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1981 SPRING PROGRAM SUMMARY

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1981 SPRING PROGRAM SUMMARY

1. INTRODUCTION

The 1981 Spring Program of the National Severe Storms Laboratory was patterned closely after the 1980 program. Principal objectives of the 1981 observations were to collect high quality data from a large array of simultaneously active sensors to 1) enhance the data base of the Storm Electricity Group engaged in determining lightning hazards, lightning characteristics, and the relationships between the various storm electrical phenomena and the other observable storm parameters, 2) support efforts sponsored by other agencies to examine severe storm and other meteorological phenomena, and conduct experiments on storm hazards to aircraft, 3) capture data on the tornadic storms that occur very infrequently within our dual mapping area, 4) observe the wind fields and convection in the prestorm environment, and 5) support other specific experiments as storm situations warranted.

This was basically an in-house program involving 34 of NSSL staff, two of staff from NWS/JSPO Radar Techniques Development Branch, 13 students and several visiting scientists and observers that were directly engaged in the observational efforts. Actually the entire NSSL staff - secretaries, managers, administrative staff, the Director, and all other support personnel - were committed to the Spring Program, and it was only through their extra efforts that success was attained. Total cost, not counting the base salaries of staff, was about $129,000. Partial support for the program came from the FAA, NASA, and ONR.

A number of other participants were involved with their own equipment and support. These came from 1) the University of Oklahoma for studying lightning echoes using 23-cm radar, for hail intercept experience, and for placing an instrument package near tornadoes (TOTO, from the Wave Propagation Laboratory; 2) the University of Mississippi for storm electricity observations from a mobile van; 3) Miami University (Oxford, Ohio) for corona measurements; 4) NASA-Langley for turbulence and lightning hazards to aircraft; 5) NASA-Huntsville, 6) State University of New York at Albany, and 7) New Mexico Institute of Mining and Technology for observing lightning from above the storm with U-2 aircraft; 8) Bendix Corporation and 9) Collins Radio to test airborne Doppler radar systems; and 10) Los Alamos Scientific Laboratory to use instrumented rockets for determining tornado parameters.

Nineteen of the planned 20 experiments were attempted, and 17 experiments accomplished at least their minimum goal. The core period of operations was planned for 1 April through 30 June. To conserve funds, the program was officially terminated 22 June, although specific observations in support of the CV990 and Airborne Doppler experiments continued through 2 July. Within the main core period, operations were conducted on 22 days, beginning with 3 April and ending with 3 June. Severe weather was documented on 10 days - 11, 12, 13, 22, 28, 30 April; 13, 17, 22 and 23 May. Major observational periods, characterized by many sensors active for an extended time, occurred on 8 days - 3, 13, 28, 30 April; 17, 22, 23 May and 2 June.

This volume is intended to present information to researchers inside and outside NSSL on the 1981 Spring Program. It includes a listing of the objectives and special requirements of the experiments, a brief description of the instrumentation used, a presentation of the operational procedures and a summary of the observations and preliminary impressions of each operational period. Some of the data obtained during this program will undoubtedly be used for many years for specific analyses and interpretations. Researchers interested in any of this data may contact either J.T. Dooley, Data Dissemination Coordinator at NSSL, or the principal investigator of the experiment of interest.

2. EXPERIMENTS DURING 1981 SPRING PROGRAM

Section 2.1 lists the twenty experiments proposed for the spring operation and the corresponding principal investigators or coordinators. The objectives and special requirements of each experiment are presented in section 2.2. Selection of Doppler radar antenna, transmitter and receiver parameters for specific modes of observation is shown in section 2.3.

2.1 Experiments and Principal Investigators or Coordinators

1.	Lightning Mapping and Storm Electricity	Taylor, Rust
2.	Lightning Ground Strike Location	MacGorman
3.	Storm Electricity Experiments from Mobile Laboratory	Arnold[1], Rust
4.	L-Band (23-cm) Radar Echoes from Lightning	Mazur[2], Taylor
5.	Corona Beneath Severe Storms	Church[3], Rust
6.	S-Band (10-cm) Radar Echoes from CG Lightning Channel	Rust, Taylor
7.	Drop Levitation and Doppler Properties of Lightning Echoes	Zrnic', Taylor
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1. University of Mississippi
2. University of Oklahoma
3. Miami University (Oxford, Ohio)

2.2 Experiment Objectives and Requirements

2.2.1. Lightning Mapping and Storm Electricity [Taylor, Rust]

A. Objectives:

1. Locate the source of lightning discharge processes in space (x, y, z) and time for severe and nonsevere storms.

2. Determine lightning initiation regions and what storm structure and dynamics influence its progression.

3. Measure progression speeds for different lightning processes.

4. Determine storm characteristics that influence production of intracloud flashes and of lightning lowering negative charge to ground and positive charge to ground.

5. Determine relationships among coevolving fields of precipitation, wind, turbulence and lightning.

6. Determine lightning characteristics during the genesis, maturity, and dissipation of storms.

7. Measure lightning parameter characteristics indicative of tornadic, severe (nontornadic) and nonsevere storms.

8. Track lightning activity, identify electrically active storms and provide ground truth for NSSL experiments, NASA programs and other agencies and coworkers.

B. Requirements:

1. Daily forecast, weather briefings, and nowcasting for severe and nonsevere storms.

2. Dual Doppler operation in sector scanning mode (Dual-Mapping-A mode) for storms within 60 km of NRO-CIM baseline sector width 70° min., 120° max. and elevation angle to top storm (15 km or to 10 dBZ height).

3. WSR-57 operation when storms are within 75 km of Norman, photographic data (tape when operator is available), 0° and one rotation at each of 5 elevations such that $\Delta EL = 150/r$ ($\Delta EL \lesssim 8°$).

4. Meteorological coordinator on duty to interpret storm development.

5. Doppler coordinator on duty to coordinate scans in elevation and azimuth at NRO and CIM to accommodate regions of lightning activity within selected storms.

6. L-Band lightning echoes, normal fixed azimuth or rapid scan.

2.2.2 Lightning Ground Strike Location [MacGorman]

A. Objectives

1. Provide ground strike locations in real time for storms within 300 km range.

2. Examine the evolution of ground strike characteristics during lifecycle of storms.

3. Measure influence of storm parameters on cloud-to-ground flashing rates, strokes per flash, ground strike point density, polarity, location and amplitude.

4. Tabulate ground strike characteristics continuously for lightning climatology.

5. Examine correspondence between ground strike location and other lightning parameters.

B. Requirements

1. WSR-57 radar data collected to a range of 300 km during regular operations, minimum data requirement one zero elevation scan every 10 minutes.

2. WSR-57 digital data to a range of 300 km needed for at least one selected storm day.

3. Single or dual Doppler data during regular operations (Long-Range-Doppler or Dual-Mapping-A mode).

4. Dual VHF mapping, field charge, and L-Band lightning echoes.

5. Possible need for WSR-57 data beyond spring operational period.

2.2.3. Storm Electricity Experiments from Mobile Laboratory [Arnold, Rust] (Joint program with University of Mississippi, Dr. Roy Arnold)

A. Objectives

1. Provide spatial and temporal documentation of lightning in severe storms.

2. Document electrical phenomena associated with tornadic storms.

3. Record optical waveforms of lightning and ground-truth data for U2 overflights.

4. Provide a second station for electrical documentation of selected storms in dual VHF mapping area.

B. Requirements

1. Daily forecast, weather briefing, nowcasting and operational coordination with other experiments.

2. WSR-57 data for storms near mobile unit.

3. Single or dual Doppler data for selected storms (Long-Range-Doppler or Dual-Mapping-A mode).

4. Radio communications between mobile unit, SEB, nowcaster, and telephone in forecast room dedicated to mobile operations.

2.2.4. L-Band (23-cm) Radar Echoes from Lightning [Mazur, Taylor] (Cooperative program with University of Oklahoma, Vladislav Mazur)

A. Objectives:

1. Determine characteristics of radar echoes from lightning.

2. Associate lightning radar echoes with electric field charges and with location and progression of discharges determined with VHF mapping system.

3. Locate lightning radar echo region in severe storms and relative to mesocyclones and tornadoes.

4. Examine circular versus linear polarization for obtaining lightning echo data.

B. Requirements

1. WSR-57 operation at zero elevation in surveillance mode to a range of 200 km.

2. Single or dual Doppler data in sector scanning mode (Long-Range-Doppler or Dual-Mapping-A mode).

3. Dual VHF mapping, field change, lightning ground strike location and mobile platform data.

2.2.5. Corona Beneath Severe Storms [Church, Rust] (Cooperative program with Miami University, Oxford, Ohio, Dr. Chris Church)

A. Objectives

1. Measure corona current over large area beneath severe and tornadic storms.

2. Determine contribution large storms make to the earth/electrosphere current system.

B. Requirements

1. Operation of SAM sites equipped with corona probes.

2. Access to SAM site raw data.

3. Corona, E field, and precipitation current recorded at SEB.

4. WSR-57 film data for storms over the SAM site network during regular operation.

5. Lightning ground strike location.

2.2.6. S-Band (10-cm) Radar Echoes from CG Lightning Channel [Rust, Taylor]

A. Objective

1. Measure lightning channel radar characteristics, radar cross section and decay time.

2. Investigate Doppler properties of lightning echoes.

B. Requirements

1. Norman Doppler (Radar-Echoes-from-Lightning-over-Tower mode) beam fixed at azimuth to center of Brookhaven water tower at an elevation to give low ground clutter from sidelobe pickup.

2. SEB recording of raw log video and 1 component of complex video (I or Q) on analog tape.

3. Dual VHF mapping.

4. Field change data.

5. Video and photographic recording of lightning.

2.2.7. Drop Levitation and Doppler Properties of Lightning Echoes [Zrnic', Taylor]

A. Objectives

1. Determine effects of lightning discharges on motion, coalescence and growth of hydrometeors.

2. Measure characteristics of Doppler spectrum of lightning, i.e., cross section per unit volume, spectrum width, and duration of signature.

B. Requirements

1. Norman 10-cm Doppler radar antenna pointing vertical to collect time series data (Drop-Levitation mode).

2. Cimarron Doppler radar scans of storm volume over Norman (Dual-Mapping mode).

3. Dual VHF mapping with Norman looking vertical and Cimarron looking over Norman.

4. Field change data.

2.2.8 U-2 Lightning Study [Vonnegut, Orville, Vaughn, Rust]
(Cooperative program with State University of New York at Albany, Dr. Bernard Vonnegut and Dr. Richard Orville; New Mexico Institute of Mining and Technology, Dr. Marx Brook; and NASA-Huntsville, Mr. O.H. Vaughn)

A. Objective

1. Provide ground truth of lightning characteristics (optical waveform, IC/CG identification, location of lightning channels, number of strokes) and compare these parameters with airborne measurements to help develop satellite sensor for lightning detection.

B. Requirements

1. Regular forecast and accurate next-day forecast for preparation of U-2 flight.

2. Communication with U-2 for control of flight track and to provide real-time storm information.

3. Single Doppler or WSR-57 data for storms under flight path within 300 km of Norman.

4. Storm electricity operations including optical waveforms, field change, video and photographic lightning channel data, VHF mapping, ground strike location, and mobile platform.

[Another possible experiment involves the Orbiter, OSTA-1 mission which has the same objectives and requirements listed above if the flight occurs during the Spring Program.]

2.2.9 Turbulence and NASA Aircraft [Lee]

A. Objectives

1. Acquire direct strikes of lightning to the F106 aircraft at typical jet aircraft operating altitudes for characterization by the Langley Research Center (LaRC) Direct Strike Lightning Measurement System.

2. Provide wind and turbulence measurements inside severe convective storms for correlation with NSSL ground-based Doppler weather radar measurements of mean wind and spectrum width.

3. Provide data for the other F106 Lightning experiments.

   . AF Geophysics Lab Field Mills
   . Boeing Data Logger
   . LaRC Atmospheric Chemistry Experiment
   . U Wash X-Ray Experiment
   . NSSL Lightning Optical Signature
   . LaRC Composite Fin Cap

4. Provide "truth" measurements of wind and turbulence for the the NSSL/FAA flight evaluation of commercial Doppler weather radars carried on board an FAA DC-9 aircraft. Two or three of these radars will be tested by the FAA in VFR conditions at ranges of up to 200 km for a total of 10 hours each.

B. Requirements (1 April - 30 April)

1. Aircraft control and WSR-57 for tracking.

2. Norman or Cimarron Doppler (Long-Range Doppler, Dual Mapping-A or Dual-Mapping-Turbulence-C mode).

3. Daily forecast and briefings.

4. Storm electricity observations including field change, VHF mapping, ground strike location, and L-band radar to vector aircraft into lightning area and for lightning characteristics.

2.2.10 Airborne Doppler [Lee]

A. Objective

1. Compare new generation airborne Doppler weather radars with NSSL ground-based Doppler radar for FAA DC-9 aircraft using Bendix and Collins Doppler radars.

B. Requirements (FAA, 1 April - 15 June; NASA, 1-30 April)

1. Daily forecast and briefings.

2. Norman or Cimarron Doppler radar (Long-Range-Doppler or Dual-Mapping-A mode) coordinated with aircraft radar for simultaneous coverage of the same storm cells.

3. NASA F-106 aircraft with turbulence measurement equipment.

4. Aircraft control and WSR-57 for tracking.

2.2.11 Prestorm and Areas of Deep Convection [Doviak]

A. Objectives

To measure the structure of wind and reflectivity in clear air or in Areas of Deeper Convection (ADC) prior to storms and to determine if the onset and intensity of the precipitation can be predicted using observations with Doppler radar. This includes the following:

1. Identification of frontal boundaries, divergence, and deformation in real time giving the radar meteorologists and nowcaster current status on the changing environment as well as a cursory comparison between satellite photographs, and other field observations.

2. Mesoscale wind mapping using both single and dual Doppler analysis.

3. Observations of ADC's and their possible evolution into convective precipitation. Relate their structure and movement to the wind fields.

B. Requirements

1. Daily forecast and weather briefings.

2. Norman and Cimarron Doppler radars (Prestorm mode) must be available for data acquisition at least 2-3 hours prior to anticipated convection.

3. Rawinsonde releases upon discretion of meteorological coordinator.

4. KTVY tower data (normal operation).

5. Surface network (normal operation).

6. Recordings of lightning events (to aid determination of time of thunderstorm initiation).

7. Cloud photography from NSSL roof before and during initiation of convection. Pointing of camera will be directed by the meteorological coordinator.

8. Tornado intercept project and storm-electricity mobile platform data on cloud development $\lesssim$ 130 km.

2.2.12 Storm Evolution [Burgess]

A. Objectives

1. Understand the complete four-dimensional evolution of thunderstorms. Note that a partial data set during any phase of evolution is valuable. Those storms which evolve into supercell status are the most sought after because of their higher frequency of tornado production.

2. Delineate the storm-produced mechanisms and organization which culminates in tornado occurrence.

3. Specify the distribution and characteristics of hail and strong winds.

4. Relate supercell radar parameters to storm electricity production.

B. Requirements

1. Forecasts and briefings, meteorological coordinator on duty and meteorologist at CIM Doppler.

2. Dual Doppler operation (Dual-Mapping-A mode) on storms within dual-Doppler area, reflectivity scope photographed to 115 km range.

3. WSR-57 radar surveillance with 10-minute tilt sequences to storm top recorded on 35 mm film.

4. Storm electricity sensors including VHF mapping, field change, ground strike location, and L-band radar.

5. Coordinated storm photography and visual verification of severe phenomena by Tornado Intercept Project.

6. Surface network data.

7. Rawinsonde data on several sides of storm, releases upon request.

8. Damage surveys.

2.2.13 Gust Front Experiment [Lee]

A. Objectives

1. Determine downdraft location, size, and intensity.

2. Measure depth of outflow.

3. Identify indicators for predicting intensification and dissipation.

4. Estimate turbulence associated with gust fronts.

B. Requirements

1. Dual Doppler radar operation (Dual-Mapping-Gust-Front-B mode)

2. Surface network data.

3. Rawinsonde releases just after gust front passage and after storm.

2.2.14 Tornado Intercept Project [Davies-Jones]

A. Objectives

1. Obtain close-in time lapse movies of rotating wall clouds.

2. Obtain close range movies of tornadic debris clouds.

3. Report in real time to NSSL the location of any tornadoes occurring within high PRF Doppler range.

4. Provide the storm electricity van with supplementary photography and visual observations.

5. Verbally and photographically document severe weather events and storm structure for the Storm Evolution experiment.

6. Acquire unique data on tornadoes using special sensors such as "Vonnegut" cameras and sound packages.

7. Learn more about the different classes of tornadic storms and the differing locations of tornadoes within these storms.

8. Support any special Tornado Projects such as TOTO (a portable, meteorological, instrument package built by the Wave Propagation Laboratory for positioning in front of advancing wall clouds and tornadoes).

9. Take time-lapse movies of cumulus congestus in the prestorm environment.

B. Requirements

1. Forecaster, Nowcaster/Storm-Intercept Coordinator required before and during storms and Meteorologist Coordinator on duty.

2. WSR-57 operation, polaroid photographs of scope at 0° elevation each 10 minutes when situation warrants, tilt sequence for close range storms, scope on long range when target storms are over 200 km range.

3. Limited number of special rawinsondings to aid Nowcaster.

4. FM radio system operational.

2.2.15 High PRF Experiment [Zrnic']

A. Objectives

1. Measure maximum rotational speeds in a tornado.

2. Deduce tornado parameters from Doppler spectra.

B. Requirements

1. Doppler radar data (High-PRF mode)

2. WSR-57 surveillance.

3. Photographs and movies of tornado and damage survey.

4. Meteorological Coordinator.

2.2.16 Lifetime of Thunderstorm Features [Zrnic']

A. Objectives

1. Determine lifetimes of significant storm features.

2. Establish scanning strategy for weather radars near airports.

B. Requirements

1. Single Doppler radar (Lifetime-of-Features mode) for rapid sector scans at four levels of a storm within 120 km range.

2.2.17 X-Band and S-Band for Dual Wavelength [Ray]

A. Objectives

1. Obtain S-band time series and PPP and X-band time series data when storms pass overhead.

2. Study relationships between microphysics, dynamics, and storm electricity parameters.

B. Requirements

1. Norman Doppler operation (Drop-Levitation mode)

2. X-band radar operation.

3. Dual antenna site used for above.

4. Time series gates for X-band and S-band colocated.

2.2.18 Dual Polarization [Doviak]

A. Objectives

1. Demonstrate that the difference in reflectivity between orthogonally polarized WSR-57 and Doppler radars might be related to shape of the hydrometeors in a thunderstorm.

2. Demonstrate that these data can be used to improve the resolution of rainfall rate when used in combination with radar and sparse rain gage network and to relate rate to the kinematics of the storm.

B. Requirements

1. Dual Doppler scanning with storm over rain gage network of the Agricultural Research Station (Dual-Polarization mode).

2. WSR-57 normal scan rates of elevation increments of 2° starting at 1° and synchronized with Norman Doppler.

3. Digital WSR-57 data with time constant of 0.094 s, range averaging interval 1 km and record every 2° azimuth.

4. NRO and CIM Dopplers coordinated for the same height increments through storm.

5. Radar calibration via sun flux after experiment.

6. Rain gage data.

2.2.19 CV990 Experiment [Doviak]

A. Objectives

1. Combine airborne Doppler lidar observations with observations of clear air and thunderstorms made with NSSL's dual 10-cm Doppler radars, instrumented tower, surface network, and rawinsonde data.

2. Advance knowledge of severe storm phenomena and its forecast through analysis of data from the following experiments.

   a. High resolution intercomparison of wind components.

   b. Boundary layer (mean flow, turbulence, and waves), including structure, lifetime of turbulence, nocturnal jet, and heat island.

   c. Prestorm experiment including frontal zones, cloud lines, dryline, and front intersection.

   d. Cumulonimbus experiment including lateral entrainment, cloud top turrets, anvil cloud, gust front, and flanking line.

B. Requirements (last week of June and first part of July)

1. Forecast and weather briefings.

2. Dual Doppler (Prestorm, Dual-Mapping-A, Long-Range-Doppler, or Turbulence mode), special coordination with aircraft.

3. Tower operation.

4. Surface network operation.

5. Rawinsonde data.

6. Aircraft control and WSR-57 for tracking.

2.2.20 Limited Hail Intercept [Nelson, Pflaum]
(Cooperative program with University of Oklahoma, J. Pflaum)

A. Objectives

1. Collect hail from storms within dual Doppler area.

2. Gain experience in collection and coordination procedures.

B. Requirements

1. Daily forecast.

2. Nowcaster/Storm Intercept Coordinator.

3. WSR-57, normal mode, film data every 5 minutes.

4. Dual Doppler sector scans on storm of interest.

5. Hail chase vehicle with FM radio system.

6. Dry ice and chests for hail samples.

2.3 Doppler Radar Setup

2.3.1 Prestorm:

1. Long pulse; τ=5 μs, Record PP only
2. High Gain/AGC off
3. Number of PP samples = 64
4. DI Pos. 3
5. Time series off
6. Free run mode
7. Antenna rotation 6° s^{-1}
8. NRO scan: Start at 180° cw, Ele= 0.4°, 0.8°, 1.2°, 0.4°, 0.8°, 1.2°, 2°, 3° to 10° [CIM scan: Start at 270° ccw, Ele= 0.4°, 0.8°, 1.2°, 0.4°, 0.8°, 1.2°]
9. Repeat every 30 min/syncronize starts

2.3.2 Dual Mapping: A-Basic

1. Interlaced sampling, PRT = 768 μs, Record PP only
2. Low Gain/AGC On
3. Number of PP samples. 32
4. DI Pos 0
5. Time series off
6. Free run mode
7. Antenna rotation 8° s^{-1}
8. AZ sector 70° or more
9. EL = 0.4°, 0.8°, 1.2° then ΔEL = $60/r_c$ (r_c range to storm in km) Δ EL not to exceed 6°.

If storm is over a radar site, then use 360° cw or ccw antenna rotation 12°/s, ΔEL = 6°.

2.3.3 Dual Mapping: B-Gust Front

1. Uniform PRT Record PP and time series
2. High gain/AGC off
3. Number of PP samples 64

4. DI Pos. 3

5. Time series on Ns = 64, spacing 4 μs, 0 steps

6. Initial delay NRO (100 or 110 μs)
   [CIM (106 or 300 μs)]

7. Record on time 0.2s

8. Antenna rotation 8° s^{-1}

9. AZ sector 70° or more

10. EL = 0.4°, 0.8°, 1.2° then switch to Dual Mapping A until the top is reached.

2.3.4 Dual Mapping: C-Turbulence

1. Uniform PRT = 768 μs Record PP and time series

2. Low gain/AGC on

3. Number of samples PP 64

4. DI Pos. 3

5. Time series on Ns = 64, spacing = 8 μs, 0 steps

6. Initial delay determined during operation

7. Record on time 0.2 s

8. Antenna rotation 8° s^{-1}

9. AZ sector 70° or more

10. EL-only 3 consecutive determined in real time then switch to Dual Mapping A.

2.3.5 High PRF

Fixed

1. PRF = High (B channel)

2. Time series = ON INT off

3. AGC off

4. Auto step = ON

5. No. of steps = 2

6. Gate spacing 2 μs

7. No. T/S samples = 128 = No. PPP samples

8. Time constant = 4

9. Rotation rate = 0.83 s^{-1}

10. Time increment = 0.3 s

11. Elev 0.5°, 0.5°, 1.0°, 1.5°/repeat

To Be Specified

1. Trip (1st = 0, 2nd = 1)

2. Initial range delay (μs)

3. Azimuth limits

4. Sector width = 20° for 1st trip (0-43 km)
   = 10° for 2nd trip (43-86 km)

2.3.6 Turbulence

1. Uniform PRT = 768 μs Record PP and time series

2. Low gain/AGC on

3. Number of samples 64

4. DI Pos. 3

5. Time series on Ns = 64, spacing = 2 μs, 0 steps

6. Initial delay set during operation, will be decremented or incremented in steps of 20 μs

7. Record on time 0.2s

8. EL and AZ in manual, possible changes will be communicated.

2.3.7 Lifetime of features

1. Uniform PRT = 768 μs, Record PP only

2. Low Gain/AGC on

3. Number of samples 64

4. DI Pos 3

5. Time series off

6. Record on az 0.8°

7. Antenna rotation 8° s^{-1}

8. EL1= 0.4° and three more determined in real time ($EL2=170/r_c$, $EL3=370/r_c$ $EL4 =510/r_c$

9. AZ sector set in real time.

2.3.8 Long Range Mode:

1. Short pulse, interlaced sampling, record PP only.

2. Low gain/AGC on

3. Number of PP samples 64

4. DI Pos. 0

5. Time series off

6. Free run mode

7. Antenna rotation 6° s^{-1}

8. AZ sector and/or PPI

9. EL = 0.4°, 0.8°, 1.2° then in steps of .8° for range between 60-120 km, beyond 120 km ΔEL = 5°.

2.3.9 Radar Echoes from Lightning over Tower

1. AZ = 263.9°

2. EL = 3° (max. minimize clutter!)

3. Antenna stationary (servo drive off)

4. Reduce transmitter power 30 dB

5. Time series and PP data

6. Gate spacing 1 μs, range delay 16 μs, 0 step
Number of samples 4096, Record 0.1 s

7. Low gain AGC/on

8. DI Pos. 3

9. Coordinate with SEB for analogue tape recording of log video, and either I or Q with time mark superposed.

10. Immediately after experiment and before changing elevation, scan back and forth 10° on either side of tower and record time series and PP data with 64 samples.

2.3.10 Drop Levitation

1. Uniform PRT=768 μs, Record time series and PP
2. Low gain/AGC on
3. Number of samples 4096
4. DI Pos.4
5. Time series on Ns = 4096 spacing 4 μs, 0 steps
6. Initial delay 6 μs
7. Use vertical shrouded antenna.
   Cimarron to scan over Norman, using dual mapping A values with AZ scan of 100° - 160°.

2.3.11 Dual Polarization

1. Interlaced sampling, PRT = 768 μs, Record PP only
2. Low Gain/AGC On
3. Number of PP samples 32
4. DI Pos. 0
5. Time series off
6. Free run mode
7. Antenna rotation 8° s^{-1}
8. AZ sector 55°
9. El = 0.4° and then in steps of 0.7°; synchronize scans with WSR-57

3. INSTRUMENTATION

This is a brief description of equipment used during the 1981 Spring Program. Where appropriate, we have included what parameters were observed, the accuracies, rates, frequencies, heights, limitations, etc. involved with each sensing device, and the type of data recording used. No detailed specifications are included here. For further information please refer to the 1980 Spring Program summary or contact the cognizant person at NSSL.

