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SUMMARY OF T-28 PARTICIPATION IN THE NORTH DAKOTA TRACER EXPERIMENT (1993)

By: Andrew G. Detwiler, Kenneth R. Hartman,
Gary N. Johnson, and Richard F. Kelley

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North Dakota Atmospheric Resource Board
State Water Commission
900 East Boulevard Avenue
Bismarck, ND 58505

Institute of Atmospheric Sciences

South Dakota School of Mine and Technology

501 E. St. Joseph Street

Rapid City, South Dakota 57701-3995

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1. INTRODUCTION

The South Dakota School of Mines and Technology (SDSMT) armored T-28 aircraft was deployed to Bismarck, North Dakota, for the six-week period 21 June through 30 July 1993. There it participated in the North Dakota Tracer Experiment (NDTE), a cooperative study of transport, dispersion and entrainment; ice initiation and evolution; storm structure; atmospheric chemistry; and cloud electrification in High Plains convective storms.

The NDTE operations involved the following major facilities in addition to the T-28:

- University of North Dakota (UND) Cessna Citation II
- Weather Modification, Inc. (WMI), Beechcraft Duke
- UND 5-cm Doppler radar
- National Oceanic and Atmospheric Administration (NOAA) Wave Propagation Laboratory (WPL) NOAA-C 3 cm circularly-polarized Doppler radar
- a mobile Cross-Chain Loran Atmospheric Sounding System (MCLASS) unit from the National Center for Atmospheric Research (NCAR)
- a suite of aerosol sampling instrumentation from Colorado State University maintained at the NDTE Operations Center
- routine satellite and meteorological data, and numerical model output, available through the McIDAS weather information facility, the National Meteorological Center, and the Canadian Atmospheric Environment Service
- National Lightning Detection Network (NLDN)
- One- and two-dimensional cloud models operated by SDSMT and the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center.

Details of the various experimental protocols and operational procedures are contained in **The NDTE Field Operations Plan**, available from the North Dakota Atmospheric Resource Board, State Water Commission, 900 East Boulevard Avenue, Bismarck, ND 58505. Participants came mainly from the institutions associated with the above facilities, as well as from the NOAA National Severe Storms Laboratory. Students from various undergraduate institutions participated under the umbrella of a Research Experience for Undergraduates effort funded by the National Science Foundation and directed by staff from SDSMT.

Primary funding for NDTE operations, and in particular for T-28 participation in the field operations, came through the National Oceanic and Atmospheric Administration (NOAA) Federal-State Cooperative Program in Atmospheric Modification Research through Cooperative Agreement NA27RA0178-01. The T-28 operations were supported through North Dakota Atmospheric Resource Board contract ARB-IAS-93-1 under that Agreement. Base funding for maintenance of the T-28 as a national facility comes from the National Science Foundation and the State of South Dakota, under Cooperative Agreement ATM-9104474. The T-28 facility is appreciative of both the opportunity to participate in the NDTE, and the base support that allows it to be capable of such participation.

The NDTE operations were conducted in the central North Dakota region. The locations of various primary facilities are mapped in Fig. 1, taken from the NDTE field operations plan. The T-28 was based at Executive Air, a fixed-base operations enterprise at the Bismarck Municipal Airport, on the south side of Bismarck.

The primary role of the T-28 in the NDTE was to penetrate upper regions of convective clouds following the dispersal of sulfur hexafluoride (SF_6), (an inert manmade tracer gas), 3 cm radar chaff, and/or 100 μm diameter fluorescent beads, in lower regions of the cloud. A sensitive gas analyzer on the T-28, leased from and maintained in the field by North American Weather Consultants, was used to follow the transport and dispersion of SF_6 through the cloud. Data from the T-28 analyzer are to be combined with data from a similar analyzer on the UND Citation to provide detailed mappings based on simultaneous samples from different levels and regions of target clouds.

A particle sampler on the T-28 (provided by Nancy Knight of NCAR) was capable of in-flight collection of ice-phase hydrometeors. These hydrometeors could be examined for the presence of fluorescent beads which may have served as embryos for their initiation or been collected during growth of the hydrometeors.

Additional instrumentation on the T-28 characterized the complete particle spectrum from few-micrometer cloud droplets to several-centimeter hailstones, provided information on vertical winds, and measured the

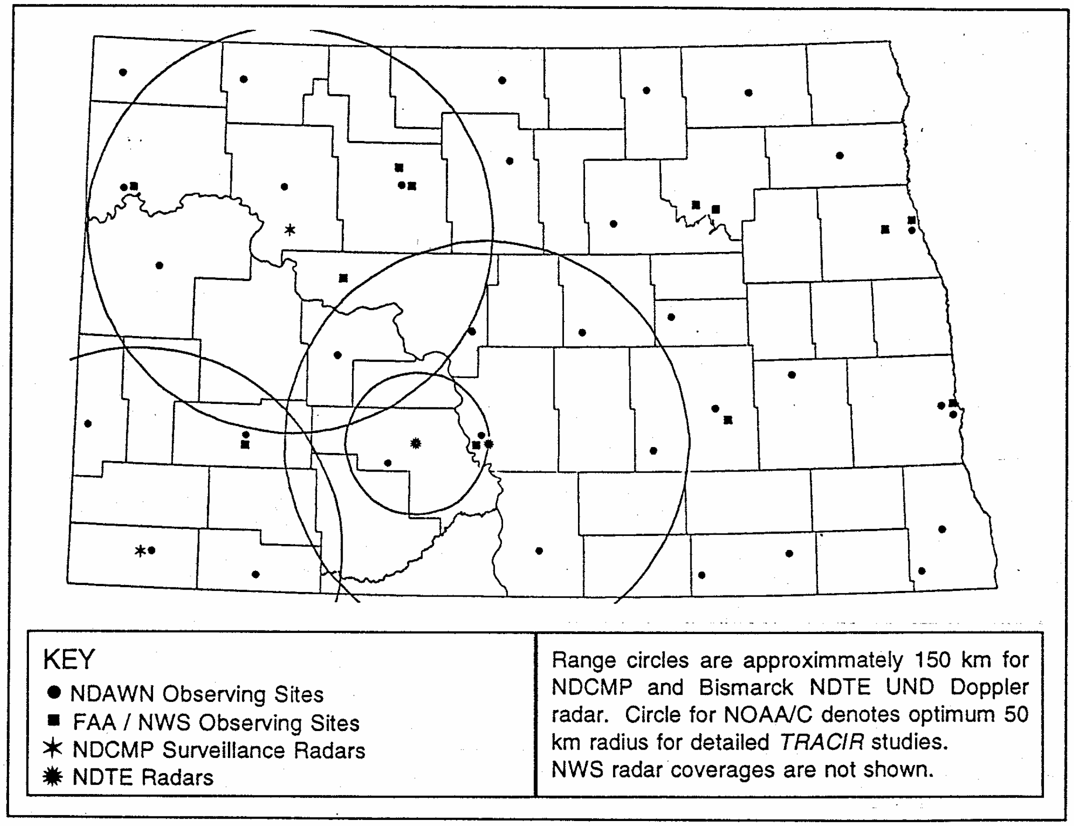

Fig. 1: Locations of various facilities utilized during the NDTE. "NDAWN" is a network of automatic weather stations; "FAA/NWS Observing Sites" are locations where hourly weather observations are made manually or via automatic equipment; "NDCMP Surveillance Radars" are two 5-cm radars operated in support of the North Dakota Cloud Modification Project cloud-seeding operations; and "TRACIR" studies are studies involving tracking of 3-cm radar chaff using the circularly-polarized NOAA-C 3-cm radar.

ambient electrostatic fields in the target clouds and their vicinities. Aircraft position was provided by a Trimble Global Positioning System unit. Position information and selected meteorological data were telemetered to the Operations Center in real time to aid in the direction of flight operations.

A summary of T-28 instrumentation carried during the NDTE is contained in Appendix A. Appendix B describes parameters routinely computed and archived in the standard T-28 data set. Appendix C lists the data reduction equations employed in reducing the NDTE data.

2. FLIGHT OPERATIONS

On each of the 40 days of the project, excepting those designated in advance as days with no operations and three days when equipment problems precluded flight operations, the T-28 was ready for participation in one of the seven NDTE experiments involving it. These experiments involving the T-28 are summarized in Table 1 and described in more detail in the operations plan. Table 2 lists all T-28 flight activities connected with the NDTE and Table 3 summarizes research flight activities by date and experiment type.

Short accounts of flight activities on 13 of the 14 days with research flights are presented next. (The T-28 did not participate in any NDTE experiment on 29 June.) Following these accounts, Table 4 summarizes selected properties of the convective clouds penetrated, by penetration.

TABLE 1

Summary of NDTE Experiments Involving the T-28

Exp 1	-	Transport and hydrometeor evolution in feeder clouds, mid-cloud treatment
Exp 2	-	Transport and hydrometeor evolution in feeder clouds, cloud-base treatment
Exp 3	-	Transport and hydrometeor evolution in cumulus congestus, cloud-base treatment
Exp 4	-	Transport and hydrometeor evolution in cumulus congestus, mid-cloud treatment
Exp 5	-	Entrainment and hydrometeor evolution in cumulus congestus, linear upper cloud treatment
Exp 6	-	Entrainment and hydrometeor evolution in cumulus congestus, treatment on cloud perimeter
Exp 8	-	Anvil studies

TABLE 2

T-28 Flights - Summer 1993

Date (1993)	Flight No.	Time (h)	Purpose
20 May	593	1.3	Local test
23 May	594	2.5	Ferry to RKS (fuel stop)
23 May	595	0.9	Ferry to SLC
30 May	596	1.8	Ferry to CPR (fuel stop)
30 May	597	1.1	Ferry to RAP
14 June	598	1.4	Local test & pilot checkout
14 June	599	1.3	Ferry to BIS
22 June	600	1.7	Research
26 June	601	2.5	Test
29 June	602	1.3	Research
30 June	603	1.9	Research
1 July	604	1.7	Research
3 July	605	1.9	Research
6 July	606	2.1	Research
8 July	607	1.9	Research
9 July	608	1.8	Research
15 July	609	1.6	Research
18 July	610	2.8	Research
22 July	611	1.6	Research
23 July	612	1.9	Research
25 July	613	2.0	Research
27 July	614	2.2	Research
29 July	615	1.2	Test (tower fly-bys)
30 July	616	1.3	Ferry to RAP
Total		41.7	

TABLE 3

NDTE T-28 Experiment Summary

Date	Mission	Description	SF_6 Detected	Comments
22-Jun	Exp 1	mid cld; fdr	Only 1 pass; no SF_6 detected	T-28 not well-coordinated with others
29 Jun	None			
30-Jun	Exp 6	perim; cu cong	many passes; SF_6	
	Exp 4	mid cld; cu cong	3 passes; SF_6	
1-Jul	Exp 1	mid cld; fdr/dghter?	no SF_6	mdt strong cnvctn
	Exp 1	mid cld; fdr/dghter?	no SF_6	
3-Jul	Exp 1	mid cld; fdr	no SF_6	T-28 in 2nd mission; strng cnvctn Stayed with same cell whole flt
6-Jul	Exp 2	cld bs; fdr	SF_6	Modest size cloud 2nd case of day
8-Jul	Exp 1	mid cld; fdr	no SF_6	vigorous
	Exp 1	mid cld; fdr	small SF_6	hvy icng
9-Jul	Exp 2	cld bs; fdr	no SF_6	very vigorous; caught hail
	Exp 2	cld bs; fdr	no SF_6	very vigorous
15-Jul	Exp 1	mid cld; fdr	no SF_6	very vigorous; slushy hail
18-Jul	Exp 1	mid cld; fdr	small SF_6	small storm; sheared
	Exp 1	mid cld; fdr	no SF_6	small storm; sheared
22-Jul	Exp 6	perim; cu cong	SF_6	collapsing; weak; SF_6 not entrnd Duke and T-28 only
23-Jul	Exp 2	cld bs; fdr	no SF_6	T-28 not well coordinated w/release vigorous; in SD
25-Jul	Exp 6	perim; cu cong	weak SF_6	collapsing
27-Jul	Exp 3	mid cld; cu cong	no SF_6	
	Exp 2	cld bs; fdr	SF_6	vigorous; icing

Flight 600, Tuesday, 22 June

Experiment 1 - Mid-cloud treatment of feeder clouds

1631-1748 CDT

Weather

A convergence line with convection developed west of Bismarck late in the morning. An arc of convective cells extended southward from north central North Dakota through south central South Dakota by early afternoon.

Activities

By 1420, the operations director was trying to contact air crews to arrange launches. Duke and Citation were off ~1530, and found cloud base near 790 hPa or 2.5 km (8300 ft).

Aircraft worked cells initially 40-50 km SW of Bismarck, but moving towards Bismarck. The Duke and Citation performed a coordinated release of SF_6 and chaff prior to arrival of the T-28. The Citation may have detected SF_6, but it is not certain, as its analyzer had some pressure regulation trouble. NOAA-C was able to see the chaff, but just barely. (NOAA-C subsequently requested longer chaff releases.)

The T-28 tried to line up with the other aircraft for the second release of the day for an Experiment 1. It is not known if the T-28 went through the same cell in which the release occurred. The T-28 did penetrate a 15 m/s updraft with just less than 2 g m^{-3} cloud water, accompanied by a few 2D-C shadow/or counts. It made one penetration (~1725) and then returned home as the attitude indicator was not functioning. The penetration was near 6.1 km (20 kft) altitude and the SF_6 analyzer output was oscillating. No obvious SF_6 signature showed up among the oscillations.

The cell the T-28 went through was not electrified, but lightning and significant fields were detected as it was maneuvering in the storm area. Post-flight consensus was that the cells in this storm were not true feeders, but rather daughters.

Intercept teams got nice photos of funnel clouds from the storms the aircraft worked, but after the aircraft mission was complete. Everyone was down by about 1745 when these storms passed over the airport. More storms came in from the SW a couple of hours later. Some pea-size to 1-inch hail was collected NE of Bismarck (including at Bruce Boe's home).

Instrumentation notes:

(1) The Humphrey accelerometer was not working properly; the pitch, roll, and vertical acceleration data are not usable. This forces computation of the updraft using the Cooper method for this flight. This method works reasonably well when acceleration relative to the ground is computed using the GPS ground-speed data; however, these GPS data have some occasional discontinuities that produce huge spikes in the Cooper updraft time series.

(2) The 2D-C probe was in an every-other-buffer-empty mode of operation.

(3) Foil in the impactor did not advance.

(4) RsmT and RFT temperature data disagreed by 1 - 2 degrees (but tracked each other).

(5) The field mill test was not good because high voltage charging arced to the airframe.

Flight 602, Tuesday, 29 June

1852-1939 CDT

The T-28 jointed other project aircraft after they had just completed an isolated mid-cloud experiment (Experiment 4). The convection was so weak that all aircraft returned to base without performing any additional experiments.

Flight 603, Wednesday, 30 June

Experiment 6 - Cloud-perimeter treatment of an isolated cumulus congestus
Experiment 4 - Mid-cloud treatment of an isolated cumulus congestus

1526 - 1657 CMT

Weather

Bismarck weather was sunny but moist in the morning, with a short-wave expected through by mid-afternoon. Forecast was possible RW, with slight chance of TRW and then drying out later on. Some convection started by noon in western North Dakota.

Activities

The decision of the operations director was to stand by from 1330 for a small-cloud mission. The Duke took off at 1450, and the Citation took off at 1505. The Duke and Citation began working a small cloud mission west of Bismarck, using SF_6 and chaff, but trouble was encountered with the chaff cutter.

By 1550, the first small-cloud study was completed by the Duke and Citation. Beginning at 1601, all three project aircraft coordinated on a cloud perimeter treatment of an isolated cumulus congestus. The release was at 17 kft with the Citation penetrating above at 19 kft and the T-28 below at 15 kft. The T-28 encountered SF_6 several times. The Citation did not encounter SF_6 at 19 kft, but did find it after descending to 17 kft.

At 1630, a third experiment was begun involving all three aircraft in a mid-cloud release in an isolated cumulus congestus (Experiment 4). After initially penetrating an untreated cloud, the T-28 penetrated the treated cloud and encountered the SF_6 plume. The T-28 completed one additional penetration, then returned to base.

Instrumentation notes:

(1) The Humphrey accelerometer was out for repair. Thus there are no pitch, roll, or acceleration data. Cooper updraft computation method must be used.

(2) There are still empty image frames showing up in 2D-C data.

(3) No impressions on foil.

All other instrumentation appeared to operate nominally well.

Flight 604, Thursday, 1 July

Experiment 1 - Mid-cloud treatment of feeder cloud

1504-1625 CMT

Weather

Weather was cloudy in the morning, with a short wave passing over during the day. Expected TRW with small possibility of hail providing some clearing occurred and heating occurred. As of noon, activity appeared on radar in South Dakota and western North Dakota. The vertical profile of horizontal winds showed weak winds and weak shear.

Activities

The call came at 1350 to be ready to launch at 1500. There was thunder around the airport, with a heavy rain shower at the airport around 1408. The Duke took off at 1436, with the Citation right behind.

The T-28 was off at 1505 with rain at the airport. The Duke made a mid-cloud release in a feeder cloud near 220°/18.6 nmi at 1511, reporting 1000 fpm (5 m/s) updrafts at 17 kft. The T-28 made six penetrations at 15 kft in this cloud, encountering updrafts to 1500 fpm (8 m/s), turbulence, and icing, but no SF_6.

The three aircraft began their next mid-cloud release experiment around 1549 in another feeder near 220°/20 nmi. Near 1555, the Duke reported a 3000 fpm (15 m/s) updraft and hail during the second portion of its release. The T-28 made five penetrations in this cloud with the early penetrations characterized by turbulence and strong updrafts, while the later ones were characterized by much weaker convection. The T-28 broke off from this experiment at 1616. It did not encounter SF_6 in this cloud.

There was some debate at the debriefing as to whether the last study was a true feeder cloud case or not. It may have been more of a daughter cell than a feeder cell.

Instrumentation notes:

(1) The Humphrey accelerometer was still out for repair. Cooper updraft computation method must be used.

(2) Maximum imprint sizes on the foil were 5 - 8 mm, in agreement with maximum particle sizes from the 1-D hail spectrometer data. Foil is heavily wrinkled for first part of flight. No punch marks.

(3) Field mill tests were not good due to high voltage probe arcing within plexiglass mounting block.

(4) The 2D-C is still having the problem of empty frames in the odd-numbered buffers, but not as badly as on previous flight.

(5) The data system went down briefly and was then restarted around 1503.

Flight 605, Saturday, 3 July

Experiment 1 - Mid-cloud release in feeder cells

1748-1927 CDT

Weather

Thunderstorms came and went overnight. There was one over the airport at 0800. Crews were ready to fly by 1000, as per instructions from the previous evening. However, the operations director decided to wait for something later in the day.

The 1200 UTC, Bismarck sounding was very unstable with wind shear that could support tornadoes. Hail was also possible. A warm front was forecast to move up into the North Dakota/South Dakota border area. If it moved north as far as BIS then there was a chance for even more severe weather. Strong moist southerly flow up over the Plains lay ahead of a trough advancing over the Rockies.

Helicity was very high with CAPE near 2000 expected in the afternoon, presenting a good supercell situation, particularly further south.

Activities

The decision was to go for a Duke and Citation flight in the early afternoon, and a three-aircraft mission later in the afternoon. The second mission began with the T-28 taking off at 1725; the Duke at 1800; and the Citation at 1808. They worked cells in a line initially near 280 deg/40 n mi from the Bismarck VORTAC. Cells along the north end of a line associated with a previous clear-air convergence line were particularly vigorous. A chaff/SF_6 feeder experiment (Experiment 1) was performed. The T-28 penetrated from 1830 through 1910. The initial penetrations were through quite vigorous convection, with the pilot reporting accelerations of 4 g's. Updrafts/downdrafts exceeded 20 m s^{-1}, cloud water exceeded 3 g m^{-3} in the freshest of the updrafts, and buoyancy was 3-4°C in the updrafts, all near 5.2 km (17 kft) altitude. Things quieted down on later penetrations. The pilot reported he stayed with the same cell for the entire mission.

After the T-28 departed, the Duke and Citation did two more studies, both mid-cloud releases on feeders, before returning.

Instrumentation notes:

(1) The foil impactor ran only for the first and possibly part of the second penetration. Large particles appeared near the end.

(2) The J-W sensor was not turned on until 1756.

(3) There are still no Humphrey accelerometer data. The Cooper updraft computation must be used.

(4) Empty-frame problems continue in the 2D-C data.

(5) There was a glitch in the data system timing near 1759. Times are correct before and after the discontinuity.

Flight 606, Tuesday, 6 July

Experiment 2 - Cloud-base treatment of feeder cells

1604-1745 CDT

Weather

North Dakota was still under the influence of wrap-around flow from a low to the NE. There was a chance of TCu if some clearing allowed heating; some clearing had occurred already by briefing time in western North Dakota.

Activities

Early in the afternoon, the operations director scrambled the aircrews and called for a 1500 takeoff. The Duke and Citation performed one feeder-cloud-type experiment on small clouds, and then were joined by the T-28 for a second similar experiment. The aircraft joined in a study of a cloud complex that began almost right over NOAA-C. Clouds were originally distinct aloft but joined at the bases. It was decided to call it a feeder cell experiment. Tops were reaching just over 20 kft (6.1 km), although a general altostratus debris obscured things from 16 kft (4.9 km) to above 20 kft. The SF_6 and chaff release were at cloud base, just below 5 kft (1.5 km). (Experiment 2) The T-28 encountered SF_6 at least 4 times at 12 kft (3.7 km), but the Citation was unable to find SF_6 near 16-18 kft (4.9-5.5 km). The case was so close to NOAA-C that it had to do RHI scans through vertical.

The aircraft lined up for a third case (to be called either a sub-cloud thermodynamics or a feeder study), but it was aborted because of a failure of the SF_6 analyzer on the T-28 (due to a battery failure) and lack of on-station time for the Citation. The Duke and T-28 did two in-trail small Cu penetrations on the way home.

Instrumentation notes:

(1) The foil was okay, with particles to 7-8 mm. There were no punch marks.

(2) The 2D-C still has a problem with empty image frames in odd buffers.

(3) Return of the accelerometer allowed computation of Kopp updraft, with pitch and roll data, although acceleration was not recorded because of a software mixup.

(4) The SRI dischargers worked well; this was the first flight with good data from them. Electric field structure during the penetrations was somewhat complicated, apparently because more than one cell was penetrated on most runs.

(5) It was found that the fifth field mill saturates at 350 kV/m.

(6) The SF_6 detector quit after ~1.5 hour due to a discharged battery.

(7) The hail spectrometer detector pod window was broken during flight.

Flight 607, Thursday, 8 July

Experiment 1 - Mid-cloud treatment of feeder cells

1528-1706 CDT

Weather

The forecast was for a short wave to pass through the region later in the day. Instability was sufficient for thundershowers and possibly small hail.

Activities

All three aircraft got off around 1530, heading for a rendezvous near 260 deg/60 n mi.

The T-28 worked two feeder cell studies (Experiment 1) with other aircraft in front of a SW-NE line of thunderstorm cells approaching Bismarck from the west. The aircraft worked from S to N along the line as the mission progressed. There was one encounter with SF_6 by the T-28 on the second case, first penetration. The hail catcher was opened on the second case, but caught nothing. The pilot reported the storms were wet - he carried up to 1.5" of ice. The plane landed at ~1706 and was still dripping as it rolled up to the hangar.

An intercept team reported pea-size hail from the region of the second case. A few small hailstones were reported by a staff member driving between the downtown area and the airport ~1645; this was probably not from the storm worked by the project aircraft.

Instrumentation notes:

1) The J-W liquid water compensation wire was broken during flight.

2) The foil was heavily wrinkled and did not contain many valid impressions. A large fraction of the impressions were pushing through from the back. There were one or two spots with valid impressions up to 7 mm. The foil apparently ripped after the first or second penetration.

3) The 2D-C showed a mixture of stellars and graupel in spots (on the second case), with graupel up to 1-2 mm. There were many empty frames in both odd and even buffers.

4) The SRI dischargers continue to work well. On this flight, they both often discharged the same sign.

Flight 608, Friday, 9 July

Experiment 2 - Cloud-base treatment of feeder cells

1806-1938 CDT

Weather

A cold front was forecast to come through the area near mid-afternoon, with positive vorticity advection behind it.

Activities

The Duke and Citation got off at 1745 and headed toward a big storm at 290 deg/30 n mi. There was high reflectivity up to 35 kft (10.7 km) with tops to 45 kft (13.7 km).

T-28 performed penetrations on three feeder cell groups ahead of a thunderstorm complex advancing from the west, and also parts of the mature thunderstorm cells, to the north of Bismarck. It encountered hail and accelerations of 2-3 g's in spots, and also took a lightning strike (about 1909). The first and third complexes were coordinated cases with the other two aircraft.

Instrumentation notes:

1) The foil ran out during the flight. Some timing punches were visible, and the foil was wrinkled.

2) Some marble-size hail was caught while the hail sampler was open between 182328 and 182645.

3) Imaging on the hail spectrometer worked through most of the first penetration, then stopped.

