds with Silver Iodide and Sulfur Hexafluoride; Experiment 4, Cloud-Base Treatment of Feeder Clouds with Chaff; Experiment 5, Cloud-Base Treatment of Isolated Cumulus Congestus Clouds with Silver Iodide and/or SF_6; Experiment 6, Mature Storm Studies Including Dynamic, Electrical and Chemical Measurements; Experiment 10, Surface Release of Sulfur Hexafluoride Tracer; Experiment 15, Tracer Studies of Entrainment in Cumulus Congestus; and Experiment 16, Mid-Cloud Treatment of Feeder Clouds with Fluorescent Particles. Summary descriptions of these experiments can be found in the Data Inventory (Hirsch, 1989). For most of these experiments, multiple aircraft and multiple radars were involved, as well as support from other facilities based on the ground.

This report summarizes the T-28 NDTP field operations and provides an overview of the data collected. Scientific analysis of the T-28 data, and related data as appropriate, is proceeding under other support from the North Dakota Atmospheric Resource Board and the National Science Foundation.

2. DESCRIPTION OF THE T-28 SYSTEM, PERSONNEL, AND PROJECT LOGISTICS

The T-28 and its basic instrumentation complement, as configured for the NDTP, are described in IAS Bulletin 90-1. The aircraft was equipped for measurement of a variety of cloud microphysics, kinematic and state variables, as well as navigation and aircraft performance variables. This instrumentation is summarized in Table 1.

During 1989, the T-28 also carried two special sets of instrumentation. The first was a sulfur hexafluoride (SF_6) analyzer supplied by North American Weather Consultants. This was used in experiments involving tracing air motion by sampling SF_6 concentrations at various levels after the SF_6 had been dispensed from a separate release aircraft (or, in Experiment 10, from the ground). Rigorous daily maintenance and calibration were performed in the field by North American Weather Consultants personnel. The second special set of instrumentation was a suite of four electric field mills borrowed from the New Mexico Institute of Mining and Technology and the National Center for Atmospheric Research. These rotating-shutter-type field mills were mounted in two pairs, one pair facing vertically up from the canopy and down from the baggage bay door, and the other facing laterally from each wing tip. They were used to provide in situ estimates of the vertical and lateral components of ambient electric field.

The new data acquisition system, installed early in 1989, consisted of an IBM PC-AT-compatible industrial grade microcomputer with 32 analog input channels and 16-bit analog-to-digital converters. The system was configured to accept two-dimensional image data from the PMS 2D-C probe, droplet size spectrum and concentration data from the PMS FSSP probe, hail concentration and size information from the IAS hail spectrometer, and standard meteorological data. Data were stored on a 40-megabyte streaming tape cartridge. The basic recording rate was once per second; however, several variables were recorded at higher rates. Electric field mill data, in particular, were recorded at 20 Hz. A summary of all of the quantities recorded, including some derived parameters which were computed after the fact from recorded variables, is included in Appendix A.

Data were recorded in a proprietary format designed by Science Engineering Associates, who designed and built the data acquisition system. The original data recording is on 3M MCD-40 minidata cartridges. Users of T-28 data from the 1989 NDTP will need to have IAS personnel provide reduced data in some standard format for their uses.

T-28 NDTP project personnel were: Dan Custis, pilot; Jon Leigh, mechanic; Gary Johnson, engineer; Ken Hartman, programmer; Dennis Musil, project meteorologist; Andy Detwiler, facility scientist and Paul Smith, facility manager.

TABLE 1: BASIC T-28 INSTRUMENTATION 1989

VARIABLE	INSTRUMENT	RANGE	ACCURACY	RESOLUTION (as recorded)	NOTES
STATIC PRESSURE	ROSEMOUNT 1301-A-4B	0-15 psi (0-103 kPa)	±0.015 psi (±0.1 kPa)	0.0002 psi (0.002 kPa)	• Bench calibration, 3/89
	ROSEMOUNT 1301-A-4B	5-15 psi (35-103 kPa)	±0.015 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 CONCENTRATION	0 - 6 g/m³	±20%	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 concentration ~±20%. Depends on processing.
PRECIPITATION PARTICLE SIZES AND CONCENTRATIONS	WILLIAMSON FOIL IMPACTOR	1 - 20 mm	0.25 mm	0.25 mm	• Sampling rate 1.4 m³/km
	PARTICLE MEASURING SYSTEMS, INC. 2D Cloud Probe	Size 25 - 800 μm	±25 μm	25 μm	• Computed ice and water concentration can vary ±50% with processing technique • Sampling rate: 0.1 m³/km; DAS can accept ~250 particles/sec (2500/km)
	HAIL SPECTROMETER	Size 4.5 mm - 5.4 cm Concentration 0 - 100/m³	±1 size class	1 size class	• 14 size classes; images available • Sampling rate 100 m³/km • Alternates with particle camera
	NCAR PARTICLE SAMPLER				• A batch sampler, primarily for hailstones • Sampling rate 2.6 m³/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.

For the first week of the project, the T-28 was hangared at the small National Guard hangar just south of the main terminal building at the Bismarck Municipal Airport. It was then moved to the Executive Air hangar just north of the main terminal building to make room for the University of North Dakota Citation at the National Guard hangar.

For safety and accuracy, T-28 storm penetrations were directed from the ground by Dennis Musil. He operated out of the NDTP Operations Center, site of the CP-3 5-cm Doppler weather radar at the Bismarck airport. Aircraft track information was displayed on the CP-3 radar display using information from the FAA air route surveillance radar located near Alexander in northwestern North Dakota. Because of the distance of the project location from the FAA radar, reliable radar tracks were not available when the aircraft was below ~10,000 ft MSL. The distance factor also led to some uncertainty in the track positions. That, coupled with concerns about the effects of attenuation on the C-band weather radar data, impaired the capability to conduct precision penetrations in some storms with high reflectivity factors.

3. FLIGHT OPERATIONS

The T-28 was a potential participant in many of the experiments specified for the NDTP. However, its priority use was for investigations of large hail-bearing storms, mainly Experiments 1 through 4 (tracer experiments on feeder clouds), and Experiments 6 (mature storms) and 16 (hail embryo tracing). Operations directors typically held the T-28 for launch until well after other project aircraft were in the air, waiting for the development of potentially hail-bearing clouds. There was a scarcity of large hail-bearing clouds having feeder cells within the region of dual-Doppler coverage for the NDTP. Therefore the T-28 was launched for just six convective storm studies during the six-week project. Relatively mature storms were encountered on all of these flights, most in their decaying stages. None turned out to contain large hail.

A summary of all T-28 flights during the project is contained in Table 2. Flight track data are contained in Appendix B; Appendix C contains pilot's notes for each penetration of the research flights; and Appendix D contains notes from the weather briefings on days on which the T-28 operated. Additional information concerning the activities on days of research flights is contained in the following paragraphs.

TABLE 2: T-28 FLIGHTS FOR NDTP

DATE	FLT #	FLT TIME (h)	INFORMATION
6-11-89	510	1.2	Ln Bismarck for Project
6-16-89	511	2.0	Lcl Test
6-17-89	512	1.4	Lcl Test
6-19-89	513	1.9	To MSP - Prop Repair
6-21-89	514	2.3	Return to Bismarck
6-23-89	515	2.6	Research
6-27-89	516	2.6	Research
7-06-89	517	3.0	Research
7-07-89	518	2.6	Research
7-10-89	519	1.8	Research
7-15-89	520	2.4	Research and Inst. Test
7-17-89	521	2.0	Research
7-22-89	522	2.0	Ferry Bismarck to Rapid
Total Flight Hours		27.8	

Date: 23 June
Take-off: 1414
Land: 1650
Flight: 515

Summary: Research flight in support of Experiment 6, Mature Storm Studies. The T-28 first headed north and west of Bismarck, performed one penetration and then proceeded south of Bismarck and made four more penetrations. Operations were frustrated by rapidly evolving clouds. There were also numerous operational problems with radio communications, radar, and display of aircraft tracks. Clouds had unusually low equivalent potential temperatures, weak dynamics and only moderate liquid water concentrations. Radar reflectivities were also quite low at the penetration altitude of 4000 m MSL. The hail spectrometer indicated particles up to 1.4 cm in size. Following the final penetration south of Bismarck, the T-28 and NOAA P-3 linked up for a side-by-side electric field mill intercomparison. The two flew wing tip to wing tip over the Bismarck airport in clear air 1 km above the ground.

Data quality problems on this flight include: 1) the second DME was not locked on to any station; 2) the 2D-C data included a high frequency of zero-element images appearing in both buffers, making the data practically unusable; and 3) foil in the foil impactor ran out during the flight.

Date: 27 June
Take-off: 1915
Land: 2125
Flight: 516

Summary: T-28 coordinated with Duke (project aircraft used for release of SF_6 and AgI) in mid-cloud treatment of feeder cells with SF_6 (Experiment 1). Operations were carried out in what appeared to be feeder cells in three different systems south and west of Bismarck, followed by penetration of a larger cloud on the return leg to Bismarck. Ten penetrations were accomplished on this flight. The initial penetrations were carried out at nearly 6000 m MSL. The SF_6 analyzer was at the outer limit of its range of stability at this altitude. By the time of the second penetration the characteristic oscillations with ~10 s period were observed in the analyzer output, indicating that the instrument could not function at this altitude. To improve the performance of the analyzer, the aircraft subsequently dropped about 500 m in altitude.

Despite the oscillations there was an apparent plume hit during the first penetration and some possible plume hits in several subsequent penetrations. The indicated SF_6 concentrations were very low, on the order of a few tens of parts per trillion. This is consistent with visual and radar observations which indicated that the clouds were weak and in a dissipating stage during the penetrations, even though respectable updrafts were occasionally encountered by the Duke. The early T-28 penetrations encountered moderate amounts of supercooled cloud water with low ice particle concentrations. Very little hail was observed on this flight.

The foil also ran out on this flight; very few particle impressions were observed on the foil that was exposed.

Date: 6 July
Take-off: 1731
Land: 1944
Flight: 517

Summary: Four penetrations were made in relatively weak thunderstorms, 75 to 80 nautical miles south of Bismarck (Experiments 1 and 6). Penetrations were at 4500 m MSL, the melting level, generally in east-west directions. Due to the distance of the aircraft from the tracking radar near Alexander, flight tracks were not available in real time and penetrations were accomplished visually by the pilot with general guidance from the meteorologist working at CP-3. This type of penetration work was possible only because the storms were weak, although they were arranged in a roughly east-west line resembling a feeder system. DME No. 2 was locked onto the Dupree, South Dakota VORTAC. VOR and dual DME data were used after the flight to reconstruct a high quality aircraft track for use in research. Moderate vertical drafts were observed, but the storm had low cloud liquid water concentrations. The hail spectrometer showed particles up to more than one centimeter on the third penetration.

The data acquisition computer failed during taxi and again on take-off; it was rebooted at altitude and worked well for the rest of the flight. High temperature during start-up and taxi at the ground seemed to be the problem. The VOR was intermittent during the flight, probably also due to high temperature in the cockpit.

Date: 7 July
Take-off: 1338
Land: 1531
Flight: 518

Summary: This was a coordinated Experiment 3, Treatment of an Isolated Cumulus Congestus, involving the Duke, the University of North Dakota Citation and the University of Wyoming King Air (two aircraft instrumented for general cloud physics and dynamics measurements as well as SF_6 detection), along with the T-28. The non-echoing cumulus was approximately 30 nautical miles west of Bismarck during the first penetration. Two more penetrations were made approximately 15 to 30 nautical miles north of Bismarck, in clouds with weak echoes and less satisfactory coordination between the aircraft (Experiment 6). The clouds lacked real organization.

The T-28 did not encounter any strong SF_6 plumes; however, there were several episodes of relatively narrow pulses that would correspond to SF_6 concentrations on the order of a few tens of parts per trillion. These are in the noise level for the T-28 instrument due to the lack of pressurization in the T-28 cockpit. However, useful information may be extracted from these data if they are analyzed in detail. Clouds were in a weak or dissipating state during all of the penetrations, but indications of hail larger than 1 cm were found.

Date: 10 July
Take-off: 1933
Land: 2133
Flight: 519

Summary: A series of seven penetrations were made through a moderate thunderstorm 50 nautical miles northwest of Bismarck. The T-28 was operating solo during this effort in support of Experiment 6, Mature Storm Studies. Penetrations were generally between 4,500 and 6,000 m MSL. Storms had maximum reflectivities of 50-55 dBz, generally well below T-28 penetration altitudes. Reflectivities at penetration altitudes were probably 40 dBz or less. The aircraft was in-cloud early in the flight from 2000 to 2030 as it penetrated to the northwest, never broke out of cloud, then turned and returned towards Bismarck. One final penetration was made during descent from 4,200 m on the return to Bismarck airport. Stronger updrafts and higher cloud liquid water concentrations than in previous ones during this project were encountered on this flight along with moderate hail. The hailstone concentrations ranged up to 20 m^{-3}, with the largest observed size being 2.9 cm. The storms were electrically active.