3.1 Doppler Radars

NSSL operates and maintains two 10-cm Meteorological Doppler Systems, one (NRO) located at NSSL and the second (CIM) at Page Field, 41 km to the northwest. The NRO and CIM radars are nearly a matched pair, with each radar recording either or both of the three moments (power, mean velocity, and spectrum width) of the Doppler spectrum at all ranges and the time series samples of the Inphase (I) and Quadrature phase (Q) video signals sampled simultaneously at 16 range locations. In the normal mode the systems have a choice of four pulse repetition times (PRT's) and several options in transmitting pulses: (a) a uniform train for Doppler spectral analysis, (b) an interlaced PRT (dual sampling mode) for automated range de-aliasing of multiple trip targets and monitoring of range overlaid echoes, (c) long transmitted pulse with (3-5 μs) for maximum sensitivity to detect clear air echoes, and (d) a high pulse repetition frequency (PRF) mode (NRO only) for measuring tornadic wind speeds. Data is recorded on magnetic tape.

3.2 WSR-57

The third 10-cm radar is an incoherent surveillance radar (WSR-57) located at NSSL. This radar has an angular resolution of about 2° and a range resolution of 1 km (for most experiments). It provides reflectivity estimates and scans at a rate of 18° s^{-1} in azimuth and automatically steps in elevation at increments selected by the WSR-57 operator. This radar is usually operated hands off in a preset surveillance mode. Data is recorded on 35-mm film (of CRT monitor), intermittent Polaroid of console CRT, and occasionally digital magnetic tape.

3.3 VHF Lightning Mapping System

A wide-band VHF system, employing time-difference-of-arrival techniques, provides azimuth and elevation angles to individual sources of electromagnetic impulses from lightning discharges. Acceptable elevation angles are limited to 45° above the horizon; azimuth angles are limited to a 60° sector, selectable in 30° increments. Angles are determined to 0.5° accuracy for lightning occurring within a nominal 60 km range. Maximum instantaneous rate of reception is 16,000 per second. Data are recorded on 9-track magnetic tape with time synchronized to WWV. A real-time azimuth-elevation display is available to assist in detecting and tracking thunderstorms. Simultaneous observations are made at NSSL in Norman (NOR) and at Page Field (CIM), being co-located with the NSSL Doppler radars. The equipment at NOR can be switched into an overhead viewing mode to observe lightning activity within a cone extending down to approximately 30° above the horizon.

3.4 Storm Electricity Building (SEB)

The SEB serves as a central location for acquisition of storm electricity data and coordination with other areas of experimental data collection. Instrumentation located at and in the area near the SEB is used to measure various electrical phenomena such as electric field changes associated with lightning; optical transients from lightning; and visual, photographic and video documentation of lightning and storms. Data are recorded on analog magnetic tape and strip chart with time code synchronized to WWV. The electric field, precipitation current density, and corona current are recorded on digital tape cassette at the SAM site near the SEB.

3.5 Lightning Strike Locator

The cloud-to-ground (CG) lightning location system provides the time, location, peak field strength and number of component strokes for each CG flash that lowers negative charge within about 400 km of Norman. The system consists of four remote direction finders (DF's) which independently determine the azimuth angle to the lower portions of CG channels. Direction finders are located at Norman (DF1), Ft. Sill (DF2), Cordell (DF3), and Watonga (DF4). We tested a modification on DF1 and DF2 for locating CG flashes that lower positive charge, as well as the more frequent flashes that lower negative charge. Azimuth, number of strokes, and electric field strength of a lightning flash are transmitted back to a central processing unit in Norman by leased telephone lines. The central processing unit or position analyzer computes the intersection point of the azimuth angles and outputs data to digital magnetic tape, hard-copy printer, and plotter in real time. These devices are located in the storm electricity building.

3.6 L-Band Radar

A 23-cm radar is located at the SEB for acquisition of radar echoes from lightning. The lightning echoes are recorded on the same magnetic tape as the electricity phenomena and on a separate video cassette recorder. Because of its long-range capability for observing lightning (250 km), this radar is also used to acquire data on storms being studied with the Mobile Electric Laboratory with aircraft penetrating thunderstorms.

3.7 Stationary Automated Mesonetwork (SAM)

Fourteen meteorologically instrumented stations were used during the Spring Program and these were located close to NSSL so that they could be routinely serviced without additional manpower cost. Each site provided wind speed and direction, wet and dry bulb temperatures, pressure, rainfall, and corona current. Sixty one-second samples were averaged, and these were recorded on magnetic cassette tapes. In addition, wind data was recorded at six Low Level Wind Shear Alert System (LLWSAS) stations maintained by the FAA for detecting wind shift lines along the approach paths of aircraft flying into Will Rogers World Airport.

3.8 Rawinsondes

The 1981 mesometeorological rawinsonde network was established at three locations in central Oklahoma. GMD-1 rawinsonde equipment was used to obtain soundings with a VIZ Manufacturing Company (ACCU-LOK) instrument. These instruments were factory calibrated (pre-baselined). Personnel from the U.S. Air Force Sixth Weather Squadron (Mobile) located at Tinker AFB in Oklahoma City manned and operated two sites, one at Edmond, Oklahoma, and the other 5 miles south of Tuttle, Oklahoma. After 22 June, the Edmond and Tuttle sites were closed and only a single site at Tinker AFB was operated. The U.S. Army Field Artillery Board operated one site at the west range on Ft. Sill, north of Cache, Oklahoma.

Specialized data acquisition and processing procedures were used to bring data to the laboratory in near-real time. Each site was equipped with standard commercial telephone and a standard ASR-33 teletypewriter with paper tape punch and acoustic coupler. At Tinker AFB, a Model 3610 computer system was used for processing the raw rawinsonde data. At NSSL an HP 9825A received the output data from the Model 3610 CPU and plotted the data in graphic form on a standard skew T, log p diagram.

3.9 Meteorological Tower (KTVY)

The 461-m KTVY television antenna tower has been used as a multi-level boundary layer sensor facility since 1966. Currently, it is instrumented at seven levels -- 7, 26, 45, 89, 177, 266, and 444m. Thirty-five channels of weather data are routinely recorded on 7-track magnetic tape, partitioned into 7 horizontal wind speed, 7 wind direction, 6 vertical wind speed, 7 dry bulb temperatures, 4 wet bulb temperatures, 2 digital pressures, 1 rain gage, and 1 pryometer (sundial). An approximate one-second sample interval is used during storm periods and generally a 10-second sample interval is used during non-storm conditions.

3.10 Mobile Intercept Vehicles

3.10.1 Tornado Intercept Project

The Tornado Intercept Project (TIP) operated only one chase van (NSSL 1) during the 1981 Spring Program. Emphasis was placed on obtaining verbal and photographic documentation of thunderstorm features (especially tornadoes). Thus, the equipment carried into the field included three 16-mm movie cameras, two 35-mm slide cameras, tripods, lenses, various other photographic accessories and supplies, portable tape recorders for verbal commentaries, and maps. A "Vonnegut" camera (Vonnegut and Passarelli, 1978) was also taken along to detect luminosity (of electrical origin) in tornado funnels. The van was equipped with FM radio and a radio telephone. FM communications with the Nowcaster at NSSL were routed through a repeater located at the 440 m level on a KTVY television tower 40 km north of NSSL. Beyond the FM system's range (roughly 115 km from the repeater), the radio telephone was used whenever an open channel was available; otherwise, the Nowcaster was contacted by public telephone. Direct, short range, inter-vehicle communications, provided by a second FM radio channel, enabled the crew to exchange information with other field teams.

NSSL provided partial support to Dr. Bluestein and his Oklahoma University intercept team for the deployment of TOTO.

3.10.2 Storm Electricity Experiments

In a joint program with Dr. Roy Arnold of the University of Mississippi, a van has been equipped to function as a Mobile Electricity Laboratory. Most of the instrumentation at the SEB is duplicated in the mobile lab. This provides the opportunity of making quantitative electrical measurements and video recordings of the storm in a position that is relatively fixed within the severe storm; in particular in the inflow region beneath the precipitation-free cloud base.

Data are recorded on analog magnetic tape, strip chart, and video tape. Additional documentation is provided with 35-mm and 16-mm film.

3.10.3 Hail Intercept

The hail intercept project for 1981 was very limited in scope and, therefore, little equipment was required. An FM radio was used for communication with the Nowcaster and other intercept teams. The main activities included documentation of hail events and notation of problems associated with the hail intercept process.

3.11 Aircraft

3.11.1 Turbulence and NASA Aircraft: F-106

The NASA F-106 used during the 1981 severe storm cooperative program of NASA, FAA, and NSSL was instrumented essentially as in the 1980 Spring Program. Some modifications were made, and these included: 1) placement of vertical accelerometer nearer to the aircraft's center-of-gravity; 2) installation of active noise filtering circuits in analog data section before digital recording on board the aircraft; 3) addition of two movie cameras to record lightning strikes (One camera located in front of the pilot's windscreen is used to record lightning strikes to the nose and nose boom; the other located midway on the aircraft's fuselage is directed rearward to cover the tail and the trailing edge of the wing.); 4) installation of video camera to record the airborne radar and stormscope displays; 5) installation of three field mills for measurements of vertical and lateral electric fields; and 6) adding of additional sensors to the electric flux density measurement system.

3.11.2 Airborne Doppler (D-9)

This experiment was done jointly with the FAA at the request of the Air Transportation Association. Airborne Doppler systems were to be flown aboard an FAA DC-9 twin-engine jet airliner during the spring season. The data on board the aircraft was to be video-taped and compared with Doppler radar data obtained by the NSSL radars. Due to delays in aircraft availability, only the ground-based testing was completed. On 15 June, Bendix Avionics installed on the ground an X-band Doppler radar designed for use in aircraft. Concurrent data from the Norman Doppler and Bendix systems were obtained on 18 and 19 June before the Bendix system was removed. Collins installed both C-band and an X-band Doppler radar for ground testing on 19 June. Thunderstorm data were obtained on 26 and 30 June before the equipment was returned on 3 July.

3.11.3 Lightning Study: U-2

The NASA U-2 is a single-engined jet aircraft designed for high altitude (above 60,000 ft MSL) flights. Cruising speed is around a true airspeed of 150 m s^{-1}. Besides the normal navigational and aircraft instrument recordings, systems to measure electric field changes, optical transients, and spectra of lightning were installed. Due to operational schedules and problems no data were obtained with the U-2 during this program.

3.11.4 CV990 Experiment

The CV990 is a 4-engine jet transport instrumented to measure several parameters of meteorological interest. In addition to the standard measurements of temperature and humidity, the aircraft's INS and air speed instrumentation give in situ real time data on wind relative to the ground. The most novel observing instrument is the CO_2 Doppler lidar. The experiments performed in Oklahoma were the first in which dual Doppler radar data were collected simultaneously with Doppler lidar data. The Doppler lidar system used in the Oklahoma tests is a pulsed CO_2 system operating at a wavelength of 10.6 μm. The measurement of atmospheric winds with this system is accomplished by detection of radiation scattered by naturally available aerosols within the atmosphere. As a consequence, the performance of this system is determined largely by the presence or absence of aerosols in the desired measurement region.

4. OPERATIONAL PROCEDURES

4.1 Operational Scenario

Because of the austere budget and limited human resources under which NSSL must function, every effort was made to minimize our expenditures while pursuing our mission through observations of severe storms in Oklahoma during the spring thunderstorm season. The core operational period extended from 1 April through 30 June, with plans to hold back the beginning of operations until a good thunderstorm system ushered in the season and to terminate the operations in June when the weather systems begin to switch into summer conditions. Weekly work schedules were designed to observe all storm systems regardless of time of day or day of week while holding the excess workload and overtime to a minimum.

Let us assume an "average" day in which at the beginning of the work day (7:00 a.m. Central Standard Time), there were no thunderstorms within 250 km of NSSL and small likelihood of a storm within 100 km before 10:00 a.m. A meeting would be held at 8:30 a.m. between the Program Coordinator, Forecaster, Equipment Status representative, and the Coordinators for Meteorological Data, Doppler Radar, Storm Electricity, Aircraft, and Mobile Observations. The prime purpose of the meeting was to decide on a preliminary operational plan for the day which would be updated and presented at the morning weather briefing (10:30 a.m.). If thunderstorm activity was already occurring within 100 km of NSSL with strong likelihood of storms moving closer, the Program Coordinator would call an emergency meeting to decide an immediate course of action.

At the morning weather briefing, conducted seven days a week, the weather situation was summarized, a forecast indicating location, movement, and time of formation of severe and nonsevere storms was given, and an outlook for the next day was presented. The Program Coordinator then discussed the general operational plans for the day for all participants in the Spring Program. These plans were sufficiently flexible to allow for modifications as weather conditions developed. If conditions were favorable for storms, the observational period and mode of operation was indicated for the Doppler radars, WSR-57, Storm Electricity, mobile observations and other efforts.

After operations began and a storm was selected, all sensors were brought to focus on it. A cognizant observer was on duty to interpret Doppler observations. The Program Coordinator was responsible for keeping observations optimized with changing storm conditions. The selection of experiments and the mode of operation of the sensors depended upon the type of storms expected and the priorities assigned to the various experiments. The main focus of the Program was on activities of the Doppler Radar and Storm Electricity Research Group with special emphasis given to Storm Electricity. Experiments by other groups were accommodated, however, as changing storm conditions warranted assignment of new priorities. The observational objective was that all sensors collect temporally and spatially dense data throughout the period a storm was within nominal range.

Quality control of all sensors was an important item in our observations. Also, standby electric power for the Norman Doppler and Storm Electricity facilities was activated when there was high probability that storms would be in the Norman area. This afforded not only continuation of observations during power failure but increased safety of the personnel through uninterrupted tracking of weather hazards. Safety of Mobile Intercept personnel was an important consideration, especially after dark, and was furnished in part by continued radar surveillance until the teams had returned or were free of hazardous conditions.

If tornadic activity occurred within the nominal range of our sensors, damage survey teams were organized to survey the storm's path.

A debriefing was called at 10:00 a.m., prior to the scheduled weather briefing; each morning there were operations on the preceding day. This included all Principal Investigators, Coordinators, and cognizant observers. Debriefing reports included 1) storm occurrence, location and time, 2) Doppler and WSR-57 coverage, 3) storm electricity participation, 4) mobile intercept operations, 5) aircraft operations, and 6) the experiments conducted along with the level of success, quality of data, expected results, and problems encountered.

Usually operations did not begin until the afternoon. If observations were made past midnight, no operations were planned until afternoon of the following day. Saturday and Sunday were non-work days unless the forecast on Friday indicated strong probability of storms for the weekend. After the Program Coordinator decided not to plan operations for a specific day, that was designated as a "no-work" day and personnel were released from operational duty. If weather conditions changed, the type of operations made and the number of experiments conducted were dependent on who was able and willing to report to their assignment.

Personnel were kept informed of weather conditions and planned operations by recorded telephone messages. These messages were updated at about 11:00 a.m. after the weather briefing at 10:30 a.m. If no definite decision for operations had been made by that time, the message indicated the call-in time for an updated message. Notification of planned operations was accomplished by calling each individual via public telephone. Key personnel were also issued pagers to be used if individuals could not be reached by telephone.

Beginning 28 May, in an effort to reduce expenses, several actions were taken. Weather briefings were presented at 10:30 a.m. only on days of high probability for severe storms in the nominal dual mapping area. Operations were restricted to begin after 1:00 p.m. and prior to 9:00 p.m. Mobile intercept teams were restricted to 200 km range from Norman. A 4800 baud data line and 6 telephones were deactivated. Communication pagers were turned in. One rental vehicle was returned.

Additional restrictions were put into effect June 10. Weather briefing time was moved to 12:30 p.m. Rawinsonde operations were terminated at Edmond, Tuttle and Ft. Sill. The mesonetwork (SAM) was shut down for all but the five sites nearest to Norman.

Routine operations in support of the Spring Program terminated on 22 June. Operations in support of the Airborne Doppler and CV990 experiments continued as planned. These included forecasting, NRO and CIM Dopplers, WSR-57, KTVY Tower, the Tinker AFB rawinsonde site, and the remaining SAM sites.

4.2 Personnel Assignments (Alternates)

Assignments of NSSL personnel for the 1981 Spring Program are presented here with alternates shown in parentheses.

1. Program Coordinator: Taylor (Doviak, Rust)
2. Briefing Team: Taylor (Doviak), Rust, Burgess (Rabin), Lee, Sirmans (Carter), Zrnic'
3. Forecaster: Lee, Burgess (Hane, Rabin)
4. Nowcaster/Mobile Lab. Coordinator: McGinley (Ziegler, Kelleher)
5. Equipment Status: Sirmans (Carter)
6. Meteorological Data Coordinator: Burgess (Brandes, Rabin)
7. Doppler Radar Coordinator: Zrnic' (Brown, Brandes)
8. Storm Electricity Coordinator: Rust (MacNiven)
9. Meteorological Scribe: Rabin (Vasiloff, Istok)
10. S.E.B. Coordinator: MacNiven (Cameron, Cunningham)
11. Aircraft Coordinator: Lee (Wilk)
12. Norman Doppler Radar Operators: Anderson, McGowen (Sirmans)
13. Cimarron Doppler Radar Operators: Schmidt (Carter), Kelly, Clark (Istok)
14. Norman VHF Mapping Operator: MacGorman (Jain)
15. Cimarron VHF Mapping Operator: Mach (Jain, Kelly)
16. L-Band Radar Operator: Mazur (Cameron)
17. S.E.B. Operators: MacNiven, Cunningham, Cameron, Fisher
18. Ground Stroke (CG) Locations: MacGorman (Cunningham)
19. WSR-57 and IFF: Jennings (Kelly)
20. WSR-57 Operator: Nelson (Young, Zittel, K. Johnson, Kelleher)
21. Doppler Real-Time Display Operator: Hennington (Zahrai)
22. Mobile Meteorological Obs.: Davies-Jones, Lucas, Anderson, Burre (Kessinger, B. Johnson, K. Johnson, Ziegler, Vasiloff)

23. Mobile Electricity Obs: Arnold (Rust)

24. Mobile Hail Intercept: Nelson, Pflaum

25. Rawinsonde Control: Showell (Helm)

26. Quality Control: Dooley, Sirmans, Carter, Clark
    Doppler operation: Sirmans
        NRO Anderson
        CIM Schmidt
    Doppler meteorology: Brandes
    WSR-57 operation: Nelson
    SAM sites: Fredrickson
    Tower: Johnson
    Rawinsonde: Smith (Helm)
    VHF mapping: Taylor
    SEB electric: Rust
    Ground strike location: MacGorman
    L-band radar: Mazur

27. Photography: Goldsmith (Clark)

28. Stationary Automated Mesonet: Wardius (Reece, Fredrickson)

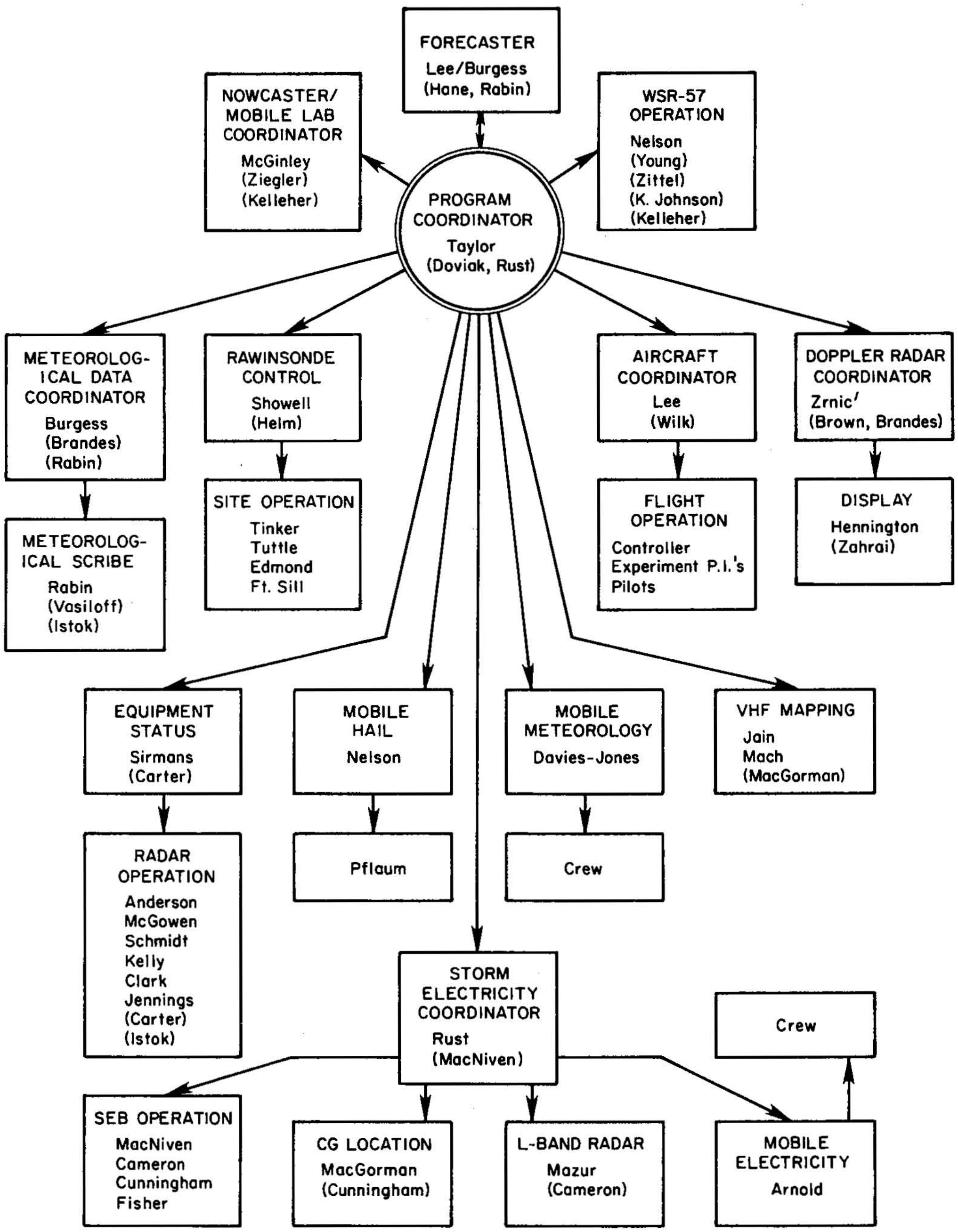
29. Tower Operations: Johnson (Carter, Reece)

30. Lightning Photography at NSSL: Jain (Fisher)

31. Damage Survey Team: Brown (Burgess/and others as needed)

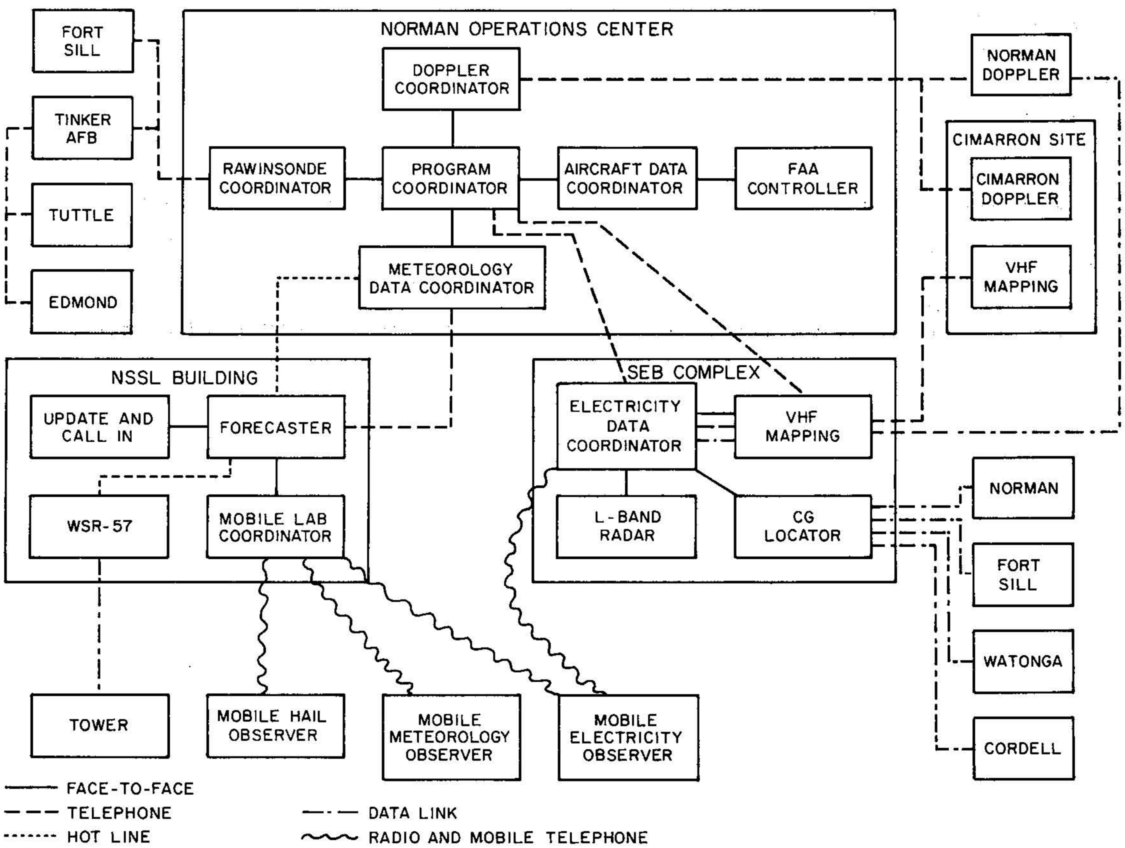
4.3 Notification of Personnel

Personnel were notified as indicated in this flow diagram when a decision was made concerning the beginning of an operation. Some groups were not notified if specific experiments did not require their participation. In general, the Program Coordinator, after consulting with the Forecaster, communicated with the key person in the various groups. The key people would then in turn contact others down the chain.



4.4 Communication Network

The communications during operations are presented here. Face-to-face contact was available in the NRO Operations Center, in the SEB Complex and in the NSSL Building. Telephone communications were available as indicated and a telephone hot line was installed between the Meteorological Data Coordinator, Forecaster and WSR-57 area. Data link lines also connected various observational data to main recording areas. Radio and mobile telephone communications were available for the Mobile Intercept teams.