4) A replacement NCAR 2D-C probe was carried in place of ours. It had noisy images in the first halves of buffers (as with the 2D-P-probe we borrowed during 1991), and also had no end-element voltages.

5) There was no field mill test, and SRI dischargers were removed for this flight. The dischargers were put on the Citation for this day and this also interrupted the power to the high voltage power supply used for the field mill tests on the T-28.

Flight 609, Thursday, 15 July

Experiment 1 - Mid-cloud treatment of feeder cells

1822-1948 CDT

Weather

It was drizzly and overcast in the morning, with a warm front to the south and a short wave approaching in upper level flow. Good low level moisture was present; TRW were overhead by noon, with many embedded storms on radar all over North Dakota.

Activities

A power outage around 1400 prevented the Duke crew from opening hangar doors and getting off. The Duke finally went out at 1445, did some chaff work with NOAA-C, and then returned at 1710 for a second 3-aircraft mission.

Heavy rain at the airport delayed things for a while. Then the Duke and Citation went off at 1800 for a target at 250 deg/40 n mi. The T-28 went off at 1823 to join the other aircraft. All three aircraft worked "feeders" (Experiment 1) along the south end of a line of storms with tops to 46 kft. The T-28 reported encounters with slushy graupel, but no solid hail. These particles hit the windscreen and streamed rearward before freezing to the airframe. The aircraft worked a line of three convective cells with updrafts in excess of 20 m/s. The youngest updraft to the SE had almost no precipitation, while precipitation was progressively more developed in cells further northward. These storms were west of Bismarck near the NOAA-C site; NOAA-C staff reported more than three inches of rain and pea-size hail from the storm the aircraft were working.

NOAA-C, tracking chaff released by the Duke, reported that chaff quickly got drawn into the main part of the storm from the release level of 16 kft in "feeders". The T-28, only 3 kft (1 km) above the mid-cloud release level, did not catch SF_6. The Duke reported 2000 fpm updrafts at release level and the T-28 4000 fpm at his level. The Citation encountered SF_6 once, on its first penetration. The Citation was subsequently unable to follow its pointer due to high reflectivities at the pointer position.

The Duke also released fluorescent beads. Intercept teams were potentially in position to catch precipitation containing them, as was NOAA-C.

The T-28 was brought in by 1945 to beat the next surge of storms through the BIS area. The aircraft lost some paint, and the tape on the J-W bundle and right wing discharger was shredded.

The project radar did ATI scans through the night as the storm soaked eastern North Dakota. Widespread flooding occurred in Bismarck and other cities.

Instrumentation notes:

(1) J-W head #130 was used in this flight. The J-W broke near the beginning of the second penetration, around 1851.

(2) The foil jammed at some point(s); it was heavily wrinkled with no punch marks. Some impressions were > 1 cm. Large particles apparently caused rips in the foil central area in spots.

(3) Only 52 image buffers were recorded from hail spectrometer. Only the first one was partially full of valid images. The rest were single streaks.

(4) Our 2D-C probe was returned to the aircraft, but with a board out of the NCAR 2D-C. The images were good. After beginning descent, about 1000+ buffers of empty images were recorded due to fogging of the optics.

(5) Initial indications of an SF_6 "hit" on first penetration were later judged to be false.

(6) The SRI dischargers worked in their typical pattern.

(7) The hail catcher was still under repair. A coupling in the hail catcher was replaced after Walter Grotewold, NCAR contractor, sent a new one in. The window deicing coil was an open circuit, so the unit was shipped back to Grotewold to repair and return.

(8) Electrical signatures got more complex as the flight went on. Vertical field was only associated with cells with well developed precipitation.

Flight 610, Sunday, 18 July

Experiment 1 - Mid-cloud treatment of feeder cells

1454-1710 CDT

Weather

An isolated Cb was anviling out to the west at noon. Activity in our area was expected by 1400 or so. A shortwave was forecast to be crossing the Dakotas; air was very unstable in the west, with LI's of -5 and reasonably high CAPE. Drying and cooling was forecast in behind the wave, maybe as early as early evening. There was some concern that the actual drying might be even faster than predicted by the models.

Activities

The Duke went up ~1415, the Citation ~1435, and the T-28 at 1454. First they worked some cells on the S end of a line near 224 deg/31 n mi. It was called a feeder cell case although the storms were not huge and topped out around 26 kft. First tracer release was made 1501-1506 (before the T-28 got there) at 13.5 kft. The Duke reported 2200 fpm updraft on the 1st pass and 2700 fpm on the return pass. The Citation reported that the cell did not look that vigorous but contained severe turbulence as well as quieter portions. NOAA-C tracked chaff from 1506-1542. The Citation found SF_6 at 1509 at 20 kft, and again in clear air at 1519 (also at 20 kft?). The T-28 had a weak SF_6 hit on its 1522 penetration below the release level (its second of the treated cell).

The second treated cell, further south in same complex, was also called a feeder cell. Release was from 1547-1551 at 15.4 kft. The Duke reported 2000-3000 fpm updraft with drops and graupel on windscreen, more vigorous than the first case. NOAA-C was able to see the chaff just after release and then it was out-of-range. The Citation found SF_6 on its first pass after the release but none after that. The T-28 was at 19 kft, where it encountered 10-13 m/s updrafts with heavy icing in some portions of its penetrations, but no SF_6. It did penetrations on the treated cell and other cells in the complex until 1655. The cells were quite vigorous in spots.

The Duke failed to find a third suitable candidate and returned; the Citation also returned after failing to find SF_6 in the second treated cell at various levels to near 25 kft.

The T-28 pilot reported that many of the penetrations were not too severe. The aircraft coordinator reported that when the T-28 penetrated visually, it seemed to be several km E of the strongest-looking parts of the storm on radar. When the coordinator vectored him using the radar, the T-28 encountered more vigorous convection. The coordinator attributed the disparity between visual and radar views to the fact that the upper parts of the clouds were shearing away from the lower parts. After the flight, propeller anti-ice boots were noted to be lifting at inboard edges.

Instrumentation notes:

(1) The hail catcher was not available.

(2) The foil did not transport at all.

(3) The right wing discharger lost all rubber and metal tips.

(4) Some hail spectrometer images were available early in the flight, but not after that.

(5) The first successful field mill test during the field project with correct polarity was obtained from 1500-1501. The high voltage probe mount had been reworked and the probe was replaced with a straight wire.

(6) HV current did not register during the successful field mill self-charging test.

(7) The data system clock was +6 seconds compared to WWV.

Flight 611, Thursday, 22 July

Experiment 6 - Cloud perimeter treatment of isolated cumulus congestus

1112-1227 CDT

Weather

Rain began early, between 0500 and 0600, with intermittent TRW. The Operations Director decided to go for an 0930 launch of the Duke and Citation and to hold the T-28 for a group flight later in the day. The Duke got off on schedule, heading for a target at 225 deg/35 n mi, with cells building on the S end of a line to the W of Bismarck. The Citation tried to get off but had its weather radar fail, and scrubbed its mission. With the Duke up and workable storms in hand, the Operations Director decided to send the T-28 out. The Duke first did a chaff-only cloud top release that was part in- and part out-of-cloud. NOAA-C was able to follow the mixing of the chaff throughout the cloud volume, its detrainment into the planetary boundary layer, and its re-ingestion into new clouds.

After this, the Duke was joined by the T-28 at 15 kft for another isolated cloud-perimeter release experiment (Experiment 6). The towers had significant shear. A quasi-isolated cell west of the main line of convection near 250 deg/30 n mi was treated at 17.3 kft. NOAA-C saw the ring for 25 min and it dispersed only slowly as the cloud collapsed. The chaff did not really get entrained into the cloud, but the tracer did subside and the T-28 had four SF_6 hits as the chaff subsided through 15 kft. Most of the hits were outside cloud. The T-28 had 1500 fpm updraft on the first penetration but weaker values after that. It was the impression of the Duke crew that the truly isolated cells were shearing off while the clumped cells would grow for longer periods before they, too, collapsed.

Both aircraft returned to base to try to beat the main line of convection into Bismarck. The T-28 did a radar approach due to a non-functional VOR. Frequent lightning and fairly heavy rain were in the airport vicinity during landing, but both aircraft managed to land during separate lulls over the airfield. Brief pea-size graupel/hail was noted around the airfield as the line passed over.

Instrumentation notes:

(1) The VOR failed in flight, but was functional in the hangar afterward.

(2) There was no field mill test or in-cloud event markers.

(3) Due to the fact that the in-cloud event mark was not activated, the foil impactor did not activate and no foil was exposed.

(4) Although some hail images were obtained, they were probably not real particles, as the only 1-D hail counts were on descent when the spectrometer probably fogged.

(5) There were some episodes of very high FSSP droplet concentrations. The J-W cloud water concentration (LWC) was very low relative to FSSP-integrated LWC.

(6) The SRI dischargers worked; some odd bi-polar signatures appeared in computed E_z. Fields were high only when a penetration included something other than the target cell.

Flight 612, Friday, 23 July

Experiment 2 - Cloud-base treatment of feeder clouds

1652-1823 CMT

Weather

The day started early, with an attempted tower fly-by at Mandan Airport. It was scrubbed at 8 a.m. due to persistent fog. Showers were occurring later in the morning and continued into the afternoon.

Activities

The Duke was off at 1641, the Citation around 1650, and the T-28 at 1655. They headed for a storm on the South Dakota border to the SE of Bismarck.

The T-28 performed a series of penetrations of a thunderstorm near 155 deg/80 n mi from Bismarck. The storm had a broad, precipitation-free updraft on the earliest penetrations and appeared to be composed of several separate cells on subsequent ones, with increasing amounts of precipitation and downdrafts eroding into the updraft of cells further downshear. The storm electrified during the period of the penetrations. The Duke did a tracer release on a feeder about 2 n mi S of the T-28, but in a region related to the storm the T-28 was working. The T-28 had completed only two penetrations of the main storm subsequent to this release when it had to return due to popped rivets on the upper wing panels. The Citation stayed with the release area for 15 minutes but found no SF_6 at its altitude (near 20 kft).

The storms were fairly vigorous and wet, with 2-3 g/m^3 reported by the Citation and T-28 in penetrations of young cells.

Instrumentation notes:

(1) The foil jammed during/after the first penetration. There was some wrinkling, and large particle impressions in spots.

(2) There were no usable hail spectrometer images.

Flight 613, Sunday, 25 July

Experiment 6 - Cloud-perimeter treatment of an isolated cumulus congestus

1746-1926 CDT

Weather

Rain fell overnight and into the morning, with some clearing to the west by 1000. The forecast was for suppressed activity in W North Dakota with TCu/TRW later in the afternoon.

Activities

Standby began at 1600, with TCu and small TRW (some producing lightning) present near Dickinson. The call came at 1645 to launch at 1730. The Duke and T-28 got off nearly on schedule, but the Citation had computer problems that delayed it until 1800.

The aircraft aimed for cells in the general area of 260 deg/60 n mi. They performed a mid-cloud cloud-perimeter release (Experiment 6) around a TCu with the T-28 below (13 kft) and Citation above (20 kft), the Duke release altitude (16 kft). The cloud collapsed during the subsequent observation period. The Citation had multiple encounters with high SF_6 concentrations, sometimes well away from the visible cloud. The T-28 had two possible weak hits. On its last penetration, the T-28 had to nose down to try to get into the tops of the cloud as it collapsed below 13 kft.

The three aircraft then lined up for a formation intercomparison flight at 13 kft. They were in formation from 191620 through 191920. They subsequently overflew the field at a low altitude, providing a photo opportunity at the operations center.

Instrumentation notes:

(1) There was electronic noise and many empty buffers in the 2D-C data, and not just upon descent.

(2) The foil wrinkled in spots. There were sporadic large particle impressions. All but possibly the second time punch came through.

Flight 614, Tuesday, 27 July

Experiment 3 - Mid-cloud treatment of an isolated cumulus congestus
Experiment 2 - Cloud-base treatments of feeder cells

1500-1644 CDT

Weather

An upper low was expected to move east today. Embedded showers, possibly thundershowers, were expected mainly to the north as this low tracked eastward and wrap-around moisture came into the area. There was a pretty strong cap at 700 hPa.

The Duke and Citation were off about 1445 to initiate a mid-cloud treatment of an isolated cumulus congestus (Experiment 5) around 1500 near 200 deg/12.5 n mi. This cloud began to lose its base around 1506 as radar reported precipitation reaching the surface and 50 dBz reaching to 16 kft. NOAA-C detected the chaff, but the Citation did not find SF_6 at 19 kft.

Near 1515, the T-28 began penetrations of the treated cloud. NOAA-C reported that a more active part of the treated cloud on the NE side had ingested some chaff. Apparently the treated cell collapsed as its northeastern neighbor developed.

The three aircraft then moved NE of Bismarck and began a cloud-base treatment of a cell near 042 deg/6.5 n mi (Experiment 2). The T-28 began penetrations near 1534, prior to treatment, in a region with very active convection. The Duke saw this line building to the S, and also noted lightning. The Duke initiated a cloud-base loop-shaped release near 1545 that carried under most of the line of convective cells. The T-28 continued penetrating at 15 kft, finding active convection and encountering heavy icing conditions. It encountered SF_6 twice near the southern end of the line. The Citation encountered SF_6 aloft in this same cell during several penetrations between 19 kft and 26 kft. The T-28 hail catcher was opened at 161630, while on the N end of a penetration of this line of cells, but nothing of significance was found in it after landing.

The Citation investigated the anvil region beginning at 1630 and eventually spiraled down through the remaining cloud as it returned ~1730. The Duke did a separate chaff release near NOAA-C without support from other aircraft. NOAA-C noted transport from cloud base through 15 kft in feeders.

Instrumentation notes:

(1) Data from 160355 -> 160500 are missing due to a data system glitch.

(2) The J-W appeared to ice up in spots. (Head #130.)

(3) The FSSP flow tube iced up due to an open connection in the deice heater circuit.

(4) Nothing of note was caught in hail catcher.

(5) Three to four foil punch marks came through for the early penetrations, but later ones apparently did not. There appears to be foil for the entire flight.

Flight 615, Thursday, 29 July

Tower Fly-By

0603-0703 CDT

Weather

Clear.

Activities

The T-28 participated in tower fly-by operations at the Mandan Airport. Between 0622 and 0652, it made four passes each at 160, 140, and 120 kts indicated airspeed past project director Bruce Boe in his instrumented "cherry picker."

Temperature probes and pressure sensors appeared to work well.

Further summary information for these flight days is contained in the appendices. Appendix D contains plots of T-28 flight tracks for each NDTE research flight. Appendix E contains weather summaries for each research day.

3. SUMMARY OF DATA COLLECTED

Table 4 provides a synopsis of key observations, by cloud penetration, during the research flights. The convective condensation level based on the 12 UTC BIS soundings on all days was around 2 km ± 0.4 km with corresponding temperatures of 8°C ± 2°C. Thus the T-28 penetrations were most often 2 to 4 km above cloud base.

The variables tabulated in Table 4 are as follows:

Hr, Min, Sec - times, in Mountain Daylight Time, 24-hour format, when the aircraft began a cloud penetration. Attempts are made to keep the aircraft data system clock set to WWV. Only small deviations (plus or minus a second) may be present on any given flight, unless otherwise noted in daily summaries.

Duration - duration, in seconds, of the cloud penetration.

Avg z - average altitude, in geopotential meters in a standard atmosphere, during the penetration period. There may be a significant difference (hundreds of meters) between this altitude and actual geometric altitude.

Avg Hdng - average direction of penetration, relative to magnetic north, in deg.

Avg T - average temperature, in degrees Celsius, during the penetration as determined from the Rosemount aircraft tem perature sensor. This sensor is subject to wetting effects and the average temperature may be biased low by a degree or more on many penetrations.

Max LWC - maximum 1-s value of total cloud liquid water concentration, in g/m^3, as determined by the FSSP or J-W cloud water meter. The J-W instrument has been shown to respond mainly to droplets with diameters less than 30 micrometers; the FSSP may underestimate water concentration when droplet concentrations exceed ~500 cm^{-3}.

W_{min}, W_{max} - peak negative and positive vertical winds, in m/s, during the period, estimated from changes in aircraft pressure altitude computed from centered 2-s differences with some corrections applied. The peak downdrafts tended to occur near the beginnings of penetrations and are probably not reliable estimates of the actual air

TABLE 4

T-28 NDTE Penetration Summary

Hr	Min	Sec	Duration (s)	Avg z (m)	Avg Hdng (deg)	Avg T (C)	Max LWC (g/m^3)	Wmin (m/s)	Wmax (m/s)	Max 2DC (1/liter)	Max Hail (1/m^3)	HailMxD (cm)	Max Abs E (kV/m)	Pilot Comments
Flt 600, 22 June 93:														
17	25	10	115	5900	53	-13.8	1.9	-8	14	98	0.0	0.0	0	
Flt 603, 30 June 93:														
16	2	50	79	4553	275	-10.3	0.4	-5	4	106	0.0	0.0	9	
16	5	24	64	4541	81	-9.9	0.3	-4	6	68	0.0	0.0	5	Rime
16	7	11	52	4561	241	-9.5	0.1	-2	5	51	0.0	0.0	2	
16	9	7	34	4572	91	-9.5	0.0	-3	7	35	0.0	0.0	1	Cloud breaking up
16	10	57	115	4550	262	-9.9	0.3	-3	4	34	0.0	0.0	0	
16	14	36	17	4578	89	-9.7	0.0	-3	3	27	0.0	0.0	0	
16	16	13	27	4578	255	-9.4	0.0	-1	5	27	0.0	0.0	0	
16	18	19	34	4523	31	-9.5	0.0	-2	6	19	0.0	0.0	0	Cloud dissipating
16	25	13	17	4545	279	-10.6	0.9	-4	5	0	0.0	0.0	0	
16	26	55	14	4519	89	-10.1	0.7	-4	1	0	0.0	0.0	0	
16	36	25	37	4576	28	-10.7	0.6	-4	5	0	0.0	0.0	0	Abort pass; wrong cloud
16	38	35	16	4546	189	-9.3	0.0	-5	1	0	0.0	0.0	0	
16	40	36	20	4554	345	-9.5	0.0	-4	5	10	0.0	0.0	0	
16	41	13	40	4572	167	-10.2	1.0	-6	6	1	0.0	0.0	0	
Flt 604, 1 July 93:														
15	15	56	100	3892	168	-4.1	1.9	-8	10	185	0.0	0.0	1	500 up; lgt rain
15	19	46	109	3988	300	-4.9	1.7	-4	6	178	0.0	0.0	18	no ice
15	22	33	120	3990	183	-5.2	1.8	-9	7	135	0.0	0.0	11	turb & up to west; lt ice; no hail
15	25	50	100	3996	328	-5.2	2.6	-6	10	163	0.0	0.0	2	1500 up
15	28	33	126	4104	148	-6.1	2.2	-10	8	226	0.0	0.0	7	smooth ride
15	31	30	150	3980	326	-5.1	2.4	-8	7	145	0.0	0.0	1	hvy ice; hi blwr
15	48	41	142	4645	240	-8.9	2.4	-10	9	227	1.0	0.6	5	1500 up
15	51	56	73	4673	360	-9.2	1.9	-12	12	206	0.0	0.0	1	more turb
15	54	13	98	4739	168	-10.3	0.7	-8	9	587	0.0	0.0	4	
15	57	30	88	4742	340	-10.2	0.7	-10	3	641	0.1	0.4	28	1.5" ice; pstatic
16	0	14	94	4758	186	-9.8	0.6	-14	10	905	0.2	0.6	19	turb
16	2	56	96	4686	349	-9.4	0.7	-10	6	705	0.2	0.4	35	pstatic
16	5	54	86	4744	160	-10.1	0.6	-11	5	492	0.2	0.6	26	pstatic
16	8	48	71	4765	310	-10.0	0.4	-10	11	746	0.1	0.4	49	pstatic; missed cloud
16	13	19	91	4667	131	-9.7	0.3	-9	5	386	0.2	0.8	64	
16	15	52	28	4700	328	-10.0	0.2	-8	6	140	0.0	0.0	13	

TABLE 4 (continued)

Hr	Min	Sec	Duration (s)	Avg z (m)	Avg Hdng (deg)	Avg T (C)	Max LWC (g/m^3)	Wmin (m/s)	Wmax (m/s)	Max 2DC (1/liter)	Max Hail ($1/m^3$)	HailMxD (cm)	Max Abs E (kV/m)	Pilot Comments
Flt 605, 3 July 93:														
18	30	2	72	5571	104	-8.2	3.7	-21	20	331	0.0	0.0	14	
18	32	20	85	5531	285	-8.3	2.9	-10	20	519	1.4	1.0	28	3 to 4 g's; 3000 up
18	35	28	82	5508	105	-9.3	2.5	-12	12	459	7.0	1.4	32	
18	38	19	117	5518	275	-8.1	1.5	-17	23	427	17.1	2.0	49	ltng @183900, 2 flashes
18	42	56	202	5494	89	-9.5	4.5	-10	13	636	4.5	1.7	51	ice covered; hail catch; ltng @184520
18	47	57	210	5481	226	-8.9	1.3	-12	16	443	13.5	2.0	30	
18	54	44	244	5505	91	-9.8	1.1	-16	12	592	0.1	0.6	38	
19	0	2	198	5419	229	-8.9	0.7	-11	10	455	0.1	0.6	28	
19	4	11	184	5477	134	-9.1	2.0	-12	15	279	0.0	0.0	30	
Flt 606, 6 July 93:														
16	31	41	80	3702	41	-4.0	1.3	-7	14	132	0.0	0.0	24	
16	35	7	107	3630	219	-3.2	1.8	-8	17	324	0.8	0.9	38	
16	38	26	121	3552	29	-3.2	1.4	-4	15	225	0.0	0.0	26	SF_6 hit
16	42	17	122	3576	220	-3.3	1.6	-11	18	304	0.0	0.0	20	SF_6 hit; ltng@164318
16	45	59	148	3395	30	-2.4	0.6	-10	8	180	0.0	0.0	44	SF_6 hit; pstatic
16	50	6	194	3403	222	-2.1	1.9	-5	13	191	0.5	4.5	50	
16	54	23	232	3396	29	-2.4	1.1	-12	12	198	0.0	0.0	68	SF_6 hit; ltng@165646
16	59	39	254	3393	221	-2.0	1.5	-8	5	169	0.0	0.0	62	SF_6 hits??
17	4	52	222	3393	32	-1.8	1.6	-6	8	199	0.0	0.0	51	hvy turb @170500
17	37	14	13	2717	275	1.4	0.9	-3	5	0	0.0	0	-1	In-trail pen w/Duke
17	38	20	18	2698	237	1.6	1.1	-4	7	0	0.0	0.0	1	In-trail pen w/Duke
Flt 607, 8 July 93:														
15	59	40	117	4995	70	-11.8	2.5	-12	5	156	0.0	0.0	3	
16	2	43	100	4955	204	-11.6	1.9	-14	4	143	0.0	0.0	1	lgt ice; hi blwr
16	6	30	344	5069	51	-12.3	2.3	-11	17	1110	6.8	1.4	53	1.5" ice; pstatic; SF_6 hit; ltng@161015
16	12	22	181	5055	209	-13	4.3	-9	15	594	1.7	0.8	26	3000 up @161400; pstatic
16	16	28	355	4984	59	-12.1	3.7	-17	8	1301	24.2	2.0	55	ltng @161745; 161837; 161918; 162005
16	25	24	238	5010	289	-13.3	2.8	-14	7	1426	3.0	1.0	46	pstatic; hail sample 162822-163137
16	30	8	182	5063	106	-12.8	2.9	-11	14	1320	21.6	2.0	52	ltng @163137
16	35	17	262	5016	281	-13.2	1.2	-14	6	926	13.1	1.0	35	pstatic
16	41	15	229	5044	105	-13.2	1.0	-7	6	1028	19.7	2.4	39	hvy pstatic; SF_6??
16	47	17	81	5050	275	-13.7	0.4	-9	5	491	0.0	0.0	23	
16	50	30	123	5063	100	-13.4	0.2	-6	10	704	0.9	1.0	32	hvy pstatic
16	52	53	150	4920	106	-13.4	0.1	-9	9	363	0.0	0.0	1	

TABLE 4 (continued)