Due to the length of time spent in-cloud, foil data are available only for the first cloud penetration. Communications with the project meteorologist were a problem, particularly during the first penetration when the aircraft reached almost 80 nautical miles range from Bismarck.

Date: 14 July
Take-off: 1535
Land: 1742
Flight: 520

Summary: The T-28 participated with the Citation and P-3 during a ground release of SF_6, silver iodide and radar chaff (Experiment 10). The T-28 flew north and south legs across wind at various altitudes between 150 m and roughly 1 km above ground level. There was also a short intercomparison flight with the Citation.

Both the Citation and T-28 recorded many plume intercepts. The Citation found SF_6 up to within 200 feet of cumulus tops, at roughly 12,000 ft MSL.

The T-28 data acquisition computer failed several times during the flight due to heat in the baggage bay; three data segments could be retrieved following the project. The pilot was opening and closing the cockpit because of the heat problems and it was found that opening and closing the cockpit produced spikes in the SF_6 analyzer data that resembled plume intercepts. Interpretation of SF_6 analyzer data from this flight will require some care.

Date: 17 July
Take-off: 1457
Land: 1639
Flight: 521

Summary: Activity on 17 July began in the morning with the takeoff of several of the project aircraft to investigate a series of severe storms passing over the Bismarck area. The T-28 took off at 1457 and performed a total of four penetrations of a large line of cells oriented north-south which passed over Bismarck and dissipated during the T-28 flight. The T-28 effort was in support of Experiment 6, Mature Storm Studies. The line was wide and the earlier penetrations were long. Cloud conditions were very cluttered and the flight virtually IFR for the entire time. The first three penetrations were to the north of the most intense part of the line where radar reflectivities exceeded 55 dBz, the limit set for safe T-28 operations.

Moderate vertical drafts and liquid water concentrations were observed. The aircraft picked up about an inch of ice during the first penetration and retained it during most of the flight. Very high ice particle concentrations were found on the first three penetrations. The T-28 encountered hail up to 1.4 cm on this flight.

The FSSP data may be somewhat questionable due to the icing. In addition, there were some apparent influences of the icing on the Rosemount temperature sensor.

4. DATA SUMMARY

4.1 Tabular Summary

A general summary of the data collected during T-28 NDTP cloud penetrations is given in Table 3. It contains a summary of penetration data from the six research flights involving cloud penetrations.

A seventh flight, Flight 520 on 14 July, involved tracing sulfur hexafluoride plumes released from the ground in clear air. The VOR was intermittent during this flight due to high temperature in the cockpit (as well as the low operating altitude), and the data are broken into segments due to three failures of the T-28 data acquisition system. Estimates of aircraft position accurate to within roughly a kilometer can be made using the pilot's notes if such information would be of use to NDTP investigators.

In Table 3a positions of **cloud entry** and **cloud exit** are given as latitude/longitude. The tabulated values are in degrees and then decimal minutes. **Altitude** (Table 3b) is computed from the observed static pressure as the geopotential altitude in the mid-latitude standard atmosphere. The penetration maximum **equivalent potential temperature** (θ_e) is computed assuming 100% relative humidity with respect to liquid water.

The values of peak **up-** and **downdrafts** during penetrations are taken from computations according to the method proposed by Kopp (1985). The rate of change in aircraft pressure altitude is computed as a centered difference over 2 s. This represents a change from the prior standard practice in T-28 data reduction; in past years, this computation has been done using a 9 s running average of the change in aircraft altitude. The new practice typically results in somewhat higher peaks compared to the old practice. It also makes the computed updraft more sensitive to noise in the static pressure reading. This noise can, on occasion, introduce ± 10 m s^{-1} updraft/downdraft couplets into the computed updraft.

The maximum **liquid water concentration** given is the maximum reported by either the JW cloud water meter or the PMS FSSP. In general, for concentrations less than ~0.8 g/m^3, the FSSP tended to indicate higher values than the JW. For water contents greater than this, usually the JW indicated higher values than the FSSP. The differences were generally within 20% of the higher value.

The 2D-C maximum **shadow-or** concentration is an estimate of particles larger than approximately 25 μm detected by this probe. This may include some of the larger cloud droplets, but can generally be considered as representing ice particle concentration in most T-28 penetrations. The volume sampling rate for the 2D-C is taken to be

TABLE 3a: T-28 DATA SUMMARY (PENETRATION TIMES AND LOCATIONS)

DATE	IAS FLT #	TAKEOFF (HH:MM)	LANDING (HH:MM)	PEN #	TIME ENTRY (HH:MM:SS)	TIME EXIT (HH:MM:SS)	POSITION ENTRY (LAT.)	POSITION ENTRY (LONG.)	POSITION EXIT (LAT.)	POSITION EXIT (LONG.)
23 June	515	14:14	16:50	1	15:09:00	15:15:00	46 54.58	101 02.15	46 38.57	100 54.77
				2	15:39:27	15:39:49	46 40.15	100 53.12	46 41.57	100 54.57
				3	15:42:15	15:46:42	46 39:37	100 51.22	46 36.48	100 29.78
				4	15:49:24	15:52:36	46 35.50	100 31.33	46 29.58	100 44.32
				5	16:02:16	16:04:04	46 38.02	101 17.82	46 39.95	101 25.70
27 June	516	19:15	21:25	1	20:09:45	20:10:06	46 6.18	101 55.15	46 5.78	101 53.63
				2	20:24:39	20:25:31	46 21.87	101 15.33	46 23.38	101 10.82
				3	20:28:27	20:29:18	46 23.33	101 9.35	46 22.58	101 13.63
				4	20:34:29	20:36:36	46 20.87	101 11.05	46 22.82	101 5.13
				5	20:38:15	20:38:55	46 23.33	101 09.35	46 21.58	101 11.50
				6	20:41:43	20:42:27	46 16.15	101 18.65	46 14.42	101 22.97
				7	20:45:26	20:46:23	46 12.72	101 21.68	46 13.53	101 16.52
				8	20:49:41	20:51:54	46 15:18	101 13.63	46 8.37	101 16.80
				9	20:56:01	20:56:58	46 9.98	101 16.82	46 12.43	101 13.85
				10	21:04:06	21:06:33	46 22.63	100 56.95	46 28.30	100 47.25
6 July	517	17:31	19:44	1	18:08:47	18:11:45	45 29.86	101 04.13	45 28.35	100 50.24
				2	18:13:49	18:28:28	45 29.60	100 41.82	45 25.17	100 56.60
				3	18:32:54	18:39:17	45 32.67	100 51.00	45 30.53	100 21.65
				4	18:45:51	18:49:50	45 25.33	100 21.54	45 22.73	100 34.34
7 July	518	13:38	15:31	1	14:35:15	14:45:21	46 51.32	101 24.73	46 49.85	101 15.03
				2	14:50:02	15:07:38	46 50.43	101 2.32	46 58.37	100 30.65
				3	15:09:42	15:20:53	46 58.52	100 24.82	47 0.95	100 19.03
10 July	519	19:33	21:33	1	20:01:50	20:16:03	47 10.50	101 43.67	47 35.37	102 19.00
				2	20:16:51	20:30:05	47 34.97	102 15:25	47 13.75	101 39.68
				3	20:46:06	20:51:25	47 19.72	101 14.63	47 30.65	101 33.53
				4	20:54:03	20:59:49	47 32.08	101 28.37	47 18.15	101 8.92
				5	21:02:56	21:09:57	47 12.58	101 3.27	47 37.48	101 10.70
				6	21:09:57	21:18:58	47 37.48	101 10.70	47 16.73	101 7.25
				7	21:18:58	21:25:51	47 16.73	101 7.25	46 58.35	100 52.82
14 July	520	15:35	17:42							
17 July	521	14:57	16:39	1	15:25:25	15:34:23	47 1.83	100 58.17	46 42.32	101 26.17
				2	15:41:00	15:52:00	46 51.35	101 13.22	47 12.78	100 28.17
				3	16:01:08	16:07:08	47 9.38	100 35.72	46 53.12	100 52.40
				4	16:20:11	16:22:54	46 36.40	100 43.43	46 37.62	100 29.55

TABLE 3b: T-28 DATA SUMMARY (TEMPERATURE, VERTICAL WIND, CLOUD WATER, ICE PARTICLES)

DATE	IAS FLT #	PEN #	ALT. (m)	T AVE. (°C)	θ_e Max (K)	UP MAX (m/s)	DOWN MAX (m/s)	LWC MAX (g/m³)	FSSP MAX CONC (#/cm³)	2D-C MAX SH-OR (#/l)	2D-C >50 μm MAX CONC (#/l)
23 June	515	1	3950	- 8	316	3	- 4	0.81	618	260	8
		2	3950	- 8	314	1	- 7	0.50	480	41	2
		3	3950	- 8	314	8	- 6	0.30	340	278	120
		4	3950	- 8	315	4	- 8	0.60	615	353	110
		5	3950	- 8	314	2	- 5	0.10	400	143	48
27 June	516	1	5800	-13	331	3	- 4	0.65	455	1	0
		2	5950	-15	331	11	- 6	0.65	400	2	0
		3	5950	-15	329	2	- 8	0.67	400	10	20
		4	5525	-12	327	2	- 6	0.10	190	7	6
		5	5650	-13	328	6	- 8	0.17	270	5	0
		6	5500	-11	329	1	- 6	0.43	320	141	96
		7	5500	-11	329	4	- 4	0.15	11	344	167
		8	5500	-12	327	7	- 4	0.07	4	47	53
		9	5600	-13	327	2	- 4	0.10	5	79	62
		10	5525	-13	327	6	- 7	0.17	8	310	177
6 July	517	1	4450	0	339	4	-10	0.25	450	0	0
		2	4475	0	339	10	-11	0.22	440	52	41
		3	4425	0	337	4	- 8	0.20	435	39	40
		4	4400	- 1	338	8	- 7	0.18	420	0	0
7 July	518	1	4990	- 6	334	6	-12	0.10	475	8	2
		2	5075	- 6	334	4	-12	0.20	455	196	181
		3	5025	- 7	333	2	- 7	0.25	415	229	239
10 July	519	1	5850	-11	336	7	- 6	0.85	364	713	503
		2	5880	-11	338	7	- 8	0.84	423	732	633
		3	5650	-10	337	6	- 5	0.70	330	575	492
		4	5550	- 8	337	10	- 5	1.00	390	591	435
		5	4650	- 5	337	5	- 5	.54	369	173	157
		6	4680	- 4	337	7	- 6	1.24	331	216	177
		7	4650↓	- 4↑	335	5	- 7	1.16	391	29	32
14 July	520										
17 July	521	1	5720	-13	332	11	-14	1.55	580	1756	1363
		2	5570	-13	332	12	-11	0.77	175	1603	1921
		3	5570	-13	333	13	-16	0.80	165	1459	1615
		4	5540	-12	330	9	-11	0.25	17	365	294

TABLE 3c: T-28 DATA SUMMARY (PRECIPITATION PARTICLES, ELECTRIC FIELDS)

DATE	IAS FLT #	PEN #	2D-C MAX SIZE (mm)	HAIL MAX CONC (#/m³)	HAIL MAX SIZE (mm)	FOIL MAX CONC (#/m³)	FOIL MAX SIZE (mm)	φ MAX (kV/m)	φ MIN (kV/m)
23 June	515	1	1.0	1	6.5			151	- 60
		2	0.8	0	0.0			0	0
		3	3.6	16	10.2			85	- 85
		4	2.6	10	14.3			45	-205
		5	2.9	2	7.5			25	- 90
27 June	516	1	0.0	0	0.0			1	- 1
		2	0.0	0	0.0			1	- 1
		3	2.9	0	4.5			0	- 0
		4	1.5	0	0.0			5	0
		5	0.0	0				1	0
		6	3.1	0	4.5			50	0
		7	4.5	1	6.5			77	0
		8	3.9	1	7.5			98	- 12
		9	4.4	1	6.5			30	- 33
		10	4.7	2	8.7			100	- 57
6 July	517	1	0.1	0	5.5			1	0
		2	2.6	0	8.7	145	2.9	18	0
		3	4.4	3	12.0	75	2.8	1	- 1
		4	0.0	0	4.5			1	0
7 July	518	1	0.7	0	0.0			1	- 2
		2	4.7	8	10.2			160	- 90
		3	4.7	5	14.3			135	- 90
10 July	519	1	4.4	20	.9			99	- 84
		2	4.6	8	1.3	524	4.4	103	- 70
		3	3.6	12	17.0			45	- 10
		4	4.7	14	12.0			85	- 40
		5	4.6	12	3.2			156	-196
		6	4.0	18	3.2			154	-179
		7	4.6	1	3.2			1	- 3
14 July	520								
17 July	521	1	4.7	3	14.3			157	- 85
		2	4.7	6	12.0			127	- 95
		3	4.4	0	8.7			120	-109
		4	4.8	1	7.5			89	- 82

5 ℓ s^{-1} for this computation. The maximum concentration of **particles >50 μm** is based on the 2D-C image data. This is computed using the IAS ANALYZE_2D program (see Hartman and Detwiler, 1989). It also should represent the concentration of ice particles at the altitude of the T-28 penetrations.