5. OPERATIONAL PERIODS AND PRELIMINARY IMPRESSIONS

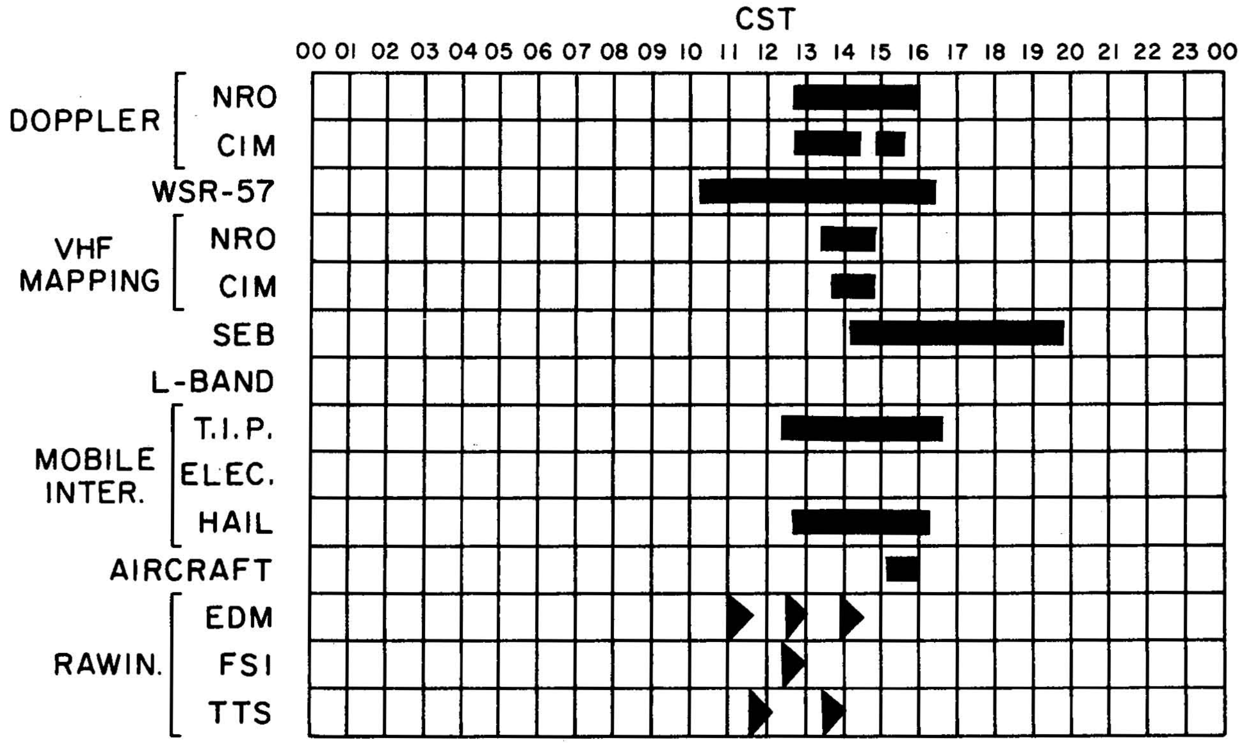
Information in this section is intended to present the meteorological setting of each major observational period, to provide an overview of sensors brought to bear on selected weather systems, and to offer guidance in the selection of periods or days for specific analyses and interpretation. All times are Central Standard Time.

Presentations are arranged chronologically beginning with 3 April and ending with 3 June. All observational periods in which multiple sensors were activated for specific experiments are included. Other observations for experiments conducted outside the main Spring Program periods are presented in Section 6.

The bar graphs for each operational period show the times each sensor or observational package was actively engaging in data collection. Times were obtained from observer's logs and Debriefing Reports. Observation summaries for the Lightning Strike Locator, the Stationary Automated Mesonetwork and the Meteorological Tower are not included in the bar graphs because observations using these sensors were essentially continuous. Limited data is available from the Lightning Ground Strike Locator prior to 28 April. The L-band radar operational periods are shown separately although it was part of the overall SEB operations. The Mobile Electricity Laboratory did not begin operations until 4 May.

Preliminary impressions and highlights follow each bar graph and are intended to present the essence of the weather condition and the operation of each sensor for the period. No highlights are presented for the WSR-57 since it was usually operated in a preset surveillance mode; for the rawinsonde soundings, since they are essentially routine; or for the hail intercept project, since this was limited in scope and dealt largely this year with problems associated with the hail intercept process. The highlights for the other operations are concise, yet include sufficient quantitative information, initial impressions of data quality, and problems in data acquisition to assist researchers inside and outside NSSL to evaluate the results of each day's efforts concerning future analyses.

5.1 3 April, Friday, 1981 - Day 93



5.1.1 Weather Situation

A high amplitude upper level trough was present upstream from Oklahoma during the morning. Twelve hour 500 mb height falls associated with this trough were 150 m.

At the surface, a front/dryline system separated air to the west with 25-35 dewpoints from air to the east with dewpoints in the low to mid-60's.

Soundings at 0600 showed very moist air in the lower 150 mb beneath an inversion, and near adiabatic lapse rates above. Lifted indices were forecast in the range -4 to -7 for the afternoon.

Numerical guidance indicated major development of the low in Colorado, and movement northeastward.

A band of showers moved through central Oklahoma and eastern Kansas at mid-morning. Major thunderstorm activity developed on the dryline west of Abilene, Texas by 0900, and along the Texas-Oklahoma border by noon. A squall line moved through the operational area producing reports of wind damage near Oklahoma City and Norman, and scattered reports of small hail. These storms produced damage later in the evening in eastern Oklahoma.

5.1.2 Radar Summary

A squall line passed through the dual Doppler areas with individual cells moving rapidly to the northeast. Dual Doppler data were collected on two storms, one north and one south between 1240-1424 for storm evolution studies and for support of Storm Electricity. NRO collected lifetime data on cells 40-80 km to the south. After squall line passage, prestorm data were collected as a Pacific front approached from the west; however, no precipitation or areas of deep convection developed. Finally, NRO collected data on squall line 120 km to the southeast concurrent with aircraft penetrations.

5.1.3 Storm Electricity

5.1.3.1 Lightning Mapping

Data were collected at both sites on scattered lightning from several storms producing a minimal amount of electrical activity. No useful dual mapping data were obtained because storms were outside nominal range from Cimarron. Azimuth, elevation and impulse rate data at Norman were good.

5.1.3.2 SEB Operations

Data were obtained from all field change instrumentation at the SEB.

Several lightning flashes were observed with the L-band radar in support of F-106 penetrations.

5.1.4 Mobile Intercept

5.1.4.1 Tornado Intercept Project

The NSSL intercept team left at 1219, and penetrated a heavy precipitation core in Marlow at 1345. We proceeded south to Waurika, then east to Ringling (1451) when we encountered another heavy core. Returning home on I-35, we went through another rainshaft in the Arbuckles (1535). No hail was encountered, there was little visible lightning with these nonsevere storms, and no wall clouds or other significant visual features were observed.

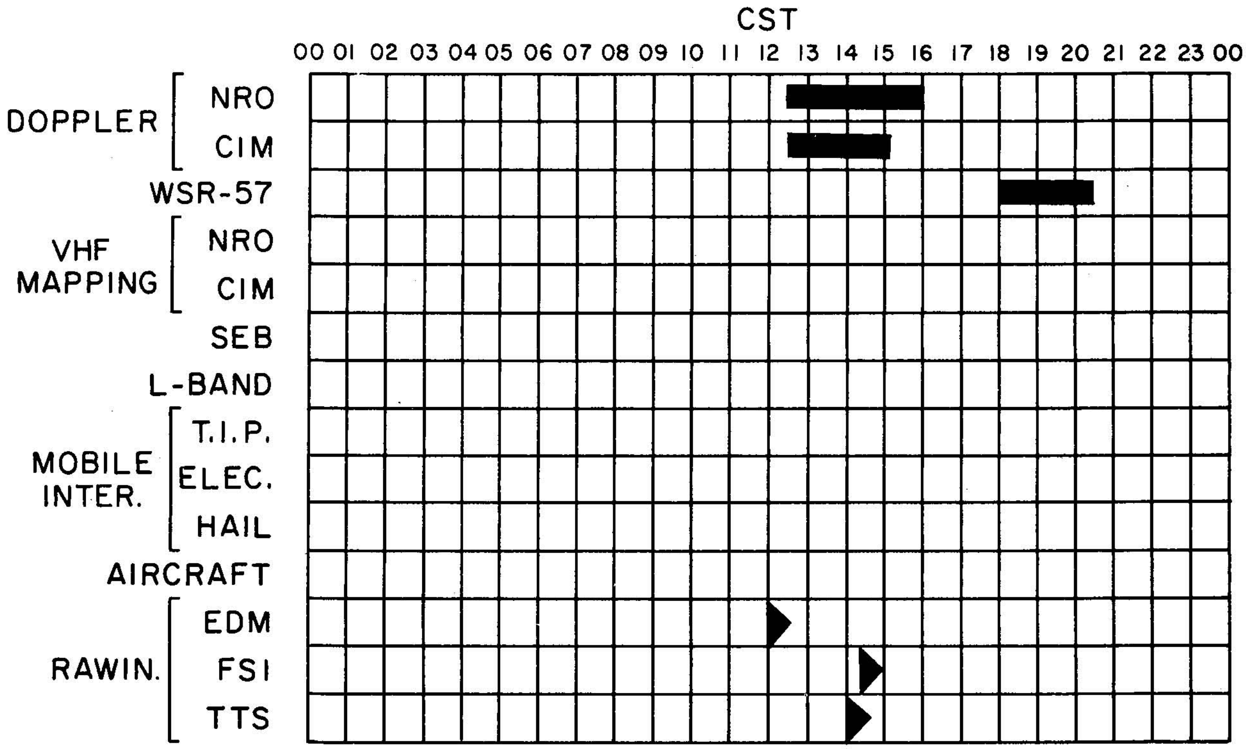
5.1.5 Aircraft Operations

The F-106 made 6 penetrations at an altitude between 11,500 and 13,500 ft. MSL of thunderstorms 140-170°, 80-140 km, from Norman between 1500 and 1600. Moderate turbulence was encountered, but no lightning strikes to the aircraft were observed.

5.1.6 Other Observations

Gust fronts systems associated with thunderstorms in the Oklahoma City area were recorded at 1 sec intervals on the KTVY-TV tower from 1257 to 1610. The Will Rogers International World Airport's LLWSAS was recorded 1334-1534.

5.2 8 April, Wednesday, 1981 - Day 98



5.2.1 Weather Situation

A mean longwave trough was positioned over the western U.S. with an imbedded shortwave near the Four Corners region. Prognostic guidance showed this trough moving northeastward, the strongest portion north of the operational area.

The morning sounding at Oklahoma City indicated moisture in the lowest 70 mb, with low level winds of 58 knots at 840 mb. Maximum wind aloft was 112 knots near 200 mb. Forecast lifted index (assuming moderate afternoon heating and some frontal lifting) was -6.

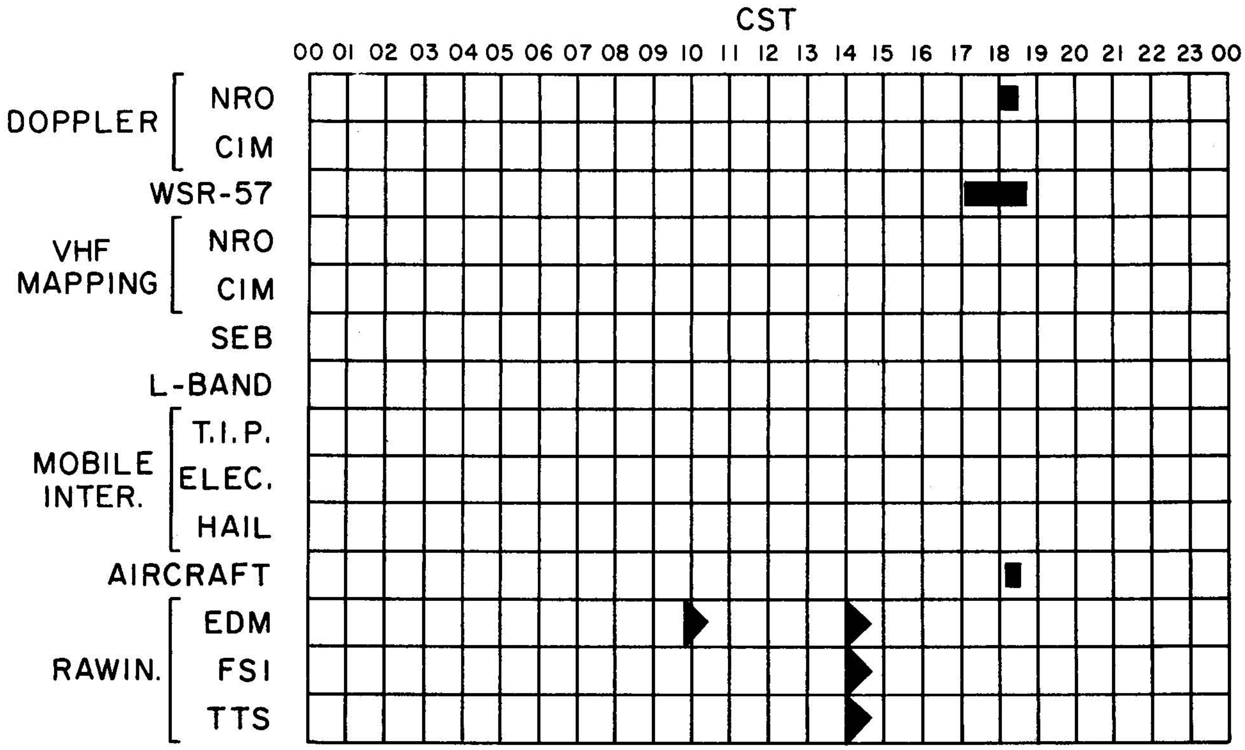
The 0600 surface chart showed a weak low pressure system over central Kansas located on a slow moving frontal system running from the northern Texas Panhandle to northwestern Missouri. By 1400 the front moved through the operational area with a dryline intersecting the front near Stillwater, Oklahoma and extending southwestward to Wichita Falls. The low in Kansas moved northeastward. The front became stationary in southern Oklahoma early on 9 April.

Thunderstorms developed on the front in late afternoon from Oklahoma City to Springfield, Missouri. No severe weather was reported even though the forecast called for a chance of severe thunderstorms.

5.2.2 Radar Summary

Prestorm data were collected on a weak front passing the area 1230-1600. The front was weak and no sharp wind discontinuity was observed; however, storms formed on the front 60 km southeast after data collection ended.

5.3 9 April, Thursday, 1981 - Day 99



5.3.1 Weather Situation

Upper air forcing was weak, consisting of two minor perturbations in the flow, one over south-central Colorado and the other in New Mexico. Twelve hour 500 mb forecasts indicated these two waves to be in western Kansas and south-central New Mexico respectively, with weak PVA across central Kansas and the Texas Panhandle.

A front remained stationary in southern Oklahoma, although it was expected to weaken during the day. Very moist air was positioned south of the front with dewpoints in the 70's. Surface winds in north central Texas and southwestern Oklahoma were E to SE at 10-20 knots. A pressure trough in the east Texas Panhandle marked the dryline position.

Morning soundings showed moderate potential for thunderstorms if some surface heating could be realized. Winds veered with height through the lower layers.

During the afternoon surface winds backed in the dry air and veered in the moist air. A few short-lived storms developed south of Childress, Texas and Altus, Oklahoma. No severe weather was reported.

5.3.2 Radar Summary

Prestorm scans revealed banded structure in the reflectivity field (10-40 km wavelength). There were data in support of aircraft penetration of a storm to the southwest; however, the storm became very weak (20 dBZ).

5.3.3 Storm Electricity

None.

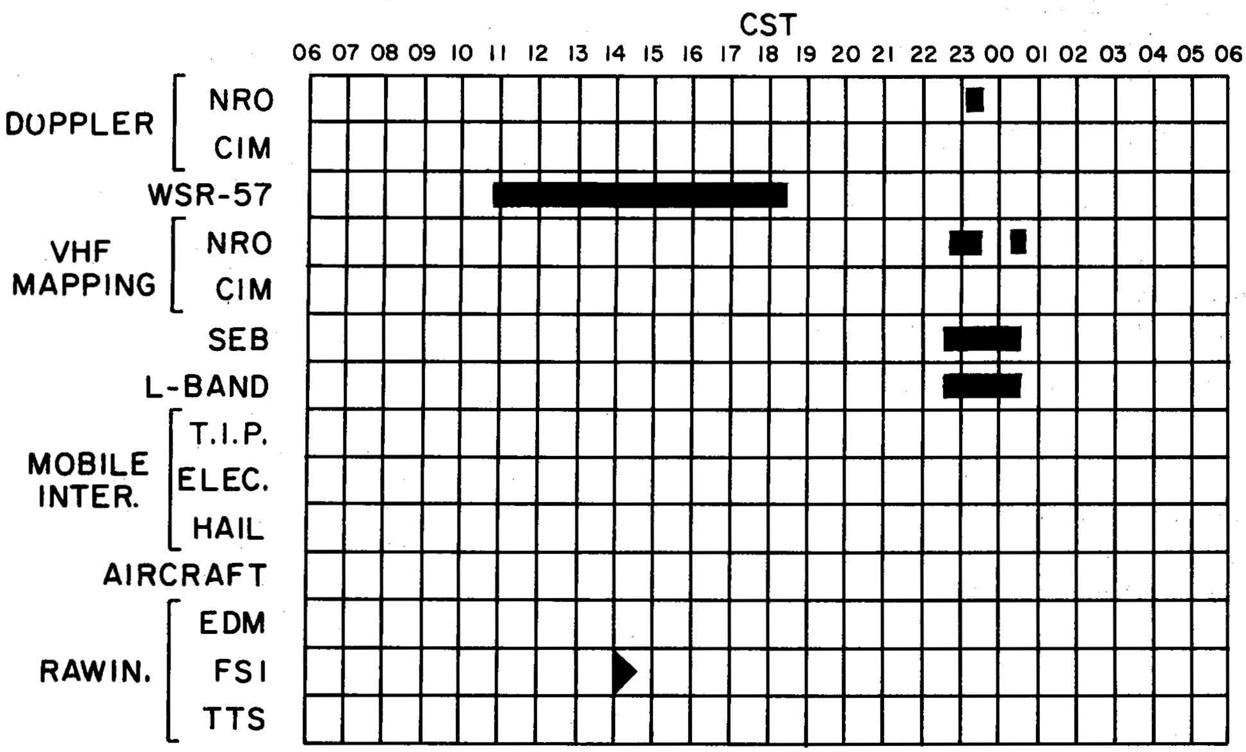
5.3.4 Mobile Intercept

None.

5.3.5 Aircraft Operations

Between 1815 and 1830 the F-106 flew through remnants of a rapidly dissipating thunderstorm at 260° and 50 km of Norman.

5.4 10-11 April, Friday-Saturday, 1981 - Day 100-101



5.4.1 Weather Situation

The longwave pattern remained unchanged with an upper level trough on the West Coast and a ridge over the East. The flow aloft was southwesterly over Oklahoma and had weakened over preceding days. A weak shortwave imbedded in the southwesterly flow was positioned over New Mexico and forecast to move across Oklahoma during the afternoon.

The surface chart showed a frontal wave in Kansas on a frontal wave, with the front extending from southwest to northeast across that state.

A moisture band was advecting northward through west Texas and Oklahoma.

Morning soundings over the operational area indicated some potential instability if strong surface convergence and moderate heating of the lowest layers could be realized. Forecast lifted indices were in the -3 to -5 range. Winds were veering with height, with strongest winds 109 knots at 200 mb. Winds at middle levels were quite weak.

By 1400 thunderstorms developed along the Texas-New Mexico border and in western Kansas on the dryline and front, respectively. The storms that developed in the Panhandle moved into western Oklahoma by 2100, configured in a bow-shaped convective line. These storms weakened significantly by 2300. No severe weather was reported.

5.4.2 Radar Summary

The only experiment was for observing radar echoes from CG lightning with radar beam over a water tower. No lightning strikes occurred in the tower during a local thunderstorm.

5.4.3 Storm Electricity

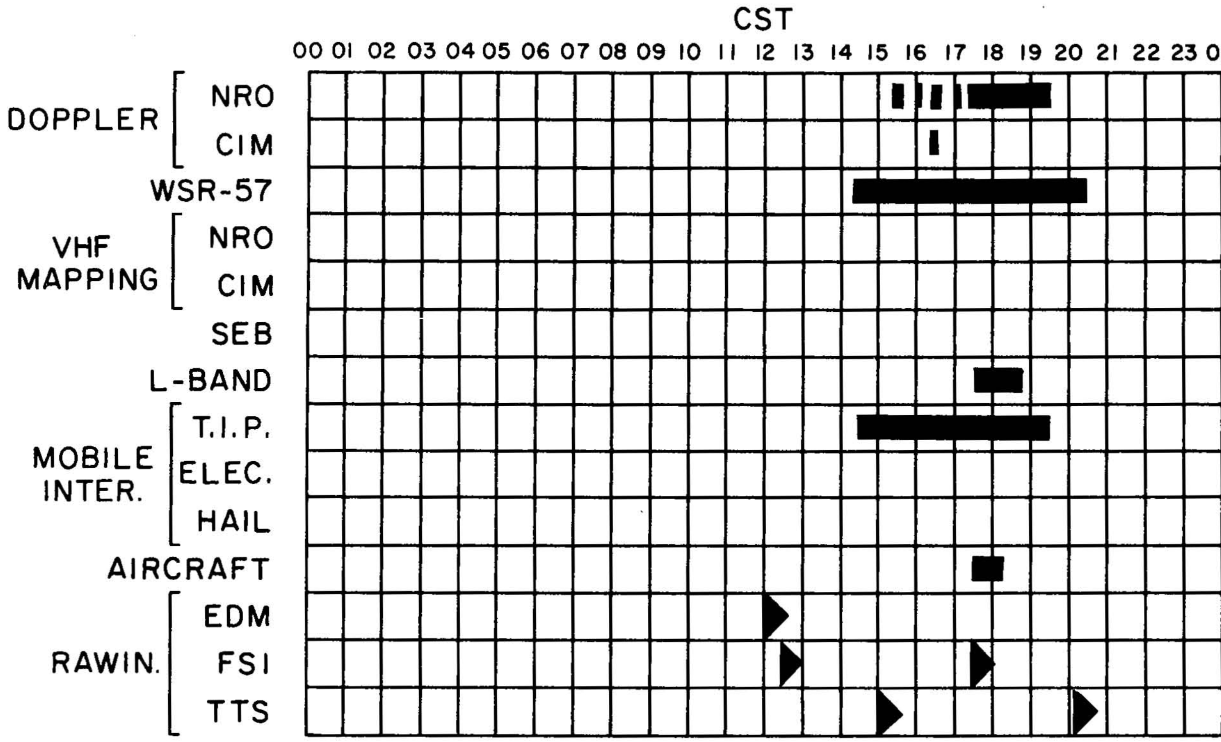
5.4.3.1 Lightning Mapping

Only the Norman site was activated. Many close-in lightning flashes observed with high impulse rates. Upward looking modification was successfully tested between 0020 and 0025 with the observation of several flashes overhead.

5.4.3.2 SEB Operations

Data were acquired from 2237-0037. All SEB systems were operational except for electric field mill. Specific experiments included lightning radar echoes with NRO and L-band and CG strikes to Brookhaven tower. The NRO data of lightning echoes overhead are good. There were no tower strikes. L-band data are okay except no antenna azimuth data were recorded.

5.5 11 April, Saturday, 1981 - Day 101



5.5.1 Weather Situation

Upper level flow was similar to that on 10 April. At 0600 another weak shortwave was located upstream in central New Mexico in southwesterly flow. A stationary front extended through northern Kansas into a weak lee cyclone in northeast Colorado. A dryline was positioned south of the low through western Kansas into the Texas Panhandle.

Strong southerly flow was bringing moisture northward. Surface dewpoints increased through the day in Oklahoma into the low 60's.

The noon sounding at Fort Sill showed very unstable air over southwest Oklahoma with a forecast lifted index of -8 assuming 3-4 hours of additional surface heating and minimal lifting.

Upper level numerical forecasts indicated that the shortwave would pass over Oklahoma during the afternoon with moderate PVA (positive vorticity advection).

By afternoon, convergence was occurring on the dryline in the east Texas Panhandle. Strong storms developed south of Childress, Texas, about 120 km south of the main surface dry push. These storms moved into southwest Oklahoma producing severe weather including large hail and wind damage.

5.5.2 Radar Summary

Storms formed about 250 km to the west-southwest by 1500. Initially, two main cells were observed; one northeast of the other. The northeast cell was strongest at 1600 with cyclonic shear and a large area of 50 dBZ reflectivity. By 1630, the northeast cell weakened while the southwest one became stronger. Data included aircraft penetrations near the weaker cells from 1730-1815 at about 180 km range. The southwest storm moved on to about 180 km where it appeared to turn to the right. Later, there was little apparent motion as repeated new development occurred along the southwest flank of the storm. A mesocyclone appeared to propagate along the flanking line.

5.5.3 Storm Electricity

5.5.3.1 Lightning Mapping

None.

5.5.3.2 SEB Operations

Intermittent recording of L-band lightning echoes in support of F-106.

5.5.4 Mobile Intercept

5.5.4.1 Tornado Intercept Project

The chase team penetrated a core 7 miles north of Altus at 1725 and five minutes later saw a possible funnel (a turbulent "tube" of cloud) 2 miles north of Altus. At 1739 we passed through the core of the "Altus storm," and were bombarded by 3/4 inch hail. Larger hail (1 inch) was seen on the ground. We stopped 5 to 7 miles south of Altus and witnessed a series of wall clouds which formed to our west, and traveled northeast into the core, which remained stationary over the city. Impressive cloudbase-striations emanated from the wall cloud-genesis region and extended over our heads. The storm remained stationary from 1740 to 1930, at which time it finally started moving northeast, with a wall cloud still evident on the right rear flank. We then headed home because light was deteriorating rapidly.

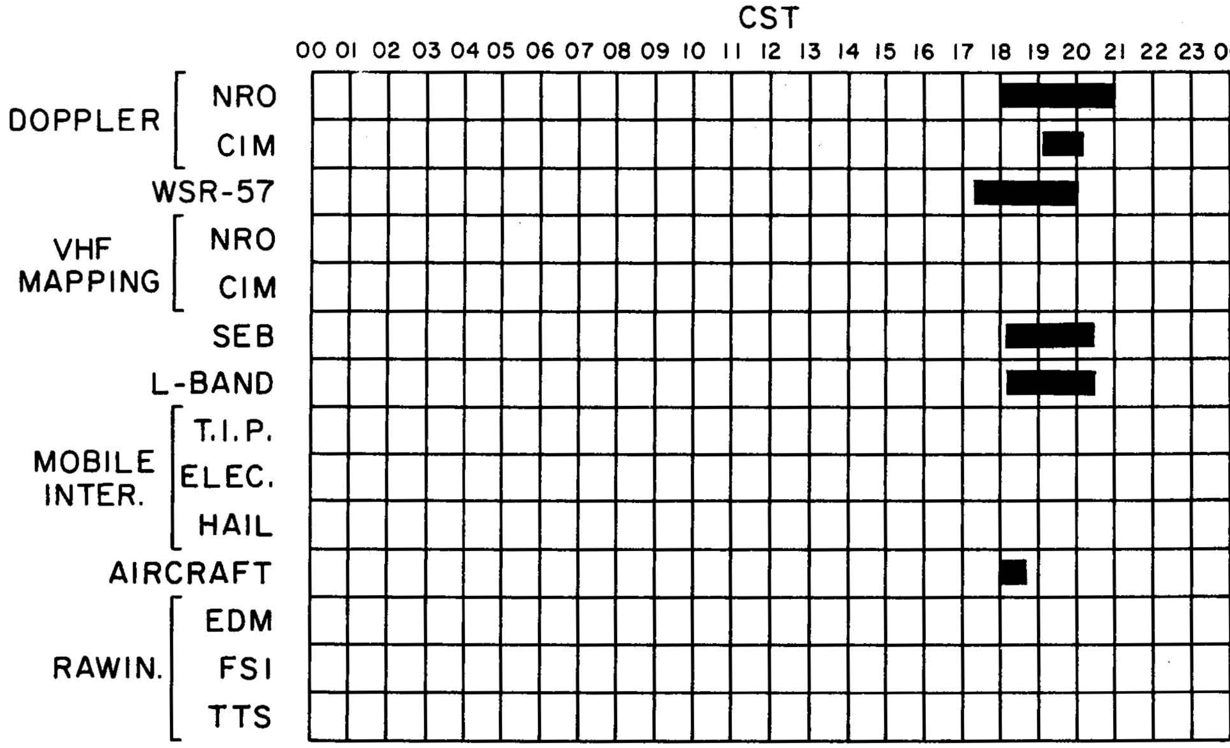
5.5.5 Aircraft Operations

The F-106 conducted 7 penetrations between 1730 and 1815 through storms east-northeast of Altus, Oklahoma. Moderate turbulence, strong electrical activity, but no strikes to aircraft.