Hr	Min	Sec	Duration (s)	Avg z (m)	Avg Hdng (deg)	Avg T (C)	Max LWC (g/m³)	Wmin (m/s)	Wmax (m/s)	Max 2DC (1/liter)	Max Hail (1/m³)	HailMxD (cm)	Max Abs E (kV/m)	Pilot Comments
Flt 608, 9 July 93:														
18	20	36	375	3812	116	-3.4	1.4	-10	18	313	28.7	4.5	41	3000 up; 2-3 g's; SF6?? N side; ltng @ 182235 & 182305 & more; hail smple 182328-182641
18	27	1	78	3594	240	-2.3	0.0	-5	4	49	0.6	0.9	8	
18	35	34	116	3524	75	-1.6	1.0	-11	5	70	0.7	0.9	4	smth ride
18	38	10	55	3536	256	-2.5	0.4	-6	-2	0	0.0	0.0	2	ltng
18	42	19	96	3524	80	-1.7	0.4	-4	4	75	0.0	0.0	4	
18	45	0	51	3509	261	-1.2	0.5	-6	1	55	0.0	0.0	4	
18	47	38	205	3687	81	-2.3	1.3	-12	12	19	1.2	2.0	13	
18	52	4	176	3669	215	-2.7	1.3	-13	10	1457	0.2	0.6	12	
18	56	28	231	3722	141	-2.8	1.5	-9	15	5123	0.2	0.6	4	up @ 185702; 2000 up & hvy turb @ 185920
19	4	49	128	3673	93	-2.2	1.2	-5	15	73	0.0	0.0	10	turb @ 190442 & 190548
19	8	15	115	3614	271	-2.2	0.9	-10	9	110	0.0	0.0	22	ltng @ 190848 & 190852; turb @ 190902
19	12	1	169	3660	91	-2.7	1.0	-7	12	237	1.2	2.0	41	ltng hit?; hail @ 191245; svr turb @ 191322
19	16	25	131	3680	271	-3.2	1.3	-10	12	3603	0.0	0.0	7	yaw @ 191730;
19	20	41	193	3681	72	-3.3	1.4	-11	11	80	0.0	0.0	6	smoother ride
19	25	46	130	3535	258	-2.9	1.4	-12	4	14	0.0	0.0	1	
Flt 609, 15 July 93:														
18	47	15	39	5853	355	-8.9	0.6	-8	5	732	0.2	0.6	41	
18	50	54	118	5903	137	-9.7	1.7	-9	19	982	11.6	2.9	24	1000 up; mdt ice; mdt turb;ltng
18	56	15	189	5988	319	-10.6	4.6	-14	18	1322	13.1	4.5	27	4000 up; svr ice; svr turb; ltng + +
19	4	0	263	5876	164	-11.0	1.5	-10	24	1025	3.0	2.9	28	2000 up; svr ice; mdt turb; ltng
19	12	22	246	5873	319	-11.7	3.5	-14	15	1020	0.0	0.0	24	2000 up; ltng
Flt 610, 18 July 93:														
15	16	3	177	4849	290	-8.0	0.8	-6	4	768	0.0	0.0	43	1000 up; lgt ice; lgt turb
15	22	16	146	4862	108	-9.0	0.4	-2	3	522	0.0	0.0	38	500 up
15	26	22	184	4856	305	-8.6	1.0	-10	3	671	0.0	0.0	39	1000 up; lgt ice
15	32	29	272	4872	179	-8.8	1.5	-10	4	520	0.0	0.0	22	300 up; 1000 down; lgt ice; vry lgt turb
15	37	31	186	4866	194	-9.3	1.2	-6	7	304	0.0	0.0	20	500 up; mdt ice; mdt turb
15	45	58	116	4826	72	-8.3	0.8	-8	4	302	0.0	0.0	15	500 up; 700 down; lgt ice
15	48	23	90	4933	188	-9.5	0.6	-12	4	778	0.0	0.0	24	500 up
15	50	45	134	4912	192	-9.3	3.2	-10	14	627	0.0	0.0	14	2000 up; hvy ice

TABLE 4 (continued)

Hr	Min	Sec	Duration (s)	Avg z (m)	Avg Hdng (deg)	Avg T (C)	Max LWC (g/m^3)	Wmin (m/s)	Wmax (m/s)	Max 2DC (1/liter)	Max Hail ($1/m^3$)	HailMxD (cm)	Max Abs E (kV/m)	Pilot Comments
15	55	14	178	4914	59	-9.2	3.3	-12	9	655	0.0	0.0	34	2000 up; mod rain; mod ice; mod turb
16	3	17	260	4912	233	-9.5	3.0	-7	11	678	0.3	0.4	31	1600 up; mdt ice; mdt turb
16	13	11	103	4846	321	-9.1	2.2	-6	7	614	0.0	0.0	43	mdt ice
16	17	20	89	4908	161	-8.7	0.7	-5	7	634	0.1	0.6	34	
16	24	58	53	4934	310	-9.7	1.1	-1	9	354	0.1	0.6	50	1500 up
16	28	41	64	4871	137	-8.7	0.7	-6	10	570	0.0	0.0	51	
16	34	39	126	5138	341	-10.3	0.2	-5	3	412	0.0	0.0	21	wasn't much activity
16	43	46	116	5243	182	-10.3	1.8	-9	16	689	0.0	0.0	29	2000 up; mdt precip w/ice; mdt turb; ltng
16	51	50	140	5133	292	-9.1	1.7	-12	10	416	0.0	0.0	10	2000 up; 1000 dwn; mdt precip; mdt ice; mdt turb
Flt 611, 22 July 93:														
11	43	26	189	4608	288	-5.4	1.2	-8	5	91	0	0.0	18	
11	56	38	52	4596	48	-5.7	0.9	-6	5	52	0	0.0	1	2000 up; SF_6 hit
11	59	16	72	4592	226	-5.5	1.1	-6	3	91	0	0.0	1	SF_6?
12	2	28	190	4579	102	-4.9	1.1	-13	5	136	0	0.0	1	SF_6 hit
12	5	42	254	4559	218	-5.0	1.2	-14	12	200	0	0.0	3	turb @ 120657; 1500 up in 2nd cell at end
12	10	42	130	4596	58	-4.8	1.1	-8	9	172	0	0.0	5	SF_6?; SF_6 hit on way home
Flt 612, 23 July 93:														
17	32	42	96	5225	105	-7.6	2.1	-6	18	232	0.0	0.0	4	2000 up; warm; ice; rain
17	35	31	108	5093	278	-7.7	2.6	-11	14	263	0.4	0.6	10	up on W edge; some ice
17	38	43	115	5187	92	-7.7	2.5	-8	14	535	0.4	0.6	14	svr turb; pstatic
17	41	17	133	5077	271	-7.2	2.4	-7	15	524	0.5	0.8	39	ice up on canopy; ltng @ 174235
17	44	57	100	5037	88	-7.1	2.4	-8	8	760	0.1	0.4	20	downdrafts
17	47	40	112	5044	276	-7.3	1.4	-8	7	507	0.0	0.0	22	pstatic
17	50	23	117	5078	90	-7.4	1.0	-9	7	717	0.0	0.0	32	pstatic; wing damaged in big bump on W side
Flt 613, 25 July 93:														
18	8	52	153	3983	21	-3.5	1.1	-10	3	141	0.0	0.0	26	
18	12	30	131	3973	197	-3.3	0.8	-7	3	204	0.2	0.6	31	lgt ice; pstatic
18	17	50	132	4004	204	-3.4	0.2	-5	4	174	0.3	0.8	5	
18	22	54	167	3991	177	-3.0	0.8	-5	4	17	0.0	0.0	0	ice ; rain; turb
18	28	57	63	4011	39	-3.4	1.7	-10	7	13	0.1	0.4	1	
18	31	13	100	3986	221	-3.3	2.0	-10	4	432	0.1	0.6	0	up; lgt ice

TABLE 4 (continued)

Hr	Min	Sec	Duration (s)	Avg z (m)	Avg Hdng (deg)	Avg T (C)	Max LWC (g/m^3)	Wmin (m/s)	Wmax (m/s)	Max 2DC (1/liter)	Max Hail (1/m^3)	HailMxD (cm)	Max Abs E (kV/m)	Pilot Comments
18	34	21	62	4008	29	-3.5	2.5	-5	9	825	0.5	1.0	1	bumps up
18	37	0	78	3954	209	-3.1	1.8	-7	5	210	7.0	1.7	2	lgt ice; no hail
18	39	59	80	3977	8	-3.2	1.9	-5	9	222	0.0	0.0	2	no rain, hail, or turb
18	42	35	74	3961	175	-3.1	1.9	-9	3	398	0.0	0.0	0	
18	46	14	52	4361	10	-5.2	1.5	-11	3	48	0.0	0.0	0	1500 up & down; ice; hi blwr
18	47	24	27	4462	19	-5.8	0.3	-5	0	139	0.0	0.0	2	
18	48	10	73	4475	23	-5.7	0.0	-5	2	65	0.0	0.0	1	1.5" ice
18	53	57	107	4140	221	-4.1	0.6	-5	3	81	0.0	0.0	1	
18	58	31	58	3992	40	-3.6	0.3	-5	3	15	0.0	0.0	0	
Flt 614, 27 July 93:														
15	16	51	45	4841	66	-9.0	0.4	-4	8	746	0.0	0.0	43	no ice; pstatic
15	19	52	62	4812	243	-8.4	0.6	-6	5	685	0.0	0.0	19	
15	23	1	47	4835	59	-9.2	0.3	-5	3	641	0.0	0.0	45	pstatic
15	25	42	77	4857	239	-9.3	1.5	-6	10	528	0.0	0.0	38	last pen this case; pstatic
15	34	16	86	4820	46	-9.1	0.5	-4	4	608	0.0	0.0	25	pstatic
15	37	8	66	4850	244	-9.3	1.7	-8	9	357	0.0	0.0	30	1500 up
15	39	38	84	4824	60	-9.4	1.9	-6	9	554	0.0	0.0	28	1500 up; 0.5" ice
15	42	24	102	4804	241	-9.0	1.8	-11	5	311	0.0	0.0	27	1500 up; pstatic
15	47	10	61	4799	40	-9.1	0.7	-6	4	501	0.0	0.0	20	1500 up; yaw&pitch @ 154730
15	49	5	61	4813	220	-8.9	2.4	-9	7	248	0.0	0.0	7	JW up 0.2; rough ride
15	52	6	108	4777	39	-8.8	4.1	-8	7	682	0.0	0.0	31	bumps; yaw; SF_6; JW still good when out here
15	56	52	170	4807	221	-9.1	2.8	-9	7	725	0.0	0.0	52	1.5" ice; hi blwr; more ice
16	1	18	95	4828	39	-9.0	3.2	-6	5	678	0.0	0.0	30	SF_6 @ 160130; pstatic; turb @ 160153
16	4	30	123	4812	222	-8.5	3.7	-8	9	747	0.0	0.0	37	
16	8	24	73	4810	349	-9.2	2.7	-6	3	282	0.0	0.0	17	2" ice
16	11	53	73	4862	151	-8.6	4.5	-4	16	541	0.1	0.4	25	
16	14	43	87	4860	334	-8.9	1.0	-9	12	868	1.8	0.8	39	
16	18	33	97	4949	142	-9.6	0.9	-4	11	916	0.1	0.6	31	ltng
16	22	13	113	4822	319	-8.9	0.7	-8	7	847	0.1	0.9	22	
16	26	22	87	4828	143	-8.8	1.0	-4	9	1140	0.3	0.6	24	ltng

motion as the aircraft is not always in steady-state flight attitude at these times. As the aircraft rolls out of a turn, there is a period of ~30 s where the pilot regains altitude lost in the turn. Updraft estimates are only reliable at steady-state constant attitude flight settings.

Max 2DC - maximum precipitation particle concentration, number per liter, observed during the penetration by the PMS 2D-C probe. This estimate is based on the maximum value of 1-s counts of the number of particles entering the 2D-C probe sample volume, per second. The probe sweeps out 5 ℓ/s. This probe responds to particles larger than roughly 25 micrometers diameter. Only the edge of a particle need be in the sample volume to trip the probe. The concentration is computed assuming all particles activating the probe are entirely within the geometric area scanned by the probe. This assumption is not strictly true and can lead to overestimates of the particle concentrations. Another assumption is that all particles passing through the beam are in focus. This is not true for the smallest ($\leq$ 200 μm) particles and leads to underestimates of concentrations.

Max Hail - maximum concentration, number per cubic meter, of particles with diameters larger than ~5 mm as determined by the T-28 hail spectrometer. This estimate is based on counts from the non-imaging, one-dimensional part of the probe circuitry. Large liquid drops may be counted by this probe as well as snow, graupel, and hail.

Hail MxD - maximum-size particle (mm) detected by the hail spectrometer during the penetration. Timing criteria are used in an attempt to reject counts due to water streaming off the probe housing, although this has been observed to be insufficient to eliminate all artifacts from the data. The maximum measurable size is 4.5 cm. Values this large in the presence of rain are probably artifacts due to water streaming off the housing. Detailed examination of the measured size spectra should be done in order to further verify the maximum sizes listed here.

Max Abs E - maximum absolute value of either the vertical or horizontal electric field component, kV/m, as determined from the T-28 electric field mills and corrected for aircraft shape effects.

3.1 Data Evaluation

The T-28 instrumentation package generally performed well. Included here are brief summaries of performance by variable and instrument.

Temperature

Rosemount Sensor: This de-iced aircraft temperature sensing unit performed well during the NDTE. It does have a tendency to get wet and can read low by up to 2°C in regions of cloud water.

Reverse-Flow: This unit was calibrated against the Rosemount unit using clear-air flight segments and by ground calibrations using chilled air. It was not consistently biased high or low, but often read differently from the Rosemount sensor, even in clear air, by up to ~1°C. This disparity is tentatively attributed to solar heating of one probe and not the other, or to variable aerodynamic behavior of the reverse flow housing at different angles of attack.

Pressure

Both static and dynamic pressure sensors were calibrated on 5 June 1993 using a DH Instruments Model PPCI-100 absolute pressure controller and RPM1-A0015 reference pressure monitor, traceable to NIST. Static pressure sensor #2 is slightly noisier than static pressure sensor #1 and warms up more slowly following start-up of the instrumentation system. Comparisons with other aircraft and with surface-based instruments are described in Section 3.2.

Position

The Trimble Global Positioning System unit performed well during the NDTE. Extended precision latitude and longitude, and geometric altitude, data were not available due to a problem in the data system interface.

SF_6 Analyzer

This instrument was calibrated before and after each flight by North American Weather Consultants. In addition, pulses of calibration gas were periodically injected into the analyzer during each flight. Calibration equations relating analyzer output voltage to SF_6 mixing ratio are given in Table 5.

TABLE 5

SF_6 Analyzer Calibration Data - North American Weather Consultants

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Time to transport from inlet port to analyzer is 3.0 seconds (averaged from fifteen measurements.)

(Span gas level is 251 ppt.)

Voltage response to the following calibration gases (M = missing):

SF_6 (PPT)	0	11	31	101	295	896	2873	Detected SF_6
6/22/93	M	.01	.06	.22	.66	1.61	M	No
6/29/93	-.05	.04	.14	.43	1.30	3.04	6.40	No
6/30/93	-.02	M	.46	.72	1.54	3.33	6.62	Yes*
7/01/93	-.07	.04	.15	.47	1.29	3.08	6.66	No
7/03/93	-.05	.06	.13	.41	1.18	2.88	6.17	No
7/06/93	-.03	.06	.13	.43	1.17	3.06	6.50	Yes*
7/08/93	-.03	.01	.11	.42	1.27	3.10	6.74	Yes*
7/09/93	-.04	.01	.08	.38	1.18	2.52	6.54	No
7/15/93	-.02	M	.09	.35	.97	2.50	6.05	No
7/18/93	-.07	.03	.11	.40	1.24	2.49	6.60	Yes*
7/22/93	-.03	.04	.14	.46	1.29	3.14	6.72	Yes*
7/23/93	-.05	.04	.12	.44	1.27	3.12	6.64	No
7/25/93	-.04	.03	.12	.44	1.28	3.11	6.78	Yes*
7/27/93	-.05	.02	.12	.43	1.25	3.12	6.80	Yes*

Note that the zero SF_6 gas is ultra-pure air, which shows what the background reading due to SF_6 (or other contaminants) is for that day.

The 30 June calibration had lots of variability in results of the multiple calibrations done; the results are questionable.

*SF_6 was detected on these days; additional information on approximate times of hits is given below.

6/30/93	1606, 1609, 1612, 1614, 1616, 1617, 1640
7/6/93	1640, 1643, 1657
7/8/93	1626
7/18/93	1523
7/22/93	1203, 1206, 120630, 1214
7/25/93	1841, 184830
7/27/93	155945, 160130

Cloud Water

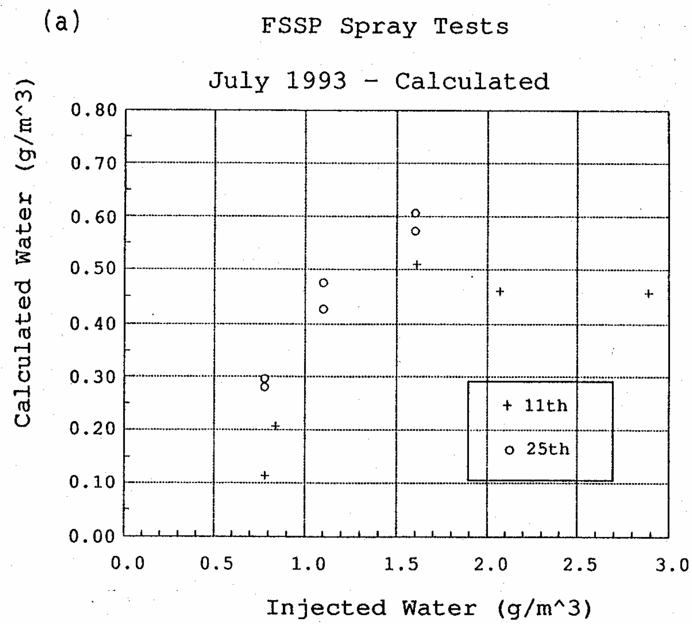
An extensive effort was made in the spring of 1993 to determine the optical and electronic response characteristics of the NCAR FSSP borrowed for use by the T-28. In addition, field tests were performed using a spray device on the ground to verify consistent operation of the FSSP and J-W. Finally, during the NDTE in-trail penetrations of two small cumulus clouds by the WMI Duke and the T-28 allowed comparison between the T-28 FSSP and J-W, and the J-W on the Duke.

The sprayer was developed by IAS for intercomparison and gross performance checks, not for absolute calibration. A high-pressure blower, working in conjunction with a precision spray nozzle, produces a water mist flowing at approximately 92 m/s which is then injected directly into the J-W and FSSP input orifices. Although the droplet size distribution has not been measured, data from the nozzle manufacturer indicate that most of the water droplets are less than 30 μm in diameter under the conditions used during our tests. We do not expect that the total water injected into the sprayer will be detected by the FSSP or J-W since we observed that water collects on the sidewalls of the sensor flow tubes. However, it should be a valid intercomparison technique.

The T-28 facility has developed two methods for reducing FSSP data. The first method is the standard method used since 1975. The counts in each size channel are divided by the geometric volume swept out by the laser beam running from one arm to the other. A bulk activity correction is applied to account for particles missed while the probe electronics are processing data from a previous particle.

The second method is called here the "calculated" method, and follows procedures developed by Darrel Baumgardner and others at the NCAR Research Aviation Facility. In this method, particles are shifted upward in size to account for response time limits in the optoelectronics and variation in laser intensity across the beam. Electronic dead time is also taken into account.

Results of the spray tests are shown in Figs. 2 and 3. Figure 2 shows that total FSSP water content computed by the "calculated" method is ~2 times higher than that computed by the "standard" method, and that results at a given rate of injected water differ by up to a factor of 2 between the two different days. Figure 3 shows that J-W results are closer to the "calculated" FSSP results than the "standard" FSSP results, but that there can be up to a factor of 2 difference in readings at the same rate of injected water, depending on the head used and the air pressure supplied to the spray nozzle. More refinements are in progress for both the spray system



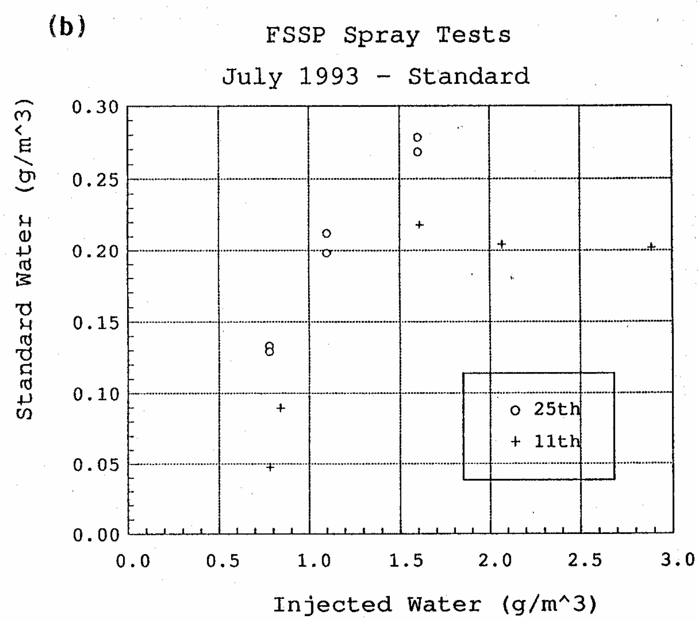


Fig. 2: A comparison between liquid water concentration as determined by the FSSP during different ground tests and the total water concentration injected into the tube containing the probe sensing volume during these tests. The purpose of these tests was to verify consistent operation of the instrument under the same conditions on different days. The spray test device is not completely characterized and the relationship between the rate at which water was sprayed and the steady-state water concentration at the location of the probe is not known. (a) Calculated water; (b) Standard water.

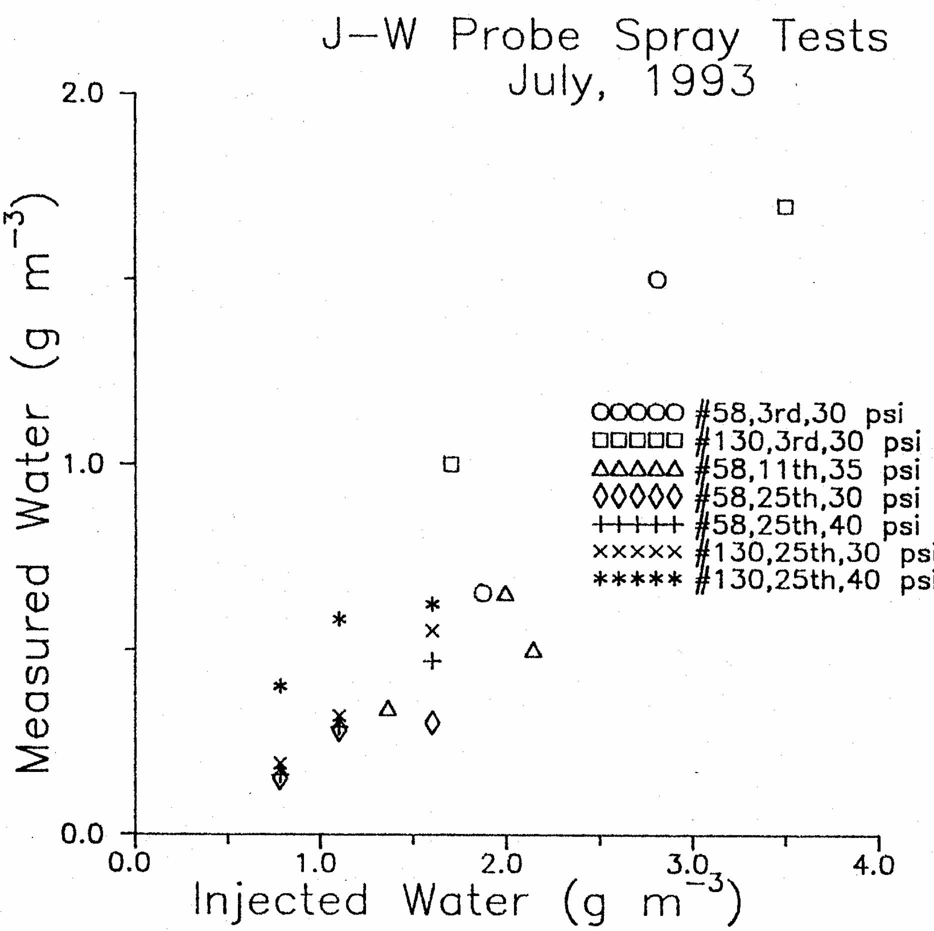


Fig. 3: As in Fig. 2, except for J-W tests.

and data reduction techniques that will render the spray test rig a quantitative tool for monitoring the status of our cloud water instruments.