In some cases, the concentration of particles > 50 μm computed from the image data exceeds the concentration of particles > 25 μm based on the shadow-or count. These numbers represent two independent estimates of maximum particle concentration. The shadow-or count represents continuous monitoring of the rate at which the 2D-C probe is triggered by the presence of particles. The maximum concentration estimated from the images represents a somewhat different quantity due to the intermittent way in which the 2D-C accepts image data (see Hartman and Detwiler, 1989). In addition, this concentration is based on particles large enough to be imaged (~50 μm) and excludes those particles which may trigger the probe but are not large enough to be imaged. For each estimate of concentration from the 2D-C image data, we require integration over 1 s of active probe sampling time. It may take up to 20 s of flight time to accumulate 1 s of active probe time in areas of high particle concentration. Thus, the peaks computed in the two different methods do not necessarily represent samples from the same volume of cloud during a given penetration.

The **2D-C maximum size** column (Table 3c) contains data on the largest particle detected by the 2D-C probe. Our 2D-C image analysis routine includes reconstruction of partially-imaged particles, if they appear to be symmetrical, following the technique of Heymsfield and Parrish (1979). The **hail maximum concentration** and **maximum size** data come from the IAS hail spectrometer which was operated in the so-called 1-D mode for this project. Images were not recorded. **Foil data** were reduced using a modification of the technique developed by Peterson (1989) for digitizing images of the foil and then counting and sizing a number of impressions in each image using automated computer algorithms. Only impressions larger than 1 mm across are included in the computed concentrations shown. Comparison between the foil data and the 2D-C data during the first penetration on Flight 519, for particles larger than a millimeter, showed that the 2D-C generally detected a much higher concentration of particles than the foil in this size range. We suspect that the foil underestimates the concentration of low-density graupel particles like those observed during this penetration.

The peak positive and negative **vertical potential gradient** values listed have not been corrected for the enhancement of the ambient electric field due to the presence of the conducting aircraft. Estimates of this factor for other aircraft suggest that the values given in Table 3c should be divided by a factor somewhere between two and three to arrive at an estimate of the actual **vertical potential gradient** in the volumes penetrated by the T-28.

A more detailed summary of foil data than is offered in Table 3 is shown in Table 4. Data quality was generally good, except for those instances noted in the flight summaries given in Section 3.

Foil data containing impressions of particles 1 mm or larger were obtained on only two flights, those of 6 and 10 July, indicating the relatively weak nature of most of the mature storm regions that the T-28 penetrated during the NDTP. More data might have been obtained from the flight on 10 July except that the foil apparently jammed near the end of the second penetration.

Replacement of a card in the PMS 2D-C, a PMS 240 card, following the flight on 23 June resulted in nearly perfect 2D-C data for the remaining research flights of the project. Replacement of the 2D-C probe tip heaters also aided the nearly flawless performance of this probe later in the project.

No particles of any interesting size were captured in the NCAR hail collector during any of the cloud penetrations.

The T-28 missed perhaps the most intense storm to pass through the project area during the season. This storm passed right over the Bismarck area early on the evening of 28 June. The T-28 had been trying to get off at about 1800 but the data system failed due to excessive heat in the baggage bay. Outside air temperature was roughly 100°F at this time. The instrument engineer cooled the computer down with some dry ice, but by the time the T-28 was ready to join the party, the operations directors were calling the other aircraft back in. A hail shaft containing low concentrations of golfball-size hail passed over the airport at roughly 1930 hours. The T-28 crew obtained an extensive sample of the larger hailstones.

4.2 Examples of T-28 Observations

4.2.1 Electric fields in feeder clouds

The addition of electric field mills to the aircraft instrumentation suite makes T-28 data useful for investigations of the relationship between cloud dynamics, precipitation development, and electrification in clouds. Feeder cell penetrations during Flight 516 (27 June) provide a good example. Figure 1 shows that there was a correlation between 2D-C shadow-or counts (proportional to ice particle concentration) and vertical potential gradient during 7 penetrations through at least two different feeder cloud elements at ~5.5 km MSL. The horizontal axes are labeled in decimal hours with tic marks at 1-minute (~6 km) intervals.

Figure 2 shows the aircraft track for this segment of the flight. The track begins at about 20:20 CDT (i.e., 20.33 decimal hours) and is labeled at 1-minute intervals with the least significant minute digit. The early penetrations show low ice particle concentrations and negligible potential gradient (Fig. 1). Beginning with the

TABLE 4: FOIL DATA -- NORTH DAKOTA 1989

FLT NO.	DATE	PEN NO.	START	STOP	COMMENTS
515	23 Jun	--	--	--	Particles too small.
516	27 Jun	--	--	--	Foil has too many pock marks, too few particles.
517	6 Jul		18:08:47	18:49:50	
		1	18:08:47	18:11:45	Nothing.
		2	18:13:49	18:28:29	
			18:14:59	18:15:19	Small particle sizes.
			18:15:39	18:16:19	Small particle sizes.
			18:16:29	18:17:39	Good sized particles.
			18:18:49	18:19:19	Small particle sizes.
		3	18:32:54	18:39:24	
			18:34:54	18:35:44	Good sizes; very few.
			18:37:04	18:38:04	Very few.
			18:38:14	18:39:24	Good sizes.
		4	18:45:51	18:49:50	Nothing.
518	7 Jul				Nothing.
519	10 Jul		20:01:50	20:29:30	No pen marks to tell where pens quit.
		1	20:02:57	20:04:45	Small sizes.
			20:06:35	20:06:43	Small sizes.
			20:07:26	20:07:55	Small sizes.
			20:10:02	20:10:28	Small sizes.
			20:10:38	20:10:58	Small sizes.
			20:12:10	20:12:38	Small sizes.
			20:12:53	20:14:02	Small sizes.
			20:20:30	20:21:00	Small sizes.
			20:23:42	20:26:15	Good sizes; dense population.
			20:26:30	20:29:30	Between 20:27:00-20:27:30; very good. 20:28:05-20:28:45; good.
521	17 Jul		15:25:25	15:43:15	Nothing.

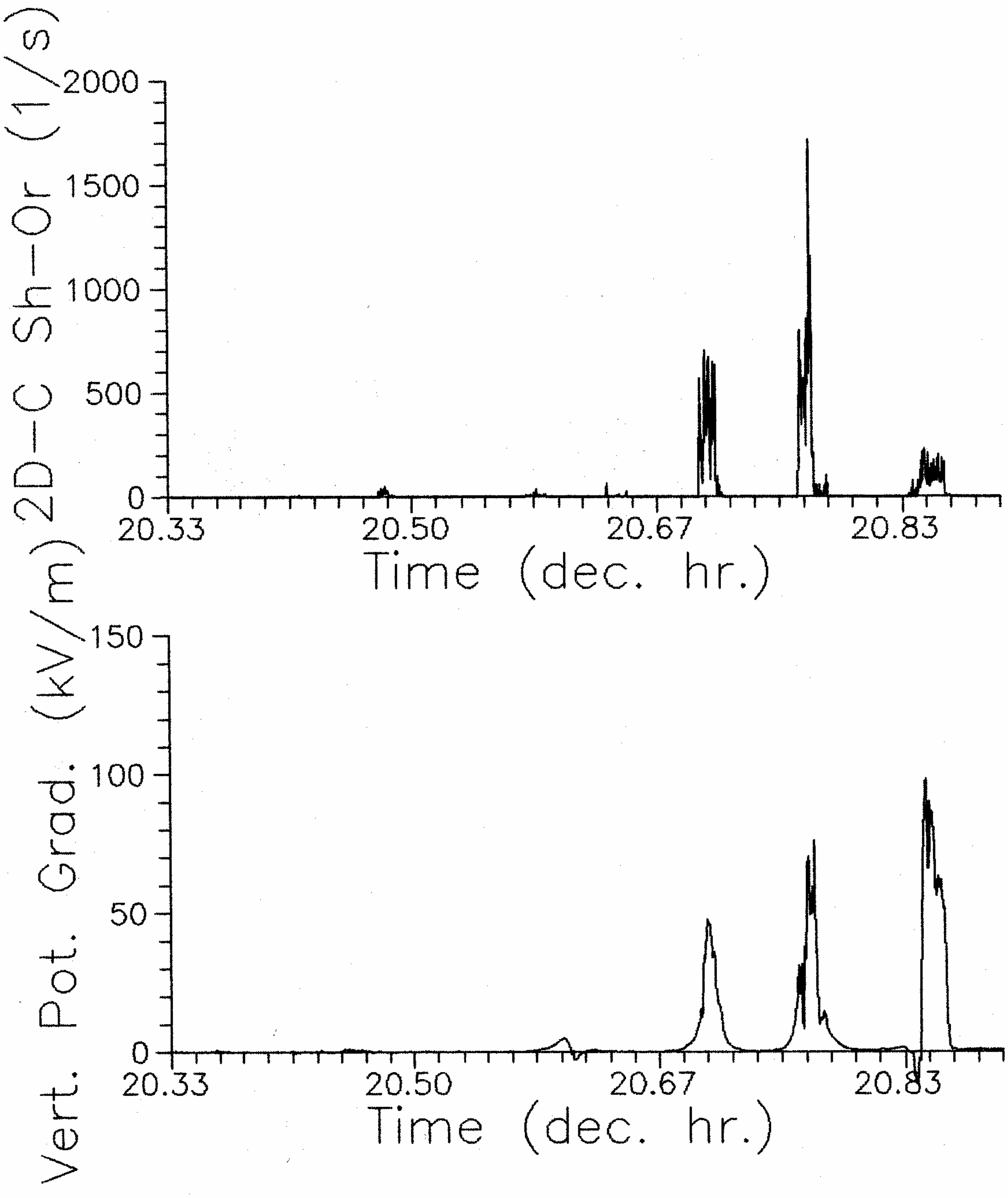


Fig. 1: T-28 data showing particle counts and vertical potential gradient for 7 penetrations on Flight 516 (27 June).

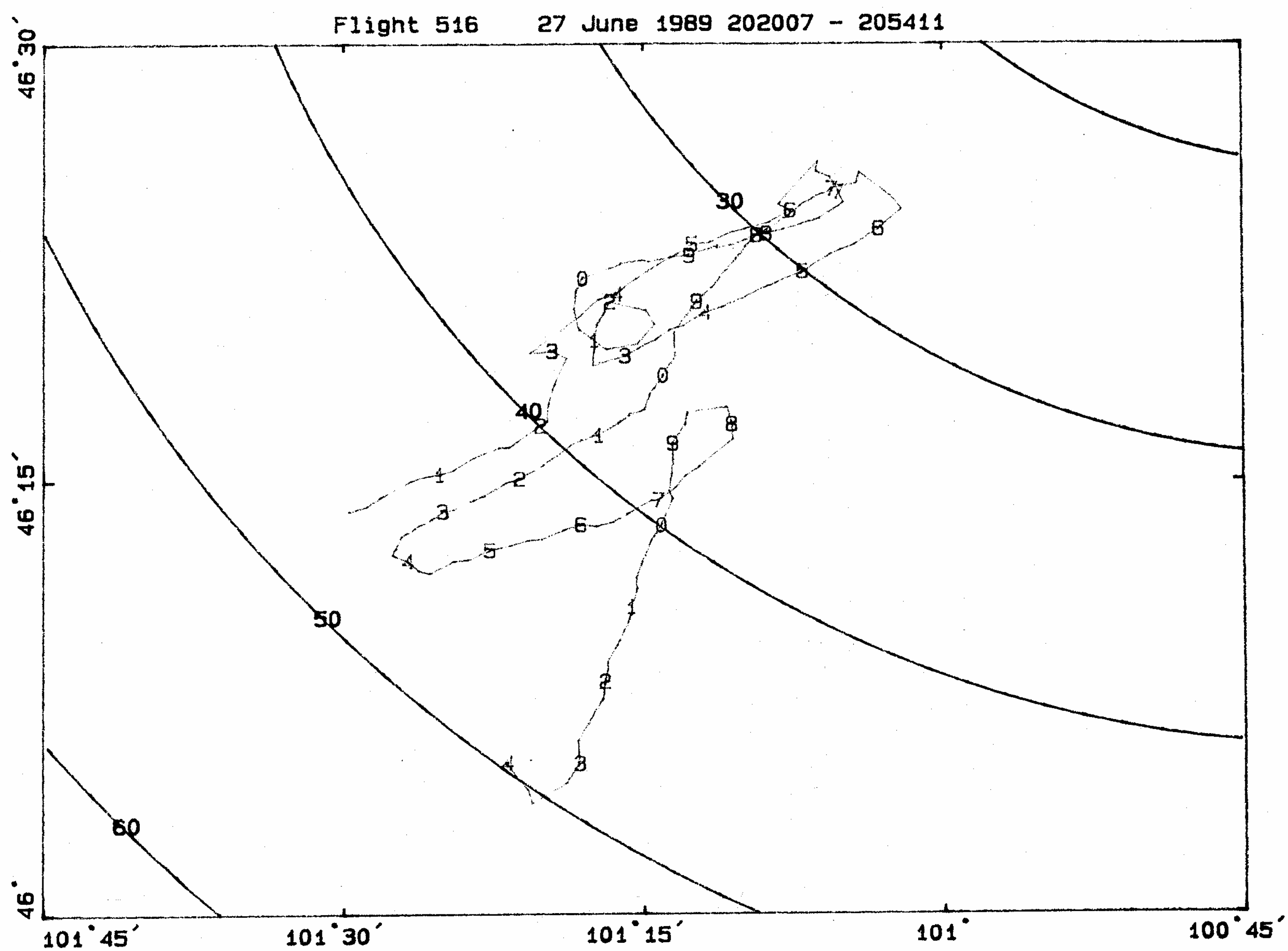


Fig. 2: Aircraft track corresponding to period for which data are shown in Fig. 1.

penetration at ~20:34 (4 min after 20.50 decimal hours), there appears to be a correlation between increasing ice particle concentrations and increasing positive potential gradient (positive charge overhead) in the cloud at the aircraft altitude. This correlation holds up through the second to last penetration shown. The final penetration, showing high potential gradient but lower shadow-or counts, is apparently through a different feeder cloud than the preceding group (see Fig. 2).