5.5.6 Other Observations

Meteorological tower operated at 1 sec interval 1400-2000 as storms approached. Winds to near 25 $m \cdot s^{-1}$ (56 mph) and a temperature increase of 3° C recorded about 2200.

5.6 12 April, Sunday, 1981 - Day 102



5.6.1 Weather Situation

Conditions on 12 April had not changed markedly from preceding days. Strongest flow in the upper air had retreated further north, yielding weak mid-level winds over Oklahoma. Vorticity centers aloft located over Colorado and Arizona at 0600 were forecast to be over Kansas and eastern New Mexico, with weak PVA over Oklahoma by 1800.

At the surface a stationary front remained in Kansas and northwestern Texas, with a weak low pressure center over Great Bend. A dryline extended southward into the eastern Texas Panhandle.

Morning soundings showed moisture 60 mb deep over Oklahoma. With an assumed high temperature in the mid-80's, strong forced lifting would be required to realize an instability of -5.

By noon the dryline had moved into western Oklahoma, however, convergence on the dryline was weak. By 1400 winds had backed in the moist air with Childress showing a marked increase in surface dewpoint (37 to 60 in 3 hours). At this time satellite imagery indicated a small cluster of towering cumulus in southwestern Oklahoma. This cluster grew rapidly, becoming strong thunderstorms by 1700. Another storm developed in northwestern Oklahoma on the front. The large storm complex in the southwest produced four tornado reports and large hail within 10-20 km of Hobart, Oklahoma. The storms moved into central Oklahoma during the late evening.

5.6.2 Radar Summary

Data were collected on strong thunderstorms in southwest Oklahoma in support of the aircraft turbulence experiment (aircraft encountered some hail). Real time observations indicated problems with spectrum width due to ground clutter (~50 percent). Data included lifetime of the mesocyclone.

5.6.3 Storm Electricity

5.6.3.1 Lightning Mapping

None.

5.6.3.2 SEB Operations

Data were collected in support of F-106 flight. Data were also obtained from L-band lightning echoes in mesocyclone region and lightning that propagates from storm core. Noisy data were recorded on some tape channels. Data quality is fair.

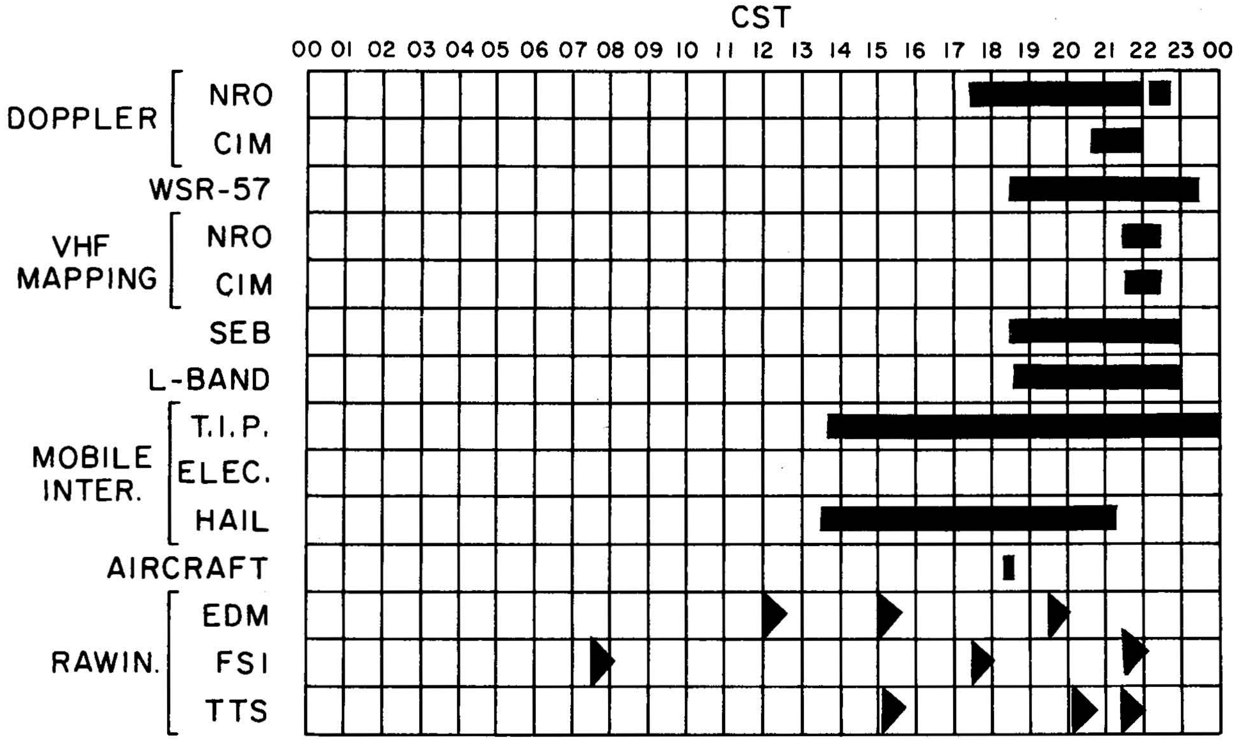
5.6.4 Mobile Intercept

None.

5.6.5 Aircraft Operations

The aircraft made 6 penetrations of thunderstorms northeast of Altus, Oklahoma, from 1800 to 1845. Moderate turbulence, lightning in area but no strike. Light hail damage to flow vanes on last penetration.

5.7 13 April, Monday, 1981 - Day 103



5.7.1 Weather Situation

Adjustments were occurring in the longwave pattern by 13 April. A wave that had been slowly moving through the longwave trough position on the West Coast was now moving rapidly eastward in response to ridge building in the eastern Pacific. This event allowed Canadian air to race southward into the plains, guaranteeing a cold frontal passage for the operational area during the evening.

Upper air charts for 0600 showed the strong shortwave moving across the Northern Plains with broad weak southwesterly flow over the Southern Plains. The LFM indicated that the trough to the north would move into the Great Lakes, with a minor vorticity center in Colorado moving across Kansas with weak PVA over Oklahoma. The front was expected to pass through the state by early on the 14th.

Morning soundings showed excellent prospects for thunderstorm development. The moist layer extended up to 850 mb. An assumed moderate input of heat into lowest layer (high temperature in the mid-80's) would leave only a small negative energy area which would be overcome by forced frontal lifting. The forecast lifted index was -9.

During early afternoon the cold front moved southward across Kansas. The dryline became well defined on the Oklahoma-Texas border. Showers and thunderstorms began in the dry air over the central Texas Panhandle on a convergence line ahead of the cold front. As the convergence line merged with the dryline, intense storms developed near the Oklahoma border by 1700. Convective activity had also formed on the front, now in the northwest part of Oklahoma. Radar at 1900 showed a broken line of echoes along the front through Kansas and western Oklahoma into the southern Texas Panhandle. These storms moved rapidly into central Oklahoma producing hail and isolated reports of wind damage.

5.7.2 Radar Summary

Data were collected on a squall line about 180 km to the west-northwest for aircraft turbulence study (maximum reflectivity was ~45 dBZ). Dual Doppler data collection began on a gust front 50 km to the northwest at 2050. Strong outflow was observed near CIM (30 m/s radial velocity at 400 m above ground). At 2205-2210, NRO recorded data on a squall line passage with the antenna pointed vertically. Radar echo study of CG lightning data was conducted by NRO at 2210-2222, no strikes were evident. Finally, more data were collected on squall line and gust front southeast of NRO.

5.7.3 Storm Electricity

5.7.3.1 Lightning Mapping

Dual VHF mapping data were collected, but Cimarron site was too far from main activity to produce good data. Very good data from Norman site resulted from nearby lightning. Mapping sites, video and photographic cameras were focused on water tower to support radar echoes from CG lightning experiment but no flashes were observed.

5.7.3.2 SEB Operations

Experiments include L-band lightning echoes versus lightning field changes; full PPI recording of L-band lightning echoes, strikes to Brookhaven tower, and +CG flashes after passage of line. Data quality apparently good.

5.7.4 Mobile Intercept

5.7.4.1 Tornado Intercept Project

An arcus cloud was intercepted 25 miles northeast of Paducah, Texas, at 1827. As we headed south for the right rear flank of the storm, the arcus cloud lost its curved shape (in horizontal planview) as the storm "lined out" (i.e., developed from an isolated storm to a squall line). We spotted a "gustnado" (vigorous dust-filled eddy on the gust front) at 1905, 10 miles north of Paducah. After dark, we were treated to an especially vivid lightning display as we headed home.

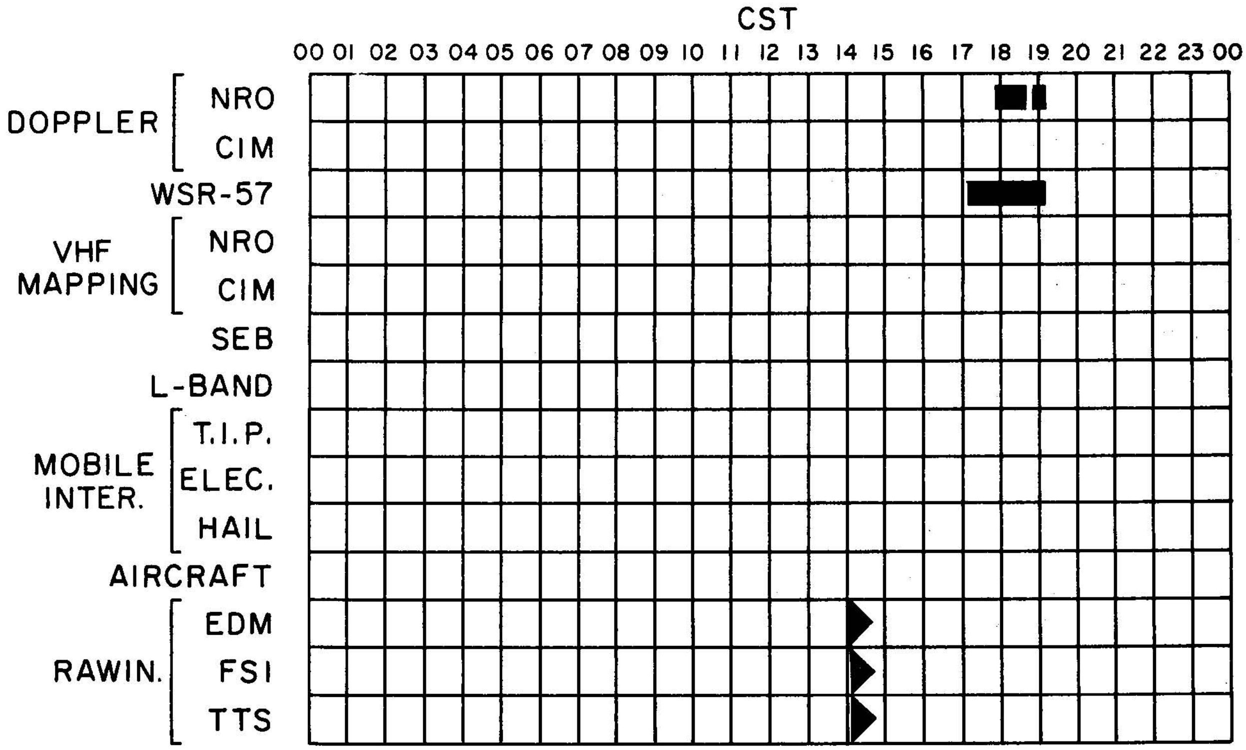
5.7.5 Aircraft Operations

Aircraft (F-106) flew one penetration 1815-1830 along leading edge of a storm 180 km northwest of Norman. Slow movement of storm precluded entry of main cells into operating range before sunset; thus aircraft returned to base. Good electrical activity and moderate turbulence encountered.

5.7.6 Other Observations

Gust front from thunderstorms west of Oklahoma City moved through area around 2200. KTVY-TV tower data recorded at 1 sec intervals 2030 to 2300. LLWSAS at Will Rogers International Airport recorded 2122 to 2258.

5.8 19 April, Sunday, 1981 - Day 109



5.8.1 Weather Situation

A slow moving low latitude upper air system was located on the West Coast with weak diffluent flow across the Southern Plains. Minor troughs were being ejected by this system. At 0600 one of these was over central Oklahoma with the next upstream trough over Arizona.

At the surface, a frontal system extended across Kansas with a weak low pressure system in south central Kansas. A dryline was positioned in the east Texas Panhandle. Dewpoints in the moist air were in the mid to upper 60's; in the dry air, mid 40's.

Prognostic guidance indicated very little upper support, however, the front was forecast to sweep across Oklahoma during the afternoon.

Morning soundings showed significant low level shear and lifted indices about -4, assuming a high temperature in the low 80's.

The front and low pressure system tracked southeastward into northeastern Oklahoma. The dryline intersected the front at the position of the low pressure center. By 1500 storms developed on the front northeast of the low. Soon thunderstorms developed down the dryline to just northeast of Oklahoma City. The 1800 sounding at Oklahoma City showed that the convective temperature had been reached with an instability of -9. The air that had interacted with the front was more unstable than forecast. Moving east, the storms passed through Tulsa, Kiefer, and Bixby between 2000 to 2100 producing 3 tornadoes which killed 5 in Bixby and caused heavy damage in Tulsa.

5.8.2 Radar Summary

Thunderstorms formed along a southwest-northeast line at least 80 km north-northeast of NRO. Data were collected in anticipation of aircraft penetration until 1845. Later, data on storm lifetime were collected on the two southwestern-most cells (55 dBZ) of the line.

5.8.3 Storm Electricity

None.

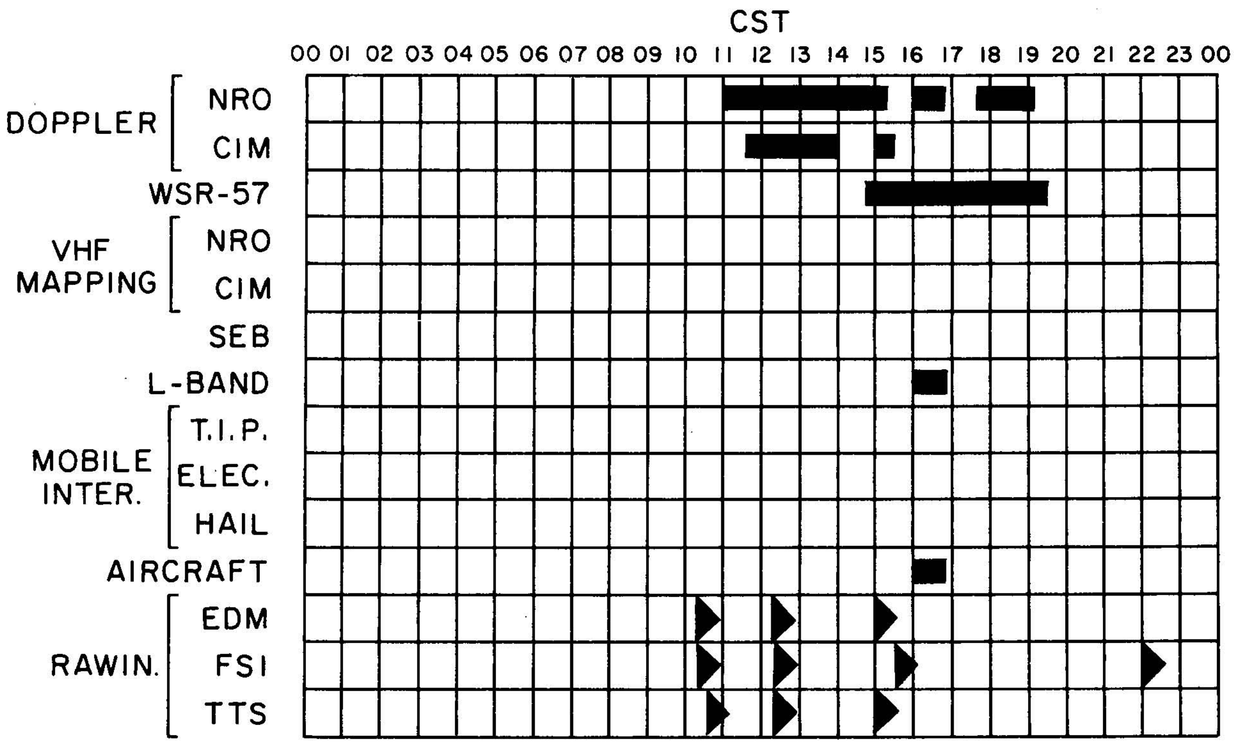
5.8.4 Mobile Intercept

None.

5.8.5 Aircraft Operations

F-106 flew from 1745 to 1845 but malfunction of ground-based transponder equipment prevented any penetrations of thunderstorms at 360° and 80 km of Norman.

5.9 22 April, Wednesday, 1981 - Day 112



5.9.1 Weather Situation

An upper level, high amplitude shortwave was located in the Northern and Central Plains with a closed barotropic-like low over northern Mexico. A cold front associated with the system in the north was moving southeastward across Kansas and the Texas Panhandle. Very moist air (dewpoints 66° F) was moving northward into eastern Oklahoma and north central Texas.

Morning soundings showed the moisture to be 80 mb deep. Forecast lifted index at Oklahoma City was -6 with very little forced lifting required. Numerical guidance indicated a strong potential for forced lifting with passage of the front and trough aloft.

Storms developed on the front after it passed Oklahoma City. First radar echoes were noted about 1430. These storms rapidly developed southwestward down the front. Storms that developed in the Waurika area produced 2 small tornadoes and some wind damage. Another part of the squall line produced damage in the vicinity of McAlester. Other tornado producing thunderstorms occurred in southwestern Texas.

5.9.2 Radar Summary

Prestorm data were collected as cold front passed the area. (Windshift was observed with no sharp boundary apparent.) Thunderstorms formed 100 km to the southeast of the radar in a southwest-northeast line about 50 km ahead of the front. Banded reflectivity structure was observed behind the squall line. Aircraft turbulence data were collected from 1600-1655 on 40-45 dBZ cells along a line (~120 km southeast). A new line formed behind the old (~1730) with some 60 dBZ echoes. Although there were reports of funnels, no mesocyclones were noted by radar.

5.9.3 Storm Electricity

5.9.3.1 Lightning Mapping

None.

5.9.3.2 SEB Operations

Only data are L-band lightning echoes recorded in support of F-106 flight. Very high IC flashing rates were recorded at an azimuth of 100° during this interval.

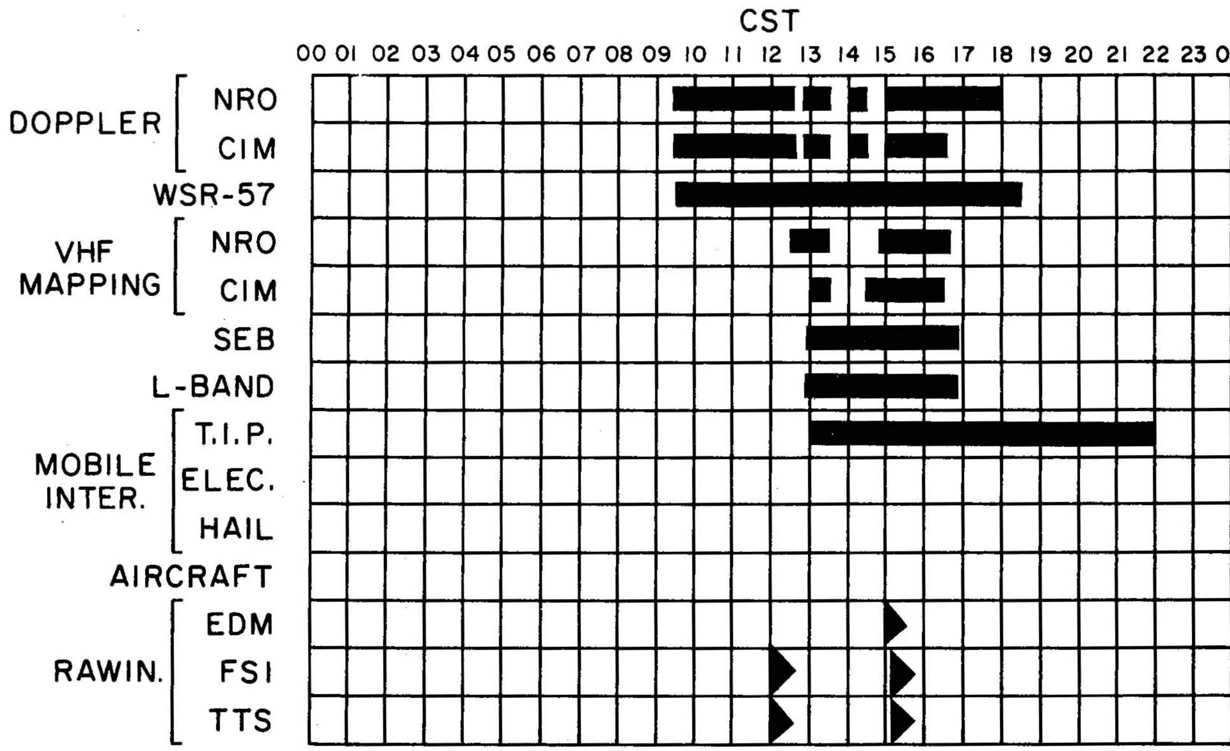
5.9.4 Mobile Intercept

None.

5.9.5 Aircraft Operations

F-106 flew 6 penetrations 1600-1700 of thunderstorms vicinity of Ada, Oklahoma. Very active lightning with some close strikes in the vicinity of the aircraft. Moderate turbulence reported.

5.10 28 April, Tuesday, 1981 - Day 118



5.10.1 Weather Situation

Upper level flow on the morning of 28 April was generally zonal across the northern half of the United States with a large closed cyclone over Baja, California. A shortwave was in the northern plains and a weak wave was located over eastern Oklahoma.

Morning surface charts showed a cold front moving southeastward across the state. A weak low pressure center was on the front in western Oklahoma. No dryline was evident. Soundings for the region indicated moisture to be deep (160 mb). Forecast moderate heating would allow instabilities to reach the -4 to -6 range.

Towering cumulus formed very early on the front from northeastern to west-central Oklahoma. By 1330 thunderstorms were active on the front and in south-central Oklahoma. By 1430 a new complex had developed in southwestern Oklahoma. These storms moved eastward producing short-lived tornadoes in the vicinity of Fort Sill, Gracemont and Binger, Oklahoma.

5.10.2 Radar Summary

Prestorm data were collected as frontal and prefrontal convergence zones moved southeast in the morning with two 25 dBZ cells. A 50 dBZ cell developed by 1245 in the southern lobe of dual Doppler area. Dual mapping continued until 1330 on this and other new cells. Another 55 dBZ storm moved through the same area between 1425-1635 (some mid-level cyclonic shear was observed). Data were then recorded every 15 minutes until 1800 as a broken squall line moved southeast.

5.10.3 Storm Electricity

5.10.3.1 Lightning Mapping

Very good dual mapping data were obtained from activity to the southwest and west of Norman within 50 km range. Considerable motion was observed in this lightning activity.

5.10.3.2 SEB Operations

L-band lightning echo experiments (beginning at 1400) included polarization changes and echo intensity. Some data recorded on analog recorder are of doubtful quality. Field change data good from 1400.

5.10.3.3 Lightning Ground Strike

All four DF's were operational. There were frequent detected flashes, but a relatively small percentage of locations. Lightning activity was within 100 km.

5.10.4 Mobile Intercept

5.10.4.1 Tornado Intercept Project

The team left at 1300 on an Anadarko, Duncan, Ringling, Wilson, Marietta route, and arrived back at NSSL at 2200. Our only noteworthy observation was a wall cloud observed at Anadarko at 1420.

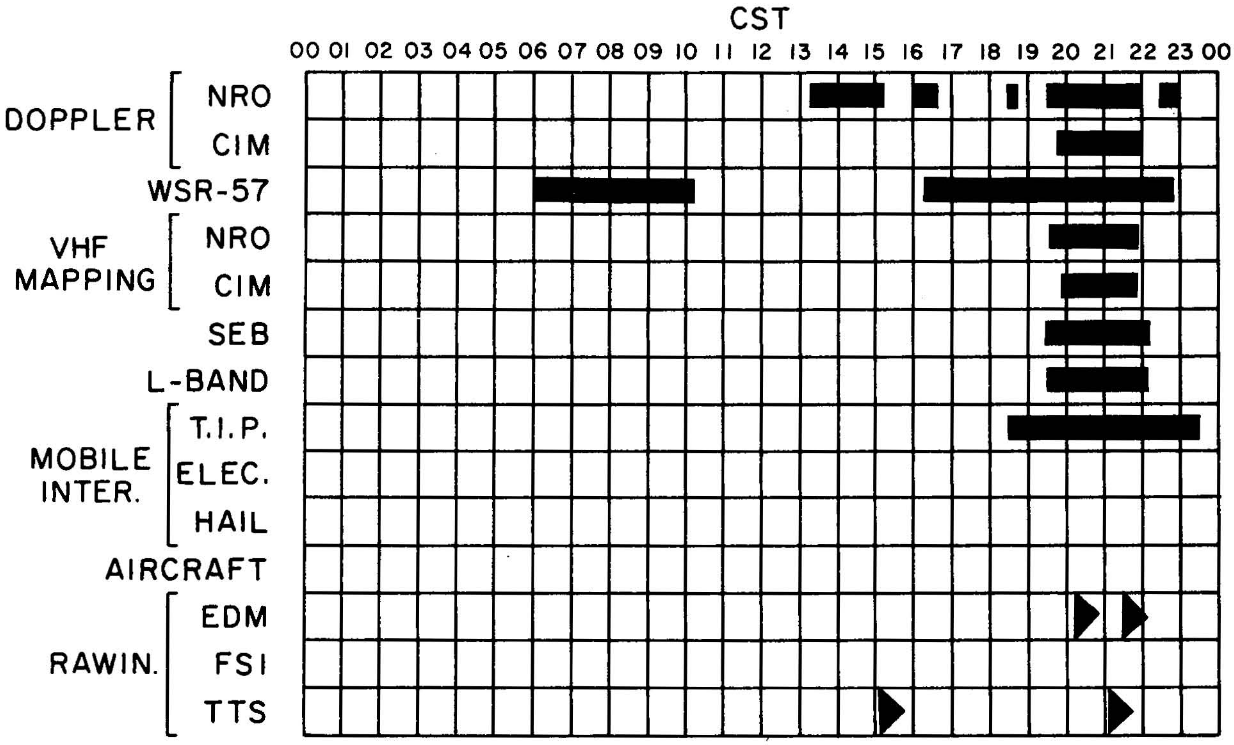
5.10.5 Aircraft Operations

None.