Figure 4 shows comparisons between the J-W on the Duke and the FSSP and J-W on the T-28 during in-trail penetrations of two small cumuli. The T-28 J-W cloud water is about half that of the Duke J-W, the T-28 "standard" FSSP cloud water agrees well with the Duke J-W, and the T-28 "calculated" FSSP cloud water is about two times that reported by the Duke J-W. Although the sounding data available are probably not completely representative of the region in which these clouds formed, estimates based on the data available suggest an adiabatic (i.e., maximum possible) cloud water concentration of 1 to 2 g m^{-3} in these clouds at the penetration

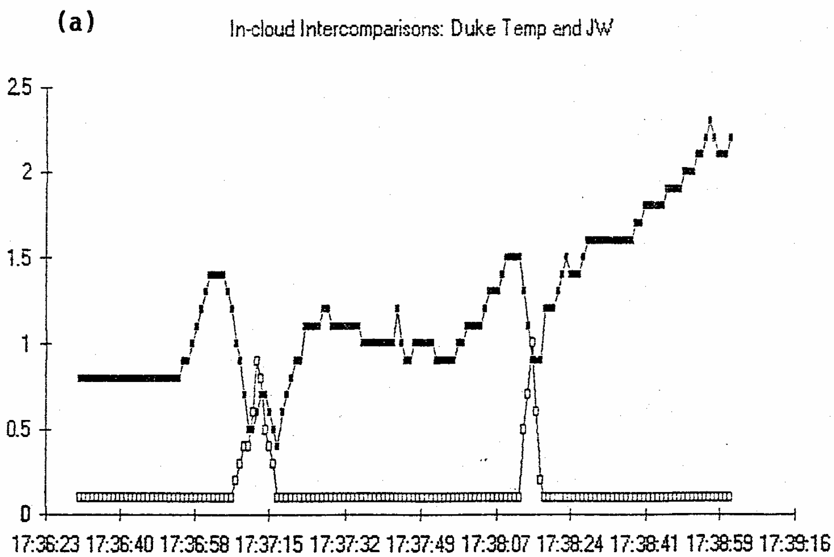


Fig. 4a: Duke temperature (solid symbols, °C) and J-W (open symbols, g/m³) readings during a Duke/T-28 in-trail penetration of two small clouds on 6 July. [Plot courtesy of Dr. Tony Grainger, UND]

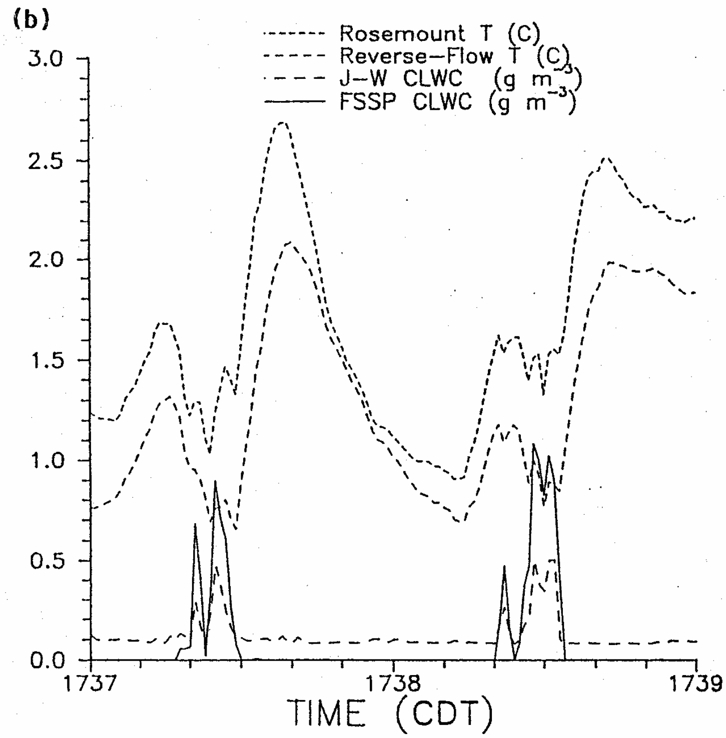


Fig. 4b: T-28 temperature and FSSP "standard" and J-W cloud water observations during the same period as the Duke readings in Fig. 4a.

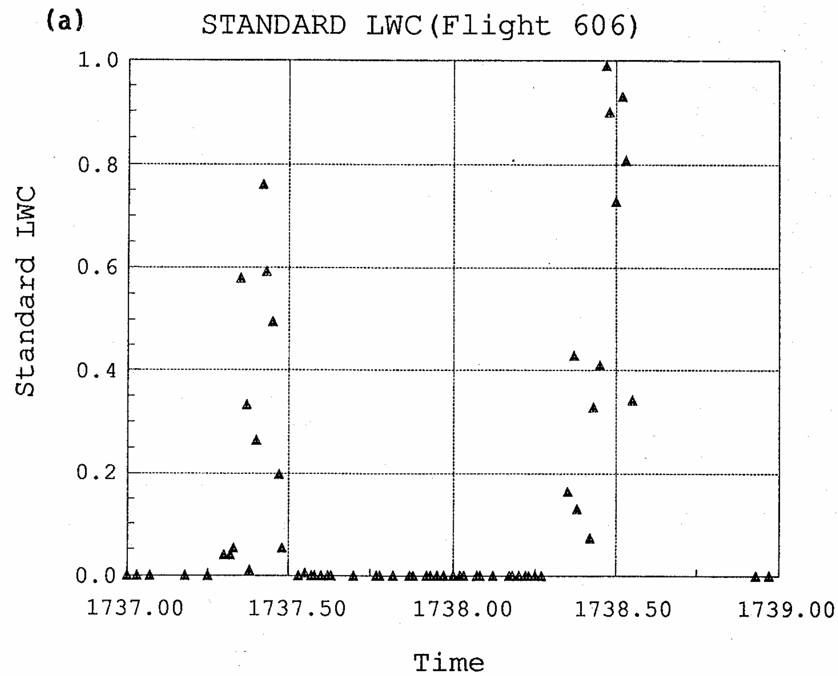


Fig. 4c: "Standard" FSSP cloud water concentration for the same time period as in Fig. 4a, but using updated channel size assignments.

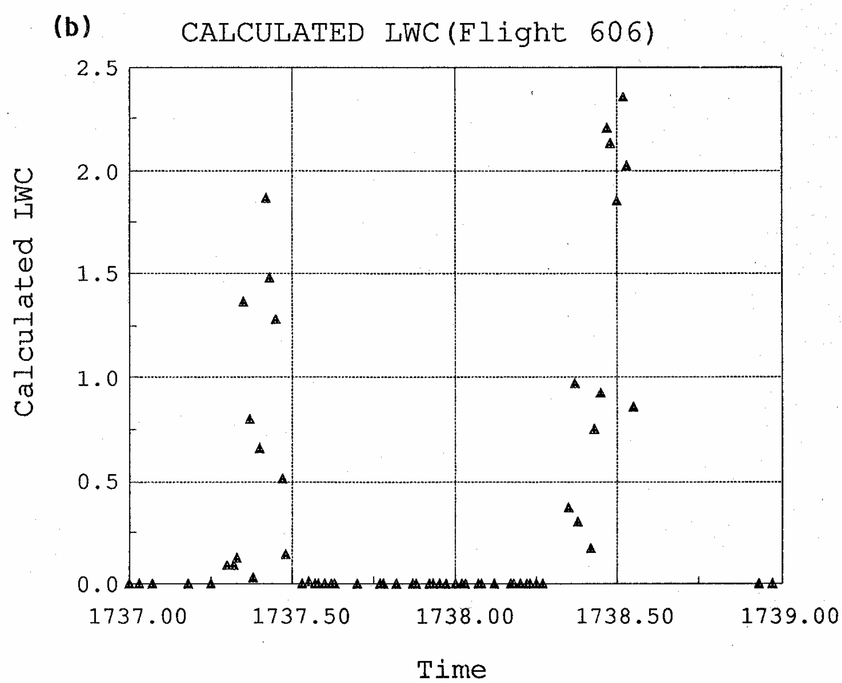


Fig. 4d: As in Fig. 4c, but computation based on "calculated" technique, and using same channel size assignments as in Fig. 4c.

altitude, in reasonable agreement with the Duke J-W and T-28 "standard method" FSSP.

FSSP: This probe performed well during the NDTE. The laser beam remained in alignment and periodic glass bead tests showed no shift in droplet size versus channel assignment. During the last flight, the pilot did note severe icing on the probe. It was determined that the main ring deicing heater had failed. It is not known if the failure occurred on this flight or a previous one. The "standard method" FSSP cloud water concentration values contained in this report were not computed using channel size assignments and beam diameter from the most recent calibration. They are slightly higher than water concentrations computed with 1993 calibration data, as can be seen by comparing Fig. 4b to Fig. 4c. All data are being reprocessed to reflect the most recent calibration.

Johnson-Williams Sensor: The T-28 facility has two working J-W heads. The sensing wires in these heads were frequently broken by impacts with ice particles, after which the alternate head is usually inserted while the broken head is repaired. Table 6 gives the history of which head was used on which flight during the NDTE, and of repairs to the individual heads. Further analysis will be required to refine interpretation of data from this instrument.

Precipitation particles

PMS 2D-C Probe: The probe in use when the NDTE began had somewhat erratic performance in one of its two on-board memory buffers, leading to blank images in alternating buffers dumped to the data system. Another NCAR 2D-C probe was used on Flight 608, 9 July. This newer probe had only 24 bits allocated for inter-particle times compared to 32 bits in the original (older) probe. We had problems with electronic noise in the images from this newer probe so it was replaced with our original probe for subsequent flights. However, the PMS 230 and 240 cards from the newer probe were substituted for the ones in the original probe for the remainder of the NDTE. This seemed to improve the performance of the original probe. A history of 2D-C probe configuration and performance is given in Tables 7 and 8.

Foil Impactor: The foil impactor had a rough season, being exposed on a number of flights to very heavy icing, which caused wrinkling and ripping of the foil and missed punches. A summary of the performance of the foil impactor on each day is included in the daily operations summaries given above.

Hail spectrometer: A new imaging interface between the IAS hail spectrometer and the Science Engineering Associates (SEA) T-28 data

TABLE 6

Record of J-W Sensing Head Installations

NDTE 1993

DATE	FLIGHT #		
6/22/93	600	Head #58	Heater fuse blown-sensor iced up
6/26/93	601	Head #58	Heater fuse replaced-heats OK
6/29/93	602	Head #58	
6/30/93	603	Head #58	
7/01/93	604	Head #58	
7/03/93	Spray Test	Head #58	
	Spray Test	Head #130	
7/03/93	605	Head #58	
7/06/93	606	Head #58	
7/08/93	607	Head #58	Compensating wire broke in flight
7/09/93	608	Head #58	Compensating wire repaired
7/11/93	Spray Test	Head #58	
7/14/93	Installed	Head #130	
7/15/93	609	Head #130	Sensing wire broke early in flight
7/16/93		Head #130	Repaired head
7/18/93	610	Head #130	
7/22/93	611	Head #130	
7/23/93	612	Head #130	
7/25/93	613	Head #130	
7/25/93	Spray Test	Head #130 & Head #58	
7/27/93	614	Head #130	Sensing wire broke

acquisition system was employed during the NDTE. It never achieved reliable operation. However, the traditional one-dimensional data containing size and concentration information for particles larger than 5 mm diameter was obtained on all flights.

TABLE 7

2D-C Data Quality Summary

Flight	Date	Notes
600	22 Jun	Odd-numbered buffers mostly empty frames; 32-bit times
603	30 Jun	Odd-numbered buffers mostly empty frames
604	1 July	Odd-numbered buffers mostly empty frames; problem with start time on 1st buffer
605	3 July	Odd-numbered buffers mostly empty frames; problem with start time on 1st buffer
606	6 July	Problems in both odd and even buffers, but odd worse
607	8 July	Problems in both odd and even buffers, but odd worse
608	9 July	Switched to another 2D-C; 24-bit times; 1st halves of buffers very noisy; generally very poor quality data
609	15 July	Switched back to original probe but swapped 230 & 240 cards; problems in odd buffers early, even buffers later. Generally good data; still 24-bit times.
610	18 July	Some problems with zero-time frames in even buffers; generally good data; 24-bit times
611	22 July	Generally good data; 24-bit times
612	23 July	Generally good data; 24-bit times
613	25 July	Good data until 5th penetration; 24-bit times
614	27 July	Generally good data; 24-bit times

The sizing accuracy of either 2D-C was not checked in the field.

TABLE 8

PMS OAP-2DC Card Switch History

DATE	FLIGHT #	
6/22/93	600	"Original" Pre-Season Cards.
6/26/93	601	"Original" Pre-Season Cards.
6/29/93	602	Replaced 230 timing card with spare.
6/30/93	603	
7/01/93	604	
7/03/93	605	
7/06/93	606	
7/08/93	607	
7/09/93	608	Replaced entire 2D-C with NCAR RAF unit.
7/10/93		Re-installed T-28 2D-C probe and put 230B and 240B cards from RAF unit into T-28 probe.
7/15/93	609	
7/18/93	610	
7/22/93	611	
7/23/93	612	
7/25/93	613	
7/27/93	614	

Electric Fields

The T-28 added a 5th field mill to its suite of atmospheric electrical instrumentation for the NDTE. This additional mill was mounted in the outboard hail spectrometer pylon, looking downward. Figure 5 shows the complete T-28 electric field mill system. As the performance parameters for the new location are not yet known, computation of ambient field components has been performed initially using only the wing-tip and fuselage mills. Although an algorithm for computation of the longitudinal field component (in the direction along the T-28 fuselage) based on the fuselage and wing-tip mills has been derived by Kathy Giori of SRI, this computation often yields unrealistic results when the aircraft is charged.

We include in our standard data set, computations of just the vertical and transverse (along the direction of the wings) components which we believe, at this time, to be reasonably reliable.

Ms. Giori also provided two instrumented dischargers for use on the T-28 during the NDTE. Their locations are shown in Fig. 6. The signs of their discharges are being used to provide additional information about aircraft charging and polarization in order to improve interpretation of the electric field mill readings. They were functional from Flight 605 (3 July) onward, except for Flight 608 (9 July) when they made a flight on the Citation.

Calculation of ambient static fields from the suite of field mills requires subtraction of the effects of aircraft charge on the mill readings. These effects are estimated by artificially charging the aircraft when it is in a region with negligible ambient fields. An on-board high voltage power supply is used to put a discharge wick into positive corona, leaving the aircraft with a net negative charge. Electric field mill readings then show the ratio of the readings at the different locations on the airframe due just to aircraft charge. Early in the NDTE it turned out that the discharge wick was shorting through its mounting block, leading to negligible discharge and only intermittent success at charging the aircraft. Also, by some unknown chain of processes, this left the aircraft with a net positive charge when charging was achieved. This problem was corrected prior to Flight 610, 18 July, and successful charging tests were achieved on Flights 610, 612, 613, 614, and 615. Table 9 displays the times and preliminary results of these tests (except for Flight 615).

3.2 Intercomparisons and a Tower Fly-By

On 6 July, the Duke and then the T-28 penetrated two small cumuli in-trail while returning to base following other operations. Data from this period were shown in Fig. 4 above. The Duke Rosemount temperature sensor reads about 0.5°C lower compared to the T-28 Rosemount temperature, but agrees well with the T-28 reverse-flow temperature sensor. The Duke J-W cloud water concentration agrees well with the T-28 FSSP integrated cloud water concentration computed using our "standard" methods of reduction. However, the T-28 J-W reading peaks at only ~50% of the peak readings from those other two instruments and the "calculated" FSSP LWC is higher by about two times the "standard" FSSP LWC as shown in Fig. 4d.

On 25 July, the three project aircraft flew in formation for several minutes, with the Duke in the lead, the T-28 on his left, and the Citation on his right. Average values for variables determined from instrumentation

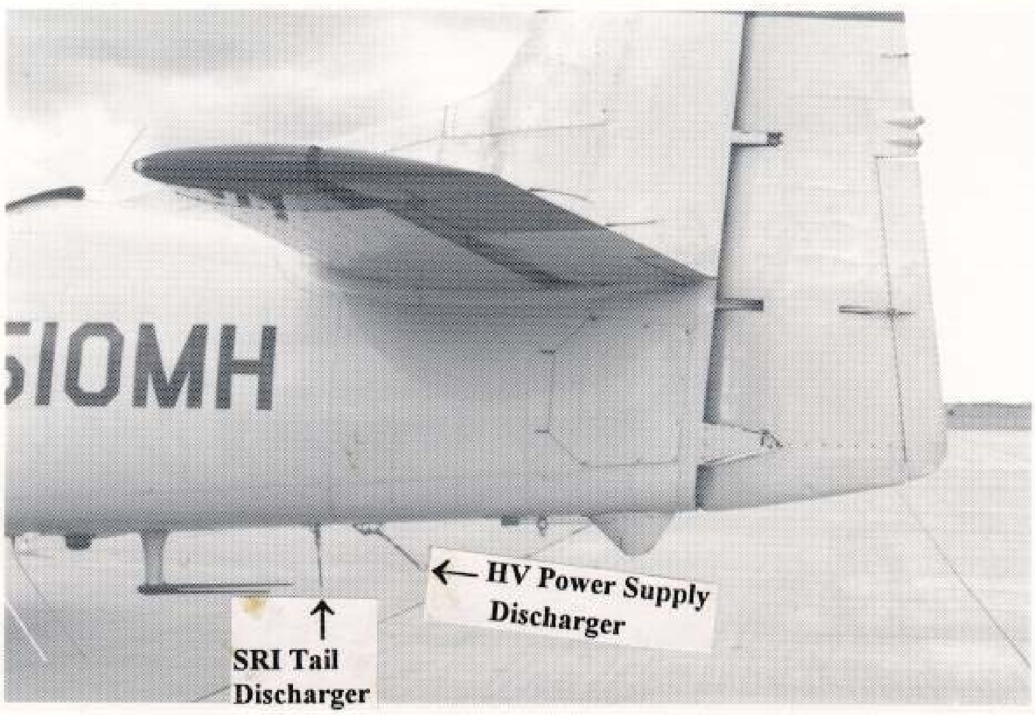


Fig. 6: Views of T-28 indicating locations of discharge wicks. [Photos courtesy of K. L. Giori]

TABLE 9

Field Mill Test Summaries, NDTE 1993

Date	Flt No	Time On	Time Off	Density (kg/m^3)	Top kV/m	Bottom kV/m	Left kV/m	Right kV/m	Fifth kV/m	Top/Bot	Left/Bot	Right/Bot	5th/Bot	Comments
18 July	610	150000	150115	0.95	-6.23	-3.87	-19.73	-19.61	-11.16	1.61	5.10	5.07	2.88	First good test with correct polarity!
23 July	612	165525	165635	1.07	-4.87	-2.25	-13.86	-13.51	-6.63	2.16	6.15	5.99	2.94	Good test
		175825	175840	0.83	-3.59	-1.61	-10.13	-9.76	-5.22	2.23	6.30	6.07	3.25	Good test
25 July	613	174745	174915	1.07	-4.70	-2.22	-14.43	-12.86	-6.96	2.12	6.49	5.79	3.13	Good test; analyzed beginning and end separately
				1.07	-4.43	-2.02	-13.30	-13.05	-6.54	2.19	6.58	6.46	3.24	
27 July	614	150135	150300	1.07	-4.55	-2.29	-13.56	-13.33	-6.87	1.98	5.92	5.81	2.99	Good test; analyzed beginning and end separately
				1.07	-5.24	-1.86	-13.20	-14.21	-5.96	2.81	7.09	7.63	3.20	

on the three aircraft for the period 19:18:00 to 19:18:57 are presented in Table 10.

It can be seen that the two T-28 temperature readings under these conditions were ~0.5°C low compared to those from the other aircraft, but were close to each other. Note the contrast between this comparison and the one on 6 July when the Duke Rosemount T and T-28 RFT agreed well over very nearly the same range of temperature, but the T-28 RsmT was ~0.5°C lower.

The pressure reading from the T-28's #1 static pressure sensor (the less noisy of the two, and the one used in calculations of pressure altitude, air density, etc.) is about 2 hPa high compared to those on the other aircraft.

The T-28 VOR is biased about 30° north of the other two (in this case, the other two are known to be more correct) while the T-28 DME agrees well with the Duke DME. A plot of the actual T-28 VOR reading versus that computed from its GPS position shows that the VOR appeared to be working well earlier in the flight but became biased northward around the time of the intercomparison (see Fig. 7).

The mean latitude and the longitude for the three aircraft, derived from the GPS units on each aircraft during the period 19:18:00 - 19:18:57 while they were in formation, are shown in Table 11 while the tracks of the three aircraft are plotted in Fig. 8. The T-28 is displaced northward ~0.004 deg relative to the other aircraft. The aircraft tracks also show the Citation in the center and the Duke on the right, whereas in fact the Duke

TABLE 10

Data from 25 July 1993 Aircraft Intercomparison

	RsmT (°C)	RFT (°C)	StPr1 (hPa)	StPr2 (hPa)	VOR (deg)	DME (n mi)
T-28	-0.3	-0.2	654.8	653.2	240	8.9
Duke	0.4	M	652.7		212	9.0
Citation	0.3	0.4	652.3		214	M

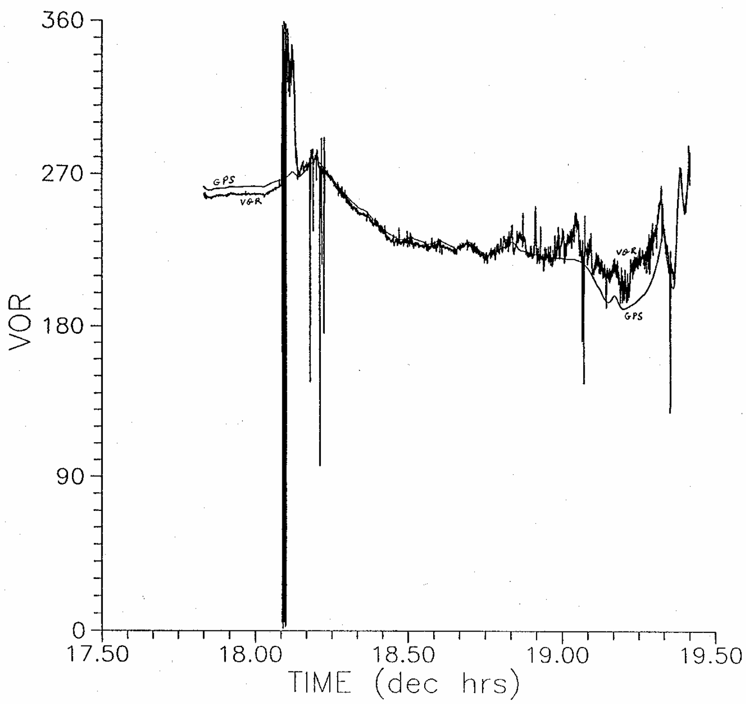


Fig. 7: VOR reading (direct, and computed from GPS positions) vs. time throughout the entire flight on 25 July.

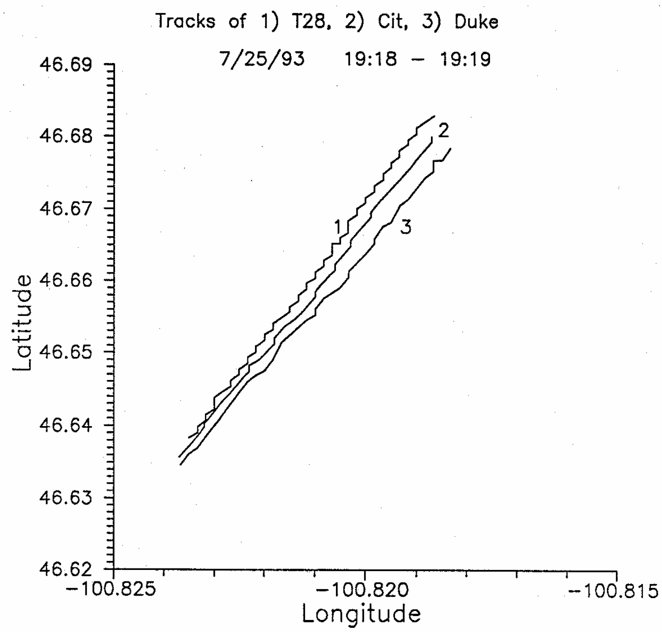


Fig. 8: Tracks of the three project aircraft, based on their recorded GPS position, during intercomparison on 25 July. Longitude axis has been expanded.

TABLE 11

Aircraft Position Data from 25 July 1993 Intercomparison

	Mean Lat. (deg)	Mean Long. (deg)
T-28	46.661	100.821
Duke	46.656	100.821
Citation	46.658	100.821

was in the center with the T-28 on his left and the Citation on his right. Some of the disparity between T-28 latitude and that of the other aircraft is apparently due to a routine in the T-28 data reduction procedure that compensates for the fact that position information fed from the GPS to the data acquisition system was considered to be ~2 s old in the case of the T-28 GPS. Thus, the T-28 positions are shifted backward in time 2 s during data reduction. This is not done on the other aircraft, which accounts for some of the disparity. Allowing for this difference in data reduction, it appears that the aircraft locations agree with each other to within ~0.002°, or ~220 m.

A tower fly-by exercise was carried out early in the morning on 29 July. The three project aircraft made a series of passes along the runway at the Mandan Airport at the level of the elevated bucket of a "cherry picker" containing temperature, wet-bulb temperature, and pressure instrumentation. A comparison between bucket readings and T-28 readings is given in Table 12. The Rosemount temperature agrees well with the bucket temperature, whereas the reverse-flow temperature is consistently ~1°C higher. There is no trend in these comparisons with airspeed. Both T-28 pressure readings are low relative to the bucket barometer, #1 sensor by ~5 hPa, and #2 sensor by ~6 hPa.

A comparison between T-28 GPS positions and the location of the bucket suggests that there is no delay in feeding GPS position from the Trimble unit into the SEA data acquisition system and that the T-28 GPS location is accurate to within 65 meters. Thus the 2 s delay will be removed from our GPS data processing before further analysis of NDTE data.