Further investigation using corroborating cloud physics data from other aircraft participating in coordinated penetrations of these clouds, as well as radar and satellite data, will be required to establish which penetrations were actually through the same cloud elements. The other aircraft data can also provide more details of the sequence of microphysical development in these elements.

4.2.2 Structures in deep convection

An example of a more traditional type of investigation using T-28 data is shown in Fig. 3. The data shown are from the first penetration on Flight 521 (17 July) through a cell in a squall line, at ~5.7 km MSL. The vertical wind data are based principally on aircraft altitude changes over a 2-s interval, as noted in Section 4.1. The profile is much more chaotic than typical T-28 profiles shown in the past, where aircraft altitude change has been averaged over 9 s. While some of this chaos might be due to increased noise in the calculation due to the smaller averaging period for aircraft altitude change, many of the prominent spikes in the vertical wind correspond precisely in time with spikes in the FSSP cloud water concentration profile shown in the upper part of Fig. 3. This suggests that much of the vertical wind structure shown may be real. The horizontal axis in Fig. 3 is marked off at 1-minute intervals, corresponding to ~6 km flight distance.

Figure 4 shows a vertical cross section of radar reflectivity through this storm along the aircraft track. The coarse-resolution radar view of the precipitation distribution contrasts markedly with the aircraft picture of the cloud as a conglomeration of weak, small-scale convective elements.

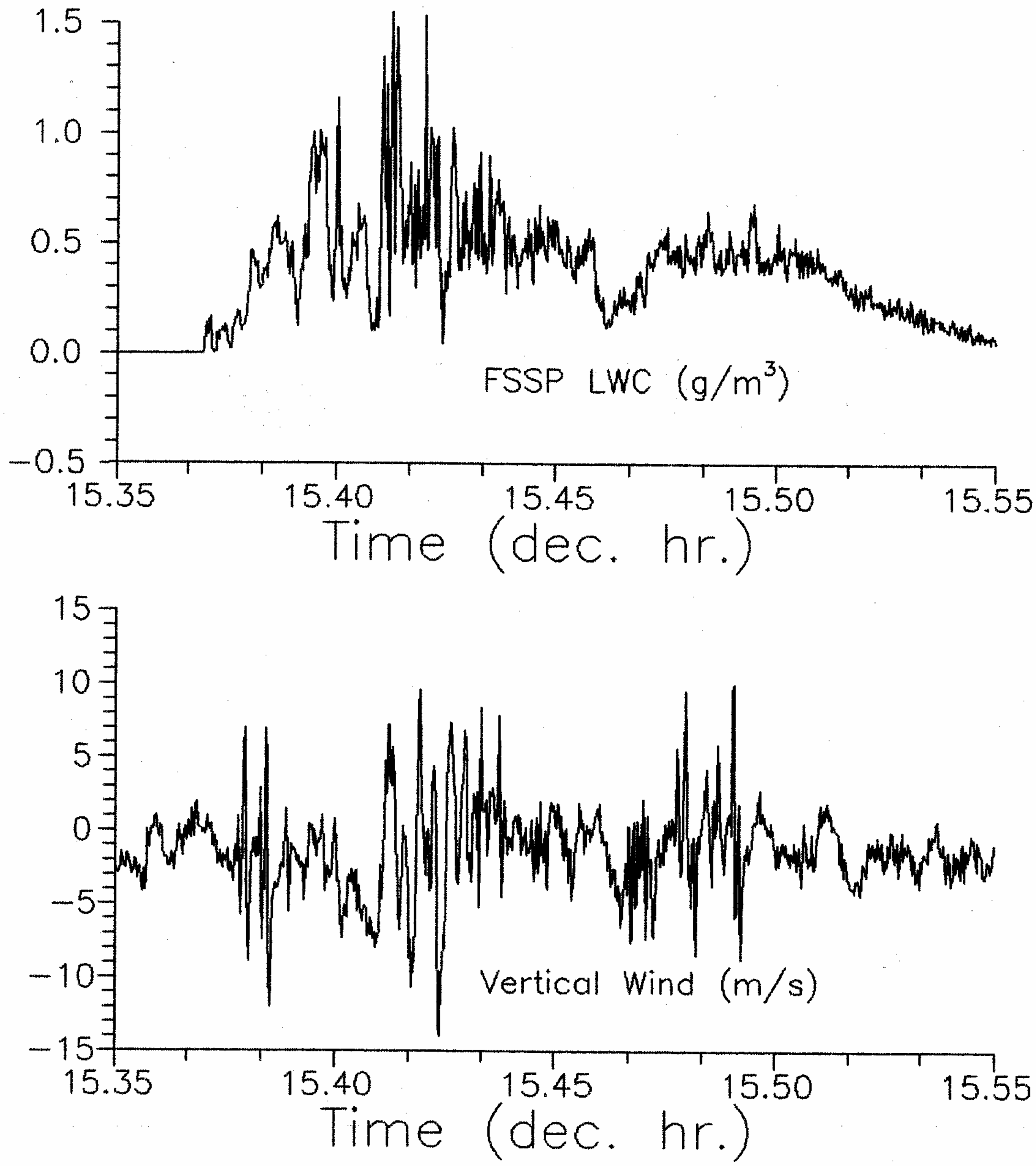
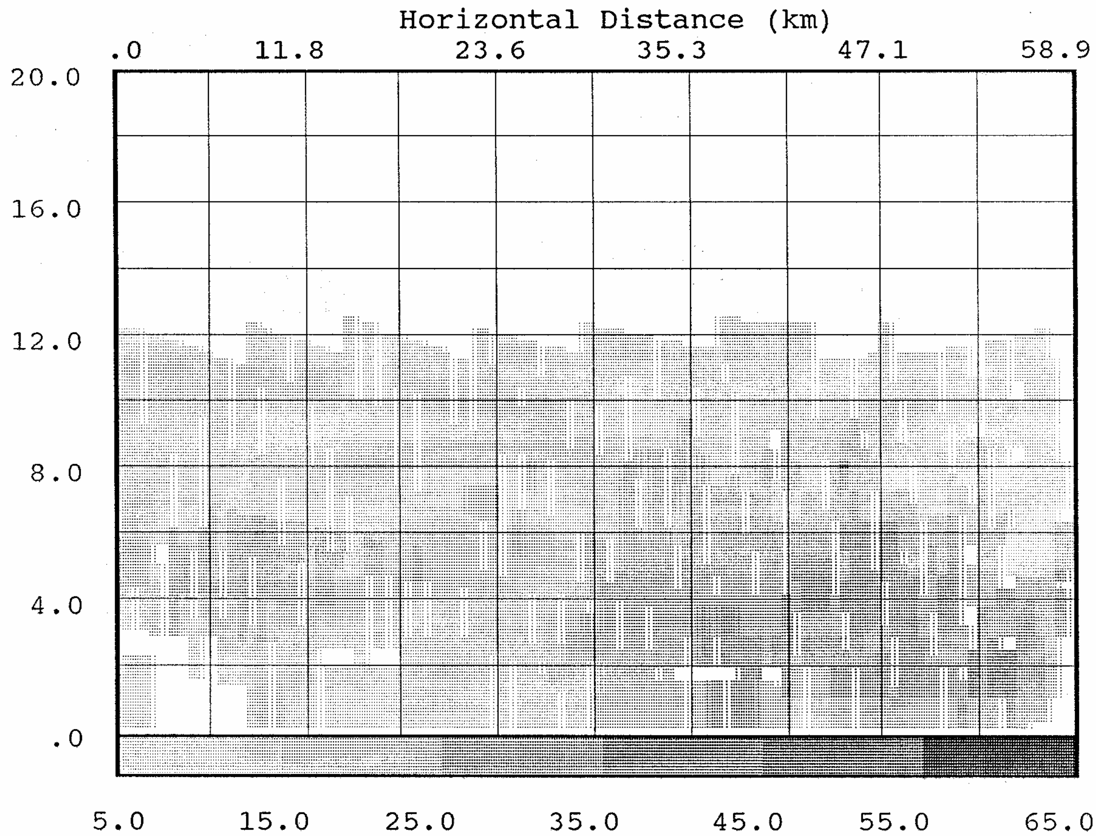


Fig. 3: FSSP cloud water concentration profile and vertical wind structure during first penetration of Flight 521 (17 July).

Radar: CP3/RP4 Site: BISMARCK
Date: 07/17/1989 Time: 15:28:20 CD
Field: DZ X-Section



X-min: .0 X-max: 58.9 X-int: 5.9
Height min: .0 Height max: 20.0 Height int: 2.0
Left Coordinate (azimuth,range): (261.3, 19.0)
Right Coordinate (azimuth,range): (337.4, 12.1)

Fig. 4: Vertical cross section of radar reflectivity through the storm along the aircraft track during the first penetration.

5. SCIENTIFIC ANALYSES

The T-28 microphysical and electrical data from the storm penetrations on 17 July were the basis of a presentation by Detwiler and John Helsdon at the 1989 Fall Meeting of the American Geophysical Union. Helsdon, Detwiler, and Musil plan further work on this case and a paper is being prepared for presentation at the American Meteorological Society Conference on Atmospheric Electricity in October. Other NDTP investigators, including Jeff Stith at the University of North Dakota, are interested in looking at the tracer and mature storm studies conducted on 6 and 7 July involving most of the project aircraft, including the T-28. Some of this work is already underway but little has been completed with the T-28 data as of the time of the writing of this report. Other analyses incorporating T-28 data will continue as the NDTP scientific effort progresses.

ACKNOWLEDGMENTS

The T-28 facility is supported by the National Science Foundation, Division of Atmospheric Sciences, under Cooperative Agreement ATM-8620145. T-28 participation in the 1989 NDTP was sponsored by funds provided through NOAA under the Federal/State Cooperative Program of Atmospheric Modification Research. We acknowledge the willing assistance and cooperation of all participants in the NDTP. This initial data survey was made possible largely by the diligence and hours of hard work by Justin Tomac and Ken Hartman.