5.10.6 Other Observations

Cold frontal passage with attendant convective clouds moved through Oklahoma City area shortly after noon. Tower data recorded at 1 sec intervals 1000 to 1400. Will Rogers International Airport LLWSAS data recorded 1315-1430.

5.11 30 April, Thursday, 1981 - Day 120



5.11.1 Weather Situation

The upper level flow this day showed a longwave ridge on the West Coast with a developing longwave trough in the east. A large cut-off low drifted southwest of Baja, California. Flow over Oklahoma was northwesterly. However, the strongest band of winds extended from North Dakota to Kentucky placing the operational area in a region of strong anticyclonic shear. A weak vorticity maximum was upstream (trough axis from North Dakota to Wyoming) and was expected to move southeastward. Numerical progs indicated that this wave would push north of Oklahoma.

Morning surface analyses showed a stationary front along the Red River with showers and thunderstorms over south-central and eastern Oklahoma. Soundings for 0600 indicated low stabilities for the afternoon. Oklahoma City with an expected high of 86 had a forecast lifted index of -6. (Actual high temperature was 89.)

Through the day skies cleared over most parts of Oklahoma. Surface winds were generally east-southeastward. A band of clouds from 100 km north of Gage, Oklahoma to Ardmore persisted through the day, becoming towering cumulus by late afternoon. Upslope winds in the Texas Panhandle initiated storms there by 1600. Thunderstorms developed in southwestern Kansas on the cloud band and southeastward into central Oklahoma by 1800. These storms formed short lines moving south-southeast over the western half of Oklahoma. Much severe weather resulted including tornadoes near Anadarko, Chickasha, Marlow, Rush Springs (1 death) and Altus. Reports continued until 2315. It appeared the midday clearing had a great impact in destabilizing the air in western Oklahoma.

5.11.2 Radar Summary

Prestorm data collected throughout the afternoon revealed a north-northwest to south-southeast boundary to the west with unusually strong convergence. There were several small cells (~80 km). Due to a break in the data collection, it was not clear if the northwest storms developed on the convergence line. This data set will be given high priority for analysis and interpretation. Dual Doppler data were collected on the northwest storm as it moved through the southern lobe of the radar network. A bounded weak echo region and cyclonic circulation were observed at midlevel. The storm eventually weakened as a new storm formed to its southeast (~2100). Dual coverage continued while a gust front and mesocyclone were observed about 70 km southwest of the radar (cyclonic shear was apparent at low levels by 2130). Finally, two scans of dual polarization data were recorded as a large area of rain covered the Agricultural Research Service network.

5.11.3 Storm Electricity

5.11.3.1 Lightning Mapping

Good dual mapping coverage was obtained from slow moving storm southwest of Norman that produced many wide-spread long-lasting lightning flashes. Data from both sites are very good. Some magnetic tape malfunctions occurred at the beginning of observations at Cimarron.

5.11.3.2 SEB Operations

All SEB systems and L-band radar were operational. Quality of data good, including video documentation of highly branched air discharges.

5.11.3.3 Lightning Ground Strike

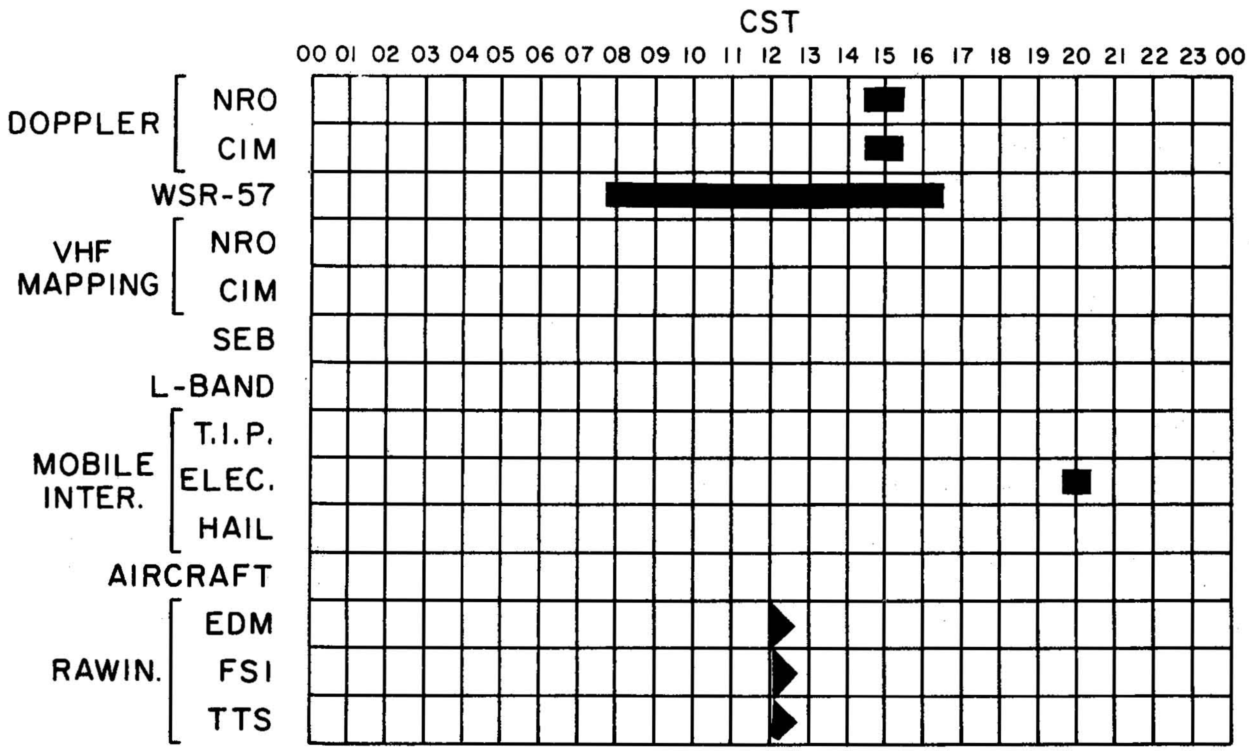
All four DF's were operational. There was significant lightning activity in the early morning and in the afternoon.

5.11.4 Mobile Intercept

5.11.4.1 Tornado Intercept Project

Leaving NSSL at 1840, NSSL 1 passed to the south of a menacing storm with a multi-tiered gustfront as we headed west toward Minco. On the storm's rear flank we spotted, in rapidly fading light, a wall cloud west of Minco at 1933. One-half inch hail fell on us when we were east of the wall cloud at 1945. This wall cloud promptly dissipated, but a new one quickly formed further to the south as the entire storm propagated south-southeastward. From 2015 to 2030 the wall cloud passed over Chickasha, and produced a small, laminar, slanted funnel over the southeast side of the city. This wall cloud then dissipated. Looking southwest into intense lightning at 2100, we spotted a new wall cloud, very low to the ground, beneath a new storm which had developed rapidly on the west side of the old one. Because of lack of roads, we could only view this wall cloud from a distance as we headed south. By 2200 the mesocyclone (still some 10 miles to the west) appeared to be weakening, so we headed for home.

5.12 4 May, Monday, 1981 - Day 124



5.12.1 Weather Situation

Upper wind flow on this day was divided into two branches; the northern branch across the upper plains and the southern branch across southern Texas. Winds aloft over Oklahoma, between branches, was weak westerly. A disturbance in the northern flow dragged a weak cold-front into the state.

Considerable moisture in a deep layer existed east of the front but the vertical stratification of temperature was such that little potential instability was present. During the afternoon, scattered convection occurred along and ahead of the front over all but northwest Oklahoma. The resulting thundershowers were weak and no severe weather was reported.

5.12.2 Radar Summary

Data were collected to obtain C_n^2 profile during overcast conditions.

5.12.3 Storm Electricity

5.12.3.1 Lightning Mapping

None.

5.12.3.2 SEB Operations

None.

5.12.3.3 Lightning Ground Strike

There was some early morning lightning 250-400 km to the NNW or NW. Later in the day, most lightning was to the SW more than 200 km from Norman. Some lightning was to the ESE about 100 km, and one small region of activity was 40-50 km NNW.

5.12.4 Mobile Intercept

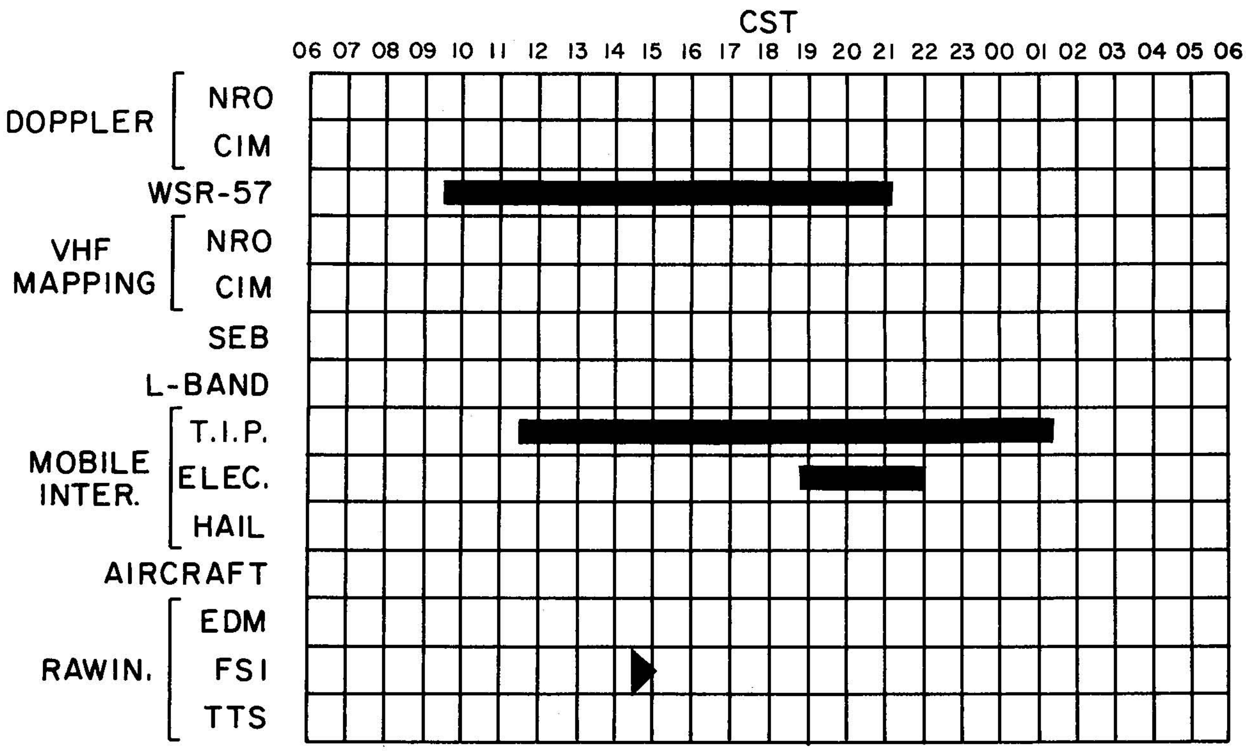
5.12.4.1 Tornado Intercept Project

None.

5.12.4.2 Mobile Electricity Lab

Data were obtained from west of Chickasha, north to Amber, and to just west of Moore, Oklahoma. Very little electrical activity was seen during weak intensification of thundershowers west of Oklahoma City metro area. Data quality is fair.

5.13 7 May, Thursday, 1981 - Day 127



5.13.1 Weather Situation

On the morning of 7 May, low-level moisture was returning northward through west Texas. A significant upper trough was centered over the Great Basin and moving slowly eastward. The first shortwave associated with the upper system was in New Mexico and Colorado, moving northeastward. At the surface, a dryline formed in eastern New Mexico by late morning and moved into extreme western Texas during the afternoon. With heating, the airmass ahead of the dryline was quite unstable and severe thunderstorms formed during the afternoon with several tornadoes in western Texas. Two thunderstorm complexes evolved; one in the Oklahoma Panhandle and southern Kansas and the other in the southern Texas Panhandle. As the complexes moved eastward into northwestern and southwestern Oklahoma respectively, they intercepted returning gulf moisture and they continued strong during the evening hours. The southern complex weakened somewhat before it got to central Oklahoma but the northern storm complex remained strong and produced severe hail damage in the northwest quarter of the state during the night.

5.13.2 Radar Summary

None.

5.13.3 Storm Electricity

5.13.3.1 Lightning Mapping

None.

5.13.3.2 SEB Operations

None.

5.13.3.3 Lightning Ground Strike

Most lightning activity in the area of coverage was to the SW near and beyond Childress. There were smaller, but active, storms north of Gage and east of Wichita, Kansas.

5.13.4 Mobile Intercept

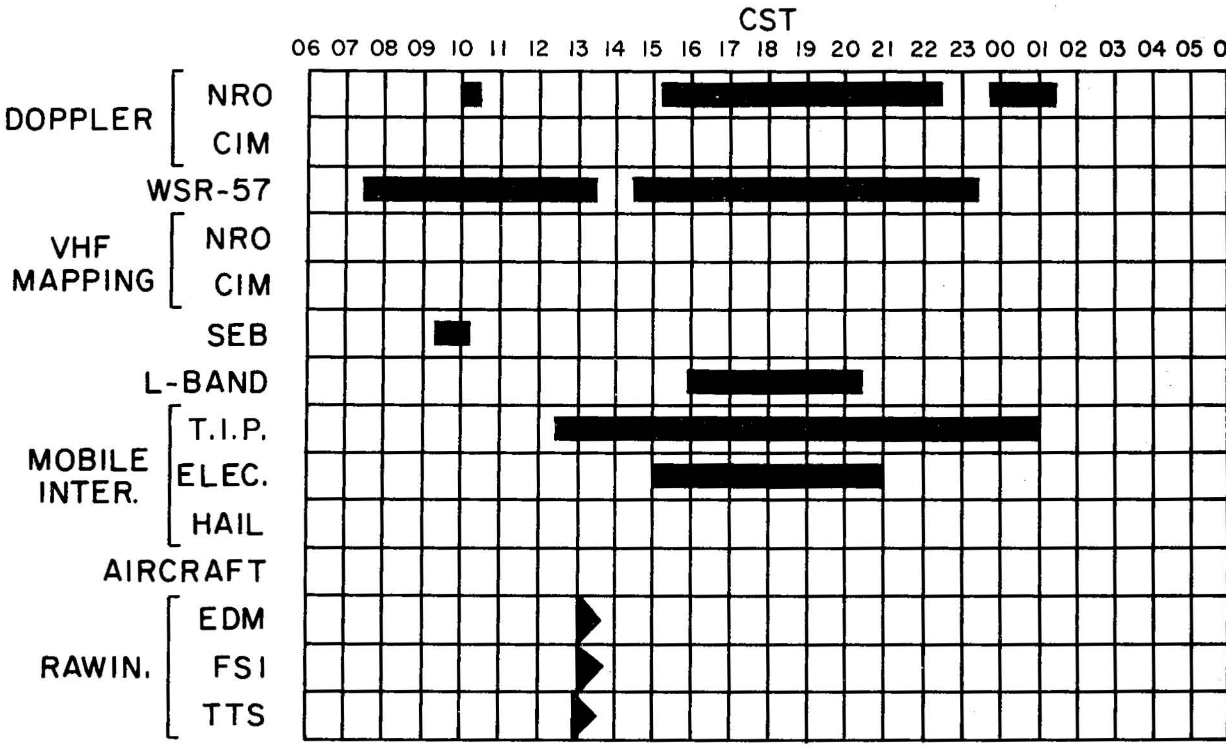
5.13.4.1 Tornado Intercept Project

The NSSL team headed out for the Texas Panhandle at 1136. Storms formed near Amarillo around 1600. Extremely heavy rain with some pea to marble-size hail reduced our visibility to a few yards in places around Memphis, Texas between 1840 and 1900. At 1922 a small, conical funnel was observed pendant from a wall cloud to our north-northeast from our position 8 miles south-southeast of Memphis. On our way home at 2002, we spotted briefly a suspicious cone-shaped cloud to our northwest from nineteen miles east of Memphis, but the lightning was too infrequent in this region of the storm for positive identification of a tornado.

5.13.4.2 Mobile Electricity Lab

Data were collected from west of Childress, Texas to Altus, Oklahoma. Observations include frequent lightning and bead lightning. All systems except 3MHz sferics were operational. Data quality is good.

5.14 8 May, Friday, 1981 - Day 128



5.14.1 Weather Situation

Convection persisted in central Oklahoma throughout the night of 7-8 May and produced a pool of cold air over most of the state by morning. The boundary between the cold, disturbed air and a favorable thunderstorm environment to the south sank southward into northern Texas during the day. A thunderstorm complex formed along the mesoscale boundary and produced much hail and wind damage near Ft. Worth, Texas, during the late afternoon and evening.

Moisture began returning to western Oklahoma during the late afternoon in advance of an approaching amplifying upper wave. The strengthening upper disturbance was associated with dramatic increases in tropospheric winds and the development of a deep surface low (995 mb) in the Texas Panhandle by evening. The airmass over the Texas and Oklahoma Panhandles destabilized rapidly and severe thunderstorms formed just after dark. The thunderstorms propogated southeastward across Oklahoma during the night as the upper wave dug southward into the Southern Plains and formed a closed low aloft. In northwestern Oklahoma, the thunderstorms were particularly severe, producing $18 million in wind and hail damage with 1 fatality and numerous injuries. The activity weakened to below severe limits by the time it reached central Oklahoma (after midnight), but the system contained a pronounced gust front along its leading edge.

5.14.2 Radar Summary

Norman Doppler collected sector scans (1510-2215) on storms 200-300 km to the south. These storms were very strong as 60 dBZ was commonly recorded at these far ranges. Norman collected full PPI data (2215-2230 and 2348-2355) as other storms approached from the NW. A gust front was clearly evident to the NW as sector scans were continuously recorded (2355-0051). Finally, the radar went to full PPI mode as the gust front approached (0051-0124).

5.14.3 Storm Electricity

5.14.3.1 Lightning Mapping

None.

5.14.3.2 SEB Operations

For the morning operation, all SEB systems operational for simultaneous data acquisition to calibrate Mobile Electricity Laboratory.

For the afternoon operation, only L-band lightning echoes were obtained in coordination with the Mobile Electricity Lab to south of NSSL.

5.14.3.3 Lightning Ground Strike

In the morning there were active storms within 150 km, but they moved beyond 150 km by 1300. In the afternoon and evening, there was lightning activity S and SE of Wichita Falls and N and NE of Gage.

5.14.4 Mobile Intercept

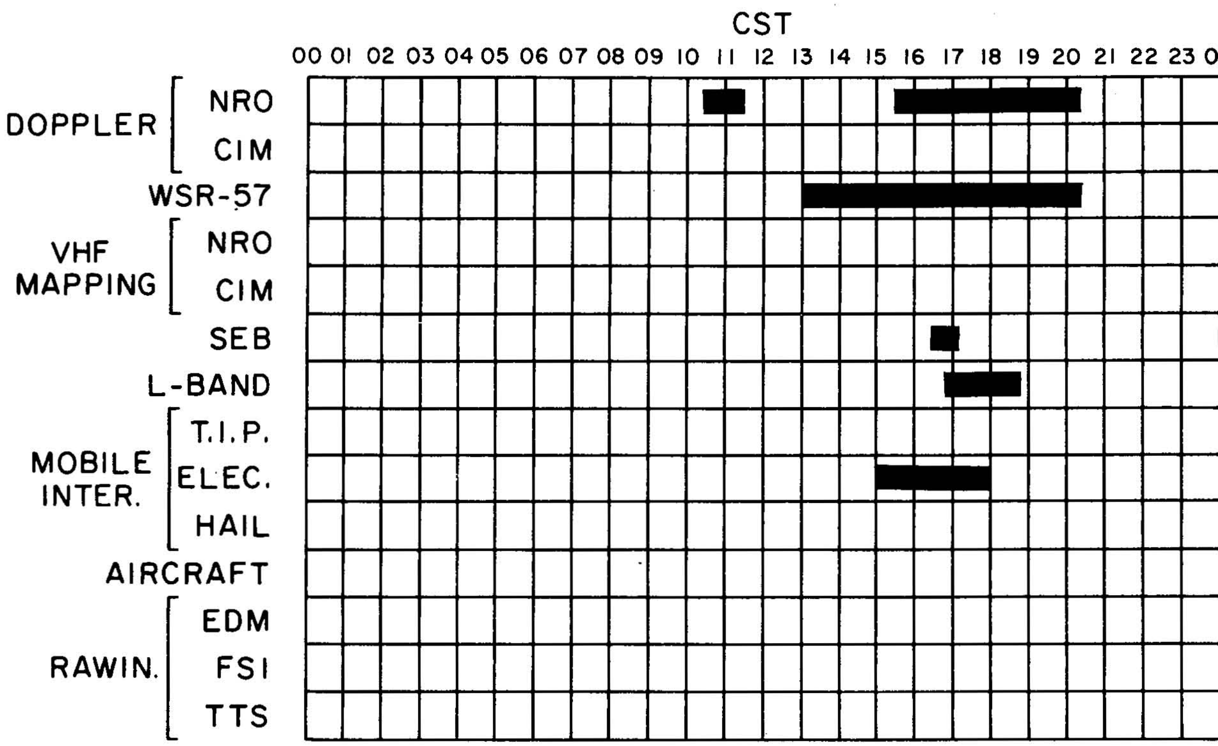
5.14.4.1 Tornado Intercept Project

Delayed by over an hour by vehicle breakdown, the NSSL team finally left for northern Texas at 1340. The time lost proved costly as it prevented us from intercepting a strongly rotating wall cloud near Possum Kingdom Lake on which the Mobile Electric Laboratory (MEL) collected data. At 1712 we passed a long shelf cloud to our west. We stopped 9 miles south of Perrin at 1745 to photograph 4-inch hail lying by the roadside. Five minutes later, a slowly rotating protuberance, which extended downward from cloudbase halfway to the ground but did not seem to be tornadic in nature, passed close by. Continuing southward, we observed a wall cloud to our west from 5 miles north of Mineral Wells at 1803. This marked the same mesocyclone which MEL had first intercepted near Possum Kingdom Lake and which had drifted very slowly to the east. For the next forty minutes we observed a series of wall clouds forming on the west side of the storm near Mineral Wells as the center of circulation was redefined at frequent intervals. Finally, we moved eastward into Mineral Wells to telephone NSSL as we could no longer see a wall cloud. As we talked (1855), we noticed that heavy rain was being swept around us cyclonically by strong winds. We were in the mesocyclone! The mesocyclone was now moving rapidly eastward and, not being in position to see a new wall cloud reported on the east side of Mineral Wells, and with darkness approaching rapidly, we broke off the intercept and headed home. The storm that we left later inflicted tremendous property losses in Ft. Worth and Dallas, mostly through widespread hail damage. On the way back, we passed through 1-inch hail at Jacksboro (2110) and marble-size hail in three other cores.

5.14.4.2 Mobile Electricity Lab

All systems were operational and very good data were obtained on storms in areas of Wichita Falls, Graham, and Mineral Wells, Texas. Three wall clouds were observed including cyclogenesis east-northeast of one. Measurements were made near and beneath wall clouds and frequent lightning was observed.

5.15 13 May, Wednesday, 1981 - Day 133



5.15.1 Weather Situation

Mid-tropospheric westerlies over North America had become concentrated into two strong branches; the northern branch over central Canada and the southern branch over the southern United States. The southern branch had a mean trough position over the southern plains (Texas and Oklahoma) which brought a succession of strong storm systems to the NSSL data collection region (13, 17, 22 and 23 May). The first shortwave disturbance was upstream of Oklahoma on the morning of 13 May. It was reflected at the surface by a cold front bisecting the state from southwest to northeast with a moderate frontal wave (surface pressure 1004 mb) situated over southwest Oklahoma.

The airmass ahead of the front was highly unstable (lifted indexes as low as -10) with substantial tropospheric winds and shears detected on morning rawinsondes. The problem for NSSL data collection was that the system was forecast too far eastward before the time of afternoon storm initiation. The front passed NSSL about noon and moved across eastern Oklahoma during the afternoon. Although the system failed to intensify further (minimum surface pressure rose to 1008 mb by evening), an intense squall line formed about 100 km east of NSSL and swept across eastern Oklahoma, northeastern Texas and western Arkansas. Thirteen tornadoes were reported including 4 in southeast Oklahoma and a violent tornado northwest of Paris, Texas, which destroyed 90% of the small town of Emberson, Texas.

5.15.2 Radar Summary

Prestorm data were collected as a low pressure center passed through the area. Thunderstorms built to the southwest along the cold front within 75 km southeast of the radar. From 1530-2020, NRO recorded data each 10 minutes on a broken squall line which moved from 100 to 350 km to the southeast. Mesocyclones were noted in several of the cells; there were reports of tornadoes from these cells.

5.15.3 Storm Electricity

5.15.3.1 Lightning Mapping

None.

5.15.3.2 SEB Operations

L-band lightning echoes and Mobile Electricity Lab data coordination were conducted on a tornadic storm. Data quality is fair. Field changes from distant lightning recorded at the SEB are of poor quality.

5.15.3.3 Lightning Ground Strike

Lightning activity was to the N and NE of Norman initially. Later there was activity to the east.