TABLE 12

Summary of T-28 Data from 29 July 1993 Tower Fly-by

Pass	IAS (kts)	Bucket T (C)	RsmT (C)	RFT (C)	Bucket P (hPa)	StPr1 (hPa)	StPr2 (hPa)
1	160	17.3	17.6	18.5	954.7	948.9	947.5
2	160	17.2	17.3	18.2		949.7	948.2
3	160	17.2	17.3	18.2		949.8	948.3
4	160	17.2	17.4	18.3		949.7	948.3
5	140	17.2	17.5	18.7		950	948.5
6	140	17.2	17.5	18.6	954.6	949.9	948.4
7	140	17	17.5	18.6		949.8	948.3
8	140	17.1	17.3	18.5		950	948.4
9	130	17.2	17	18.2		949.8	948.1
10	130	17.3	17.1	18.3		950.2	948.6
11	130	17.2	16.9	18.3	954.5	949.7	948
12	130	17.2	16.9	18.2		949.9	948.2

Taken as a group, these comparisons show that differences between aircraft-measured variables on the different NDTE aircraft are not always consistent and that accuracy may vary with the range of temperatures, pressures, positions, or water contents at which comparisons are made, and also from day-to-day within a given range.

In the absence of cloud water, the T-28 Rosemount temperature sensor is probably to be preferred relative to the reverse-flow sensor for temperature measurement. The reverse-flow sensor should be relied on in supercooled cloud with the warning that it should be compared to the Rosemount at the nearest time when both are dry. Absolute accuracy may be taken to be ±0.5°C for the Rosemount under dry conditions, with the caveat that it may read low by 1°C or more when wetted in-cloud.

Static pressure values are not likely to be very accurate near the ground (biased ~6 hPa) but will be more accurate at normal penetration altitudes (±2 hPa).

Ground spray tests show that cloud water concentrations measured by the J-W and FSSP are consistent to within a factor of 2 through the project. It is likely that the J-W is biased low in the sense that it never reads significantly higher than the actual water content, but may read less. FSSP cloud water concentrations as computed using our "standard" method also are likely to be underestimates, particularly when probe activity (proportional to droplet concentration) is high. A factor of 2 is a reasonable upper bound for the magnitude of this underestimate under extreme conditions; it will be much less than this for more usual conditions with droplet concentrations in the range of 100's per cm^3. With the calculated routines, it is found that the calculated FSSP LWC is higher by a factor of about 2 compared to the standard method of reduction. Considering the results of the 6 July Duke/T-28 intercomparison, the J-W LWC and the calculated FSSP LWC may differ by a factor of 4. The true cloud water concentration can be best estimated by careful comparisons of J-W and FSSP readings, examination of FSSP size spectra, and comparison to expected adiabatic liquid water concentrations in appropriate situations.

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APPENDIX A

Basic T-28 Instrumentation

APPENDIX A

Basic T-28 Instrumentation

VARIABLE	INSTRUMENT	RANGE	ACCURACY	RESOLUTION (as recorded)	NOTES
STATIC PRESSURE	ROSEMOUNT 1301-A-4B	0-15 psi (0-103 kPa)	±0.015 psi (±0.1kPa)	0.0002 psi (0.002 kPa)	• Bench calibration, 6/93
	ROSEMOUNT 1301-A-4B	5-15 psi (35-103 kPa)	±0.015 psi (±0.1kPa)	0.0002 psi (0.002 kPa)	• Bench calibration, 6/93
TOTAL TEMPERATURE	ROSEMOUNT 102AU2AP	-30 - +30°C	±0.5°C	0.001°C	• Platinum wire • -2 s time constant
	NCAR REVERSE FLOW	-30 - +30°C	±0.5°C	0.001°C	• Diode • Several seconds time constant • Bench calibration, 6/93 • Recovery factor adjusted, 6/93
CLOUD WATER AND CLOUD DROPLETS	JOHNSON-WILLIAMS LIQUID WATER CONCENTRATION	0 - 6 g/m^3	±20%	0.0001 g/m^3	• Accurate if all droplets have d <30 μm
	PARTICLE MEASURING SYSTEMS, INC. FORWARD SCATTERING SPECTROMETER PROBE	Size -1 < 57 μm Concentration 0 - -2000 droplets/cm^3	±1 size channel in size and ±1% in concentration at ~50/cm^3	1 size channel	• 15 discrete size channels spread over an adjustable range • Sampling rate 300 cm^3/km • Accuracy of computed liquid water concentration ~ ±20%. Depends on processing.
PRECIPITATION PARTICLE SIZES AND CONCENTRATIONS	WILLIAMSON FOIL IMPACTOR	1 - 20 mm	0.2 mm	0.2 mm	• Sampling rate 1.4 m3/km
	PARTICLE MEASURING SYSTEMS, INC. 2D Cloud Probe	Size 25 - 800 μm	±25 μm	25 μm	• Computed ice and water concentration can vary ±50% with processing technique • Sampling rate: 0.05 m^3/km; DAS can accept ~250 particles/s (2500/km)
	HAIL SPECTROMETER	Size 4.5 mm - 4.5 cm Concentration 0 - 100/m^3	±1 size class	1 size class	• 14 size classes • Sampling rate 100 m^3/km • Alternates with particle camera
	NCAR PARTICLE SAMPLER				• A batch sampler, primarily for hailstones • Sampling rate 2.6 m^3/km

APPENDIX A (continued)

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 SSA09-D0101-1 VERTICALLY STABILIZED ACCELEROMETER	±2 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-D-1B DYNAMIC PRESSURE	-3 to +3 psi (-20 to +20 kPa)	±0.1%	0.0001 psi (0.0006 kPa)	• Indicated airspeed • Bench calibration, 6/93
	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, 6/93
	GIANNINI 45218YE MANIFOLD PRESSURE	0 to 50 in Hg	±2%	0.008 Hg (0.03 kPa)	• Used in one vertical velocity calculation • Bench calibration, 3/93
	BALL ENGINEERING 101A VARIOMETER	-6000 to +6000 ft/min (-30 to +30 m/s)	±200 ft/min (±1 m/s)	0.2 ft/min (0.001 m/s)	
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 s to lock on and acquire range
	TRIMBLE TNL2000 GPS	(global)	30 m	18 m	• LORAN unit not available in 1991
ELECTRIC FIELD	NMIMT Model E-100 DC Electric Field Meter	top/bot ±650 wings ±3200 } $\frac{kV}{m}$ 5th ±340		(coarse resolution) 0.01 $\frac{kV}{m}$	

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.

revised 12/93

APPENDIX B

List of Variables Recorded or Routinely Computed From T-28 Observations

APPENDIX B

List of Variables Recorded or Routinely Computed From T-28 Observations

Each different variable in the data stream is indexed with a unique tag number. Those used for the NDTE are listed here.

Tag	Variable	Remarks
100	**Time**	The T-28 data system is always set to local time, and recorded in a 24-hour format. It is maintained within a second of WWV unless otherwise noted.
101	**Dynamic Pressure 1**	
102	**Dynamic Pressure 2**	Both dynamic pressures are read from the same pitot tube line (with the inlet out on the right wing) using two different but nearly identical sensors. [hPa]
103	**Rosemount Static Pressure 1**	
104	**Rosemount Static Pressure 2**	Both static pressures are read from the same static pressure line (inlet on the rear fuselage) using two different but nearly identical sensors. [hPa]
105	**Rate of Climb**	The instantaneous rate of change of aircraft altitude, read from a standard aircraft variometer. The recorded data are unfiltered and much noisier than the damped cockpit display. [m/s]
106	**Rosemount Temperature**	This is static temperature computed from the reading of a standard, deiced, Rosemount aircraft total air temperature probe. It commonly suffers from wetting and reads low in clouds. [°C]

107	**Reverse Flow Temperature**	This is static temperature computed from the reading of a platinum resistance element placed inside a custom-design "reverse-flow" housing. It does not normally get wet in supercooled clouds, but may get wet in warm clouds or in regions of high precipitation water concentration. Apparently, ice may sometimes build up to such an extent on the housing that temperature readings are affected even though the sensor is not wetted. [°C]
108	**Manifold Pressure**	Pressure inside the engine manifold (an indicator of power being developed by the engine) is recorded from a standard aircraft engine pressure sensor. [inches of mercury]
109	**Acceleration**	Vertical acceleration is determined by a Humphrey gyro/accelerometer. [g's]
110	**Pitch**	The accelerometer also gives angle of the fuselage relative to horizontal. [deg]
111	**Roll**	Finally, the accelerometer gives angle of the wings relative to horizontal. Angle is positive for a left bank (left wing down). [deg]
112	**J-W Liquid Water**	The J-W probe yields concentration of water in clouds represented in droplets less than approximately 30 μm diameter. [grams per cubic meter]
113	**VOR**	The VOR gives the direction to the VORTAC (a radio direction-finding beacon used by aircraft) to which it is tuned. [deg]
114	**DME1**	This is distance to the VORTAC to which the #1 DME is tuned. [n mi]
115	**DME2**	Not connected during the NDTE.

116	**Voltage Regulator**	Reference voltage used as power source for some instruments. [volts]
117	**Heading**	Indicates direction (from magnetic north) towards which the aircraft is heading. [deg]
119	**PMS End Element 1**	Voltage readings of PMS end diodes.
120	**PMS End Element 2**	
121	**Interior Temperature**	Temperature inside the data acquisition system computer in the baggage bay. If it climbs much above 32°C, one should be wary for possible data system malfunctions. [°C]
122	**SF_6**	Measure of the inert gas SF_6 detected by a sampler with an intake mounted on the canopy. If calibrated, the data units are parts per trillion; else they are raw voltage readings.
123	**High Voltage Current**	Current discharged through a discharger mounted under the rear fuselage when high voltage power supply is turned on. Current sensor functioned irregularly during the NDTE.
128	**Wing Discharge**	
129	**Tail Discharge**	Used to monitor polarization and charge buildup on the airplane. (Supplied by SRI)
130	**Event Bits**	Bits corresponding to various events recognized by the data system, including such things as the in-cloud switch activated by the pilot when visually entering cloud, activation of the cockpit voice recorder, foil impactor, etc.
131	**GPS Warning Codes**	Bits corresponding to various status messages from the GPS system.

140	**FSSP size counts**	This tag contains information concerning the number of counts in each of the 15 available FSSP size channels. [number per channel per second]
141	**FSSP total counts**	The total number of droplets counted by the FSSP during a second.
142	**FSSP average diameter**	The average diameter of all droplets recorded during a second. [μm]
143	**FSSP concentration**	The actual concentration of droplets computed from FSSP counts divided by the volume sampled in 1 s ("Standard method"). A rudimentary correction for probe activity is made. [number per cubic centimeter]
144	**FSSP Water**	The liquid water concentration computed from the FSSP data for a second ("Standard method"). [grams per cubic meter]
145	**FSSP Activity**	The fraction of time the FSSP is active during the current second.
147	**PMS 2DC Shadow Or Count**	The number of times the 2D-C probe was triggered out of its wait state by the passage of a new particle. [number per second]
148	**FSSP Equivalent Diameter**	$\sum_{i=1}^{15}\left[\frac{n_i \cdot d_i^3}{n_i \cdot d_i^2}\right]$ at one-second intervals.

149 **Variance in FSSP Equivalent Diameter** Variance around the equivalent diameter, computed as

$$\frac{\sum_{i=1}^{15} n_i \cdot d_i^2 \cdot \left(d_i - d_{eqv}\right)^2}{d_{eqv}^2 \cdot \left(\sum_{i=1}^{15} d_i\right)^2}.$$

150	**Hail size counts**	This tag contains information on the number of particles in each of the 14 hail spectrometer size channels. [number per channel per second]
151	**Slow Particle**	The number of particles rejected because they passed through the hail spectrometer too slowly (indicating they were probably water or ice shed from the probe structure rather than airborne hydrometeors). [number per second]
152	**Hail total counts (of 150)**	Total number of particles accepted by the hail spectrometer. [number per second]
153	**Hail average diameter**	The arithmetic average diameter of all particles accepted by the hail spectrometer in the last second. [cm]
154	**Hail concentration**	The computed concentration corresponding to all particles accepted by the hail spectrometer in the last second. [number per cubic meter]
155	**Hail Water**	The mass concentration computed from the observed particle spectrum assuming spherical particles and a bulk particle density of 0.9 grams per cubic centimeter. [grams per cubic meter]
160	**Top Field Mill (low res)**	The electric field indicated by the low sensitivity channel on the field mill mounted in the aircraft canopy looking up. Field mill data are recorded at 20 Hz. [kV/m]
161	**Bottom Field Mill (low res)**	The electric field indicated by the low sensitivity channel on the field mill located in the baggage bay door looking down. [kV/m]

162	**Left Field Mill (low res)**	The electric field indicated by the low sensitivity channel on the field mill mounted in the left wing tip facing outward. [kV/m]
163	**Right Field Mill (low res)**	The electric field indicated by the low sensitivity channel on the field mill mounted in the right wing tip facing outward. [kV/m]
164	**Top Field Mill (high res)**	The electric field indicated by the high sensitivity channel on the top field mill. [kV/m]
165	**Bottom Field Mill (high res)**	The electric field indicated by the high sensitivity channel on the bottom field mill. [kV/m]
168	**Fifth Field Mill (low res)**	The electric field indicated by the low sensitivity channel on the fifth field mill, located under the left wing. [kV/m]
172	**Latitude**	Computed internally in the GPS receiver. [deg]
173	**Longitude**	Also computed internally in the GPS receiver. [deg]
174	**Groundspeed**	Computed internally in the GPS receiver (by differentiating the position data with respect to time). [m/s]
175	**Ground Track Angle**	The direction towards which the aircraft is moving relative to the ground, with respect to magnetic north. [deg]
176	**Magnetic Deviation**	The difference between magnetic north and true north as indicated automatically by the GPS receiver based on the current position. [deg]
177	**Time Since Solution**	The time since the GPS was last able to compute an accurate position solution based on a sufficient number of satellites.

		The GPS updates position based on dead reckoning if it does not have a sufficient number of satellites in view. [s]
178	**GPS Altitude**	Geometrically computed aircraft altitude. [m] Note: This feature of the GPS did not function during NDTE.
200	**Date**	As indicated by the data acquisition system computer clock. [yymmdd]
201	**Month**	mm [integer number]
202	**Day**	dd [integer number]
203	**Year**	yy [integer number]
204	**Flight**	A serial number assigned to each T-28 flight beginning with the first flight. (Flight #1 occurred in 1972.)
205	**Altitude**	The altitude in a standard atmosphere corresponding to the recorded pressure. [m]
206	**Theta e**	The equivalent potential temperature corresponding to the recorded temperature and assuming saturation with respect to liquid water. [K]
207	**Saturation Mixing Ratio**	The mixing ratio of water vapor corresponding to saturation with respect to liquid water at the recorded temperature. [g/kg]
208	**Point dz/dt**	The rate of change of altitude of the aircraft computed by differentiating the pressure altitude with respect to time. This represents an independent estimate of the rate of climb to be compared to tag 105. [m/s]

209	**Indicated Air Speed**	What the airspeed would be if the aircraft were flying at sea level and indicating the observed dynamic pressure. [m/s]
210	**Updraft (uncorrected)**	The estimated upward speed of the air relative to the ground computed from changes in the aircraft altitude and other factors, but not corrected for horizontal aircraft acceleration. [m/s]
211	**Calculated TAS**	The true speed of the aircraft relative to the air computed from the observed dynamic and static pressures, and temperature. [m/s]
212	**Updraft Correction Factor**	A correction to the simple (uncorrected) updraft calculation that accounts for horizontal accelerations of the aircraft. [m/s]
213	**Cooper Updraft**	The sum of the uncorrected updraft and the correction factor. [m/s]
214	**Kopp Updraft**	An updraft calculated somewhat differently than the Cooper updraft. In most situations, it yields a less noisy and more physically plausible updraft result for the T-28 than the Cooper method. [m/s]
215	**Geopotential Altitude**	Altitude computed from changes in static pressure and temperature. [m]
216	**Turbulence**	The turbulent energy dissipation rate estimated from observed fluctuations in true airspeed. [$cm^{2/3}/s$]
217	**Air Density**	Computed from the recorded temperature and static pressure. [kilograms per cubic meter]
218	**J-W Mixing Ratio**	The mixing ratio of cloud water per unit mass of dry air based on the J-W reading and computed air density. [g/kg]

219	**FSSP Mixing Ratio**	The mixing ratio of cloud water per unit mass of dry air calculated from the FSSP water concentration. [g/kg]
220	**Hail Mixing Ratio**	The mixing ratio of hail particles per unit mass of dry air based on the computed hail water and air density. [g/kg]
260	**Ambient Vert Electric Field**	The component of the ambient electric field that is vertical in the aircraft frame of reference. Positive means a positive test charge would drift upward relative to the aircraft in the field. [kV/m]
261	**Plane Vert Electric Field**	The field due to charge on the aircraft, computed by summing the readings of the top and bottom mill and normalizing based on self-charging tests. Positive means a positive test charge would be repelled away from the aircraft due to its charge. [kV/m]
262	**Ambient Hor Electric Field**	The ambient field oriented perpendicular to the aircraft along the wings, positive meaning a positive test charge would drift to the right in the field. [kV/m]
263	**Plane Hor Electric Field**	The field due to charge on the aircraft, computed by summing the wingtip mill readings and normalizing. Positive means a positive charge would be repelled away from the aircraft due to its charge. [kV/m]
264	**Ambient Vert Field (roll cor)**	The component of the ambient field that is truly vertical with respect to earth coordinates. [kV/m]
265	**Ambient Hor Field (roll cor)**	The component of the ambient field perpendicular to the aircraft path and truly horizontal with respect to earth coordinates. [kV/m]

272	**Latitude (deg)**	GPS coordinates broken into separate degree and minute components.
273	**Latitude (min)**	GPS coordinates broken into separate degree and minute components.
274	**Longitude (deg)**	GPS coordinates broken into separate degree and minute components.
275	**Longitude (min)**	GPS coordinates broken into separate degree and minute components.
276	**Ground Track Angle (True N)**	The direction of motion relative to the ground with respect to true north, derived from the GPS ground track angle with respect to magnetic north.

APPENDIX C

Reduced Data Items Computed for NDTE

APPENDIX C

Reduced Data Items Computed for NDTE, Bismarck, ND - June-July 1993 *0

Tag #	Description		# Values Output	Units	Method of Computation	Last Mod (if this year)	
101	Dynamic Pressure #1	(10 Hz)	1	mb	6.30452E-3 * Raw - 0.0489	6/26/93	
102	Dynamic Pressure #2	(10 Hz)	1	mb	5.28371E-3 * Raw - 1.5768	6/26/93	
103	Static Pressure #1	(2 Hz)	1	mb	1.5791E-2 * Raw + 530.37	6/26/93	
104	Static Pressure #2	(2 Hz)	1	mb	1.0917E-2 * Raw + 691.92	6/26/93	
105	Rate of Climb		1	m/sec	5.625E-4 * Raw, for Raw >= 0		
					5.287E-4 * Raw, for Raw < 0		
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 + 0.1594 * mach2	5/14/93	*1
					temp = (3.09907E-3*Raw+221.54)/divisor-273.16	6/29/93	
108	Manifold Pressure		1	" Hg	3.1098E-3 * Raw + 0.159275		
109	Acceleration	(10 Hz)	1	g's	6.25E-5 * Raw	7/8/93	*2
110	Pitch	(5 Hz)	1	deg	-3.05175E-3 * Raw + 50		*2
111	Roll	(5 Hz)	1	deg	3.05175E-3 * Raw - 50		*2
112	J.W.Liquid Water		1	gm/m^3	1.83125E-4 * Raw		
113	VOR		1	deg	1.117534E-2 * Raw - 1.155475		
114	DME #1		1	naut mi	3.03269E-3 * Raw - 0.24536		
115	DME #2		1	naut mi	3.03269E-3 * Raw - 0.046623		
116	Voltage Regulator		1	volts	1.5258789E-4 * Raw		
117	Heading	(5 Hz)	1	deg	interpolation from lookup table		
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		
122	SF_6		1	volts	1.52588E-4 * Raw		*3
123	High voltage current		1	milliamp	1.52588E-4 * Raw		
128	Wing Discharge (Giori)	(20 Hz)	1	volts	1.52588E-4 * Raw		*4
129	Tail Discharge (Giori)	(20 Hz)	1	volts	1.52588E-4 * Raw		*4

APPENDIX C (continued)

Tag #	Description	# Values Output	Units	Method of Computation	Last Mod (if this year)
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	
131	GPS warning codes	1	flags	11 bit codes	
140	FSSP counts	15	number	Raw	
141	FSSP total counts	1	number	Sum of tag 140s	
142	FSSP ave diameter	1	microns	sum of diams / number	
143	FSSP concentration	1	#/cm^3	vol = 0.229 * tas denom = 1 - .55 * activ / 100 conc = tot_count / vol / denom	
144	FSSP water	1	gm/m^3	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	
148	FSSP Equivalent diameter	1	microns	Ratio of sum of diam**3 to sum of diam**2	
149	FSSP equivalent diameter variance	1	microns	Consult REDUCE.C listing	
150	Hail counts	14	number	Raw	
151	Hail slow particle count	1	number	Channel 15	
152	Hail total counts	1	number	Sum of tag 150s	
153	Hail ave diameter	1	cm	sum of diams / number	
154	Hail concentration	1	#/m^3	conc = counts / (0.1 * tas)	
155	Hail water	1	gm/m^3	mass = sum of counts * volumes * 0.9 water = mass / (0.1 * tas)	
160	Top field mill, low res (20 Hz)	1	kV/m	-1.982574E-2 * Raw + 0.026	
161	Bottom field mill, low res (20 Hz)	1	kV/m	-1.982574E-2 * Raw + 0.104	
162	Left field mill, low res (20 Hz)	1	kV/m	-9.7023E-2 * Raw - 0.5442	
163	Right field mill, low res (20 Hz)	1	kV/m	-9.7778E-2 * Raw - 1.9651	
164	Top field mill, hi res (20 Hz)	1	kV/m	-3.11585E-4 * Raw + 0.027	
165	Bottom field mill, hi res (20 Hz)	1	kV/m	-3.10364E-4 * Raw + 0.04	
168	Fifth field mill, low res (20 Hz)	1	kV/m	-1.039215E-2 * Raw + 0.49138	6/18/93
172	GPS latitude	1	deg	degree+(minute+hundredths/100)/60	
173	GPS longitude	1	deg	degree+(minute+hundredths/100)/60	

APPENDIX C (continued)

Tag #	Description	# Values Output	Units	Method of Computation	Last Mod (if this year)	
174	GPS groundspeed	1	m/s	1852 / 36000 * Raw		
175	GPS grnd track angle (mag N)	1	deg	Raw / 10		
176	GPS magnetic deviation	1	deg	Raw / 10 (Raw is 32-bits, not 16)		
177	GPS time since solution	1	secs	Raw / 10		
178	GPS altitude	1	meters	Raw / 10 (Raw is 32-bits, not 16)	6/18/93	*5
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))		
207	Saturation mixing ratio	1		smr from above		
208	Point dz/dt	1	m/s	alt - prev_alt		
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		
211	Calculated TAS	1	m/s	sqrt(rftuc*mach2*401.856/divisor)		
212	Updraft correction factor	1	m/s	calc_tas*(change in calc_tas)/2/9.775		
213	Cooper Updraft	1	m/s	updraft + updraft correction		
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		
215	Geopotential altitude	1	meters	stepwise integration of hydrostatic equation	*6	

APPENDIX C (continued)

Tag #	Description	# Values Output	Units	Method of Computation	Last Mod (if this year)
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/m^3	0.34838 * stat_pr / tempk	
218	JW mixing ratio	1	gm/kg	jw_water / density	
219	FSSP mixing ratio	1	gm/kg	FSSP_water / density	
220	Hail mixing ratio	1	gm/kg	hail_water / density	
221	RFT uncorrected	1	deg C	Reverse flow temp without divisor term	
260	Ambient vert EF	1	kV/m	(tfm / 1.9 - bfm) / 5.6	
261	Plane vert EF	1	kV/m	(tfm / 2 + bfm) / 4	
262	Ambient lateral EF	1	kV/m	(rfm - lfm) / 44.8	
263	Plane lateral EF	1	kV/m	(rfm + lfm) / 21.6	
264	Ambient vert EF (with roll)	1	kV/m	cosr = cos(roll_rad) sinr = sin(roll_rad) t264 = t260 * cosr + t262 * sinr	
265	Ambient lat EF (with roll)	1	kV/m	t265 = -t260 * sinr + t262 * cosr	
272	GPS deg lat	1	deg	integer portion of tag 172 (t172)	
273	GPS min lat	1	min	fractonal part of t172 * 60	
274	GPS deg long	1	deg	integer portion of tag 173 (t173)	
275	GPS min long	1	min	fractonal part of t173 * 60	
276	GPS true bearing	1	deg	mod(t175+t176+360,360)	

APPENDIX C (continued)

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

*1 - Because the RFT readings seemed less reliable, tag 106 was used in computations which before 1991 used tag 107.

*2 - Humphrey accelerometer failed during the project's initial flight (600). It was repaired and reinstalled on 7/6/93. The pitch and roll values were recorded for flights starting with 606, and the acceleration value was recorded after flight 606. However, the range of values for the acceleration term are from -2G to +2G rather than the desired -1 to 3.