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APPENDIX A

Reduced Data Items Computed for NDTP, Bismarck June-July 1989†

Tag #	Description		# Values Output	Units	Method of Computation	Last Mod (if this yr)
101	Dynamic Pressure #1	(10 Hz)	1	mb	6.280525E-3 * Raw + 0.88244	Spring 1989
102	Dynamic Pressure #2	(10 Hz)	1	mb	5.268222E-3 * Raw - 0.22955	Spring 1989
103	Static Pressure #1	(2 Hz)	1	mb	1.5809E-2 * Raw + 528.1485	Spring 1989
104	Static Pressure #2	(2 Hz)	1	mb	1.09617E-2 * Raw + 688.7589	Spring 1989
105	Rate of Climb	(2 Hz)	1	m/s	5.625E-4 * Raw, for Raw >= 0 5.287E-4 * Raw, for Raw < 0	6/6/89
106	Rosemount Temp		1	deg C	mach2 = 5* ((1+dyn_pr/stat_pr)**(2/7) -1) divisor = 1 + 0.195 * mach2 temp = (1.83105E-3*Raw+243.16)/divisor-273.16	
107	Reverse Flow Temp		1	deg C	divisor = 1 + 0.153 * mach2 temp = (1.7962E-3*Raw+244.3775)/divisor-273.16	5/17/89
108	Manifold Pressure		1	" Hg	3.1098E-3 * Raw + 0.159275	Spring 1989
109	Acceleration	(10 Hz)	1	g's	6.25E-5 * Raw + 1.0	
110	Pitch	(5 Hz)	1	deg	-3.05175E-3 * Raw + 50	
111	Roll	(5 Hz)	1	deg	3.05175E-3 * Raw - 50	
112	JW Liquid Water		1	g/m3	1.83125E-4 * Raw	
113	VOR		1	deg	1.117534E-2 * Raw - 1.155475	7/21/89
114	DME #1		1	naut mi	3.03269E-3 * Raw - 0.24536	7/20/89
115	DME #2		1	naut mi	3.03269E-3 * Raw - 0.046623	7/20/89
116	Voltage Regulator		1	volts	1.5258789E-4 * Raw	
117	Heading		1	deg	device not hooked up	
118	NCAR true air speed		1	m/s	3.96744E-3 * Raw	
119	End Element #1		1	volts	1.52588E-4 * Raw	
120	End Element #2		1	volts	1.52588E-4 * Raw	
121	Interior Temp (computer)		1	deg C	3.05175E-2 * Raw	new 1989
122	Sulfur Hexafluoride	(2 Hz)	1	volts	1.52588E-4 * Raw	
130	Event Code bits		1	flags	bit 0 = 1 --> system running bit 1 = 0 --> in cloud bit 2 = 0 --> foil on bit 3 = 0 --> voice recorder on	
140	FSSP counts		15	number	Raw	
141	FSSP total counts		1	number	Sum of tag 140's	
142	FSSP ave diameter		1	microns	sum of diams / number	
143	FSSP concentration		1	#/cm3	vol = 0.229 * tas denom = 1 - .55 * activ / 100 conc = tot_count / vol / denom	
144	FSSP water		1	g/m3	mass = sum of counts * volumes water = mass/vol/denom*1.E6	
145	Probe Activity		1	???	Raw / 10	
147	PMS 2d Shd Or		1	number	Raw	new 1989
150	Hail counts		14	number	Raw	
151	Slow particles		1	number	Raw	
152	Hail total counts		1	number	Sum of tag 150's	
153	Hail ave diameter		1	cm	sum of diams / number	
154	Hail concentration		1	#/m3	tot_counts / (.1 * tas)	
155	Hail equiv water		1	g/m3	mass = sum of counts * volumes water = mass / vol	
160	Top field mill, low res	(20 Hz)	1	kV/m	1.982574E-2 * Raw - 0.026	Spring 1989
161	Bottom field mill, low res	(20 Hz)	1	kV/m	1.982574E-2 * Raw - 0.104	Spring 1989
162	Left field mill, low res	(20 Hz)	1	kV/m	1.02311E-2 * Raw - 0.67475	5/3/89
163	Right field mill, low res	(20 Hz)	1	kV/m	9.74013E-3 * Raw - 0.30486	5/3/89
164	Top field mill, hi res	(20 Hz)	1	kV/m	3.11585E-4 * Raw - 0.027	Spring 1989
165	Bottom field mill, hi res	(20 Hz)	1	kV/m	3.10364E-4 * Raw - 0.04	Spring 1989
166	Left field mill, hi res	(20 Hz)	1	kV/m	1.52202E-4 * Raw - 0.70155	5/3/89
167	Right field mill, hi res	(20 Hz)	1	kV/m	1.546E-4 * Raw + 0.25	5/3/89

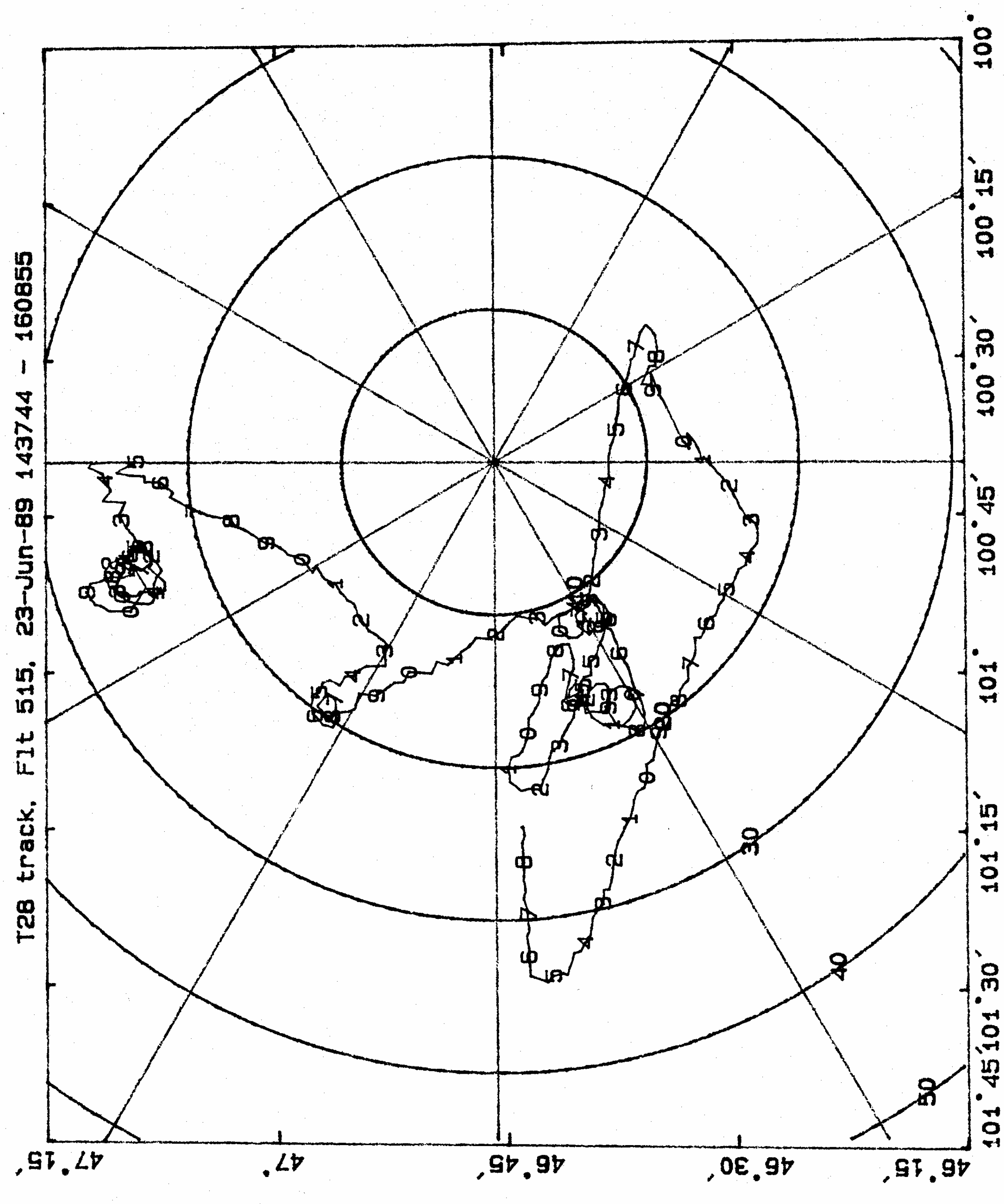
Tag #	Description	# Values Output	Units	Method of Computation	Last Mod (if this yr)
200	Date	1	yymmdd		
201	Month	1	number		
202	Day	1	number		
203	Year	1	2-dig		
204	Flight number	1	number		
205	Altitude	1	meters	4.43077E4*(1-(stat_pr/1013.3027)**.190284)	
206	Theta e	1	deg K	tempk = RFT temp in deg K svp = 6.1078*exp(17.26939*rft/(tempk-35.86)) smr = svp / (stat_pr - svp) * 0.622 ts = tempk * (1000/stat_pr)**0.286 thetae = ts*exp(597.3*smr)/(0.24*tempk))	*1
207	Saturation mixing ratio	1		smr from above	*1
208	Point dz/dt	1	m/s	alt - prev alt	*1
209	Indicated airspeed	1	m/s	c = 1 + dyn_pr / 1013.3027 ias=sqrt(5.79E5*(c**(2/7)-1))	
210	Updraft (uncorrected)	1	m/s	u1 = change in alt ((i+1)-(i-1))/2 u2 = (27 - man_pr) * 92 u3 = (1.94254 * ias - 140) * 17.7 updr = u1 + (u2 + u3) * 0.00508	*1
211	Calculated TAS	1	m/s	sqrt(rftuc*mach2*401.856/divisor)	*1
212	Updraft correction factor	1	m/s	calc_tas*(change in calc_tas)/2/9.775	*1
213	Cooper Updraft	1	m/s	updraft + updraft correction	*1
214	Kopp Updraft	1	m/s	dens = 0.34838 * stat_pr / tempk ang = pitch * 0.0174533 Kopp=u1+62.12*accel*9.775/(dens*calc_tas) -(0.02028+ang)*calc_tas	*1
216	Turbulence	1	cm**2/3/s	Much too complicated to write here. Static and dynamic pressure values, along with RFTs, are fed into a fast Fourier transform routine. Consult program listing.	
217	Air density	1	kg/m3	0.34838 * stat_pr / tempk	new 1989
218	JW mixing ratio	1	g/kg	jw_water / density	new 1989
219	FSSP mixing ratio	1	g/kg	FSSP_water / density	new 1989
220	Hail mixing ratio	1	g/kg	hail_water / density	new 1989
260	Ambient vert EF	1	kV/m	(tfm / 2 - bfm) / 2	new 1989
261	Plane vert EF	1	kV/m	(tfm / 2 + bfm) / 2	new 1989
262	Ambient lateral EF	1	kV/m	(rfm - lfm) / 5.4 / 2	new 1989
263	Plane lateral EF	1	kV/m	(rfm + lfm) / 5.4 / 2	new 1989
264	Ambient vert EF (with roll)	1	kV/m	cosr = cos(roll_rad) sinr = sin(roll_rad) t264 = t260 * cosr + t262 * sinr	new 1989
265	Ambient lat EF (with roll)	1	kV/m	t265 = -t260 * sinr + t262 * cosr	new 1989

*1 - Nine-second running averages were removed. Either instantaneous values are now used, or at most, values one behind and ahead of current value were used in computations.

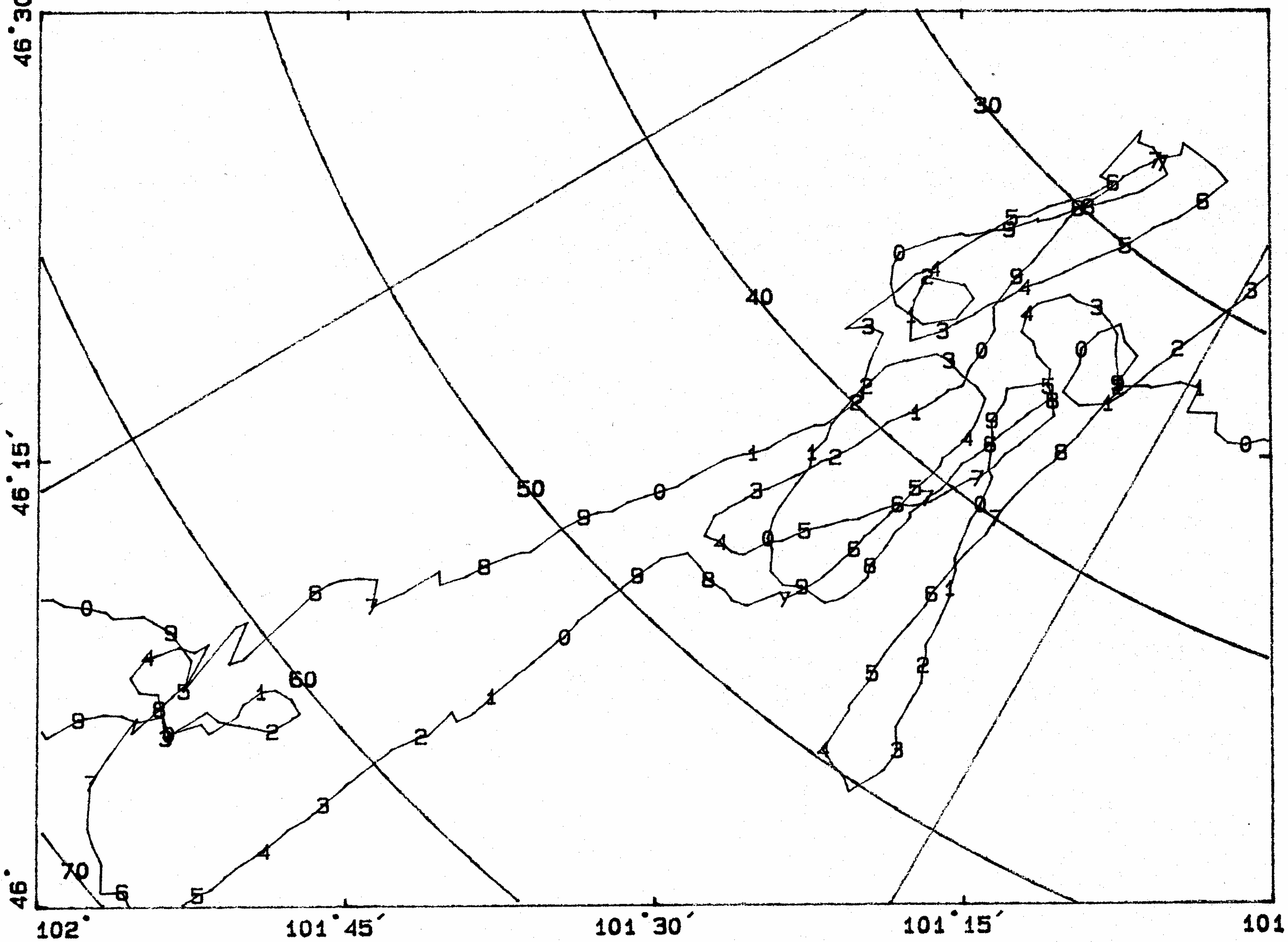
†In some cases, the equation variables are averages. Consult the listing of REDUCE.C for exact details. All parameters recorded at 1 Hz unless otherwise noted.