5.15.4 Mobile Intercept

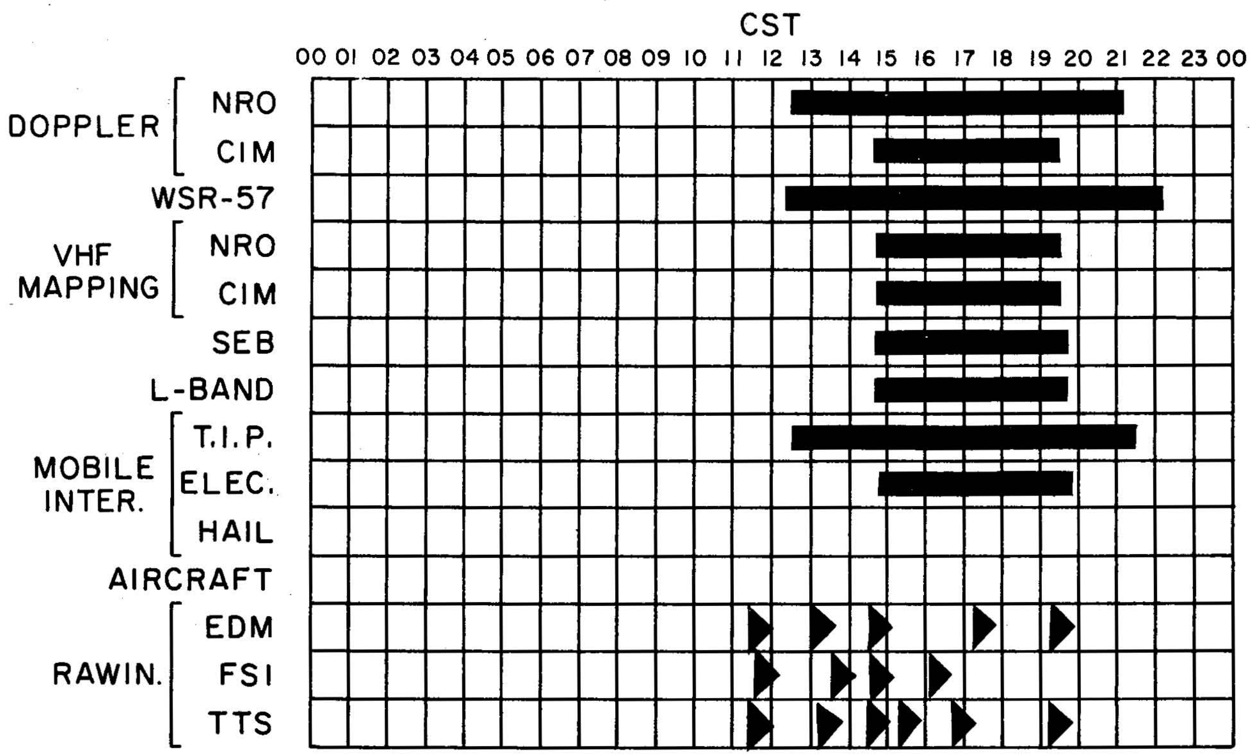
5.15.4.1 Tornado Intercept Project

None.

5.15.4.2 Mobile Electricity Lab

All systems were operational. Data obtained close to tornadoes near Atoka and Antlers. Data are apparently good.

5.16 17 May, Sunday, 1981 - Day 137



5.16.1 Weather Situation

This day was a textbook example of a classic tornado outbreak centered on Oklahoma. At dawn, a strong shortwave was located over New Mexico at the base of the southern branch, longwave trough. A warm front was located across central Oklahoma and a dryline was forming in extreme western Oklahoma. Copious low-level moisture was being advected northward into southern Oklahoma in advance of the system. Surface dew points reached the low to mid-70's in central and eastern Oklahoma by afternoon.

During the day, the upper disturbance moved eastward and intensified a surface low in northwestern Oklahoma, surface pressure fell to 999 mb. In the cyclonic flow around the low, the warm front moved northward to the Oklahoma-Kansas border and the dryline moved eastward to a north-south line just west of NSSL. The airmass within the warm sector was highly unstable and NSSL's special, serial rawinsondes indicated increasing instability with time based on solar heating, differential advection and upward vertical motion. Afternoon lifted indices were on the order of -8 in the data collection region.

A scattered line of strong thunderstorms formed just east of the dryline (1400-1500) and moved eastward. The first storm to mature and become tornadic was the one along the warm front with each succeeding development down the dryline resulting in a tornadic storm. The southern two storms in the line (both tornadic) formed and grew to maturity within the dual Doppler sampling region. The convection continued quite severe across eastern Oklahoma during the late afternoon and evening with 14 tornadoes (including 2 that were violent) and other damaging wind and hail (see Fig. 1 in Section 7).

5.16.2 Radar Summary

Prestorm data were collected as thunderstorms slowly developed ahead of a dryline. A weak cell first appeared 90 km to the northwest. Dual mapping began during the early development of the two cells in the southern lobe (1440-1525). This appears to be an excellent prestorm case because of the high resolution afforded by the location of storm initiation. Dual mapping continued (1525-1625) on the southern cell (60 dBZ maximum) in which a mesocyclone was observed. Coverage switched to the northern storm (1625-1730) which was now strongest as it passed within the northern lobe of the dual Doppler area. Severe weather reports were numerous from both storms. With a tornado reported to the east, associated with the southern storm, two attempts at the HPRF were recorded at 1730 and 1805 by NRO while CIM continued scanning the storms. Two short lines of storms developed to the west of this storm with NRO coverage beginning at 1830. Coordinated sector scans were made (1845-1925) as strong shear was observed in the middle line (tornado reported near Tecumseh). There were continuous single radar data as the storms moved east (1925-2110). Mesocyclones were observed and several tornadoes occurred during this period.

5.16.3 Storm Electricity

5.16.3.1 Lightning Mapping

Good dual mapping data were obtained on storms moving northeastward from southwest to northwest of Norman between 1447 and 1626. Both sites obtained good data on a storm north of Norman between 1626 and 1655. A newly active storm south of Norman was observed from 1655 to 1704 but the range from Cimarron was too great for good mapping, so the northern storm was again observed with good results until 1732. At that time, the storm that was observed south of Norman at 1700 had moved southeast of Norman and had become tornadic. Good single mapping data from the Norman site were obtained from this storm.

5.16.3.2 SEB Operations

Continuous data acquisition was maintained and all SEB and L-band data quality is very good.

5.16.3.3 Lightning Ground Strike

There were two regions of lightning activity within 50 km of Norman, one to the south and one to the north. The storms moved eastward out of Oklahoma during the night. There was also some lightning 100-150 km to the north.

5.16.4 Mobile Intercept

5.16.4.1 Tornado Intercept Project

We left NSSL at 1247 and stopped 10 miles west of Minco at 1345 to watch towering cumuli evolve through their life cycles to the west along the dryline. By

1430 a cumulonimbus had developed to our east, and we moved for an intercept. At 1530, this storm developed a wall cloud near Minco, but we received instructions from NSSL to head south for a storm, which was in a more favorable position for dual-Doppler coverage. (This was a fortunate decision since the northern storm only produced a single, short-lived tornado.) We encountered 3/4-inch hail from the southern storm near Dibble at 1614, and observed a wall cloud which we tracked as it moved northeastward. At 1652 we photographed a tornado 4 miles to our north near Noble. Our vehicle broke down in Norman at 1710, but fortunately we soon found the cause. Heading east on some bad roads, we lost more valuable time and our frustration mounted as MEL reported a tornado near Tecumseh at 1810. With MEL's guidance, we were able to penetrate the heavy precipitation in the hook echo region of the storm, and photograph the tornado at 1825 as it crossed the road less than a mile to our east, 3 miles west of Earlsboro. We observed a blue cloud-to-ground lightning bolt close to the funnel. Leaves were still falling out of the sky as we crossed the damage path. The tornado dissipated soon after crossing the road. This storm had established a definite pattern of new mesocyclone cores forming on the right sides of their predecessors as the older cores occluded and decayed, and this predictability enabled the intercept teams to recognize the formation of a new wall cloud and tornado near Little at 1849. This tornado crossed the road just ahead of us (to our north by less than a mile). We observed blue electrical discharges inside the funnel as a substation was hit, and then large pieces of debris floating through the air as the tornado, by now serpentine and rope-like, damaged a house and a garage just off the road. Gaps appeared in the condensation funnel, and twice the lowest segment of condensation seemed to sink into the ground as its top end lowered dramatically. The motion around the funnel, as revealed by the large debris, was still upward, however, and the observed gyrations of the funnel were probably due to waves traveling along the vortex core. Shortly after the Little tornado decayed, a large funnel briefly descended two-thirds of the way to the ground at 1854 from the same region of the storm. We stopped 3 miles north of Little to refuel, and to observe the mesocyclone to our east and another one to our west. At 1925 we decided to track the mesocyclone, which unbeknown to us contained a long-track tornado that had touched down just southeast of Little and remained weak until strengthening dramatically near Okemah. We had to proceed cautiously, however, after entering the mesocirculation and at 1943 we called off the pursuit because of darkness. We noticed strong westerly winds flowing into the rear of the mesocyclone.

This day was an extremely successful one for the Intercept Project. The MEL crew obtained close-range films of the Noble, Tecumseh and Little tornadoes, two of which are suitable for photogrammetric analysis of tornadic flow fields. The Tecumseh film was taken while the tornado was in its multi-vortex phase, and the Little footage while large pieces of debris were airborne. The NSSL team took movies of these tornadoes with a "Vonnegut" camera and no luminosity of electrical origin was detected in the funnels during the filming sequences. The OU team deployed TOTO beneath a rotating wall cloud for the first time, and obtained some interesting data. Observations of the discontinuous rightward propagation of the wall cloud-mesocyclone region of the storm and of the associated generation of a tornado family were also of considerable scientific interest.

5.16.4.2 Mobile Electricity Lab

Data were collected first in Anadarko-Chickasha region. After 1600, observations were made in region of Blanchard, Purcell, and Seminole. Three tornadoes were observed, sound packages were deployed, and continuous electrical data were obtained on a long track (20 min.) tornado. Data are very good.

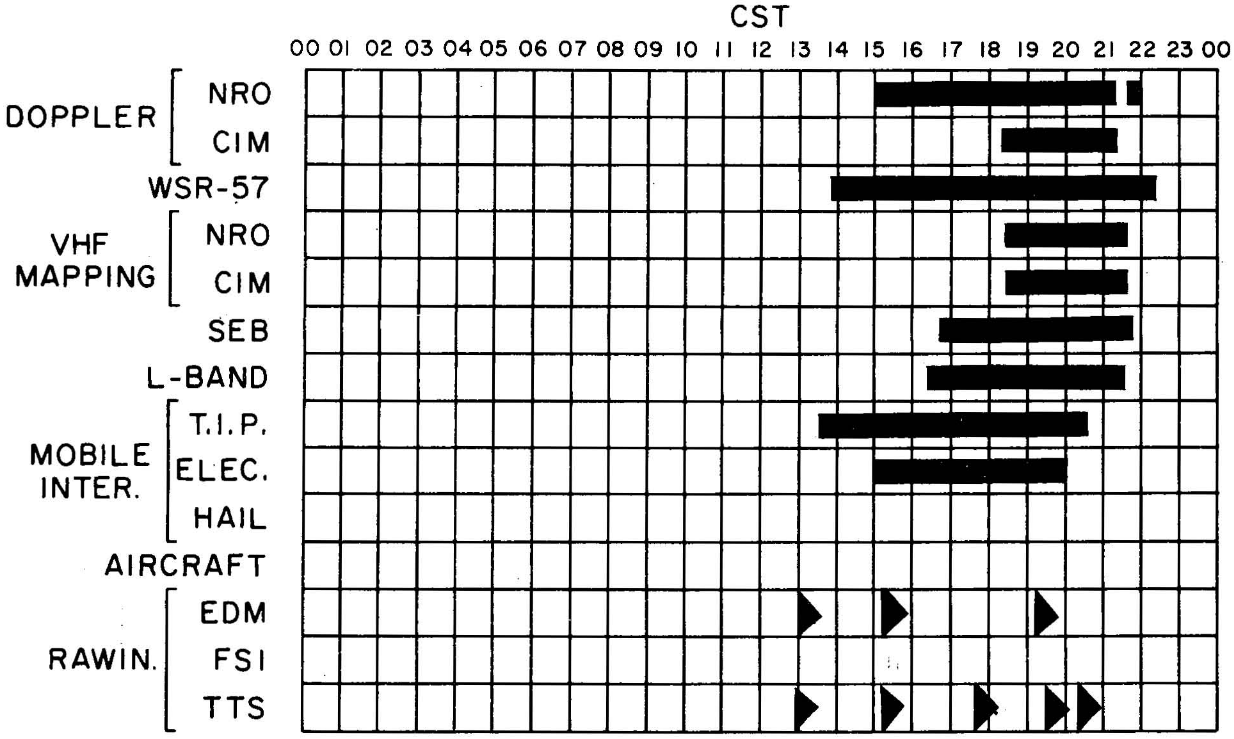
5.16.5 Aircraft Operations

None.

5.16.6 Other Observations

KTVY-TV meteorological tower observations at 1 sec intervals 1515 to 1900 CST and Will Rogers International Airport LLWSAS data recorded 1550 to 1932 CST as strong thunderstorms moved through the area.

5.17 22 May, Friday, 1981 - Day 142



5.17.1 Weather Situation

Although tropospheric winds were moderate and the airmass over Oklahoma was quite unstable (lifted indices of about -7), the morning forecast called for only a low probability of thunderstorms. The reason was the failure to detect any triggering mechanism (shortwave disturbance, cold air advection, heating to convective temperature, etc.) to aid the forecast low-level convergence along a quasi-stationary dryline in the eastern Texas Panhandle.

During the afternoon, surface temperatures in a narrow band along the dryline rose higher than expected (near 100° F) and the convective temperature was reached. Heating combined with the approach of a weak upper trough and the development of a dryline wave resulted in isolated severe thunderstorm formation just east of the dryline. The few storms produced much severe weather across western Oklahoma with one storm reaching the dual-Doppler sampling area just as it produced a violent tornado near Binger, Oklahoma (see Fig. 2 in Section 7). In all there were 13 tornadoes and several other severe events in the state. One of the tornadoes struck the eastern side of Clinton, Oklahoma, inflicting 12 injuries and $10 million in damage.

5.17.2 Radar Summary

Single Doppler coverage began as a broken line of heavy thunderstorms approached from 200 km west of NRO. A mesocyclone was first apparent (1525) 170 km to the west. Data were recorded about every 5 minutes until 1630. Very strong shear and a hook were observed as the storm moved east. Continuous data were recorded from 1630-1815. During this time, the earlier storm weakened; two new storms with mesocyclones developed and moved to 100 km west and 150 km west-northwest. There were twenty dual Doppler tilts (1815-2000) on the storm directly west as it moved east-northeast towards CIM (on the edge of the dual radar network). Two separate tops and bounded weak echo regions were observed. High PRF data were collected while a large tornado was reported on ground about 70 km west-northwest (1857-1906 and 1923-1927). Single Doppler data (2000-2020) was followed by coordinated sector scans (2020-2130) as the storm moved to the northeast, but was no longer tornadic. Finally, some additional data were collected on storms to the northwest, where weak-to-moderate cyclonic shear was observed.

5.17.3 Storm Electricity

5.17.3.1 Lightning Mapping

Fair to good dual mapping data were recorded from the storm that produced the Binger tornado. Impulse rates observed at Norman were low (because the storm was beyond nominal range) until after passing just north of Cimarron.

5.17.3.2 SEB Operations

Continuous data acquisition was maintained with SEB and L-band. SEB data are of good quality after 1725 when lightning got closer.

5.17.3.3 Lightning Ground Strike

Storms formed to the west along the Texas border between 1000-1400 and moved into western Oklahoma from 1400-1700. There were two regions of activity, a southern region that was over Cordell near 1630, and a northern region that died out. In late afternoon, another region formed to the NW of the Cordell storm. Lightning activity in the new storm intensified as it moved toward Watonga. There was also infrequent, scattered lightning in a line to the NE of Norman. Lightning in the southern storms (which included the Binger tornado) died out by 2200, but the storm complex that went over Watonga continued to produce lightning. Little or no data were recorded on magnetic tape beyond 1720 because of a malfunctioning tape recorder.

5.17.4 Mobile Intercept

5.17.4.1 Tornado Intercept Project

Encouraged by backed winds and high dewpoints ahead of a strong dryline on the western Oklahoma border, the NSSL team left at 1334. When we were 15 miles east of Cordell at 1530, we were impressed by the towers of a storm (the "Cordell" storm) to our west-southwest. At 1557 we intercepted a wall cloud at the storm's right rear flank, and observed a funnel cloud at Dill City. We stopped 2 miles north of Dill City at 1605 to film the wall cloud, and experienced strong southwesterly winds blowing into the mesocyclone. We then headed east after the wall cloud and noticed rapid downward motion on its rear side. At 1616, the "Cordell I" tornado first became visible as a vigorous dustwhirl below cloud base 2 miles to our north. The tornado passed northwest of the town. After passing through the built-up area we stopped on the north side of Cordell to take movies and slides of the tornado (which was 2-3 miles to our north) from 1620 to 1627. A dustwhirl northeast of the tornado was visible briefly at 1625. The Cordell I tornado decayed at 1627 as its base moved eastward relative to the top of the funnel and it became S-shaped. We headed north after the mesocyclone and noticed a new tornado (Cordell II) which had formed along the same track immediately after the demise of the old one. This new tornado was poorly contrasted against the sunlit precipitation shaft about 2 miles to our northeast, and we were able only to take slides of it. We lost sight of this tornado in the rain around 1637.

At 1700 it became evident that the Cordell storm had weakened considerably and that a storm to its southwest (which we call the "Binger" storm) had intensified rapidly. As we headed southwest to intercept this storm, we noticed long "inflow" clouds leading into the storm from the east. As we traveled south from the junction of highways 152 and 54 at roughly a mile a minute, we encountered successively larger hailstones with pea- (1712) followed by marble- (1716) and finally golf-ball size (1718). As we emerged from the hail, we noted a spiral rain curtain to our southwest. The MEL team, just ahead of us, reported three or four small, transient, dust-whirl tornadoes near Lake Valley between 1720 and 1738. We continued southward in search of fuel and missed these short-lived vortices. We found an open gas station at Mountain View, and called NSSL during our stop (1741-1753). The right rear flank of the storm had a peculiarly smooth, laminar appearance with the flanking cloudline increasing uniformly in depth with proximity to the main storm tower. This contrasted greatly with the more irregular, stair-step, cumuliform flanking line which we were accustomed to seeing. We observed a tornado ("Alfalfa I") 6 miles to our northwest between 1804 and 1807 while driving northward 2-5 miles south of Alfalfa. MEL's movies revealed that this tornado reversed direction (i.e., started moving to the south) before dissolving. Sterling Colgate of Los Alamos Scientific Laboratories fired instrumented rockets from an airplane at this tornado, but the desired penetration of the vortex was not achieved due to equipment malfunction. The storm copied the earlier Cordell storm by immediately producing another tornado ("Alfalfa II") along the same track as the first one. We stopped 1 mile south of Alfalfa to film this tornado, which was about 5 miles north-northwest of us (and larger than its predecessor), during its 13-minute life (1708-1721). From our position, the structure of the mesocyclone was revealed beautifully by the clouds. A low, dark band of clouds, curving cyclonically into the wall cloud from the south, visualized the gust front. To the west of the gust front, a clear slot (Lemon and Doswell, 1979) divulged the presence of a rear-flank downdraft. The extensive, sunlit, vertical wall on the south side of the wall cloud marked the updraft-downdraft interface. We could clearly tell that the tornado was in a mesocyclone core which was occluding, and that a new mesocyclone core was forming to the southeast of the old one along the bulge in the gust front.

The new core quickly produced a minor tornado at Swan Lake, 6 miles east of us, at 1830. This tornado was a narrow column of dust spanning the sub-cloud layer. We headed east to catch up with the new core, and ran into a thick cloud of blowing dust at 1846-1848, 3 miles west of Binger. Visibility was reduced to a few yards. The dust was being whipped up from plowed fields by strong northerly winds sweeping around the back side of the mesocyclone. At 1850 we stopped on a hill overlooking Binger to film a massive tornado 1 or 2 miles to the northeast. This maxi-tornado was a wide column of dust extending up to cloudbase with small suction vortices, highlighted by sunlight reflected off their condensation filaments, dancing around the base of the column. As we watched, the dust column became more opaque and we lost sight of the sub-vortices. Dust bands were flowing into the tornado from both the north and south sides. A rain curtain wrapped around the huge vortex cyclonically, gradually obscuring our view. At 1855 we headed east in pursuit of the receding tornado. Unfortunately, the terrain east of Binger is rugged, and we were only able to catch occasional glimpses of the tornado to our north.

We stopped on a hill 2 miles west of Cogar to view the tornado (which was near Scott, about 4 miles northwest) at roughly the time NSSL was collecting high-PRF data. The condensation funnel was from two-thirds to one kilometer wide at this time, and the tornado's distinct rumbling sound was clearly (but faintly) audible. At 1911, as the gustfront overtook our position, a "gustnado" passed close by. We moved east once more at 1913, and saw the tornado again, this time as a diffuse dustcloud, 2 miles north of Cogar at 1919. We spotted a rope tornado, probably the decaying Binger tornado, to our northwest at 1927 from 6 miles east of Cogar. The Binger storm produced another tornado 5 miles northwest of Union City at 1935, which we were not in position to see. As we headed home because of darkness, we observed that the storm still had a menacing wall cloud as it moved across northwest Oklahoma City.

Thus, concluded another very profitable day for the Intercept Project. MEL had obtained close-range movies of Cordell I, Alfalfa I and II and Binger tornadoes. The OU team had also filmed the Cordell I tornado, and we (the NSSL intercept crew) had taken movies of Cordell I, Alfalfa II and Binger. The NSSL and MEL films of Cordell I overlapped in time, so that stereophotogrammetry of a tornado can be attempted for the first time. Because of low light, fast film was used for the brief footage taken of the Binger tornado, and the only quantitative windspeed estimates possible are of cloud tag motions in the wall cloud. TOTO was deployed within 1 mile of both the Cordell I and Binger tornadoes, and windgusts up to 32 $m \cdot s^{-1}$ (72 mph) were recorded (Bluestein, 1982). Photographs of the Alfalfa mesocyclone beautifully illustrate typical mesocyclone structure and evolution. The observed sequence of vortex events in the storms starting from funnel clouds and transient, small tornadoes and progressing to far more significant tornadoes, has interesting theoretical implications.

5.17.4.2 Mobile Electricity Lab

There is a short period of electrical data on the Cordell tornadic storm. A total failure of the research power system resulted in no other data recorded on this day. Excellent movies and slides of the Binger tornado are available.

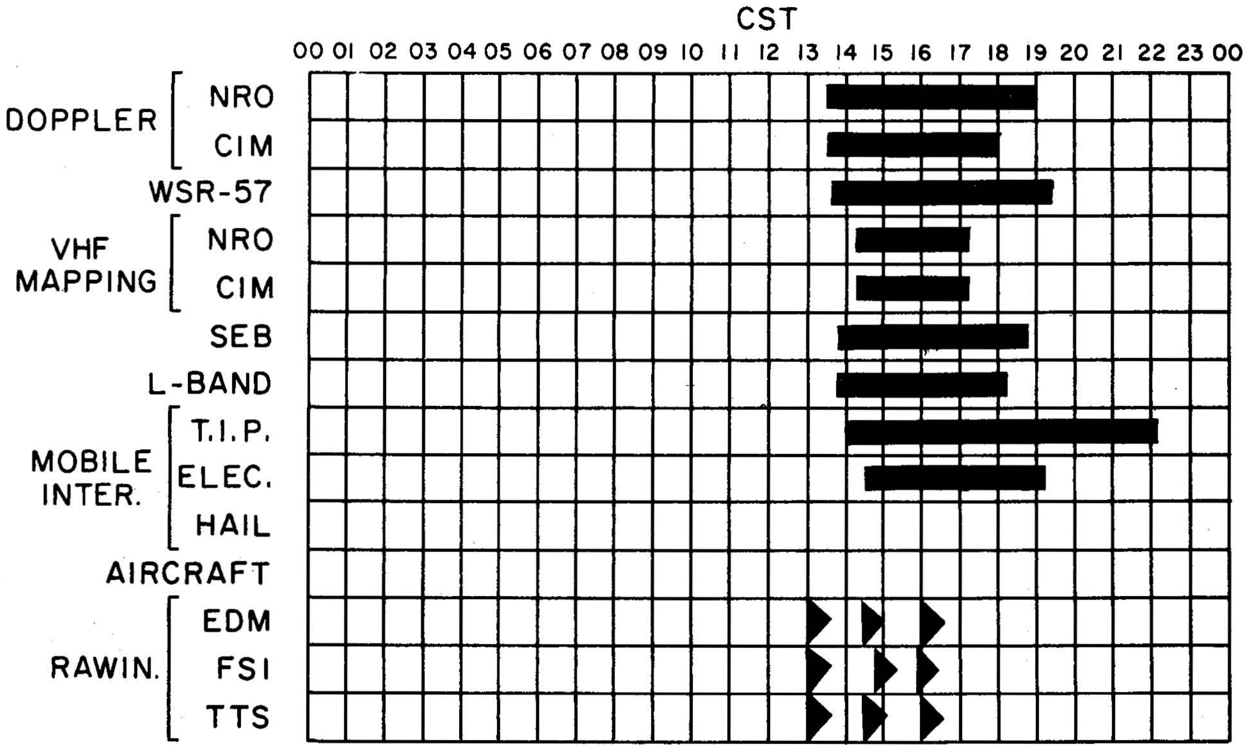
5.17.5 Aircraft Operations

None.

5.17.6 Other Observations

KTVY-TV tower operated at 1 sec intervals 1745-2215 and Will Rogers International Airport LLWSAS data recorded 1820-2140 CST as severe thunderstorms moved through central Oklahoma.

5.18 23 May, Saturday, 1981 - Day 143



5.18.1 Weather Situation

A surface cold front, extending north-south through the Great Plains, had moved into extreme northwest Oklahoma by dawn and was forecast into the data collection area by mid-afternoon. The front was being pushed southward by a building high pressure ridge over the Northern Plains states; strong north winds and significant pressure rises were occurring across western Kansas. Aloft, a moderate shortwave was approaching from the west with PVA expected from Texas to Iowa. East of the front in Oklahoma and in a broad region of the plains, the airmass was quite unstable (lifted index of -9 over central Oklahoma at midday).

During the afternoon, frontal waves formed in Iowa and in northwest Texas, providing additional convergence along the advancing front. Storms formed all along the front and joined into a 1000 mile long squall line by evening. There was an outbreak of severe weather associated with the squall line; 29 tornadoes and over 40 severe thunderstorms were reported between 1430 and 2230. In Oklahoma alone, there were 11 tornadoes and much severe weather. Activity in Oklahoma monitored by NSSL began in the dual-Doppler area and moved southeastward with most of the severe reports to the southeast of the prime data collection region.

5.18.2 Radar Summary

Data consisted of dual mapping of a hailstorm to the north alternated with single Doppler coverage of a storm to the south which was associated with tornadic activity.

5.18.3 Storm Electricity

5.18.3.1 Lightning Mapping

Dual mapping data was obtained on storms north of Norman. Impulse rates were low but the correlation of lightning activity between the sites was very good.

5.18.3.2 SEB Operations

Continuous data acquisition with SEB and L-band. Data quality is very good. Flashing rates were high. After 1800 there were data of long propagating lightning observed on back side of line.