*3 - The SF_6 analyzer was hooked up again prior to the start of the field season. Voltage values can be converted to parts per trillion using calibration data taken before and after a given flight and correcting for the baseline value which is pressure dependent.

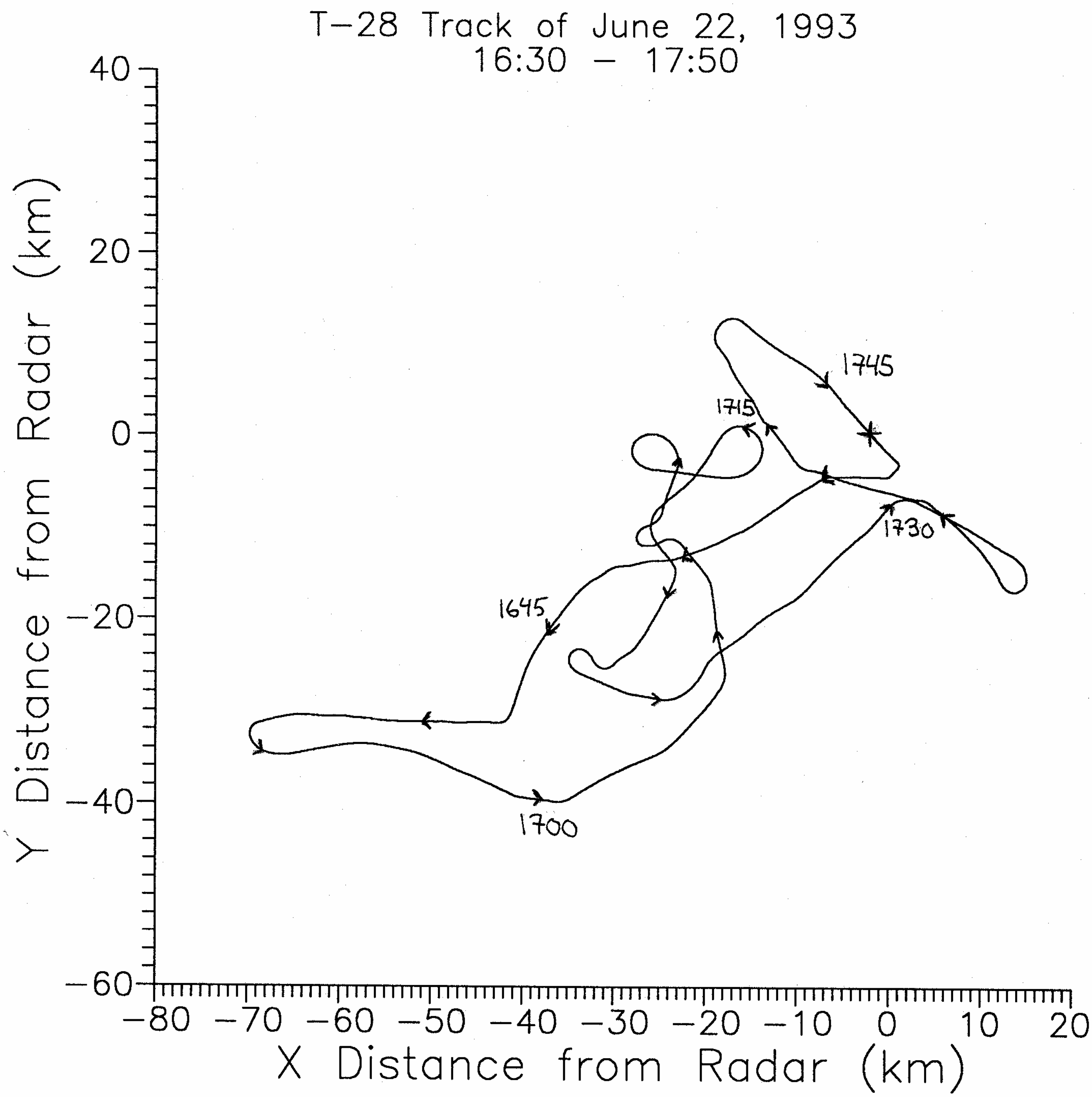
*4 - In 1991, these tags were used to measure charging and discharging. For this project, one wick was placed on the right wing and a second was installed toward the rear of the plane. Due to a design error, no valid measurements of discharging were recorded until flight 606. The sensors were also not available for flight 608 (used with the Citation instead).

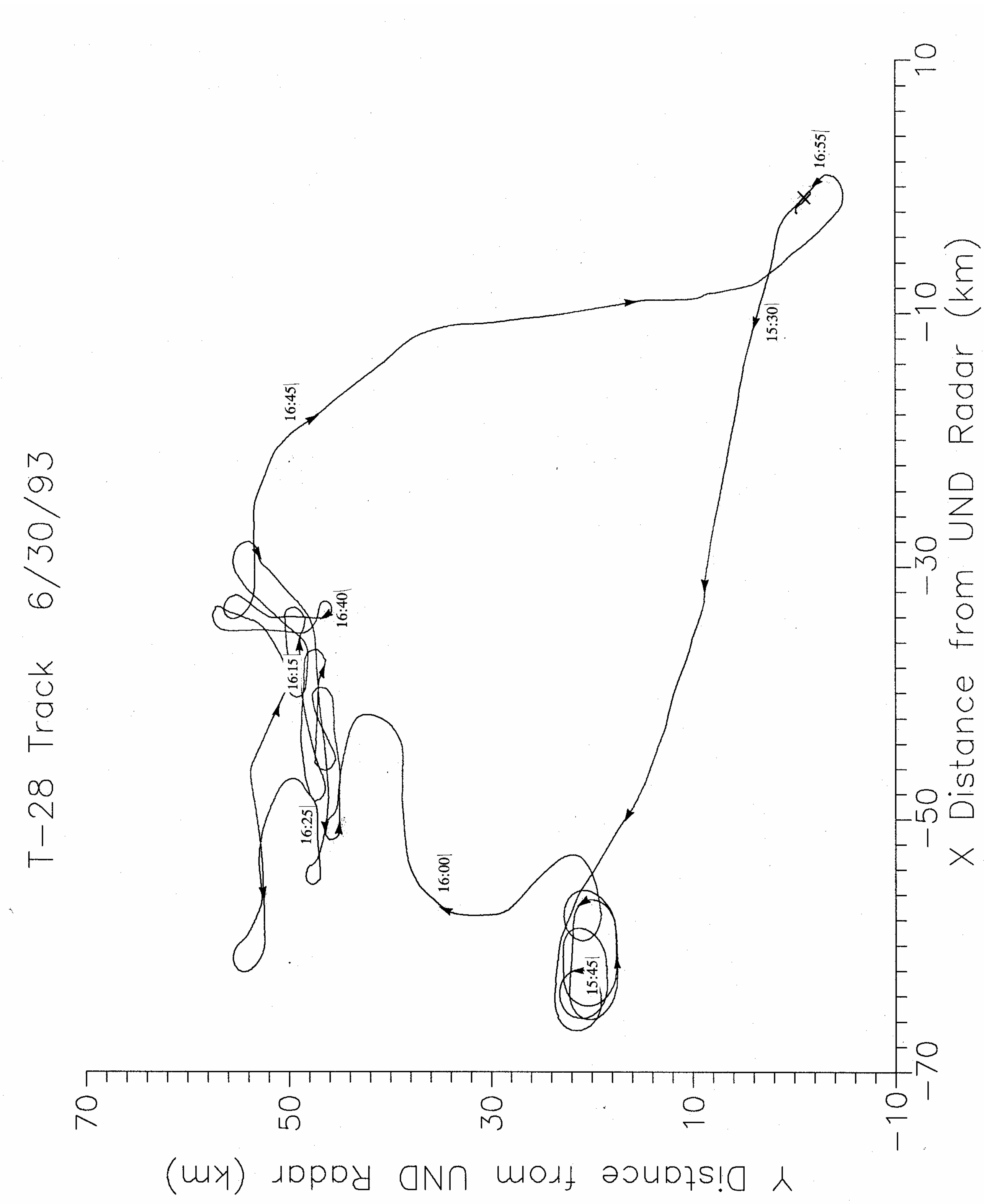
*5 - No useful data was recorded, since GPS extended precision mode did not work during the project.

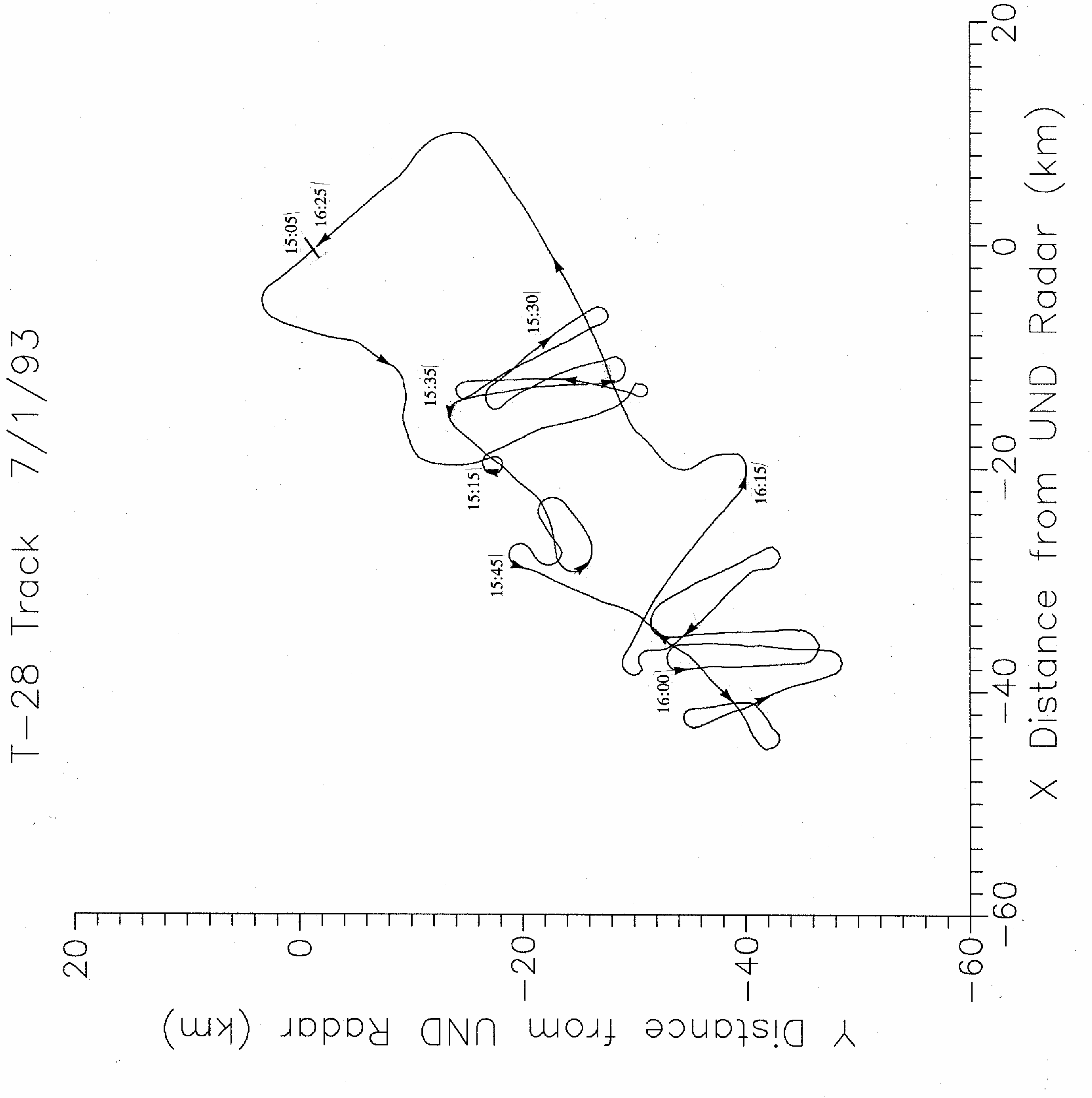
*6 - Some data files include this variable. It is computed during an optional second phase of processing, using static pressure and temperature changes.

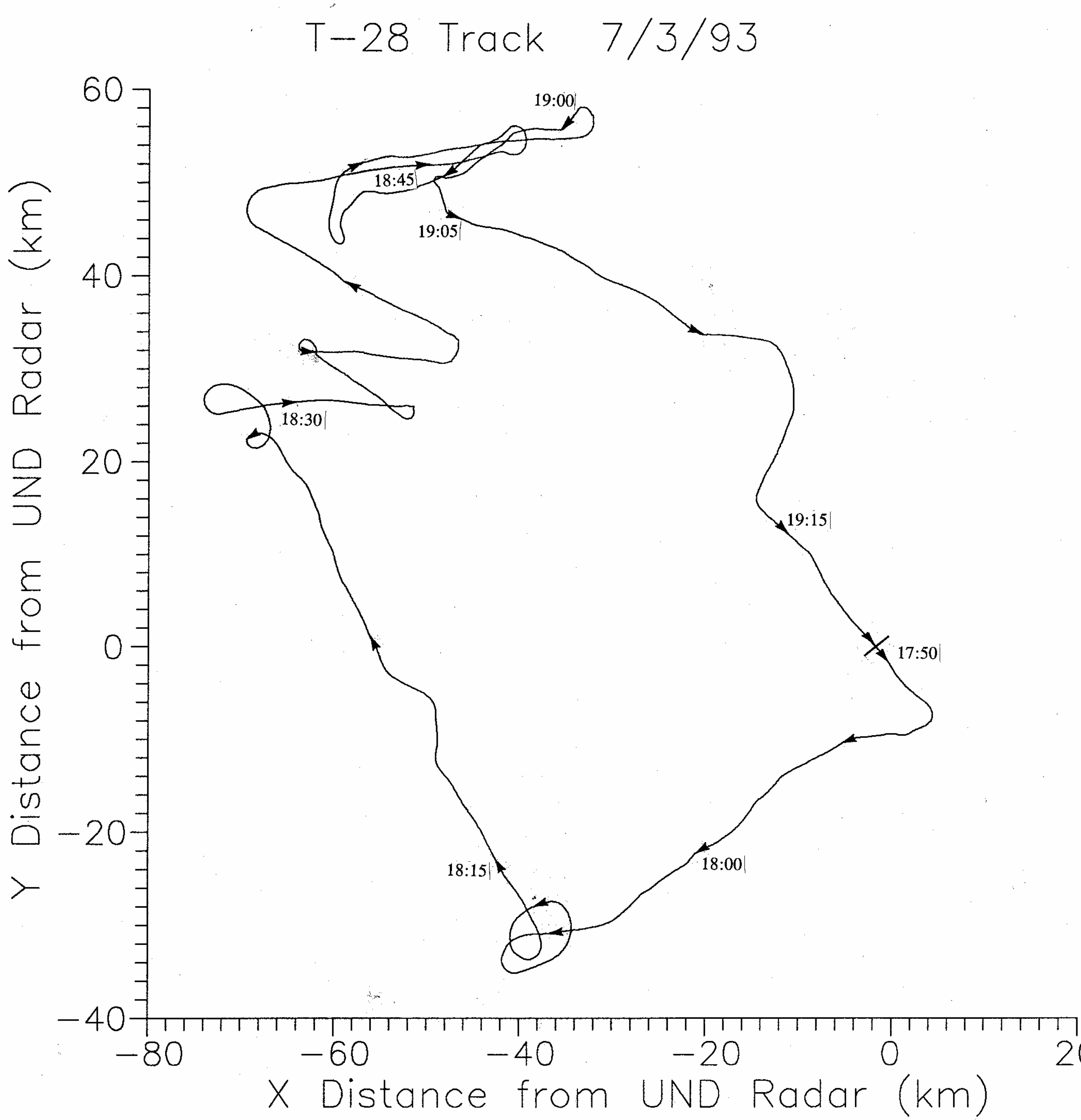
APPENDIX D

Flight Tracks


T-28 Track of June 22, 1993
16:30 – 17:50
Y Distance from Radar (km)
X Distance from Radar (km)
40
20
0
–20
–40
–60
–80
–70
–60
–50
–40
–30
–20
–10
0
10
20
1645
1700
1715
1730
1745

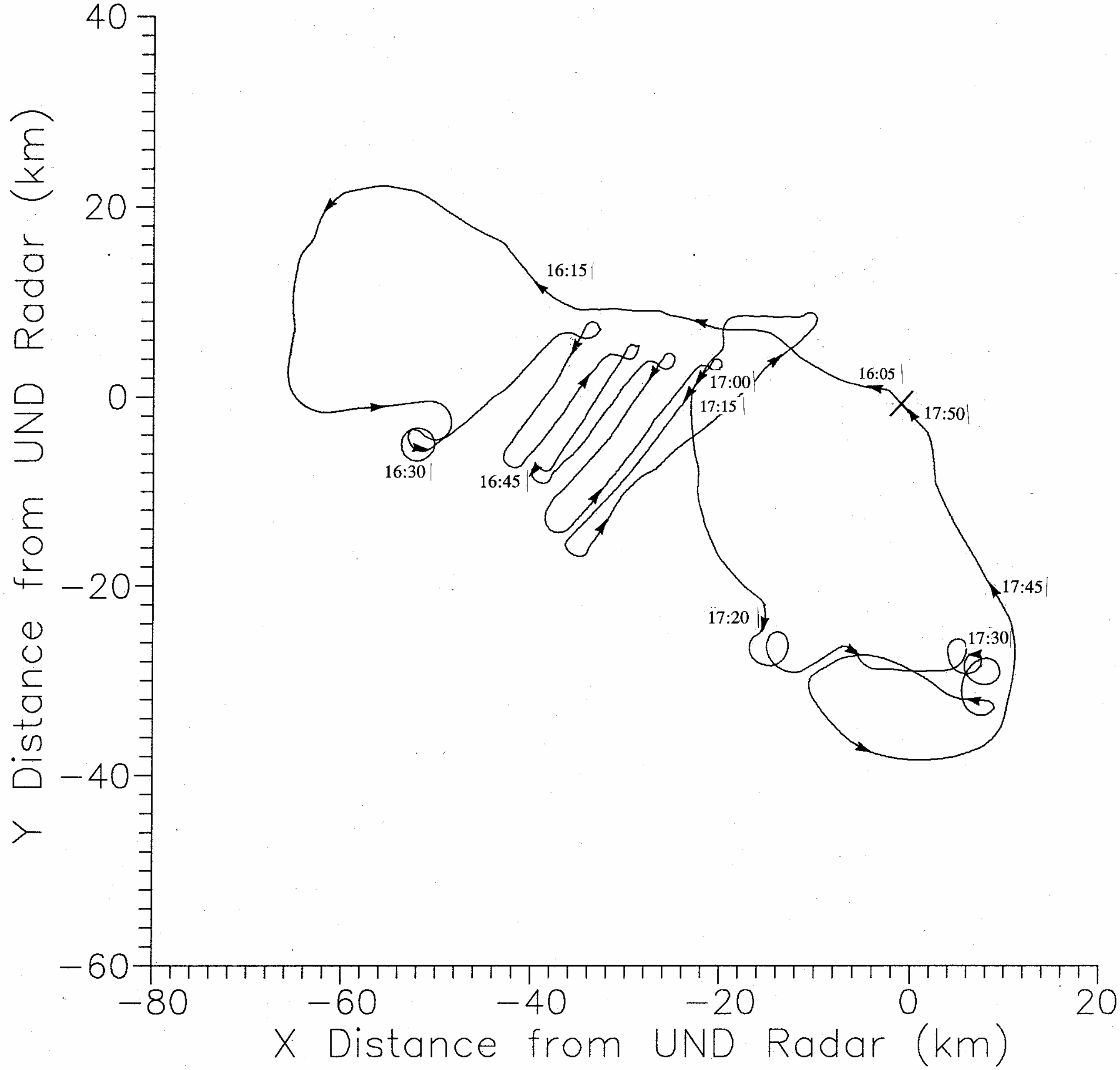

T-28 Track 6/30/93
X Distance from UND Radar (km)
Y Distance from UND Radar (km)
-70
-50
-30
-10
10
70
50
30
10
-10
15:30
15:45
16:00
16:15
16:25
16:40
16:45
16:55


T-28 Track 7/1/93
X Distance from UND Radar (km)
Y Distance from UND Radar (km)
-60
-40
-20
0
20
15:05
16:25
15:30
15:35
15:15
16:15
15:45
16:00

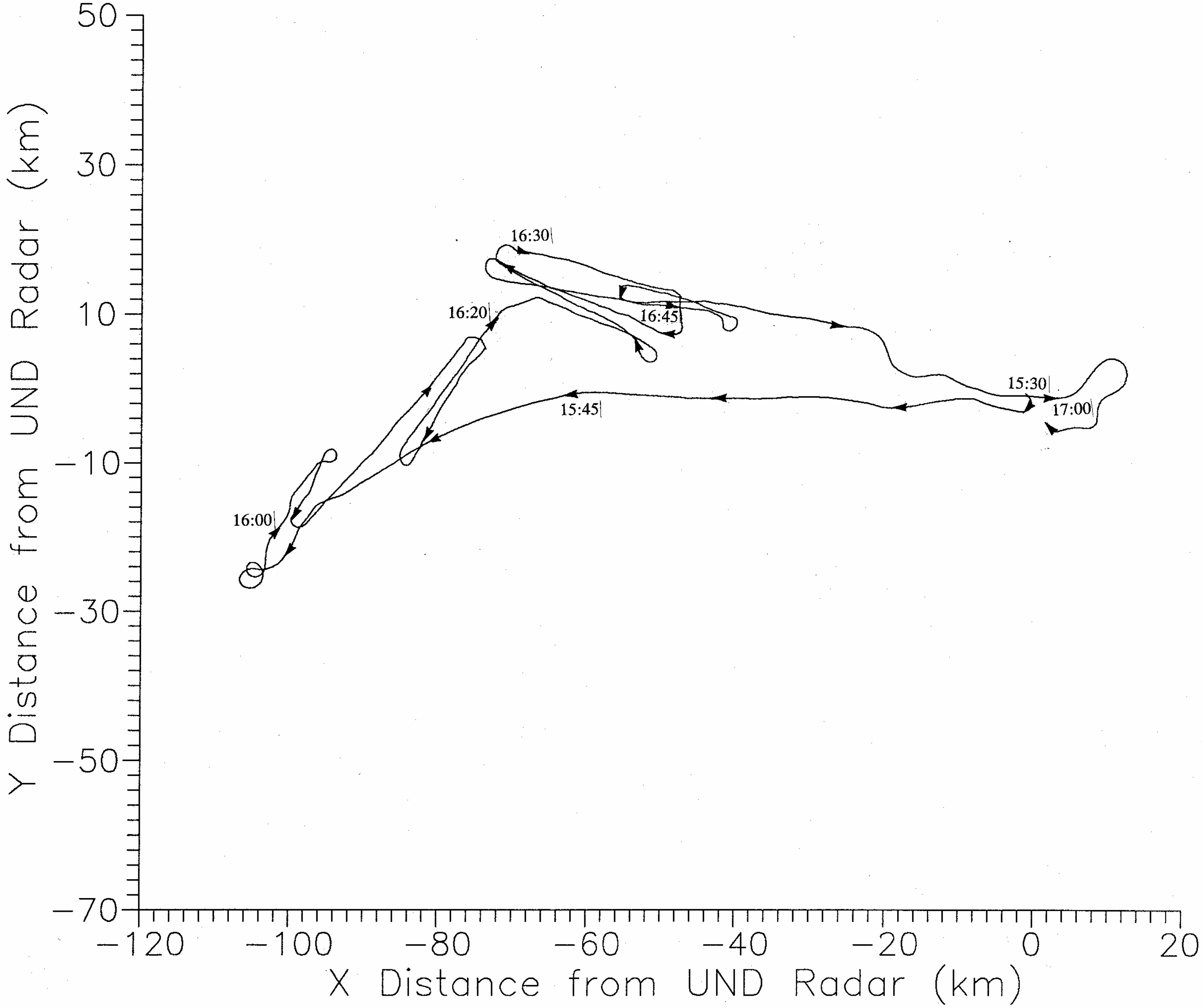


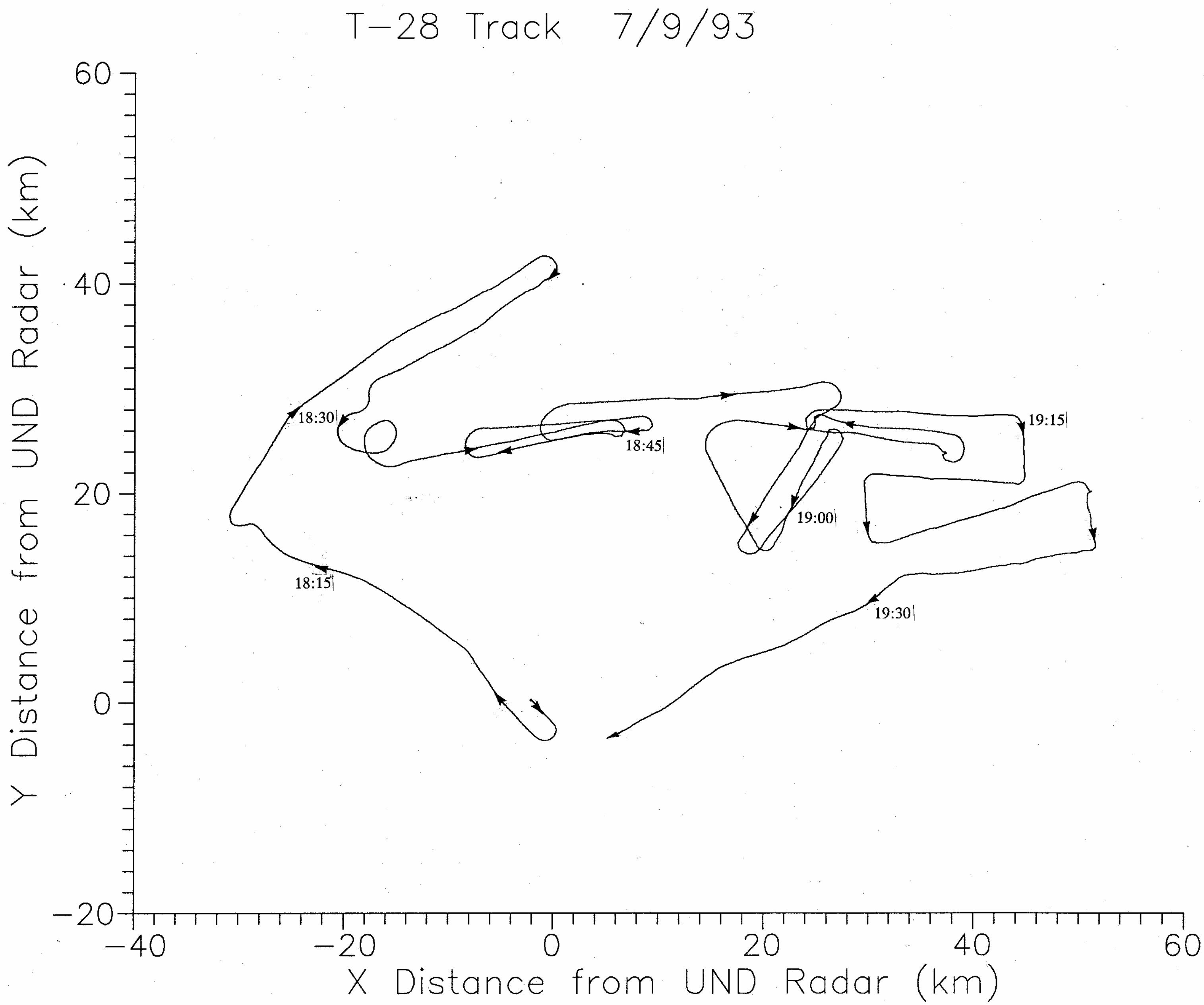
T−28 Track 7/3/93
19:00
18:45
19:05
18:30
19:15
17:50
18:00
18:15
60
40
20
0
−20
−40
−80
−60
−40
−20
0
20
Y Distance from UND Radar (km)
X Distance from UND Radar (km)