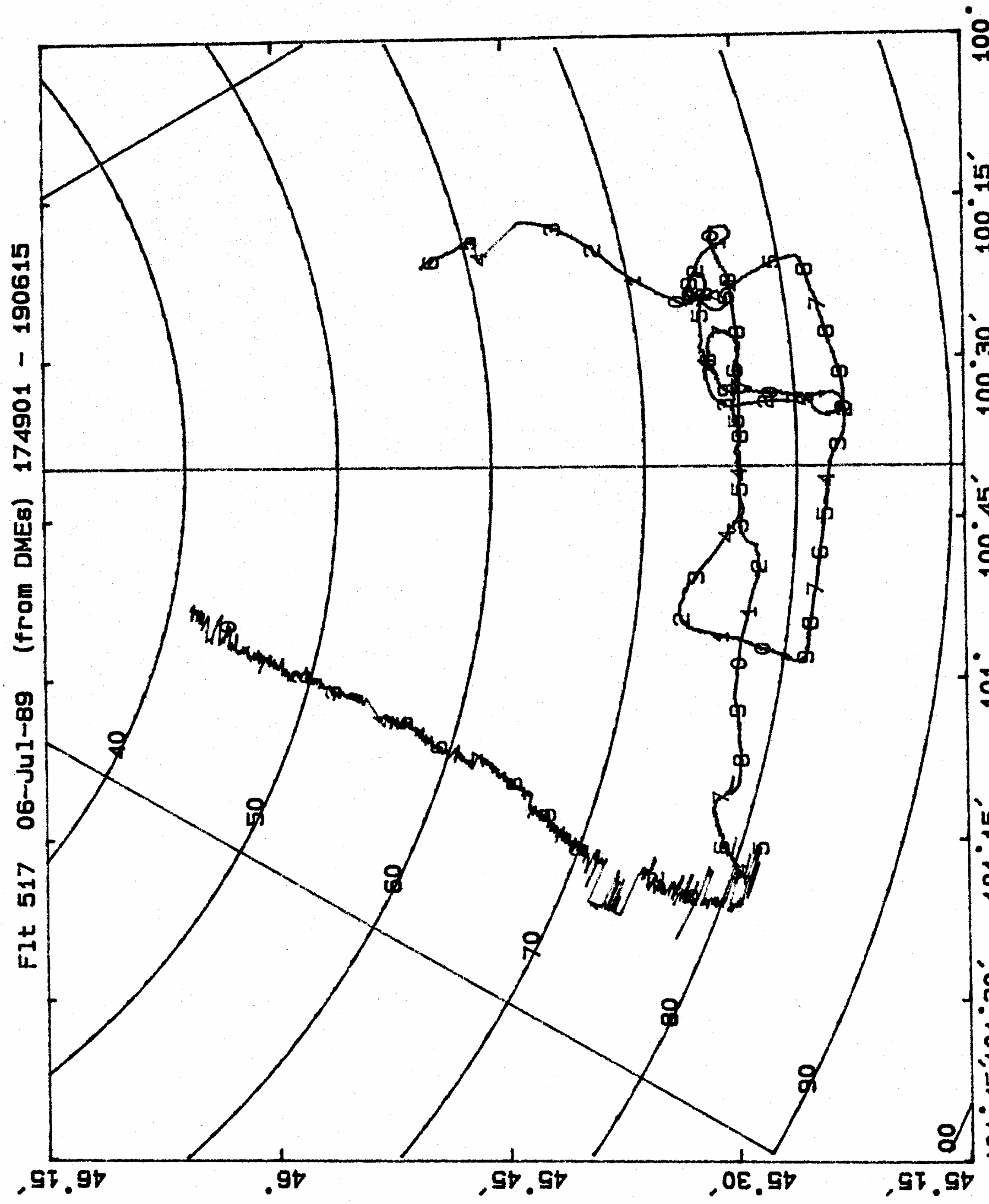
APPENDIX B

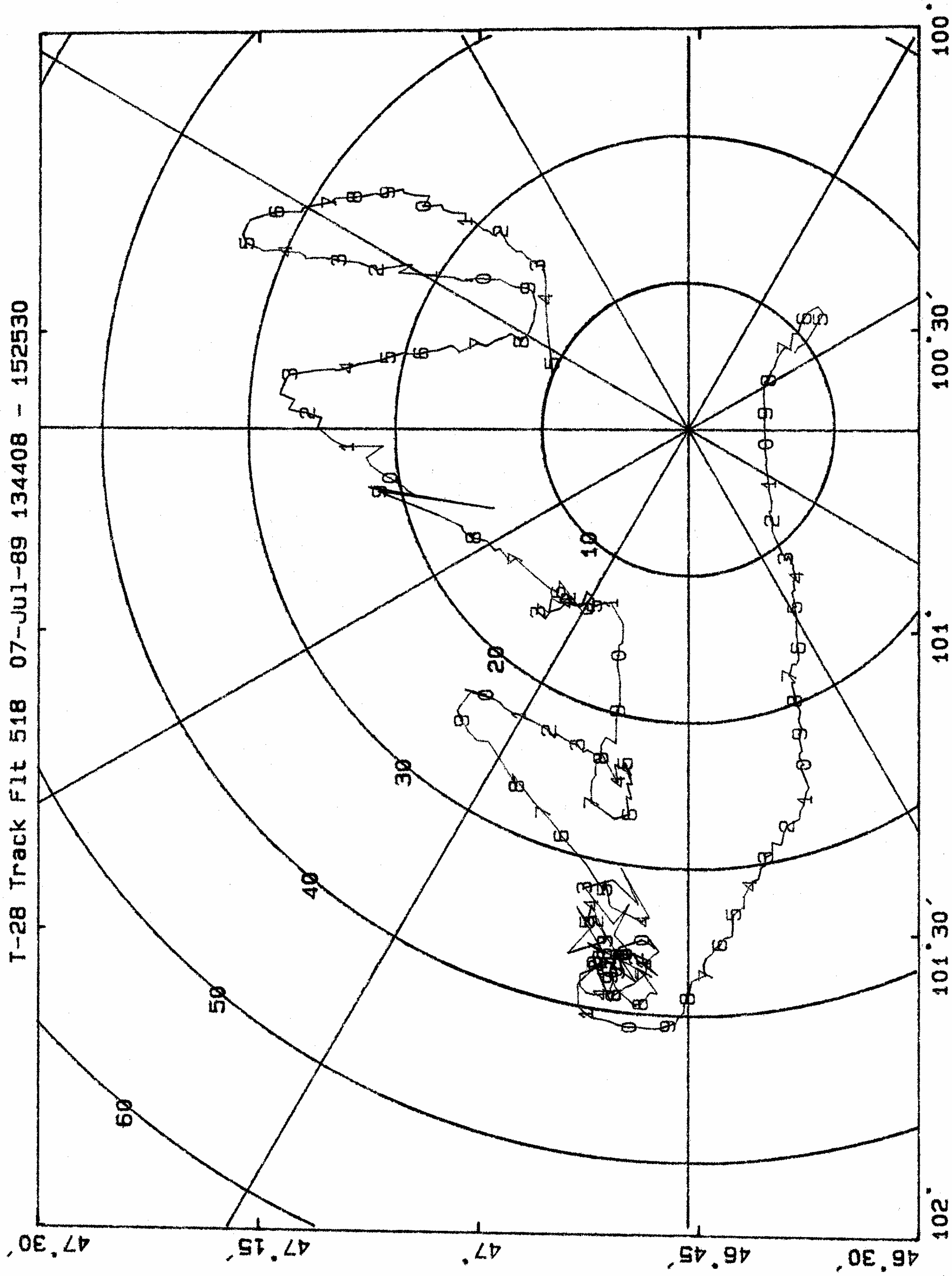
Flight Tracks

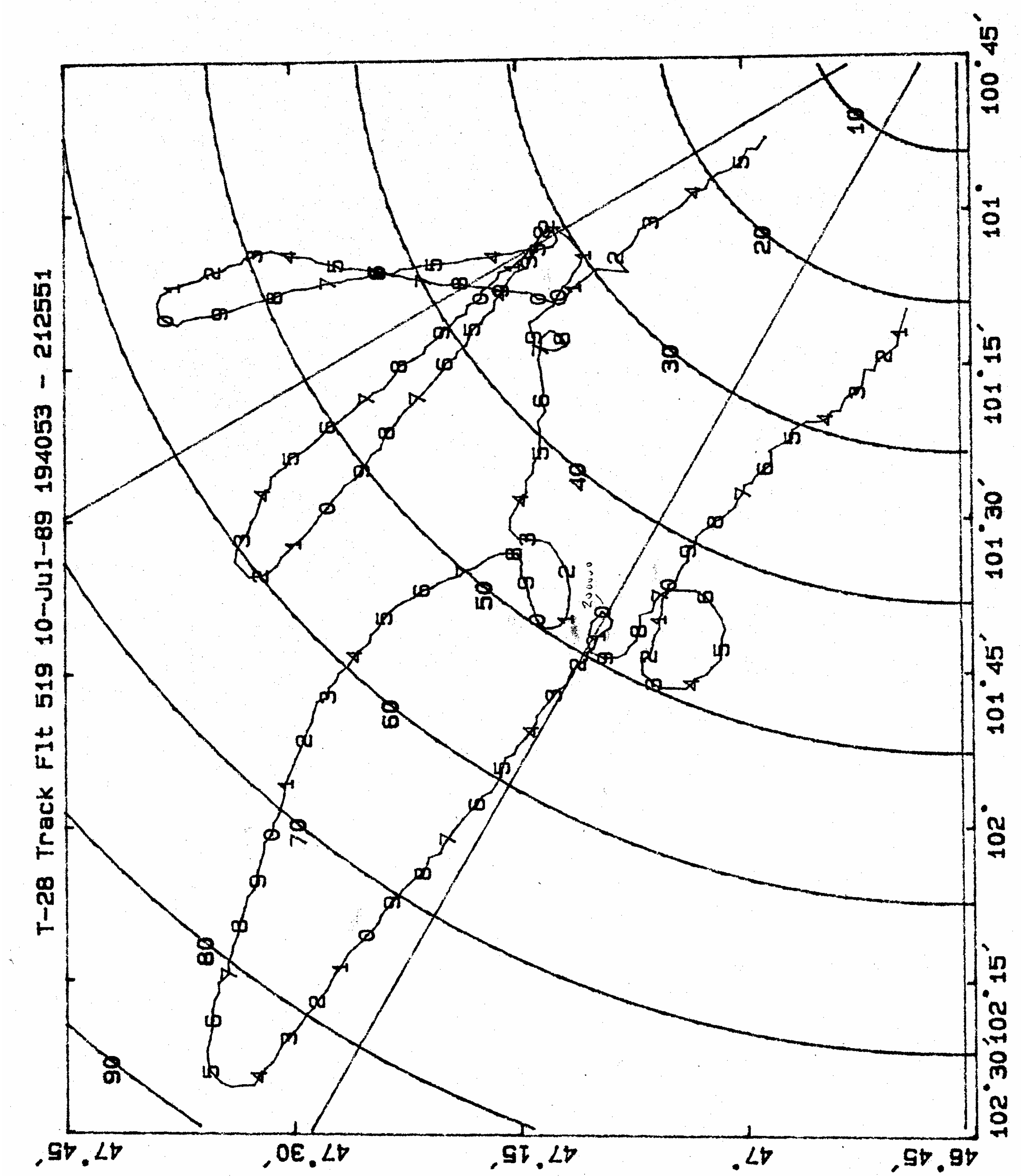

T28 track, Flt 515, 23-Jun-89 143744 - 160855
47°15'
47°
46°45'
46°30'
46°15'
100°
100°15'
100°30'
100°45'
101°
101°15'
101°30'
101°45'
30
40
50