5.18.3.3 Lightning Ground Strike

Two local regions of lightning activity were apparent at 1400; one about 50-80 km S of NRO and one 30-100 km north and NE. The main region of activity was located near Vernon, Texas.

Lightning activity started filling in along a line stretching through Oklahoma from Texas to Kansas at 1530 and was reasonably solid by 1630. The line moved eastward.

5.18.4 Mobile Intercept

5.18.4.1 Tornado Intercept Project

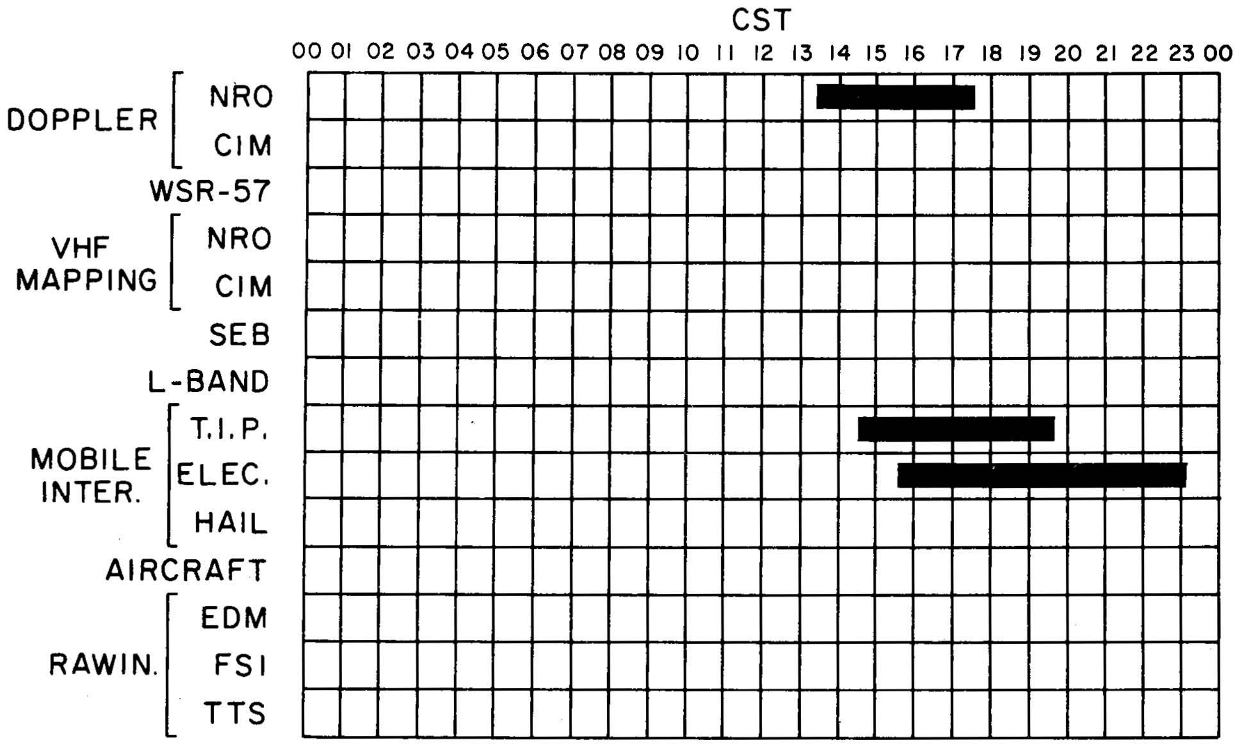
The team left NSSL to conduct a damage survey of the Binger tornado. By 1300 a line of towering cumulus had developed on the dryline to our east. An hour later the line contained cumulonimbi, and we headed SE to intercept the one with the most potential for severe weather. At 1543 we briefly encountered marble-size hail, falling from a high based cloud, when we were 15 miles south of Lindsay. We noted 1 inch hail on the ground in Elmore City (1554). MEL informed us at 1610 that there was a tornado a few miles east of us. Intervening rain prevented us from seeing the tornado, but we did observe a pair of short funnels along the gustfront to our SE. At 1615 we spotted in the cloudbase, a small-scale anti-cyclonic circulation, which crossed the road from south to north just ahead of us. At this time we were traveling east and were 5 miles east of Katie. Within a mile, we crossed the damage path (light damage to trees and barns) of the tornado which we had missed by five minutes. From 1630 to 1639 we stopped to refuel 3 miles west of Davis and were overtaken by a mesocyclone (evident by its spiralling rain curtains) from the SW. The Nowcaster advised us to pursue a stronger meso-cyclone a few miles to the east. Near Sulphur at 1650 we observed "staccato" lightning (intense cloud-to-ground lightning of brief duration) from the storm's anvil, the first of many such flashes seen during the next hour. On the north side of Sulphur at approximately 1710 we spotted an area of rapid, small-scale rotation in the turbulent cloudbase, and moved out of its path. One of the private storm chasers reported flying debris (small tree limbs) with this circulation as it passed him. We stopped east of Sulphur to continue observation of the mesocyclone.

By 1740 it was clear that the storm had weakened dramatically, and we went south in search of other storms. However, we soon realized that the storms were "lining out" (i.e., forming a squall line with a gustfront in advance and, hence, losing their supercellular identities), so we returned to NSSL.

5.18.4.2 Mobile Electricity Lab

All systems were operational as data were taken on tornadic storms southeast of Elmore City area. Research power failure at 1730 caused an end to data collection. Visual observations, filming, etc., continued until 1910. Data quality is currently unknown.

5.19 28 May, Thursday, 1981 - Day 148



5.19.1 Weather Situation

After the passage of the storm of 23 May, the southern branch of westerly flow across the United States weakened noticeably. Furthermore, the southern branch mean trough position retrograded westward and left Oklahoma near a ridge axis. Weather systems affecting the data collection region during the rest of the program were weaker and less organized. Such a weak disturbance moved across the central plains on 28 May with the tail end of the associated frontal system crossing Oklahoma. Despite the lack of synoptic-scale forcing, the airmass over Oklahoma was conducive to thunderstorms since it was warm, moist and unstable.

A mesoscale convective complex (MCC) boundary, propagating perpendicular to the front, moved southward into northern Oklahoma near noon and severe thunderstorms formed shortly afterward. This activity was confined to northeastern Oklahoma during the afternoon, well out of the prime data collection area. During the late afternoon and evening, a second MCC formed along the front in western Oklahoma and moved eastward, passing across the data collection area after dark. Three reports of severe weather in southwestern Oklahoma occurred before dark.

5.19.2 Radar Summary

There were sector scans to the northeast followed by full PPI's (1320-1455) as severe weather was reported near Tulsa; later a northwest-southeast line of storms developed >200 km to the southwest. Sector scans followed on these later storms. New cells (55 dBZ) eventually formed within 100 km to the southwest by 1700, but these had short lifetimes.

5.19.3 Storm Electricity

5.19.3.1 Lightning Mapping

None.

5.19.3.2 SEB Operations

None.

5.19.3.3 Lightning Ground Strike

There was a region of lightning activity SW of Childress at 1400. Activity moved NE from Childress into Oklahoma at about 1700.

5.19.4 Mobile Intercept

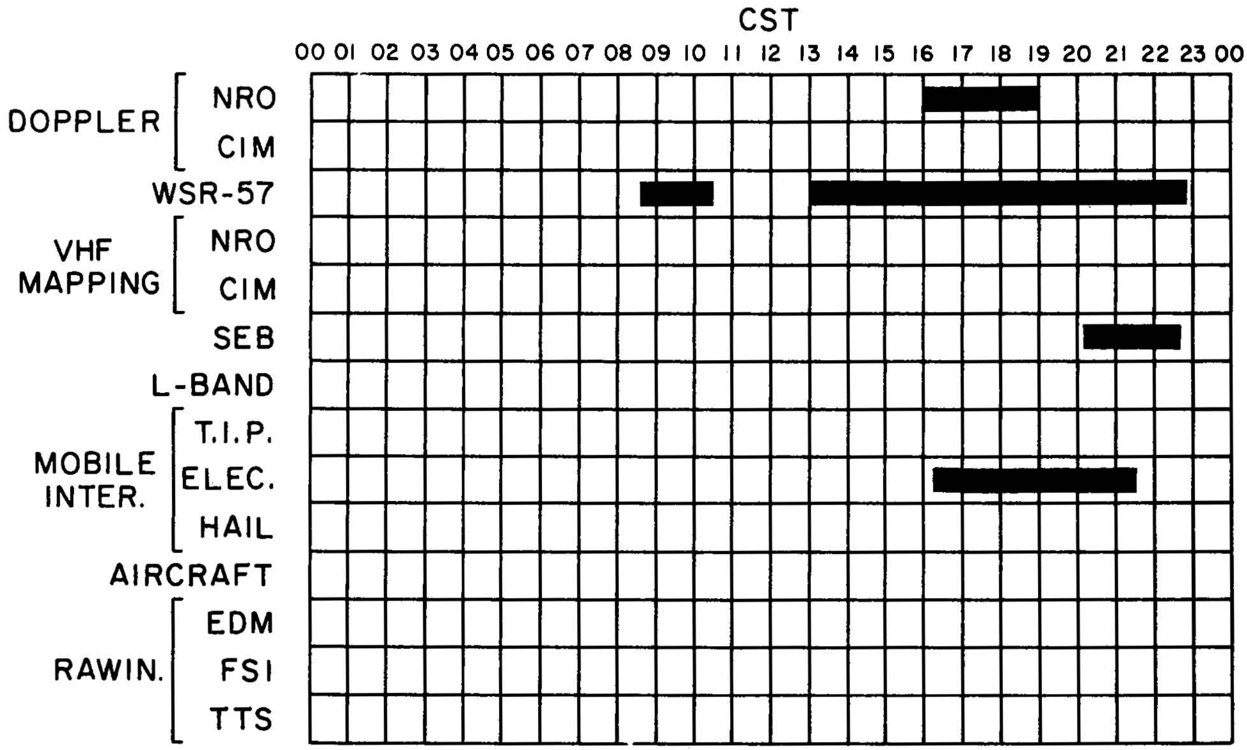
5.19.4.1 Tornado Intercept Project

NSSL 1 intercepted a nonsevere storm 10 miles south of Carnegie at 1735 just as it was "raining out" (i.e., dissipating).

5.19.4.2 Mobile Electricity Lab

All systems were operational continuously for first 3 1/2 hours while tracking a storm in Vernon, Texas, area. Data quality is apparently good.

5.20 1 June, Monday, 1981 - Day 152



5.20.1 Weather Situation

With a surface high pressure area having passed to the east of Oklahoma and southerly winds returning moisture northward, Oklahoma was again set for the arrival of another series of weak upper air disturbances to trigger thunderstorms. Beginning during the night of 31 May - 1 June and continuing through the evening of 3 June, numerous lines of convection passed across Oklahoma from west to east.

At dawn on 1 June, a quasi-stationary front lay north/south across the Texas Panhandle and West Texas and a weakening squall line was in western Oklahoma. A minor upper disturbance, initially over western New Mexico was forecast to interact with the front over the Texas Panhandle and produce a squall line which would arrive in the data collection region between dark and midnight.

It was anticipated that the weak storms in western Oklahoma would die by noon and not be suitable for data collection.

In large part the forecast was correct. A squall line did form in the Texas Panhandle during the afternoon and did move eastward into central Oklahoma about 2100. Also, early showers in Oklahoma did dissipate by noon. However, continued low-level southerly advection combined with afternoon heating produced a very unstable airmass over central Oklahoma (lifted index estimated at -8). A line of thunderstorms, perhaps organizing along the outflow boundary left over from the dissipated morning convection, developed unexpectedly over the data collection region between 1600 and 1700. Several of the storms were severe with much hail damage reported; $10 million in Oklahoma City and Edmond alone. Unfortunately, the inability to correctly forecast development prohibited dual-Doppler data collection on the early activity.

5.20.2 Radar Summary

Data collection was in the form of full PPI's as scattered thunderstorms developed in central Oklahoma. Later, a squall line formed ~100 km to the west.

5.20.3 Storm Electricity

5.20.3.1 Lightning Mapping

None.

5.20.3.2 SEB Operations

All SEB systems except L-band up. Data quality good.

5.20.3.3 Lightning Ground Strike

In the morning, there were storms north of Lawton, west and NW of Watonga, in north Texas, and the Texas Panhandle. In the early afternoon, there was some lightning east of Norman and in North Texas, and a line of activity started forming in the Texas Panhandle. By 1600, there were lines of activity west of Wichita Falls, from Oklahoma City to Dodge City, and from Lubbock to south of Gage. This last line persisted and moved eastward and southeastward. By 1800, it was from south of Lubbock through Cordell to Wichita, Kansas. By 2100 there was a line through Oklahoma City and Lawton to south of Lubbock.

5.20.4 Mobile Intercept

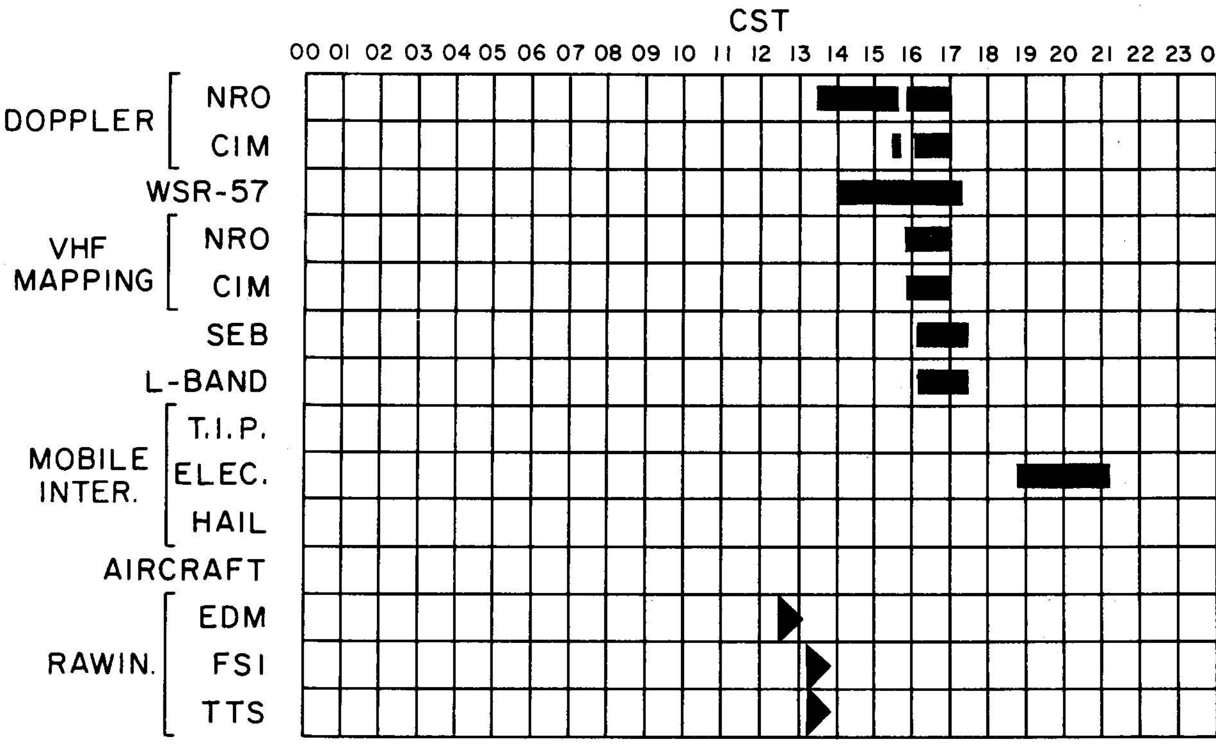
5.20.4.1 Tornado Intercept Project

None.

5.20.4.2 Mobile Electricity Lab

All systems were operational while in vicinity of Perryton, Texas. Data quality is good.

5.21 2 June, Tuesday, 1981 - Day 153



5.21.1 Weather Situation

Much the same situation existed as that of 1 June; the front remained quasi-stationary in the Texas Panhandle and weak convection was again occurring over central Oklahoma during the morning. With the approach of another weak upper disturbance, another nighttime squall line was forecast to approach from the west, but, in addition, afternoon convection along mesoscale boundaries from previous convection was anticipated.

Southerly, moist flow continued at low levels and the air mass over central Oklahoma was highly unstable (afternoon lifted index of -7). Two isolated thunderstorms formed during the late afternoon in north-central Oklahoma, possibly along an old outflow boundary, but were not as significant as those of the previous day although they produced hail damage. An intense squall line, which produced tornadoes, swept through the Texas Panhandle during the afternoon and across western Oklahoma during the night.

5.21.2 Radar Summary

The prestorm data collection mode was employed until about 1600; scattered short-lived cells (<30 dBZ) formed within 100 km of NRO. Cells to the northwest became strong (~60 dBZ) and were in the edge of the northern lobe of the Doppler network as dual scans were collected (1605-1700).

5.21.3 Storm Electricity

5.21.3.1 Lightning Mapping

Only fair data were obtained from a storm located north of Cimarron. The correlation between flashes was very good although the impulse rates were low.

5.21.3.2 SEB Operations

SEB and L-band data acquired. Field change data poor quality due to distance to flashes.

5.21.3.3 Lightning Ground Strike

In the morning, there was lightning activity near the Dallas-Ft. Worth area and over Enid. The activity in north Texas continued throughout the afternoon. Between 1300 to 1600, a new region of activity formed just north of Amarillo and there was scattered activity in Oklahoma, most concentrated north of Watonga. The Watonga and Panhandle storms intensified and moved SE. By 2400, the Watonga storm was dying out over Norman.

5.21.4 Mobile Intercept

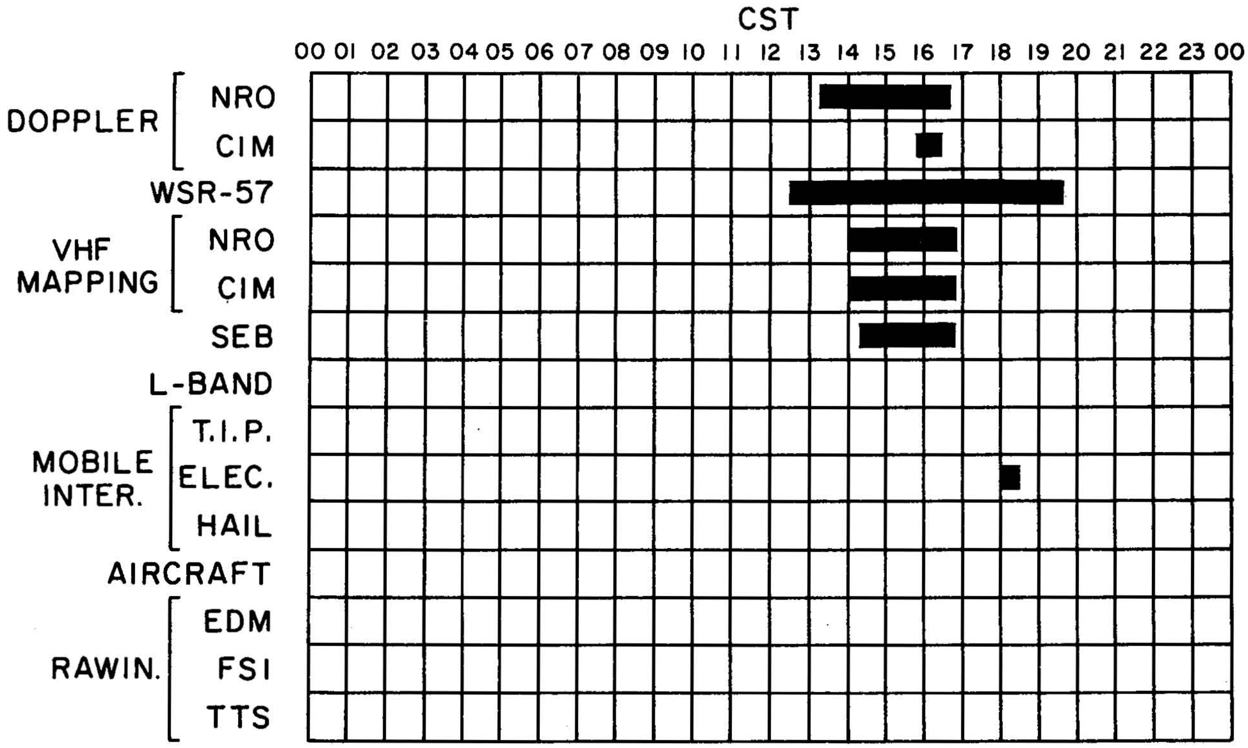
5.21.4.1 Tornado Intercept Project

None.

5.21.4.2 Mobile Electricity Lab

All systems were operational including S-band radiometry observations.

5.22 3 June, Wednesday, 1981 - Day 154



5.22.1 Weather Situation

The shortwave in the Texas Panhandle slowed its progress during the night 2 June - 3 June and on the morning of the 3rd was centered over the western Oklahoma border. It had been transformed into a very small closed circulation observable up through the 500 mb height. The circulation was dramatically apparent as a well defined swirl on satellite photographs. Extending south from the circulation center were several cloud lines (apparent convergence lines) which produced lines of thunderstorms that rotated east and northeast across Oklahoma during the day as the circulation center migrated across northwest Oklahoma.

On this day the atmosphere remained quite disturbed because of the passage of several squall lines. Much vertical mixing and added clouds which reduced insolation led to less airmass instability (afternoon lifted index of -3). In general, there were more storms but fewer severe storms. One strong, although not severe, squall line passed across the NSSL data collection region during the late afternoon, accompanied by a well-defined gust front. Much data were collected on this line. After its passage, radar data collection was terminated for the day.

5.22.2 Radar Summary

Moderate convection already present in the morning approached from the west. PPI data were collected about every 5 minutes (1315-1425), followed by sector scans to the southwest and west (1425-1553). A 50 dBZ cell developed along an approaching line of showers in the southern lobe of the dual radar network; dual scans were recorded (1553-1625). The cell passed over NRO as the reflectivity increased to 60 dBZ and was accompanied by small hail. Vertical HPRF data were collected (1628-1640) with occasional lightning overhead (one strike occurred in the vicinity of the radar (1636)).

5.22.3 Storm Electricity

5.22.3.1 Lightning Mapping

Very good dual mapping data were obtained after a line of thunderstorms moved within nominal range from west of Norman. Observations were switched to the vertical looking mode at Norman (1632-1652) as storm moved overhead and recorded a number of flashes simultaneously observed at Cimarron.

5.22.3.2 SEB Operations

All sensors operational, data quality very good.

5.22.3.3 Lightning Ground Strike

In the afternoon, the most intense storm was initially south of Altus in Texas, moving ESE. There was a line from Texas to Kansas west of Norman, with less intense activity in Oklahoma. The line moved over Norman at approximately 1600-1700. There was infrequent lightning to the NW at less than 50 km between 1700 and 2100. Magnetic tape data are of questionable quality.

5.22.4 Mobile Intercept

5.22.4.1 Tornado Intercept Project

None.

5.22.4.2 Mobile Electricity Lab

Primary objective was S-band radiometry observations. Data were acquired on storm in Texas. Data quality is good.

6. OTHER OBSERVATIONS

Several other experiments were conducted after the last major storm period of the season on June 3 and also after the official end of the Spring Program on June 22. These include the Lightning Strike Locator, the Airborne Doppler and the CV990 Experiment. The weather situation for June 29 - July 2 and a summary of these special observations are presented in this section.

6.1 18 June, Thursday, 1981 - Day 169

6.1.1 Bendix/Collins Systems

Thunderstorm data were collected in conjunction with Bendix system.

6.2 19 June, Friday, 1981 - Day 170

6.2.1 Bendix/Collins Systems

Thunderstorms were in the area. Data were collected for airborne system test. Collins Doppler radars (X- and C-band) arrived for ground-based testing.

6.3 26 June, Friday, 1981 - Day 177

6.3.1 Bendix/Collins Systems

Thunderstorm data were collected for Collins test.

6.4 29 June, Monday, 1981 - Day 180

6.4.1 Bendix/Collins Systems

None.

6.4.2 Weather Situation

The mid-latitude westerlies had retreated north of Oklahoma by this date and tropospheric winds were light. With significant daytime heating (temperatures 95° to 100° F) and abundant gulf moisture, the atmosphere was convectively unstable (lifted index of -4) and suitable for thunderstorms.

A complex of thunderstorms formed on a stationary front in Kansas during the afternoon and propagated southeastward across northern and eastern Oklahoma during the night with reported flash flooding.

6.4.3 Lightning Ground Strike

A line of lightning activity stretching from just east of Wichita, Kansas, to northwest of Cordell, to southwest of Amarillo. Norman was on the extreme southeastern edge of the line. There was scattered activity elsewhere.

6.4.4 CV990 Experiment

The CV990 arrived in Central Oklahoma at about 1230 and we immediately proceeded to implement our experiment plan. Two experiments were conducted: (1) the boundary layer experiment and (2) the lifetime experiment. These experiments and their procedures are discussed fully in a proposal for research on "Analysis of Lidar, Radar, and Satellite Measurements on Severe Thunderstorms and their Environment" and is available at NSSL. Simply stated, the boundary layer experiment utilized the airborne Doppler lidar to map wind fields in the planetary boundary layer at various levels in order to (1) determine the structure of the convective boundary layer and (2) provide supplementary measurements to the Doppler radars, and (3) to intercompare lidar and radar wind measurements. The lifetime experiment had two purposes: (1) to demonstrate that the Doppler lidar can make consistent measurements and (2) to determine the lifetime of turbulent eddies. The experiment ran smoothly and there should be excellent data for convective boundary layer studies and intercomparisons of wind measurements by two completely independent instruments.

6.5 30 June, Tuesday, 1981 - Day 181

6.5.1 Bendix/Collins Systems

Convair 990 flight on thunderstorms provided thunderstorm data also for Collins Doppler radar test.

6.5.2 Weather Situation

Several storm outflow boundaries generated by overnight convection lay across Oklahoma in the morning. Upper support was lacking but abundant moisture and heating indicated a high probability of thunderstorm development along persisting outflow boundaries.

Two storm lines formed in early afternoon; one, oriented north-south, to the west of NSSL and a second, oriented east-west, just north of NSSL. Each complex produced a strong low-level outflow boundary with the two boundaries intersecting over Norman about 1500. Localized maxima of convergence and vorticity at the intersection point may have aided in the development of a weak but damaging tornado in Norman at 1520. No other severe weather was reported and storms dissipated after sunset.

6.5.3 Lightning Ground Strike

During the morning and afternoon, lightning activity stretched from north of Amarillo through Cordell and Watonga and through Norman to Fayetteville in relatively thin lines. There was an isolated storm over Ft. Sill and scattered activity elsewhere. After 1700 storms moved eastward from McAlester. A tape drive problem caused the tape to run out in the late afternoon, and was not replaced until about 1720.