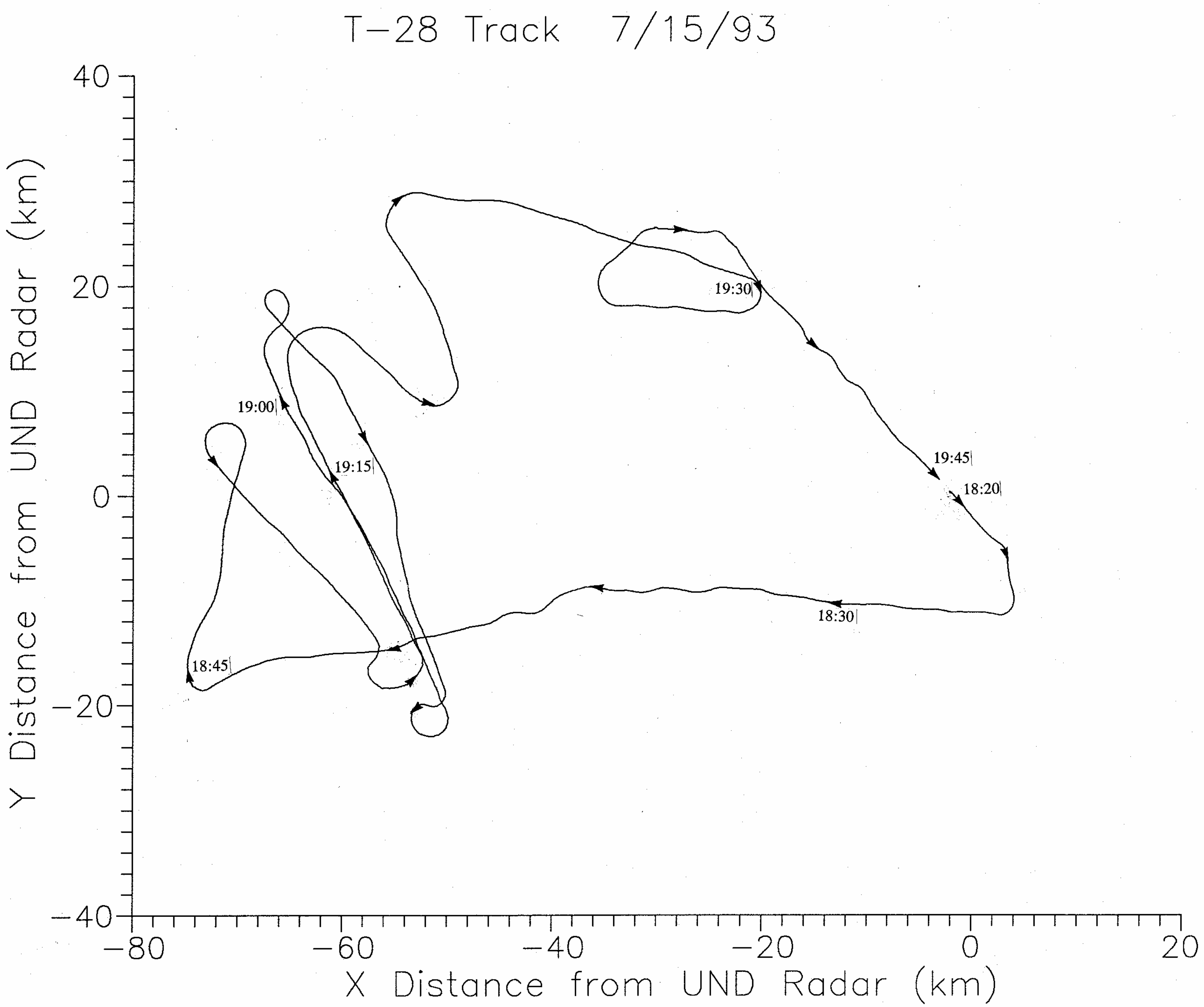
T-28 Track 7/6/93

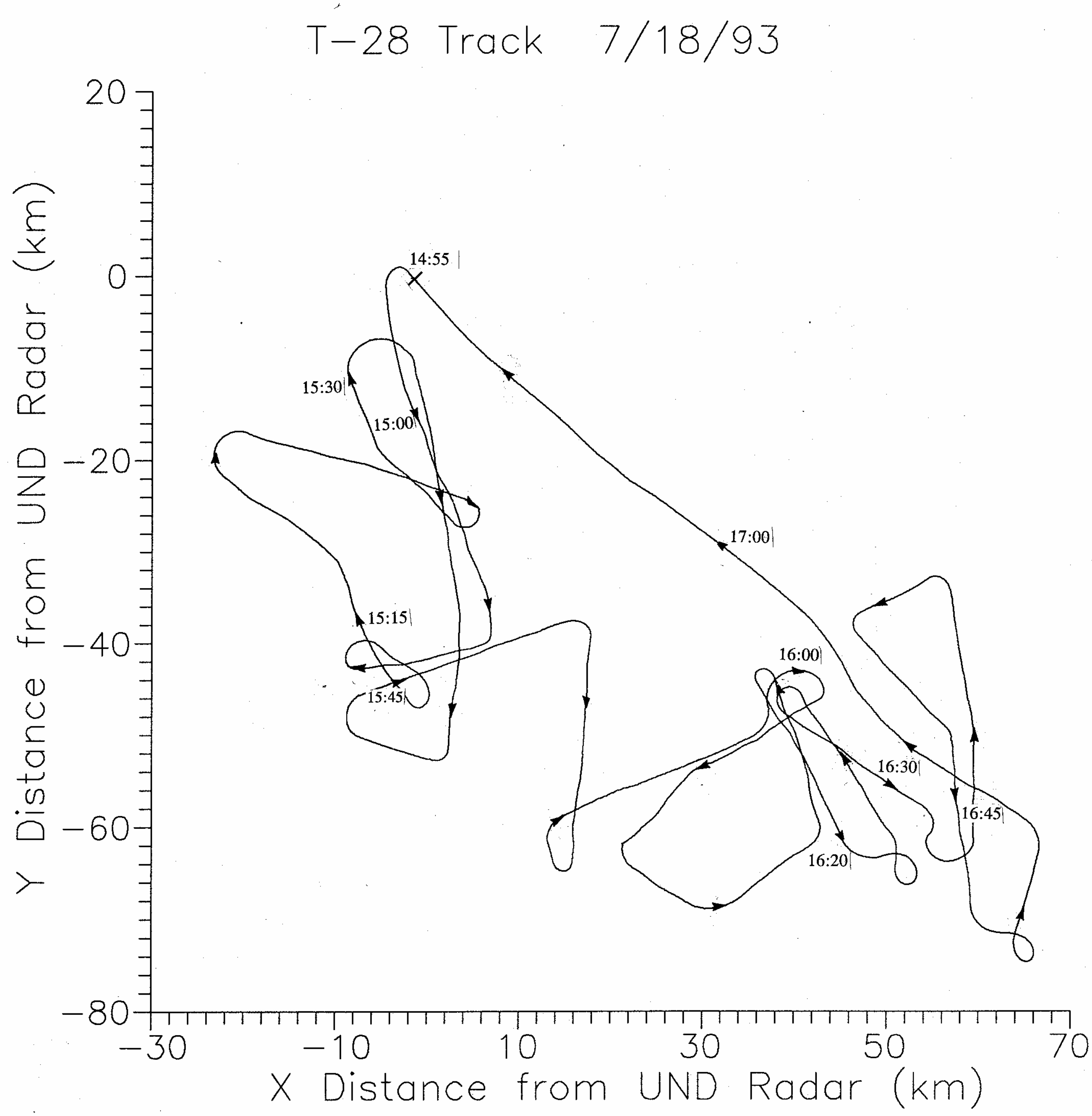


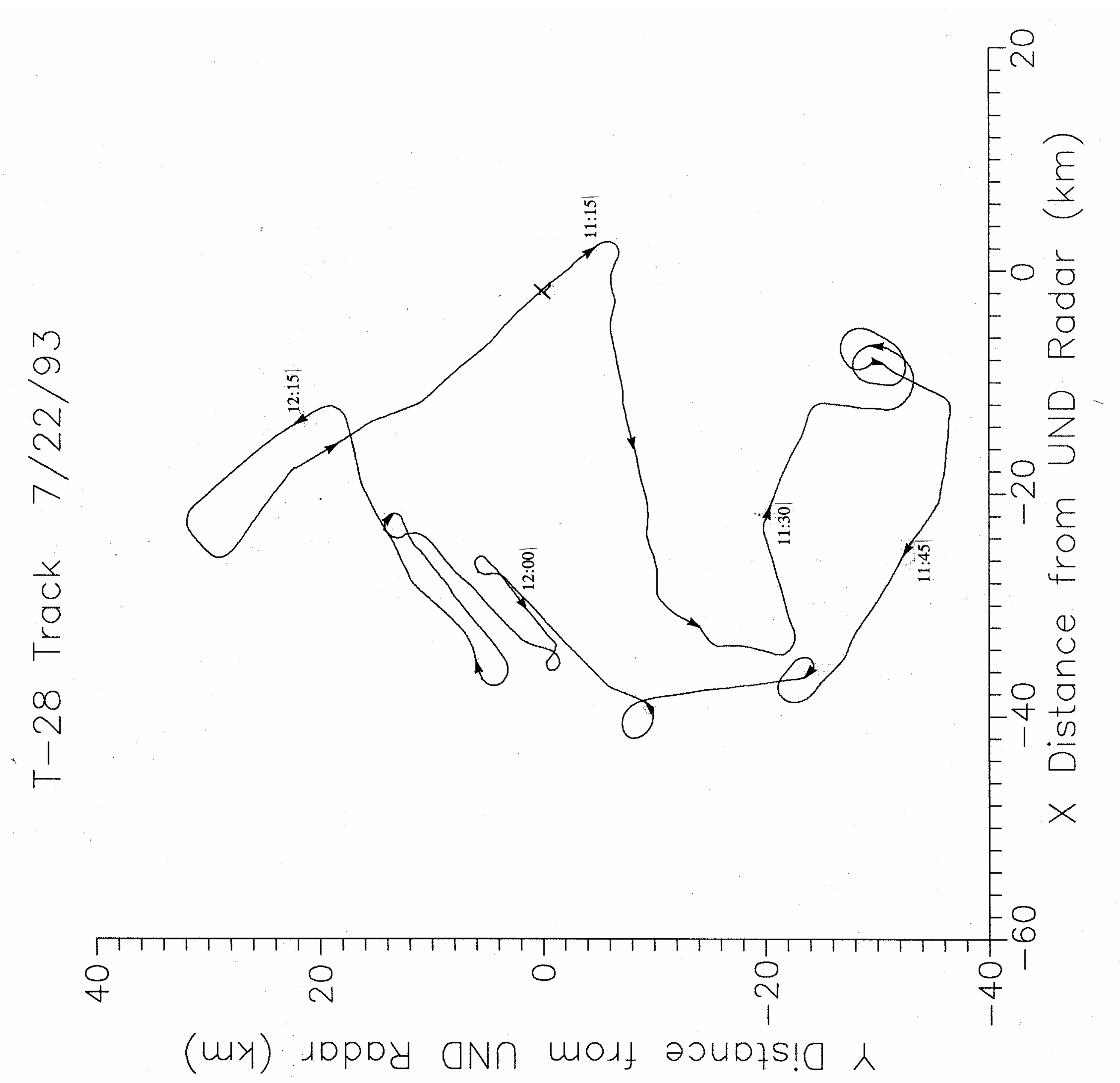
T-28 Track 7/8/93

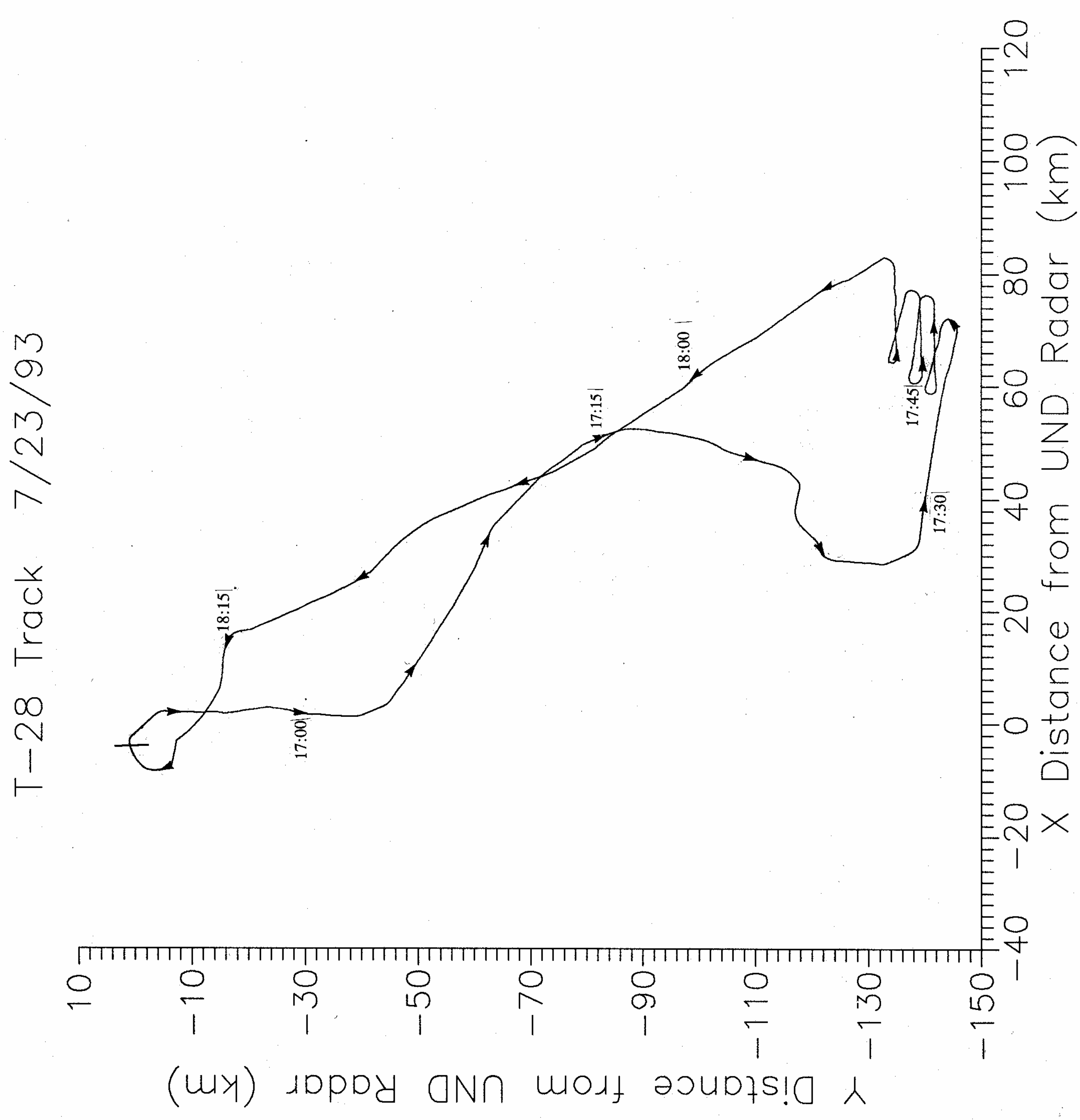


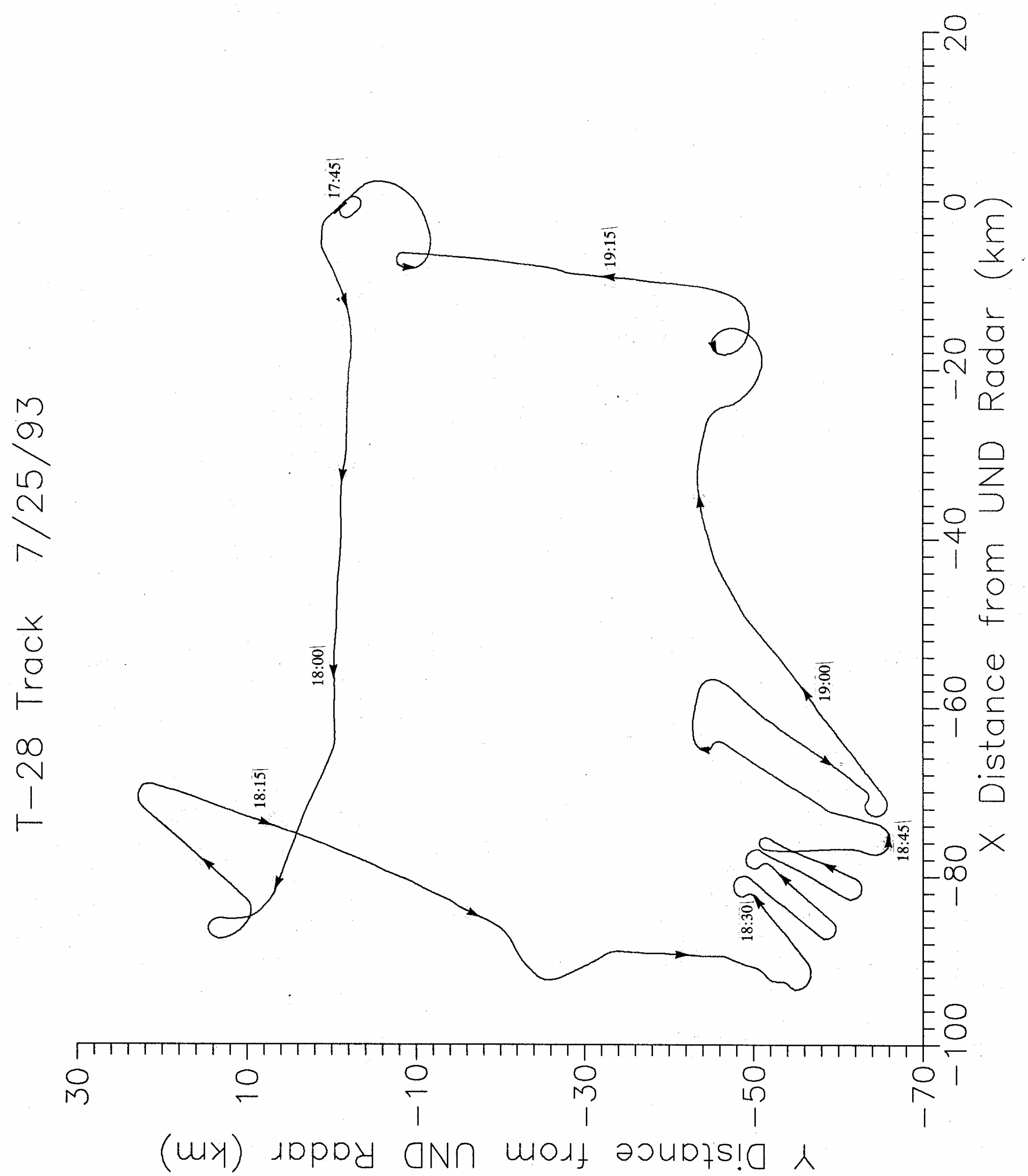

T-28 Track 7/9/93
Y Distance from UND Radar (km)
X Distance from UND Radar (km)
60
40
20
0
-20
-40
-20
0
20
40
60
18:15
18:30
18:45
19:00
19:15
19:30

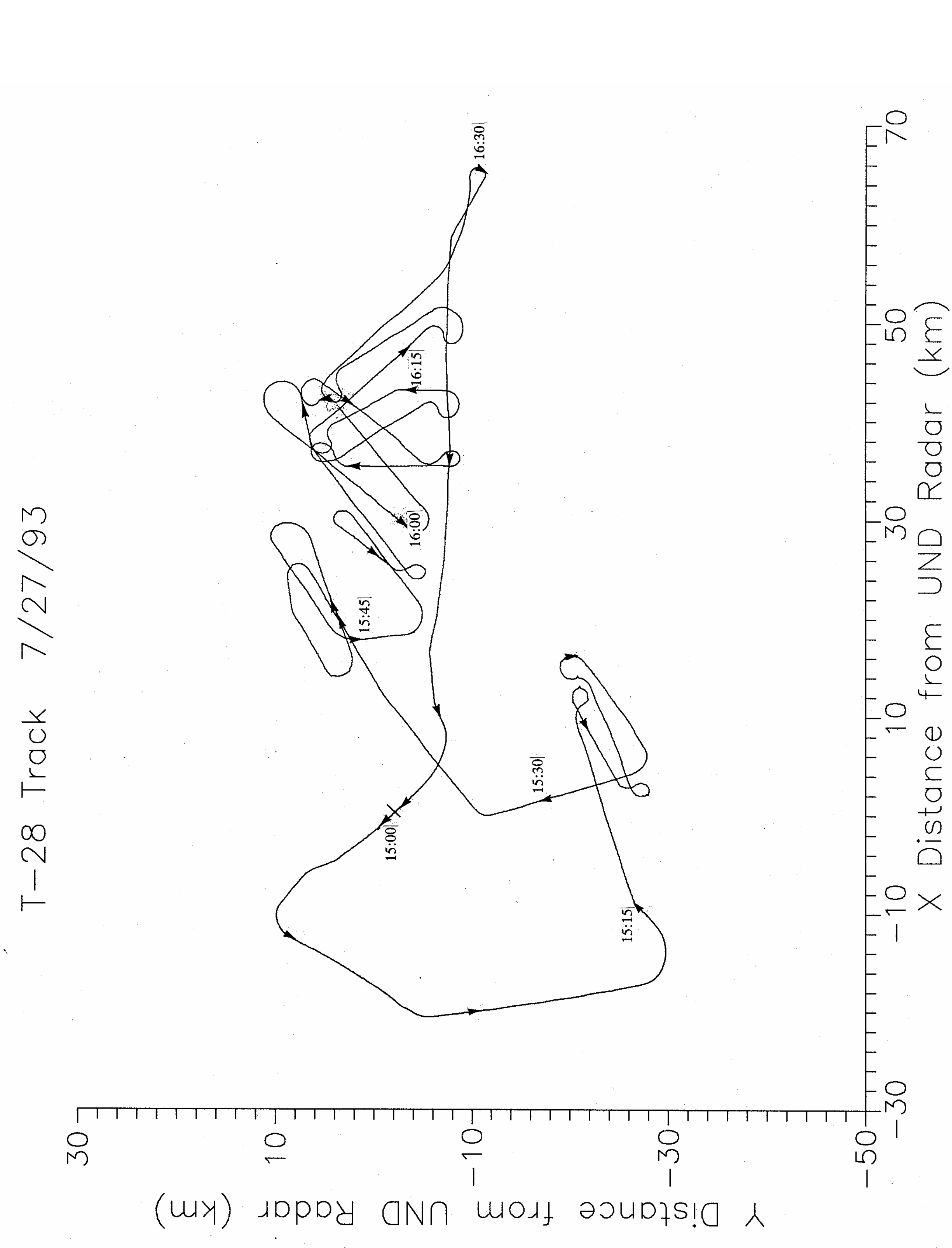

T-28 Track 7/15/93
40
20
0
-20
-40
Y Distance from UND Radar (km)
-80
-60
-40
-20
0
20
X Distance from UND Radar (km)
19:30
19:45
18:20
18:30
19:00
19:15
18:45