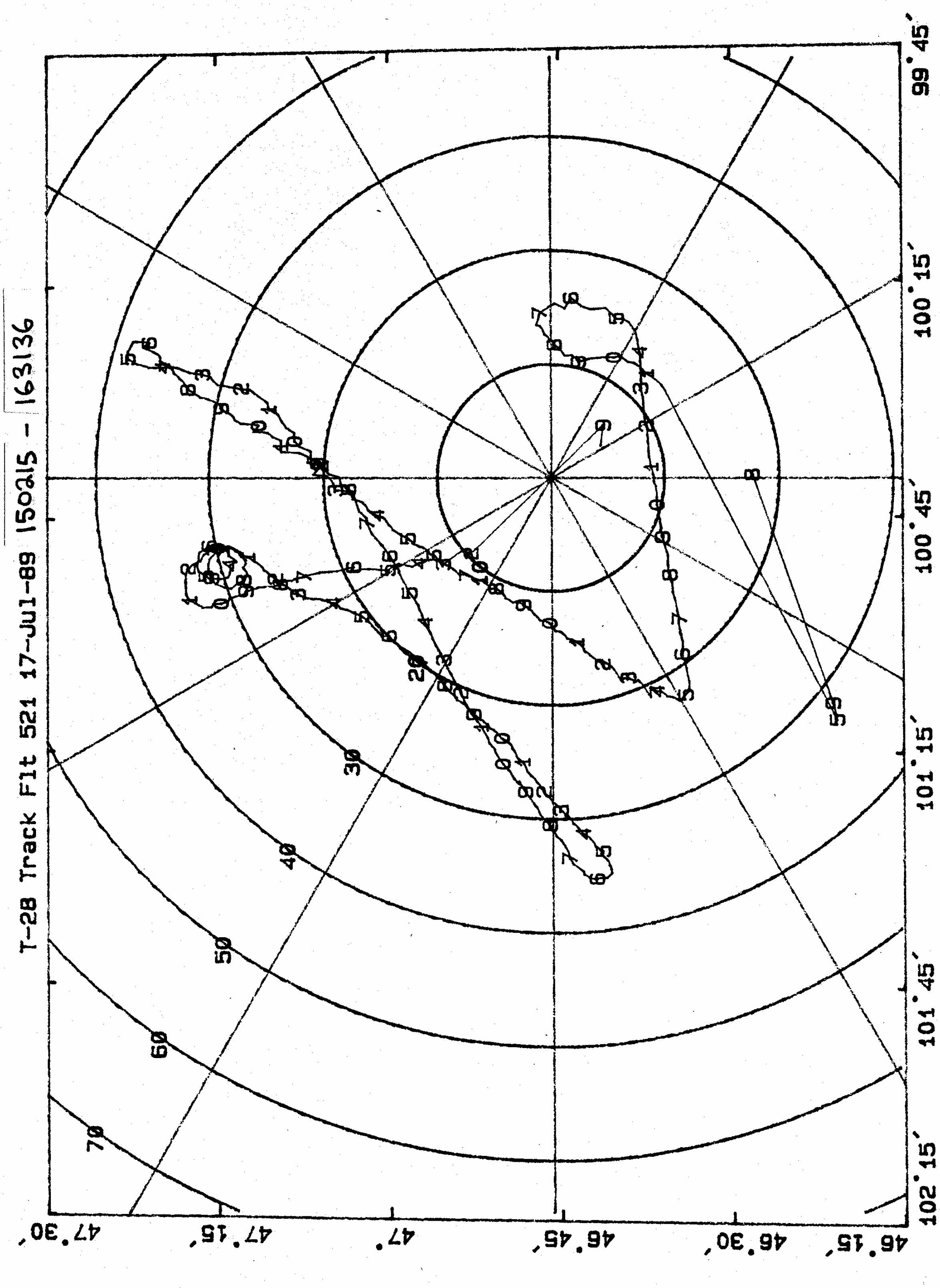
T-28 Track Flt 516 27-Jun-89 191950 - 211513




Flt 517 06-Jul-89 (from DMEs) 174901 - 190615
46°15'
46°
45°45'
45°30'
45°15'
101°45'
101°30'
101°15'
101°
100°45'
100°30'
100°15'
100°
40
50
60
70
80
90
00


T-28 Track Flt 518 07-Jul-89 134408 - 152530
10
20
30
40
50
60
100°
100°30'
101°
101°30'
102°
47°30'
47°15'
47°
46°45'
46°30'


T-28 Track Flt 519 10-Jul-89 194053 - 212551
47°45'
47°30'
47°15'
47°
46°45'
100°45'
101°
101°15'
101°30'
101°45'
102°
102°15'
102°30'
10
20
30
40
50
60
70
80
90



T-28 Track Flt 521 17-Jul-89 150215 - 163136
99°45'
100°15'
100°45'
101°15'
101°45'
102°15'
47°30'
47°15'
47°
46°45'
46°30'
46°15'
20
30
40
50
60
70

APPENDIX C

Pilot's Notes from NDTP Research Flights

PILOT'S NOTES

DATE	FLT #	T.O.	LNG.	FLT TIME	DATA TIME	# PENETRATIONS
23 JUN 89	515	1414	1650	2:26		6

TIME	POSITION (deg/naut mi)	ALT (ft MSL)	HDG (deg magnetic)		REMARKS
1510	BIS 278/15	13000	160		No precip., no turb., no ice.
1525	BIS --	--	--		No recording on tape.
1535	BIS 240/17	13000	105		Abort due to no ground radar.
1543	BIS 210/9	13000	095		Precip. static 300'↑ 450↓ No ice.
Approx 1550	BIS --	13000	--		No recording on tape.
1602:21	BIS 245/26	13000	280		300'↓, Precip. static in light precip.

DATE	FLT #	T.O.	LNG.	FLT TIME	DATA TIME	# PENETRATIONS
27 JUN 89	516	1915	2125	2:10		10

TIME	POSITION (deg/naut mi)	ALT (ft MSL)	HDG (deg magnetic)		REMARKS
2008:53	BIS 235/70	19000	090		300'↑↓, very light icing. In top with only 200' of cloud above pen. alt.
2023	BIS 220/35	19000	050		500'↑↓ Light icing.
2028:16	BIS 222/30	19000	250		Exit at 19,500'. 700'↓ 300'↑ Light to moderate rime icing.
2034	BIS 210/35	18000	060		500'↓ Cell dissipating
2042:30	BIS 214/45	18200	230		500'↓
2045:00	BIS 208/44	18000	070		500'↑
2049:41	BIS 210/38	18000	190		300'↓↑
2055:28	BIS 208/47	18200	030		500'↑
2104:00	BIS 021/31	18000	035		Light rime icing.

DATE	FLT #	T.O.	LNG.	FLT TIME	DATA TIME	# PENETRATIONS
6 JUL 89	517	1731	1944	2:13		4

TIME	POSITION (deg/naut mi)	ALT (ft MSL)	HDG (deg magnetic)		REMARKS
1808:40	BIS 160/77.7	14500	090		No activity.
1814:00	Estimated BIS 160/77	14500	270		500'↑ 200'↓ Very light turbulence.
1833:00	BIS 172/74.4	14500	120 then left 080		Light turbulence 500'↑ 400'↓
1845:50	BIS 160/82	14500	250		No activity.

DATE	FLT #	T.O.	LNG.	FLT TIME	DATA TIME	# PENETRATIONS
7 JUL 89	518	1338	1531	1:53		3

TIME	POSITION (deg/naut mi)	ALT (ft MSL)	HDG (deg magnetic)		REMARKS
1435:09	BIS 280/29	16400	038 then right to 210° then right to 270°		Most in base of clouds 500'↑ 700'↓
1451:10	BIS 285/14	16400	350, left turn 180, right to 020 then right to 170, right to 174, left to 170		In and out of bases on this penetration. 500'↑ & ↓, light to moderate turbulence. High precip static. Light turbulence. Exit BIS 020/16 @ 1507:13.
1509:41	BIS 020/20.5	16400	350 then right to 170, right to 180, right to 210		In bases of cloud. 500'↑, light with occasional moderate turbulence.

DATE	FLT #	T.O.	LNG.	FLT TIME	DATA TIME	# PENETRATIONS
10 JUL 89	519	1933	2133	2:00		7

TIME	POSITION (deg/naut mi)	ALT (ft MSL)	HDG (deg magnetic)		REMARKS
2001:50	BIS 290/50.8	19200	290		700'↑ Moderate turbulence. Moderate rime icing. Lightning.
2014:25	BIS 292/77	19200	100° then 110° then 130°		On northern edge of cell, turned 10° right. Lightning. 500'↑ Light to mod. turb.
2024:30	BIS 305/55.4	19200	160 then 240°		1500'↑ 500'↓, turned to hdg of 240° by ground.
2039:17	BIS 305/48.6	19000	250		No significant activity.
2046:00	BIS 313/41.6	18200	290		Moderate ice, canopy slid open 2". 900'↑, altitude 18800', 500'↓ Moderate precip. Descent back to 18000'.
2055:15	BIS 315/56.1	18100	140		500'↓ 700'↑, Light to moderate turb. 1200'↑.
2105:20		15000			
Approx 2115	Northwest of Bismarck	Descent			Broke into clear at 9000'.
					Out of tape and have no additional data.

DATE	FLT #	T.O.	LNG.	FLT TIME	DATA TIME	# PENETRATIONS
14 JUL 89	520	1535	1742	2:07		0 -- Flight in clear at low altitude SF_6 flights

TIME	POSITION (deg/naut mi)	ALT (ft MSL)	HDG (deg magnetic)		REMARKS
	All Radial/ DME off Bismarck				
1600		2300 - 2400	350		
		2700	170		
1608:30		2700	350		
		2700	170		
1615:22		3200	350		
		3700	170		
1623.11		3700	350		
1627:31		4200	170		
1633		4200	350		
		4700 - 4800	190		Computer failed 1636 to 1726
1641:30		4700	350		1644:08 aborted run to move 10 N.M. to west
1645:55	Along Hwy 83 17 DME/330°	6000	170		
1649:30	310/?	6000	350		
1655:00		6000	170		
1700:32		6500 - 6000	350		
1713:42	BIS 320/20.2	6500	170		
1723.32	BIS/300/10.4	6500	350		SF_6 runs terminated
1730:30	To 1733:03				Ran canopy closed/Open exercise to determine impact on readouts.
1733:30					Applied 2.5 positive G Pull up.

DATE	FLT #	T.O.	LNG.	FLT TIME	DATA TIME	# PENETRATIONS
17 JUL 89	521	1457	1639	1:42		4

TIME	POSITION (deg/naut mi)	ALT (ft MSL)	HDG (deg magnetic)		REMARKS
1525:00	BIS 310/18.5	18200	220		Moderate icing, moderate precip. Lightning 1000'↑↓
1541:00	BIS 280/21.9	18000	050 then 040		Lightning. Moderate turbulence 1500'↑ 1000'↓
1601:00	BIS 350/21	18000	210°		Heavy precip., lightning light to moderate turb. 1000'↑↓
1615					FM with 30° banks left and right.
1623:10	BIS 175/9.6	18000	080		No significant activity.
					Terminated early to land before storm affected airfield.

APPENDIX D

Daily Weather Briefing Summaries

NDCMP FORECAST-1

DATE/TIME: 6-24-89

SOUNDING PARAMETERS	12Z BIS	GGW	RAP
500 mb Temp °C	-17	-18	-13
Wet bulb 0 Kft	9.0	8.0	10.0
0°C Level Kft	10.0	9.0	10.0
-5°C Level Kft	12.5	12.0	13.5
-10°C Level Kft	15.0	16.0	17.0
700 mb $T-T_{DEW}$ °C	3.0	8.0	1.1
CCL Kft	8.0	7.0	6.0
Trop Height Kft	35.	34.	36.
Max Tops °C	-42	-50	-27
Max Tops Kft	30.0	32.0	24.0
$T_{CONVECTIVE}$ °F	78	64	61
MOS T_{MAX} °F	76	67	66
Total Totals	51	50	43
K Index	31	25	29
Sweat Index	86	81	139
Lifted Index	-2	-1	+2
Precip. Water in.	0.82	0.57	0.85
Low Level Moisture g/kg	7.5	7.7	8.1

	MLS	BIS	ISN	DIK	Y22	MOT
Temp. °F	57	65	65	58	55	65
Dew Pt. °F	40	52	55	51	52	53

Station: BIS

Kft MSL	Dir/Spd DEG KTS
Sfc	020/05
5	165/10
7	235/15
9	235/15
14	230/15
18	215/20
24	240/30
30	250/40
35	[illegible]

CLOUD DEVELOPMENT

Scale	District I TO 00Z	District I 00Z to 12Z	District I TO 00Z	District I 00Z to 12Z
No Sig Wx				7
TCU				
RW or TRW	✓	✓		
TRW+A				

FORECAST MAXIMUM TEMPERATURES

[redacted]	mid 70's
[redacted]	

FORECAST CONFIDENCE FACTORS

	SCALE 00Z		TIMING 00Z	
[redacted]	7	7	7	7
[redacted]				

SYNOPSIS SYSTM NOT AS STRNG AS XPCTD — STRONG PVA MOVE-IN FROM SW LACKS GOOD SFC SUPPORT.

EXPECT SHWRS/TSTM to develop mid AFTN + incorporate mid-level moisture. XPCT ACTVTY TO MOVE FROM SW-NE AND CONTINUE THRU TIL NIGHT.