T−28 Track 7/18/93
Y Distance from UND Radar (km)
X Distance from UND Radar (km)
20
0
−20
−40
−60
−80
−30
−10
10
30
50
70
14:55
15:00
15:15
15:30
15:45
16:00
16:20
16:30
16:45
17:00


T-28 Track 7/22/93
X Distance from UND Radar (km)
Y Distance from UND Radar (km)
-60
-40
-20
0
20
40
11:15
11:30
11:45
12:00
12:15


T−28 Track 7/23/93
X Distance from UND Radar (km)
Y Distance from UND Radar (km)
−40
−20
0
20
40
60
80
100
120
10
−10
−30
−50
−70
−90
−110
−130
−150
17:00
17:15
17:30
17:45
18:00
18:15


T-28 Track 7/25/93
X Distance from UND Radar (km)
Y Distance from UND Radar (km)
−100
−80
−60
−40
−20
0
20
30
10
−10
−30
−50
−70
17:45
18:00
18:15
18:30
18:45
19:00
19:15


T-28 Track 7/27/93
Y Distance from UND Radar (km)
X Distance from UND Radar (km)
30
10
-10
-30
-50
-30
-10
10
30
50
70
15:00
15:15
15:30
15:45
16:00
16:15
16:30

APPENDIX E

ARB Weather Summaries

NDTE Forecast Sheet	Date: 6-30-93	Briefing Time (CDT): 1200

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-12.0	-12.0	-16.0	
Wet Bulb Zero (Kft)	9.0	11.0	8.5	
0°C Level (Kft)	12.5	12.0	9.5	
-5°C Level (Kft)	15.0	15.0	12.0	
-10°C Level (Kft)	16.5	17.0	15.5	
700 mb $T-T_{DEW}$ (°C)	30.0	5.0	5.0	
CCL (Kft)	0	8.5	9.0	
Trop Height (Kft)	3[illegible].0	38	33.0	
Max Tops (Kft)	3.0	[illegible]5	15.0	
Temp Max Tops (°C)	12.0	-22.0	-8.0	
$T_{CONVECTIVE}$ (°F)	70	70	65	
MOS T_{MAX} (°F)	—	—	—	
TOTAL TOTALS	44	44	44	
K Index	/	27	22	
SWEAT Index	175	168	115	
LIFTED Index	2	4	4	
Precip. Water (in.)	.71	69	.62	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	—	—	—	

16 Z	BIS	MOT	FAR	Y22	ABR
Temp	66	64	60	66	69
T_{DEW}	57	58	59	53	62
	ISN	JMS	MLS	DIK	PIR
Temp	65	65	65	65	67
T_{DEW}	49	57	44	52	59

WINDS ALOFT AT , Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt) / Dir		Scale	Time	CF
3	calm		none		
6	7	45	cu hu		
8	8	295	cu med		
10	19	260	TCU		
12	24	245	RW	1300	7
14	41	245	TRW		
16	55	245	TRW+		
20	62	240	HAIL		
25	69	240			

SYNOPSIS

Weak S/W moving through area this afternoon. SFC heating combined with LLM will give chnc. of RW- and possible TRW- early this afternoon. Xpct clearing and drying out at lower levels after PVA passes through region.

Forecaster: JS

NDTE Forecast Sheet	Date: 7/1/93	Briefing Time (CDT): 1200

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-15.1	-13.5	-16.5	
Wet Bulb Zero (Kft)	9.0	12.0	9.0	
0°C Level (Kft)	11.0	13.0	10.0	
-5°C Level (Kft)	13.0	15.0	12.0	
-10°C Level (Kft)	16.0	14.0	14.0	
700 mb $T-T_{DEW}$ (°C)	11.0	8.0	7.6	
CCL (Kft)	6.5	8.0	8.5	
Trop Height (Kft)	35.5	37.5	35.0	
Max Tops (Kft)	35.5	39.5	24.0	
Temp Max Tops (°C)	-53.0	-57.0	-27.0	
$T_{CONVECTIVE}$ (°F)	78	72	67	
MOS T_{MAX} (°F)	78	69	75	
TOTAL TOTALS	47	55	47	
K Index	20	36	23	
SWEAT Index	208	458	84	
LIFTED Index	-2	-5	2	
Precip. Water (in.)	.72	1.09	.66	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	8.7	12.3	6.7	

Z	BIS	MOT	FAR	Y22	ABR
Temp	65	66	65	61	69
T_{DEW}	60	56	61	52	65
	ISN	JMS	MLS	DIK	PIR
Temp	59	63	63	57	63
T_{DEW}	55	60	56	55	62

WINDS ALOFT AT BIS, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt) / Dir		Scale	Time	CF
3	6	180	none		
5	23	165	cu hu		
7	28	205	cu med		
10	29	220	TCU		
12	31	225	RW		
14	35	235	TRW	1500	7
16	39	245	TRW+		
20	46	260	HAIL		6
25	44	255	Ɪ		

SYNOPSIS

S/W moving into Region today. Moisture advection ahead of it should help destabilize soundings more. Activity should develop this afternoon and persist into evening.

Forecaster: JS

NDTE Forecast Sheet	Date:	Briefing Time (CDT):

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-10.3	-8.3	-12.5	
Wet Bulb Zero (Kft)	13.0	13.5	11.5	
0°C Level (Kft)	13.5	15.5	12.0	
-5°C Level (Kft)	16.0	17.0	14.0	
-10°C Level (Kft)	18.5	9.0	17.0	
700 mb $T-T_{DEW}$ (°C)	8	30	1.1	
CCL (Kft)	[illegible]	6.5	5.0	
Trop Height (Kft)	42.5	4[illegible]	37.5	
Max Tops (Kft)	7.0	7.5	5.0	
Temp Max Tops (°C)	2.0	14.0	2.0	
$T_{CONVECTIVE}$ (°F)	89	98	64	
MOS T_{MAX} (°F)	78	81	72	
TOTAL TOTALS	49	49	47	
K Index	30	11	33	
SWEAT Index	283	434	163	
LIFTED Index	0	-4	0	
Precip. Water (in.)	1.27	.90	1.04	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	11.2	14.6	10.1	

Z	BIS	MOT	FAR	Y22	ABR
Temp	70	61	73	67	74
T_{DEW}	64	59	63	59	66
	ISN	JMS	MLS	DIK	PIR
Temp	65	69	58	64	73
T_{DEW}	61	51	58	63	67

WINDS ALOFT AT BIS, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt)	Dir	Scale	Time	CF
2	5	100	none		
5	3	175	cu hu		
7	11	180	cu med		
9	10	195	TCU		
12	8	160	RW		
14	3	85	TRW		
17	16	295	TRW+	1400	8
20	1[illegible]	235	HAIL	1400	7
25	51	210	II	✓	6

SYNOPSIS

SFC Low over SE Mt will lift NE into ND with wrm front lifting into S ND. Very unstable air should break cap this P.M. and SVR storm outbreak likely. TRW+ likely; wind shears favorable for tornadoes.

Forecaster: JS

NDTE Forecast Sheet	Date: 7/6/95	Briefing Time (CDT): 1200

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-13.7	-16.1	-16.1	
Wet Bulb Zero (Kft)	8.5	8.0	9.5	
0°C Level (Kft)	9.0	10.5	10.0	
-5°C Level (Kft)	13.0	12.5	12.5	
-10°C Level (Kft)	16.5	16.0	16.0	
700 mb $T-T_{DEW}$ (°C)	.9	4.2	1.4	
CCL (Kft)	4.0	9.5	6.5	
Trop Height (Kft)	37.0	36.0	38.5	
Max Tops (Kft)	9.5	27.5	21.5	
Temp Max Tops (°C)	-1.0	-38.0	-20.0	
$T_{CONVECTIVE}$ (°F)	57	68	68	
MOS T_{MAX} (°F)	63	70	70	
TOTAL TOTALS	39	48	50	
K Index	25	28	32	
SWEAT Index	165.7	107	129	
LIFTED Index	5	1	0	
Precip. Water (in.)	0.92	.65	.80	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	8.1	6.2	7.6	

Z	BIS	MOT	FAR	Y22	ABR
Temp	62	58	59	64	67
T_{DEW}	54	55	56	49	55
	ISN	JMS	MLS	DIK	PIR
Temp	73	60	64	63	71
T_{DEW}	57	51	53	54	52

WINDS ALOFT AT BIS, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt)	Dir	Scale	Time	CF
2	3	250	none		
4	19	320	cu hu		
7	23	320	cu med		
10	24	315	TCU		
13	21	315	RW	0100	6
15	17	325	TRW		
17	13	310	TRW+		
20	18	320	HAIL		
25	5	345	II		

SYNOPSIS

ND still under influence of wrap around moisture from Canadian Low. Thermal axis at 850 mb will allow for some instability over E. Mt., but TRW should stay W of project area.
Widely scattered RW- likely, with chnc of TCU in clearing areas.

Forecaster: JS

NDTE Forecast Sheet	Date: 7/8/93	Briefing Time (CDT):

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-16.5	-12.5	-16.9	
Wet Bulb Zero (Kft)	8.0	9.5	8.0	
0°C Level (Kft)	11.0	12.5	10.0	
-5°C Level (Kft)	13.0	14.5	12.5	
-10°C Level (Kft)	16.0	17.0	15.0	
700 mb $T-T_{DEW}$ (°C)	4	1.2	.9	
CCL (Kft)	5.5	9.0	5.5	
Trop Height (Kft)	31.0	30.5	33.5	
Max Tops (Kft)	25.0	32.0	34.0	
Temp Max Tops (°C)	-30.0	-43.0	-53.0	
$T_{CONVECTIVE}$ (°F)	68	77	66	
MOS T_{MAX} (°F)	71	72	69	
TOTAL TOTALS	51	46	51	
K Index	30	32	33	
SWEAT Index	175	179	124	
LIFTED Index	-2	-1	-2	
Precip. Water (in.)	.86	.87	.83	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	8.9	8.4	8.4	

Z	BIS	MOT	FAR	Y22	ABR
Temp	66	67	70	65	61
T_{DEW}	57	56	62	52	61
	ISN	JMS	MLS	DIK	PIR
Temp	62	67	62	65	66
T_{DEW}	56	57	53	52	62

WINDS ALOFT AT RAP, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt)	Dir	Scale	Time	CF
3	9	330	none		
5	14	80	cu hu		
7	17	95	cu med		
10	9	205	TCU		
12	16	255	RW		
14	26	270	TRW	1500	7
17	50	250	TRW+		
20	61	255	HAIL		
25	69	250	II		

SYNOPSIS

S/W will pass through region today.
Enough instability for TRW development this
P.M. Chnc of small Hail late afternoon.

Forecaster: [signature]

NDTE Forecast Sheet	Date: 7/9/93	Briefing Time (CDT):

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-15.1	-14.1	-15.9	
Wet Bulb Zero (Kft)	8.5	10.0	9.0	
0°C Level (Kft)	11.5	12.0	10.5	
-5°C Level (Kft)	13.5	14.5	12.5	
-10°C Level (Kft)	16.5	16.5	16.5	
700 mb T-T_{DEW} (°C)	6	13	1.6	
CCL (Kft)	7.0	10.5	7.5	
Trop Height (Kft)	31.0	30.0	35.5	
Max Tops (Kft)	7.0	29.5	34	
Temp Max Tops (°C)	7.0	-41	-54	
$T_{CONVECTIVE}$ (°F)	71	77	71	
MOS T_{MAX} (°F)	72	69	71	
TOTAL TOTALS	47	46	48	
K Index	26	19	31	
SWEAT Index	111	111	109	
LIFTED Index	-1	+1	-1	
Precip. Water (in.)	.83	.81	.81	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	8.5	6.7	7.6	

16 Z	BIS	MOT	FAR	Y22	ABR
Temp	70	68	72	68	71
T_{DEW}	58	58	60	50	60
	ISN	JMS	MLS	DIK	PIR
Temp	66	71	68	68	71
T_{DEW}	55	57	55	55	53

WINDS ALOFT AT BIS, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt) / Dir		Scale	Time	CF
2	4	260	none		
3	8	270	cu hu		
4	15	[illegible]	cu med		
6	15	305	TCU		
8	16	310	RW		
11	18	315	TRW	1600	6
14	19	320	TRW+		
16	20	300	HAIL		
20	25	280	][		

SYNOPSIS

NVA behind S/W in eastern ND will keep convective activity to cu ahead of CF in NW ND. Chnc of TRW with passage of CF near Peak heating time. Any PVA will lag behind front.

Forecaster: [signature]

NDTE Forecast Sheet	Date: 7/15/93	Briefing Time (CDT): 1200

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-11.5	-11.1	-15.7	
Wet Bulb Zero (Kft)	11.5	13.0	11.0	
0°C Level (Kft)	12.5	14.0	12.0	
-5°C Level (Kft)	15.0	16.5	[illegible]	
-10°C Level (Kft)	17.0	18.5	16.5	
700 mb $T-T_{DEW}$ (°C)	9	14	30	
CCL (Kft)	5.5	5.5	5.0	
Trop Height (Kft)	33.5	42.5	36.0	
Max Tops (Kft)	31.5	7.5	6.0	
Temp Max Tops (°C)	-43.0	7.0	13.0	
$T_{CONVECTIVE}$ (°F)	74	88	81	
MOS T_{MAX} (°F)	75	77	65	
TOTAL TOTALS	47	53	46	
K Index	27	27	1	
SWEAT Index	388	462	144	
LIFTED Index	0	-6	2	
Precip. Water (in.)	.97	1.10	.48	
Mixing Ratio (g kg⁻¹) LOWEST 100 MB	10.4	13.1	8.4	

Z	BIS	MOT	FAR	Y22	ABR
Temp	62	59	61		69
T_{DEW}	60	58	58		65
	ISN	JMS	MLS	DIK	PIR
Temp	65	59	59	62	68
T_{DEW}	58	56	58	61	65

WINDS ALOFT AT BIS, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt)	Dir	Scale	Time	CF
2	16	140	none		
4	29	170	cu hu		
6	23	205	cu med		
8	29	245	TCU		
10	27	245	RW		
14	29	245	TRW	1200	10
16	32	265	TRW+	1300	8
20	40	285	HAIL		7
25	25	245	][		

SYNOPSIS

LLJ advecting good LLM into Region. Good dynamics combined with some instablity will provide for TRW development. Few TRW could be severe, however SFC heating will be limited. WRM front will stay along ND/SD border, may move N late P.M.

Forecaster: [signature]

NDTE Forecast Sheet	Date: 7/18/93	Briefing Time (CDT): 1200

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-14.0	-13.0	-15.5	
Wet Bulb Zero (Kft)	9.5	12.0	8.5	
0°C Level (Kft)	11.5	13.5	10.5	
-5°C Level (Kft)	15.0	15.5	13	
-10°C Level (Kft)	17.0	17.5	16	
700 mb $T-T_{DEW}$ (°C)	1.0	18	2	
CCL (Kft)	6.0	6.5	5.5	
Trop Height (Kft)	43	45	31	
Max Tops (Kft)	-42	16	-53.0	
Temp Max Tops (°C)	31.5	10	-53	
$T_{CONVECTIVE}$ (°F)	75	72	66	
MOS T_{MAX} (°F)				
TOTAL TOTALS	48	56	46	
K Index	34	25	29	
SWEAT Index	312	476	103	
LIFTED Index	-2	-6	2	
Precip. Water (in.)	1.00	.91	.87	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB				

Z	BIS	MOT	FAR	Y22	ABR
Temp	70	70	77	66	70
T_{DEW}	60	62	62	57	64
	ISN	JMS	MLS	DIK	PIR
Temp	68	74	59	68	63
T_{DEW}	55	60	55	56	60

WINDS ALOFT AT BIS, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt)	Dir	Scale	Time	CF
SFC	0	0	none		
01	06	175	cu hu		
03	18	200	cu med		
05	12	190	TCU		
07	13	225	RW		
09	21	250	TRW	1400	8
10	22	255	TRW+		
15	23	280	HAIL	1600	6
20	29	275	][		

SYNOPSIS

S/WV in Central MT will move through region this P.M. Abudant LLM combined with SFC heating will destabilize soundings in the -4 → -6 LI range. Xpct activity mid afternoon, possibly SVR, but feel best chnc SVR will be east of BIS.

PICNIC outlook: Low 70's, WIND Light and VRB. Clear to P.C.

Forecaster: J.G.

NDTE Forecast Sheet	Date: 7/23/93	Briefing Time (CDT):

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-12.1	-10	-15.7	
Wet Bulb Zero (Kft)	9	11.5	10	
0°C Level (Kft)	12	12.5	10.5	
-5°C Level (Kft)	15	15.5	13	
-10°C Level (Kft)	17.5	18.5	15	
700 mb $T-T_{DEW}$ (°C)	9	8	6	
CCL (Kft)	7	9	8.5	
Trop Height (Kft)	35	36.5	36	
Max Tops (Kft)	34	38.5	31	
Temp Max Tops (°C)	-46	-54	-43	
$T_{CONVECTIVE}$ (°F)	80	83	76	
MOS T_{MAX} (°F)	82	81	76	
TOTAL TOTALS	46	48	49	
K Index	25	30	28	
SWEAT Index	104	277	83	
LIFTED Index	-1	-3	-2	
Precip. Water (in.)	.94	.96	.74	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	9.1	10.1	7.4	

16 Z	BIS	MOT	FAR	Y22	ABR
Temp	63	70	68	59	71
T_{DEW}	63	61	66	52	69
	ISN	JMS	MLS	DIK	PIR
Temp	65	68	69	61	70
T_{DEW}	58	63	58	60	63

WINDS ALOFT AT BIS, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt)	Dir	Scale	Time	CF
03	03	130	none		
05	08	230	cu hu		
07	07	265	cu med		
09	11	315	TCU		
11	11	290	RW	1200	8
14	16	225	TRW	1200	6
16	15	235	TRW+		
18	26	250	HAIL		
20	31	245	][		

SYNOPSIS

S/WV moving through region today will bring RW, possible TRW until late afternoon. Stabilization in S/WV ridge should keep things down this evening. Next chac of TRW/RW late tonight as next system strengthens and lifts over ND in next 36-48 hrs.

Forecaster: [signature]

NDTE Forecast Sheet	Date: 7/22/93	Briefing Time (CDT): 1200

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	—	-12.5	-14.7	
Wet Bulb Zero (Kft)	12.0	13.0	9.5	
0°C Level (Kft)	13.0	15.0	10.5	
-5°C Level (Kft)	15.0	16.5	13.0	
-10°C Level (Kft)	—	18.0	16.5	
700 mb $T-T_{DEW}$ (°C)	—	30.0	0.9	
CCL (Kft)	5.5	7.5	6.5	
Trop Height (Kft)	—	34.0	33.0	
Max Tops (Kft)	—	10.0	33.0	
Temp Max Tops (°C)	—	12.0	-49.0	
$T_{CONVECTIVE}$ (°F)	74	88	71	
MOS T_{MAX} (°F)	76	82	73	
TOTAL TOTALS	—	56	51	
K Index	—	14	35	
SWEAT Index	—	404	174	
LIFTED Index	—	-8	-2	
Precip. Water (in.)	—	1.07	.92	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	11.0	12.2	8.8	

16 Z	BIS	MOT	FAR	Y22	ABR
Temp	66	63	72	67	68
T_{DEW}	65	59	60	62	64
	ISN	JMS	MLS	DIK	PIR
Temp	69	67	67	69	72
T_{DEW}	60	60	55	60	65

WINDS ALOFT AT BIS .16 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt) / Dir		Scale	Time	CF
			none		
			cu hu		
			cu med		
			TCU		
			RW		
			TRW	1200	8
			TRW+	1200	8
			HAIL		
			][		

SYNOPSIS

TRW+ today. SFC trof, PVA, moist air means rain!

Forecaster:

NDTE Forecast Sheet	Date: 7/25/93	Briefing Time (CDT):

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-10.1	-10	-13.5	
Wet Bulb Zero (Kft)	11	10	10.5	
0°C Level (Kft)	12.0	12.8	11.2	
-5°C Level (Kft)	16.0	15.5	14.0	
-10°C Level (Kft)	18.4	18.3	16.8	
700 mb $T-T_{DEW}$ (°C)	1.4	7.0	1.0	
CCL (Kft)	3.0	8.5	7.5	
Trop Height (Kft)	36	35.3	34.5	
Max Tops (Kft)	23.5	8.5	35	
Temp Max Tops (°C)	-21	—	-53	
$T_{CONVECTIVE}$ (°F)	65.3	73	75	
MOS T_{MAX} (°F)	—	—	—	
TOTAL TOTALS	43	40	49	
K Index	32	23	33	
SWEAT Index	190	161	101	
LIFTED Index	1	5	-1	
Precip. Water (in.)	1.27	0.69	0.96	
Mixing Ratio (g kg[-1]) LOWEST 100 MB	13	8	9	

16 Z *(15Z)	BIS	MOT	FAR	Y22	ABR
Temp	—	64	68	66*	73
T_{DEW}	—	62	66	61*	64
	ISN	JMS	MLS	DIK	PIR
Temp	—	64	64	62*	71*
T_{DEW}	—	62	59	59*	57

WINDS ALOFT AT 1200 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt)	Dir	Scale	Time	CF
1.7	10	340	none		
6.0	25	350	cu hu		
10.0	10	5	cu med		
18.4	7	245	TCU		
23.5	7	95	RW		
31	15	80	TRW		
34.5	18	120	TRW+		
			HAIL		
			][		

SYNOPSIS

LOW PRESSURE SYSTEM MOVING EAST OF STATE WILL ALLOW CLEARING FROM WEST THIS AFTN. UPR S/W RDG WILL SUPPRESS SIG CONVECTION EARLY THIS AFTN WITH ONLY SCT-BKN CU EXPECTED. UPR S/W TROF APPROACHING FROM SW LT THIS AFTN WILL DESTABILIZE AIRMASS. TCU/RW- WITH A FEW CB/TRW EXPECTED OVER W AND SWRN AREAS, TOWARDS EARLY EVE.

Forecaster:

NDTE Forecast Sheet	Date: 7/27/93	Briefing Time (CDT): 1200

SOUNDING PARAMETERS	BIS	RAP	GGW	
500 mb Temp (°C)	-13.5	-11.5	-11.7	
Wet Bulb Zero (Kft)	11	10	11	
0°C Level (Kft)	13	12	11.5	
-5°C Level (Kft)	15	16	14.5	
-10°C Level (Kft)	17.5	18	18	
700 mb $T-T_{DEW}$ (°C)	7	8	1.2	
CCL (Kft)	7	11.5	05	
Trop Height (Kft)	43	45	36	
Max Tops (Kft)	11	13	18.5	
Temp Max Tops (°C)	4	-2	-11	
$T_{CONVECTIVE}$ (°F)	69	78	63	
MOS T_{MAX} (°F)	75	71	71	
TOTAL TOTALS	51	39	46	
K Index	31	20	34	
SWEAT Index	255	117	207	
LIFTED Index	-4	4	-1	
Precip. Water (in.)	.88	.54	1.13	
Mixing Ratio (g kg^{-1}) LOWEST 100 MB	11.2	6.1	11.0	

16 Z	BIS	MOT	FAR	Y22	ABR
Temp	64	61	78	62	71
T_{DEW}	56	59	69	51	58
	ISN	JMS	MLS	DIK	PIR
Temp	59	70	60	62	71
T_{DEW}	57	56	58	55	53

WINDS ALOFT AT BIS, 12 Z			CLOUD DEVELOPMENT		
Kft MSL	Speed (kt) / Dir		Scale	Time	CF
SFC	16	220	none		
04	20	225	cu hu		
07	20	215	cu med		
09	25	205	TCU		
12	34	185	RW	1200	8
14	27	190	TRW		
16	31	185	TRW+		
20	36	190	HAIL		
25	67	20	Ⅱ		

SYNOPSIS

Upper Low will slowly move east today. Some TRW occurring in occluded front. Xpct RW, possible embedded TRW, mainly North, as Low tracks eastward and wrap around moisture influences region this P.M. Bis / Class soundings show some low level instability, but capped above 700 mb

Forecaster: [signature]