Form NDARB 88005

NDCMP FORECAST-1

DATE/TIME: 6-27-89

SOUNDING PARAMETERS	BIS (12Z)	GGW	RAP
500 mb Temp °C	-10	-14	-10
Wet bulb 0 Kft	10	11	11
0°C Level Kft	12	12	13
-5°C Level Kft	15	15	15
-10°C Level Kft	18	17	17
700 mb $T-T_{DEW}$ °C	9	9	14
CCL Kft	12/0°	12/0°	12/2°
Trop Height Kft	39	39	39
Max Tops °C	-11	-48	-46
Max Tops Kft	18	33	33
$T_{CONVECTIVE}$ °F	90	87	87
MOS T_{MAX} °F	77	84	86
Total Totals	36	49	44
K Index	17	26	20
Sweat Index	229	66	212
Lifted Index	+7	-2	+2
Precip. Water in.	0.65	0.66	0.55
Low Level Moisture g/kg	5.5	6.3	5.2

16Z	MLS	BIS	ISN	DIK	Y22	MOT
Temp. °F	71	78	73	71	72	66
Dew Pt. °F	45	46	48	53	53	45

Station: BIS

Kft MSL	Dir/Spd DEG KTS
SFC	080/05
3	160/15
6	225/17
9	280/20
12	300/27
16	300/35
20	290/30
25	[illegible]
30	[illegible]

CLOUD DEVELOPMENT

Scale	District I: TO 00Z	District I: 00Z to 12Z	[redacted]: TO 00Z	[redacted]: 00Z to 12Z
No Sig Wx	✓		X	X
TCU			X	X
RW or TRW		✓	X	X
TRW+A			X	X

FORECAST MAXIMUM TEMPERATURES

[redacted]	mid 80's
[redacted]	

FORECAST CONFIDENCE FACTORS

	SCALE (before 00Z)	SCALE (after 00Z)	TIMING (before 00Z)	TIMING (after 00Z)
[redacted]	9	7	9	8
[redacted]				

SYNOPSIS WRM ADVCTN LOW LVLS - 15Z CLASS @ ELGIN SHOWS SOME DESTBLZTN - [illegible] EVNG - SLGHT CHNCE for EVNG TRW to SW - ~1900 CDT

WEDNESDAY APPEARS FAVORABLE for CNVCTN

Form NDARB 88005

BIS MAX WIND 42 Kft 280/55

NDCMP FORECAST-1

DATE/TIME: 7-6-89

SOUNDING PARAMETERS	12Z BIS	GGW	RAP
500 mb Temp °C	-11	-12	-9
Wet bulb 0 Kft	11	11	10
0°C Level Kft	15	12	16
-5°C Level Kft	17	16	18
-10°C Level Kft	19	18	20
700 mb $T-T_{DEW}$ °C	15	8	15
CCL (48°) Kft	10	9.5	15
Trop Height Kft	46	44	47
Max Tops °C	-45	-21	-33
Max Tops Kft	35	22	31
$T_{CONVECTIVE}$ °F	94	86	103
MOS T_{MAX} °F	83	76	87
Total Totals	47	40	45
K Index	21	19	21
Sweat Index	200	70	141
Lifted Index	-2	+3	+1
Precip. Water in.	1.07	0.83	0.73
Low Level Moisture g/kg	11.0	6.6	7.5

16Z	MLS	BIS	ISN	DIK	Y22	MOT
Temp. °F	77	77	69	75	71	65
Dew Pt. °F	33	57	58	51	56	56

Station: BIS

Kft MSL	Dir/Spd DEG KTS
SFC	100/04
3	085/14
6	050/11
8	340/10
10	305/19
13	290/23
16	270/44
20	270/63
30	270/92

CLOUD DEVELOPMENT

Scale	[redacted] TO 00Z	[redacted] 00Z to 12Z	[redacted] TO 00Z	[redacted] 00Z to 12Z
No Sig Wx		✓		
TCU				
RW or TRW	✓			
TRW+A				

FORECAST MAXIMUM TEMPERATURES

[redacted]	NEAR 90
[redacted]	

FORECAST CONFIDENCE FACTORS

	SCALE ← 00Z →		TIMING ← 00Z →	
[redacted]	9	8	9	8
[redacted]				

SYNOPSIS WK SHORT WAVE NEAR WESTERN BORDER MOVNG RPDLY EASTWARD - GOOD MOISTURE - RSNBLE INSTBLTY - STRONG TSTM TO SW IN S DAK.

SCTD SHWRS TO INCLUDE ISLTD TSTM EARLY AFTN - ACTVTY ENDG LATE AFTN.

ANOTHER S/W APPRS ON PROG JUST OVR WEST TOMORROW FORENOON.

Form NDARB 88005

NDCMP FORECAST-1

DATE/TIME: 7-7-89

SOUNDING PARAMETERS	12Z BIS	GGW	RAP
500 mb Temp °C	-11	-12	-9
Wet bulb 0 Kft	11.5	12	12
0°C Level Kft	14	14.5	16
-5°C Level Kft	16	16	18
-10°C Level Kft	19	18	20
700 mb $T-T_{DEW}$ °C	5	5	6
CCL Kft	10/+7	12/+6	11/+12
Trop Height Kft	46	46	46
Max Tops °C	-30	-53	-60
Max Tops Kft	27	39	45
$T_{CONVECTIVE}$ °F	93	96	98
MOS T_{MAX} °F	86	93	92
Total Totals Index	46	56	53
K Index	33	29	24
Sweat Index	110	255	430
Lifted Index	0	-6	-7
Precip. Water in.	0.90	0.85	0.90
Low Level Moisture g/kg	8.3	9.8	13.1

16Z	MLS	BIS	ISN	DIK	Y22	MOT
Temp. °F	82	80	82	66	77	76
Dew Pt. °F	51	52	59	61	55	54

Station:

Kft MSL	Dir/Spd DEG KTS
SFC	110/05
3	140/21
5	170/15
9	245/18
12	280/19
16	300/45
20	300/48
25	295/56
30	290/62

CLOUD DEVELOPMENT

Scale	District I TO 00Z	District I 00Z to 12Z	District II TO 00Z	District II 00Z to 12Z
No Sig Wx		✓		
TCU				
RW or TRW	✓			
TRW+A				

FORECAST MAXIMUM TEMPERATURES

[redacted]	lo 90's
[redacted]	

FORECAST CONFIDENCE FACTORS

	SCALE ←00Z→		TIMING ←00Z→	
DISTRICT I				
DISTRICT II				

SYNOPSIS WARM FRONT RETURNING THROUGH STATE - WEAK SHORT WAVE PASSING DURING DAY. ON-GOING ACTVTY TO CONTINUE - ENDING WITH PASSAGE OF SHRT WAVE LATE AFTN.

OUTLOOK: STRONG SHORT WAVE APPRCHING LATE SATURDAY GIVES GOOD OPPORTUNITY FOR LATE AFTN/EVNG CONVECTION.

Form NDARB 88005

NDCMP FORECAST-1

DATE/TIME: 7-10-89

SOUNDING PARAMETERS	BIS (12Z)	GGW	RAP
500 mb Temp °C	-9	-10	-7
Wet bulb 0 Kft	12	12	11
0°C Level Kft	14	12	16
-5°C Level Kft	17	16	18
-10°C Level Kft	19	18	20
700 mb $T-T_{DEW}$ °C	7	5	1
CCL Kft	10	10	16
Trop Height Kft	39	39	44
Max Tops °C	-23	-21	-6
Max Tops Kft	26	24	18
$T_{CONVECTIVE}$ °F	94	85	104
MOS T_{MAX} °F	81	76	79
Total Totals	45	40	32
K Index	30	24	23
Sweat Index	219	143	93
Lifted Index	3	4	8
Precip. Water in.	1.18	1.05	0.64
Low Level Moisture g/kg	9.5	7.9	5.0

16Z	MLS	BIS	ISN	DIK	Y22	MOT
Temp. °F		74	68	69	71	63
Dew Pt. °F		57	56	58	52	57

Station: BIS

Kft MSL	Dir/Spd DEG KTS
SFC	70/6
3	25/14
6	270/15
8	275/24
10	255/29
14	225/34
16	240/50
19	235/60
22	230/56

CLOUD DEVELOPMENT

Scale	[redacted] TO 00Z	[redacted] 00Z to 12Z	[redacted] TO 00Z	[redacted] 00Z to 12Z
No Sig Wx				
TCU				
RW or TRW	✓	✓		
TRW+A				

FORECAST MAXIMUM TEMPERATURES

[redacted]	mid 80's
[redacted]	

FORECAST CONFIDENCE FACTORS

	SCALE 00Z		TIMING 00Z	
[redacted]	8	8	8	8
[redacted]				

SYNOPSIS SHRT WV TO SW MVG IN W PART OF STATE DURING AFTN LIKELY TO PRODUCE SCTD TSTMS - MAINLY IN SW* NDak and NW SDak. XPCT ONSET ~1900 CDT - CONT'G TONITE.

OUTLOOK - MAJOR WAVE WITH ASSOCIATED FRONTAL SYSTEM TO MOVE THRU STATE TOMORROW.

Form NDARB 88005

NDCMP FORECAST-1

DATE/TIME: 9-14-89

SOUNDING PARAMETERS		BIS	GGW	RAP
500 mb Temp	°C	-10	-9	-10
Wet bulb 0	Kft	12	12	13
0°C Level	Kft	12	13	14
-5°C Level	Kft	16	16	16
-10°C Level	Kft	19	20	19
700 mb $T-T_{DEW}$	°C	1	7	5
CCL	Kft	7	4	5
Trop Height	Kft	49	54	49
Max Tops	°C	-16	-32	-39
Max Tops	Kft	23	30	33
$T_{CONVECTIVE}$	°F	76	68	64
MOS T_{MAX}	°F	77	74	73
Total Totals		41	41	46
K Index		30	25	31
Sweat Index		126	152	156
Lifted Index		3	1	-3
Precip. Water	in.	1.14	1.20	1.21
Low Level Moisture	g/kg	8.9	11.3	11.7

	MLS	BIS	ISN	DIK	Y22	MOT
Temp. °F	64	73	72	63	62	–
Dew Pt. °F	50	56	59	60	52	–

Station: BIS	
Kft MSL	Dir/Spd DEG/KTS
SFC	70/06
3	115/17
5	115/16
7	105/15
9	85/12
12	55/11
14	260/4
18	255/16
20	275/15

CLOUD DEVELOPMENT

Scale	[redacted] TO 00Z	[redacted] 00Z to 12Z	[redacted] TO 00Z	[redacted] 00Z to 12Z
No Sig Wx		✓		
TCU				
RW or TRW	✓			
TRW+A				

FORECAST MAXIMUM TEMPERATURES

[redacted]	near 80s
[redacted]	

FORECAST CONFIDENCE FACTORS

	SCALE ← 00Z →		TIMING ← 00Z →	
[redacted]	8	8	9	9
[redacted]				

SYNOPSIS UPR TROF TO SW BEING FORCED SE BY RDGNG – Residual moisture remaining – CONTINUING WDLY SCTD LIGHT SHWRS IN SURVEILLANCE AREA/POSSIBLE ISLTD TSTM TO SOUTH AFTN – CLDS & CNVCTN GENERALLY DMNSHNG – ALL OVER BY 7 CDT.

OUTLOOK: NO SIGNIFICANT CLDS TOMORROW.

Form NDARB 88005

NDCMP FORECAST-1

DATE/TIME: 7-17-89

SOUNDING PARAMETERS	BIS (Y22)	GGW	RAP
500 mb Temp °C	-12	-11	-12
Wet bulb 0 Kft	12	12	12
0°C Level Kft	14	12	14
-5°C Level Kft	16	15	16
-10°C Level Kft	18	18	19
700 mb $T-T_{DEW}$ °C	4	4	8
CCL Kft	8	8	11
Trop Height Kft	54	58	56
Max Tops °C	-49	-53	-44
Max Tops Kft	36	36	33
$T_{CONVECTIVE}$ °F	76	83	88
MOS T_{MAX} °F	79	79	86
Total Totals	51	46	49
Index	36	32	29
Sweat Index	244	153	132
Lifted Index	-4	-2	-2
Precip. Water in.	1.36	1.06	0.84
Low Level Moisture g/kg	11.8	10.0	7.4

16z	MLS	BIS	ISN	DIK	Y22	MOT
Temp. °F	71	72	64	75	75	65
Dew Pt. °F	39	62	64	57	59	62

Station: BIS

Kft MSL	Dir/Spd DEG KTS
Sfc	110/04
3	175/16
5	180/15
7	160/2
10	280/12
14	215/13
19	205/13
23	200/11
27	270/15

CLOUD DEVELOPMENT

Scale	District I TO 00Z	District I 00Z to 12Z	District II TO 00Z	District II 00Z to 12Z
No Sig Wx		✔		
TCU				
RW or TRW	✔	✔		
TRW+A				

FORECAST MAXIMUM TEMPERATURES

~~DISTRICT I~~	near 80
~~DISTRICT II~~	

FORECAST CONFIDENCE FACTORS

	SCALE (TO 00Z)	SCALE (00Z TO 12Z)	TIMING (TO 00Z)	TIMING (00Z TO 12Z)
~~DISTRICT I~~	10	8	8	8
~~DISTRICT II~~				

SYNOPSIS 500 mb short wave - sfc convergence area acting on ND during day.

Current cnvctn to organize and intensify vcnty BIS early aftn - moving through area - activity ending ~1700 CDT.

Outlook: Tuesday likely inactive convectively.