6.5.4 CV990 Experiment

The CV990 circumnavigated a thunderstorm to the west of NRO and collected some data on a gust front while the CIM Doppler was in operation. Unfortunately, because of power failures at the Norman Doppler site and a late start of the CV990, there is little time, if any, in which all systems were simultaneously operating while significant weather was in progress. However, single Doppler radar and lidar measurements should provide ample opportunity for research and interpretation of data.

6.6 1 July, Wednesday, 1981 - Day 182

6.6.1 Bendix/Collins Systems

None.

6.6.2 Weather Situation

Upper flow over the U.S. was representative of summer conditions with weak flow except in the Pacific Northwest. A cold front which moved into Oklahoma during the night of the 30th of June was now a stationary front extending from Amarillo to Fort Smith. Rainshowers occurred during the morning over central Oklahoma. Very moist surface conditions yielded lifted indices from -3 to -4 over the state.

Storms developed along the frontal boundary from the north Texas Panhandle down into south-central Oklahoma. Storms were strongest in the Panhandle. Those in Oklahoma were quite weak, developing about 1400 and dying by 1800. No severe weather occurred in Oklahoma.

6.6.3 Lightning Ground Strike

There was some lightning in the Panhandle region of Oklahoma and Texas and scattered activity east of McAlester and within 100 km of Norman.

6.6.4 CV990 Experiment

On this day three experiments were conducted (1) prestorm, (2) boundary layer and (3) lifetime. Although thunderstorms did not develop in our data collection area, we did acquire a good data set of simultaneous measurements with all observing systems during the development of cumulus congestus. Thus the data set would provide a nice complement to the data collected on June 29 during which time there was less convective activity.

6.7 2 July, Thursday, 1981 - Day 183

6.7.1 Bendix/Collins Systems

None.

6.7.2 Weather Situation

An upper level ridge over Oklahoma gave little potential for afternoon thunderstorms. Surface flow was generally southeasterly. A few light thunderstorms developed in the Texas Panhandle bringing showers to parts of extreme western Oklahoma by evening.

6.7.3 Lightning Ground Strike

There was lightning in north Texas and to the west and northwest of Norman, 100-250 km.

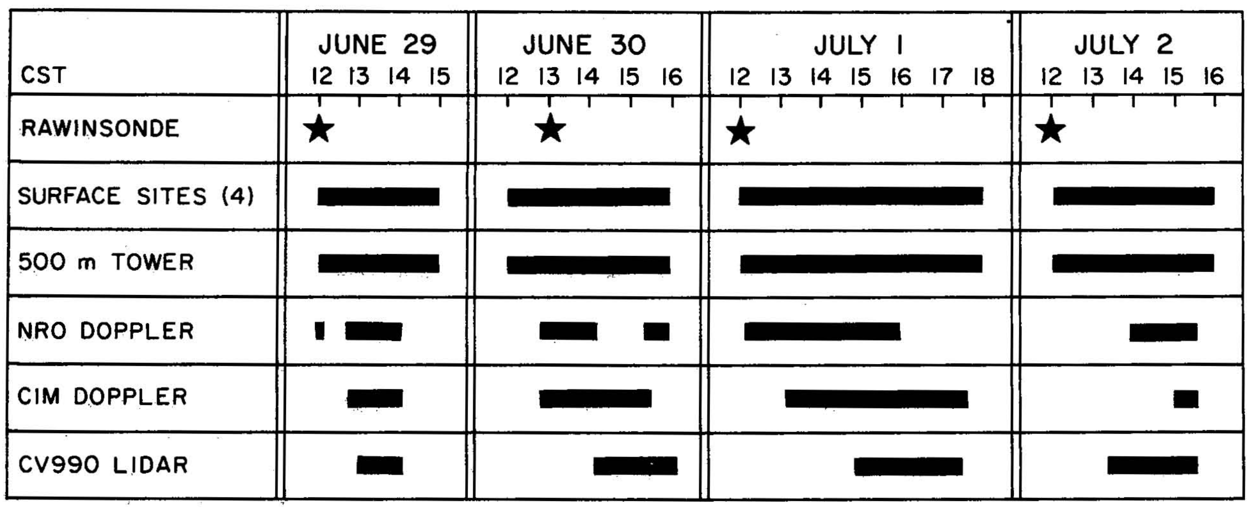
6.7.4 CV990 Experiment

On this day we ran the Intercomparison Experiment to obtain the highest temporal and spatial resolution of Doppler lidar and radar data. The experiment went well, and there is excellent data for making rigorous comparison of wind fields.

6.8 Data Collection Summary for CV990

This bar graph presents the time periods that observational instruments were operating during the time that the CV990 was airborne in central Oklahoma.

SUMMARY OF DATA COLLECTION



7. SEVERE WEATHER SUMMARY

Following is a list of wind, hail and tornado observations by the storm intercept teams and preliminary results of damage surveys conducted by NSSL personnel. Attached is a summary table of statistics on 17 and 22 May tornadoes and maps of tornado tracks. All times are Central Standard Time. The FPP scale is given for each tornado. This is the Fujita-scale intensity, Pearson-scale path length and path width, where for the first digit 0 = less than 73 mph, 1 = 73-112, 2 = 113-157, 3 = 158-206, 4 = 207-260 and 5 = 261-318; the second digit (path length) 0 = less than 1.0 mi., 1 = 1.0-3.1, 2 = 3.2-9.9, 3 = 10-31, 4 = 32-99, and 5≥100; and the third digit (path width) 0 = less than 20 yards, 1 = 20-50, 2 = 60-170, 3 = 180-550, 4 = 560-1750, and 5 = 1.0 mi. or wider.

7.1 11 April

1740 1 1/4" hail 1 mi. south of Altus.

7.2 12 April

1745 Funnel cloud 5 mi. NE of Warren in Kiowa County.

1800-1900 Swath of large hail across Kiowa County 14 miles long and several miles wide centered near Roosevelt. Hail, up to baseball size, caused much damage to wheat, autos and houses. At Roosvelt, the hailfall lasted for a full hour.

1805-1812 Tornado touched down 8 mi. west of Roosevelt in Kiowa County. Damage path was 3 mi. long, oriented WNW-ESE. Along the path, two barns were heavily damaged and numerous trees and power poles were blown over. FPP=112.

~1830 Tornado touched down 4 mi. south of Roosevelt in Kiowa County. The path length was short and damage was done only to power poles and fences. FPP=111.

~1930 Tornado touched down, momentarily 3 mi. south of Copperton in Kiowa County. No damage was reported. FPP=000.

~2000 Funnel cloud reported near Saddle Mountain in Comanche County.

~2030 Winds reported at 80 mph did little damage in the Lake Watonka area of Comanche County.

7.3 13 April

2000-2130 A swath of strong straight wind damage began east of Geary in Canadian County and continued into northwest Oklahoma City. Much damage was done to signs, trees, power lines, and windows in El Reno, Yukon, and Oklahoma City. Wind speeds were generally estimated at 70 mph except in extreme northwest Oklahoma City where an NSSL surface station measured 90 mph winds. In that area, substantial damage was done to several businesses with losses estimated at over $100,000.

7.4 22 April

1733-1756 An OU storm intercept team observed two closely spaced tornadoes that touched down intermittently during a 23-minute interval. The tornadoes were in open country 6 to 10 miles SE of Waurika in Jefferson County. The tornadoes moved little during their lifetime and did no reported damage. FPP=011 for both.

7.5 28 April

1410 A tornado was reported 5 mi. south of Binger in Caddo County. The tornado was open country with no damage reported. An NSSL intercept team noted a rotating wall cloud and 1/2" hail north of Anadarko at 1420. FPP=000.

7.6 30 April

1820 OU intercept team reported a funnel cloud at Elmore City in Garvin County.

1930-2130 A swath of wind and hail damage began 5 mi. west of Minco in Grady County and continued south-southeastward to east of Marlow in Stephens County. The damage swath was 5-10 mi. wide and 55 mi. long. Considerable damage was done in the towns of Pocasset (1945), Chickasha (2020) and Rush Springs (2100). Hail from marble to baseball size was reported which accumulated to depths of 1 foot in some places. Much damage was done to crops, roofs, and windows. Most wind damage (trees, power lines and poles, barns, house shingles, and TV antennas) was done by strong straight winds blowing from the north. In several places, however, there was evidence of acceleration and damaging winds from other directions. Evidence was consistent with the occurrence of small scale vortices, perhaps along the gust front. One such "gust-front tornado" is supposed in northwest Chickasha where a warehouse was destroyed while buildings on all sides were undamaged. FPP=200. A second supposed tornado occurred 4 mi. south and 1-1/2 mi. east of Rush Springs (2112) where a mobile home was destroyed with 1 fatality and 2 injuries. Debris trajectories indicated the tornado was anticyclonic. FPP=200. Rainfalls of 3 to 4 inches accompanied the storm. In addition, several funnel clouds were reported near Chickasha between 2015 and 2045.

2000-2030 A swath of wind and hail damage began north of Gracemont and continued south of Anadarko, both in Caddo County. Hail (2-3" in diameter) caused extensive damage to houses and crops. Strong straight winds from the north did much damage to a cotton gin, trees, power lines, TV antennas, and roof shingles. Roof portions were removed from a shopping center, TG&Y, and grocery store in Anadarko with damage estimated at $250,000. Near 2000, a funnel cloud was sighted north of Gracemont.

7.7 13 May

1545 An OU chase team observed a tornado on the ground for several minutes in an uninhabited area east of Lula in Coal County. No damage was reported but significant damage must have occurred to trees. FPP=??? Baseball size hail accompanied the storm.

1610 An NSSL chase team observed 3 tornadoes south of Coalgate near Lehigh in Coal County. Two tornadoes quickly dissipated (both FPP=000), but the third stayed on the ground several minutes, damaging two farms. Several outbuildings were destroyed. FPP=222.

1635 An NSSL chase team saw a tornado 4 mi. NE of Atoka in Atoka County. The only reported damage was to trees. FPP (estimate) = 111. Golf ball size hail accompanied the storm.

1730 A narrow, short-lived tornado was seen by an NSSL chase team 5 mi. west of Antlers in Pushmataha County. Minor damage to trees was noted. FPP=000.

7.8 17 May

(Note separate summary sheet and map for tornadoes.)

1614 Hail (3/4") was observed by an NSSL chase team just west of Dibble in McClain County.

1617 Another chase team experienced 1" hail near Lake Hefner in Oklahoma County.

1625 A third chase team encountered golf ball hail 3 mi. NNW of Washington in McClain County.

1625 Golf ball size hail was observed by a chase team at NW 50th and May Ave. in Oklahoma City.

1645-1700 Golf ball size hail covered the ground at the NSSL RAOB site just NE of Edmond in Oklahoma County.

1646-1652 A tornado was observed by an NSSL chase team in the Canadian River bed 3 mi. SSW of Noble. Damage to trees began on the west bank of the river (in McClain County) and continued for 1 mile across the river (in Cleveland County). FPP=112.

1655 Golf ball hail did moderate damage to roofs, windows, and gardens in Noble (Cleveland County). A funnel cloud was also observed just east of town by local Civil Defense.

1700-1710 A tornado touched down 2 mi. SW of Arcadia and traveled ENE for 3 mi., dissipating just NW of Lake Hiwasse (all in Oklahoma County). Along the path, 1 mobile home was completely destroyed and a second had slight damage, several power poles were blown down and heavy damage was done to timber. FPP=221.

1718-1720 An OU intercept team saw a funnel cloud NE of Arcadia in Oklahoma County. This is perhaps a continuance of the tornado described above.

1724-1725 Tornado damage occurred for 1 mi. along Oklahoma Hwy. 9 just south of Lake Thunderbird (all in Cleveland County). Many trees were downed along and north of the road with several cars forced off the highway. One family took shelter in a culvert under the highway. South of the tornado track, a large number of trees and several outbuildings were blown down by strong straight winds from the west. Hail up to 2" in diameter accompanied the storm and did light damage. FPP=112.

1810-1835 A tornado touched down 4 mi. south of Tecumseh and moved NE for 6 mi., then turned NNE for another 5 mi., ending NW of Earlsboro (all in Pottawatomie County). Considerable damage was done along the path with 2 large horse ranches destroyed and over 100 horses killed or injured, 1 house and 2 mobile homes were destroyed, and another 10 houses were damaged. A half dozen very minor injuries were reported along the path. At times, the path was 1/2 mi. wide. FPP=334.

1845-1852 A tornado began 4 mi. NNW of Seminole and moved NE for 3 mi., dissipating 1-1/2 mi. SSW of Little (all in Seminole County). Along the path, a horse ranch was heavily damaged, three houses were damaged, and several outbuildings were destroyed. FPP=213.

1900-2015 A long track tornado began 2 mi. SSE of Little in Seminole County, moved NE into Okfuskee County, passed north of Okemah about 1935, and finally dissipated at the west edge of Lake Okmulgee in Okmulgee County. An NSSL aerial survey documented the entire path but a surface survey was performed only along the first portion of the track. The damage was generally light before the tornado passed Okemah but a rural church was completely destroyed north of Cromwell in Seminole County and several barns and outbuildings were blown down. Damage was much heavier along the latter part of the path but detailed survey information is not available. FPP=444.

7.8 17 May

[The following are added for completeness but are unsurveyed.]

1425 A private chase team saw a tornado NW of Blackwell in Kay County.

1530 A private chase team saw tornado damage (trees down and signs blown over) 2 mi. east of Garber in Garfield County. They did not see the tornado but arrived just after the damage was done.

1630 A private chase team saw a tornado 5 mi. east of Marland in Kay County and noted possible tornado damage (trees) at the edge of Marland.

1815 Tornado was reported to have struck Shidler in Osage County.

1900 A private chase team watched a tornado for several minutes in open country west of Boulangerville in Osage County.

1920 A private chase team watched a large tornado on the Oklahoma/Kansas border north of Boulangerville in Osage. The tornado moved NE into Kansas for several miles south and east of Chautauqua. At times, the tornado was very large, perhpas a mile wide at the ground according to visual estimates. The tornado roar was audible from several miles away.

2045 A tornado was reported near Morris in Okmulgee County.

2245 A tornado was reported near Cookson in Cherokee County.

2355 A tornado was reported 8 mi. SW of Stilwell in Adair County.

7.9 22 May
(Note separate summary sheet and map for tornadoes.)

1617-1637 A tornado formed 2 mi. NW of Cordell in Washita County and moved NE, dissipating east of Bessie in Washita County. NSSL chase teams filmed the tornado from start to finish. At one point along the path, the tornado condensation funnel disappeared completely, reforming a short time later. Just north of Cordell, a mobile home was completely destroyed with debris thrown nearly a mile. Two barns were also destroyed by the tornado. OU intercept personnel measured windspeeds of 47 $m \cdot s^{-1}$ (105 mph) at the periphery of the tornado. FPP-223.

1720 An NSSL chase team observed 2-1/2 inch diameter hail near Cloud Chief in Washita County.

1725-1728 A tornado touched down briefly 2 mi. east of Lake Valley in Washita County. The only damage was to trees. FPP=111.

1807-1822 A tornado formed 3 mi. ESE of Cowden in Washita County and moved NNE along an irregular path for 5 mi. dissipating along Hwy. 152. At one point along the path, the funnel dissipated completely, reforming a short time later. East of Cowden all the buildings on a farm, including the house, were heavily damaged. The house was bodily moved 100 ft. to the NW away from its foundation. No other structures were in the path of the tornado but damage was done to trees, power poles and wheat. Golf ball size hail accompanied the storm. FPP=223.

~1815 A tornado was observed by a private chase team and filmed by a helicopter crew from KWTV in Oklahoma City. The tornado was in open country SW of Arapaho in Washita County. No NSSL damage survey was performed but newspaper accounts listed a convenience store destroyed and a house and barn damaged.

1829-1834 A tornado formed near the Swan Lake Community on the NE shore of Ft. Cobb Lake in Caddo County. A rotating debris cloud on the ground was observed by an NSSL chase team. The tornado lasted only a short time and the only damage was to trees and outbuildings. FPP=011.

1849-1926 The first evidence of a large tornado was a 1 mi. wide cloud of rotating dust a mile W of Binger in Caddo County. Suction vortices became apparent and produced scattered damage to farms, trees, and utility poles. Then, gradually, an extremely truncated condensation funnel formed and damage became severe just NE of Binger. In the Scott community, 9 houses and 1 mobile home were destroyed. The tornado was very intense with debris swept clean of the foundation at 2 houses and many large projectiles such as refrigerators, automobiles, trucks, combines, and utility poles were generated. In the area of Scott, the tornado damage path was 1 mi. wide. As the tornado moved NE, it narrowed slightly and was over more open country with fewer structures in the path. Several barns were destroyed NE of Scott and over 2 dozen cattle killed. Near Hwy. 37, the tornado destroyed tanks and equipment on 2 oil leases and completely demolished all buildings, including the house, at a farm. Large oil storage tanks, butane tanks and motor vehicles were moved up to 1/2 mi. by the winds. The tornado dissipated rapidly in the Canadian River bed 11 mi. west and 3 mi. north of Union City in Canadian County. In all, 12 houses and 1 mobile home were destroyed, several houses suffered minor damage and many barns and outbuildings were blown away. It is fortunate, that at all houses affected, the residents sought shelter underground or casualties would have certainly resulted. FPP-435.

~1900 A private chase team reported a tornado NW of Clinton in Washita County. The tornado was over open country and was on the ground for about 5 minutes. Other witnesses in Clinton reported seeing the tornado. No damage survey was attempted. FPP=???

1932-1935 A tornado touched down 4 mi. west and 3 mi. north of Union City in Canadian County. Along a 2 mi. damage path, the tornado destroyed 3 barns and downed utility poles. FPP=112.

~2000 A tornado formed in the SE section of Clinton and moved NNE doing heavy damage. Near the beginning of the path, a radio station 300 ft. tower was downed. In the eastern section of Clinton, several residential blocks were hit, with about a dozen homes completely destroyed and many more heavily damaged. At the Veterans Hospital, severe damage was done to a large grove of trees. The tornado moved NE of town where it damaged several planes and a hangar at the Clinton municipal airport and completely destroyed two farm houses and wrecked an electrical substation. The tornado dissipated 2 mi. ENE of Arapho. Eleven people were injured while many miraculously escaped injury in destroyed homes. Hail to 2" in diameter accompanied the storm. FPP=323.

~2000 Minor wind damage occurred at Yukon in Canadian County. Windows were blown out and trees were downed. A funnel cloud was also reported.

7.10 23 May

1540 An NSSL chase team encountered 1" hail just west of Elmore City in Garvin County.

1554 An NSSL chase team encountered 1" hail in Elmore City in Garvin County.

1600-1608 A tornado was observed by several chase teams east of Katie in Garvin County as it moved slowly eastward, dissipating west of Interstate Highway 35. Many trees were downed and several barns were destroyed. FPP=111.

1705 A tornado was observed by several chase teams to touch down momentarily just north of Sulphur in Murray County. Damage was done to trees and a barn.

7.11 2 June

~1700 A private chase team filmed a tornado on the ground for about 15 minutes, several miles south of Guymon in Texas County. No damage survey was performed but the tornado appeared to be in open ranch country.

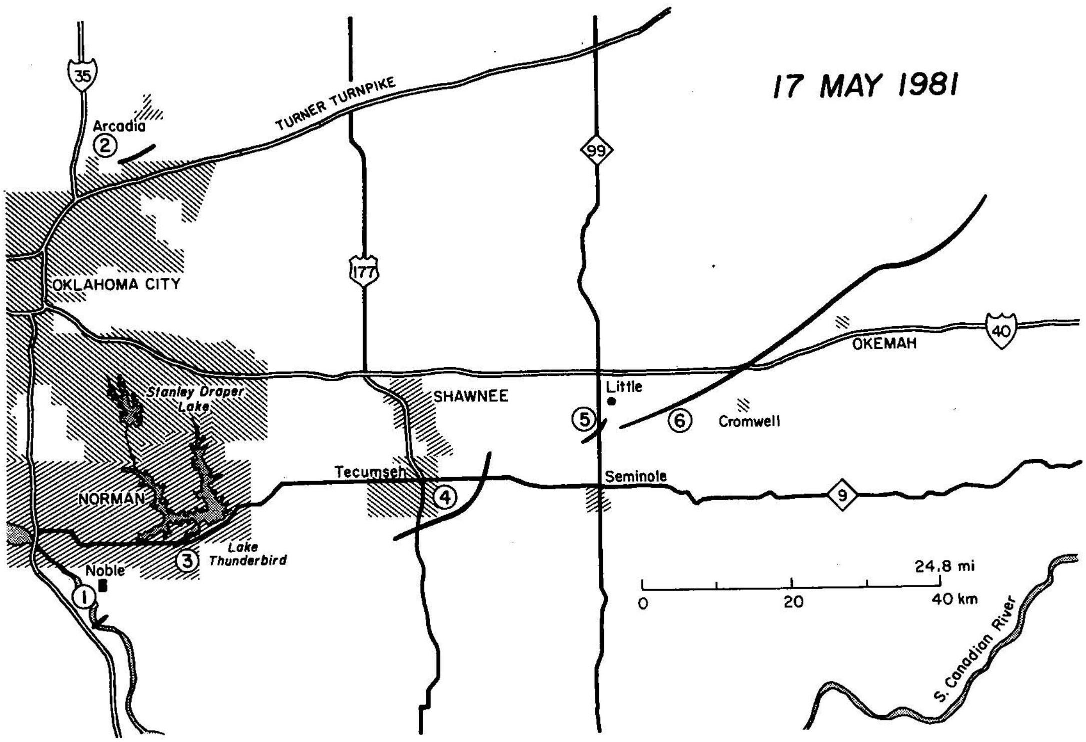


Fig. 1 Tornado tracks for 17 May 1981.

	Time (CST)	Tornado Name	F-Scale	Length (km)	Width (m)
1.	1646-52	Noble	1	1.5	100
2.	~1700-1710	Arcadia	2	5	50
3.	~1725	Lake Thunderbird	1	1.5	100
4.	1810-1835	Tecumseh	3	18	600
5.	1845-1852	Seminole	2	5	200
6.	~1900-?	Okemah	4	56	800

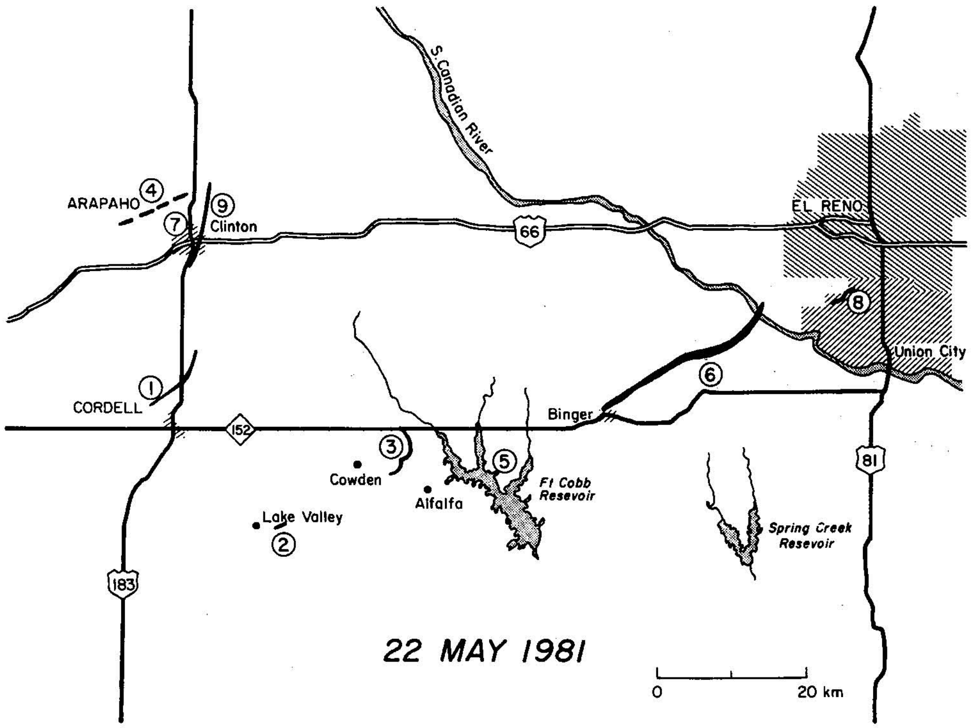


Fig. 2 Tornado tracks for 22 May 1981.

	Time (CST)	Tornado Name	F-Scale	Length (km)	Width (m)
1.	1617-1645	Cordell	2	10	200
2.	1725-1728	Lake Valley	1	1.5	50
3.	1807-1822	Alfalfa	2	8	300
4.	~1815	Arapaho	?	?	?
5.	~1829-1834	Swan Lake	0	short	narrow
6.	1849-1926	Binger	4	24	1900
7.	~1900	NW of Clinton	?	?	?
8.	1932-1935	Union City	1	3	100
9.	~2000	Clinton	3	11	300

8. ACKNOWLEDGMENTS

The success of the NSSL 1981 Spring Program is due to the enthusiastic cooperation of all who were involved in the Program plans, observational coordinations, instrument operations and data recordings. I especially wish to thank those who, through their contributions to the memorandum, have made this an important documentation of our efforts during the spring thunderstorm season that will be valued by researchers for years to come. The authors are particularly grateful for the high level of cooperation, dedication, and competence which the officers and men of the 6th Weather Squadron (Mobile), Tinker Air Force Base, and the U.S. Army Field Artillery Board, Ft. Sill, Oklahoma, have continually brought to the upper air projects of this laboratory. We are also indebted to Mss. Margaret Hayes and Joy Walton for typing and management of manuscript preparation, to Ms. Joan Kimpel for drafting, and to all in the Administration Section who contributed in many important ways. Finally, we thank Dr. Edwin Kessler for his support of this Program during severe budgetary restraints.

NATIONAL SEVERE STORMS LABORATORY

The NSSL Technical Memoranda, beginning at No. 28, continue the sequence established by the U. S. Weather Bureau National Severe Storms Project, Kansas City, Missouri. Numbers 1-22 were designated NSSP Reports. Numbers 23-27 were NSSL Reports, and 24-27 appeared as subseries of Weather Bureau Technical Notes. These reports are available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151, a microfiche version for $4.00 or a hard copy, cost depending upon the number of pages. NTIS numbers are given below in parenthesis.

No. 1 National Severe Storms Project Objectives and Basic Design. Staff, NSSP. March 1961, 16 p. (PB-168207)

No. 2 The Development of Aircraft Investigations of Squall Lines from 1956-1960. B. B. Goddard. 34 p. (PB-168208)

No. 3 Instability Lines and Their Environments as Shown by Aircraft Soundings and Quasi-Horizontal Traverses. D. T. Williams. February 1962. 15 p. (PB-168209)

No. 4 On the Mechanics of the Tornado. J. R. Fulks. February 1962. 33 p. (PB-168210)

No. 5 A Summary of Field Operations and Data Collection by the National Severe Storms Project in Spring 1961. J. T. Lee. March 1962. 47 p. (PB-165095)

No. 6 Index to the NSSP Surface Network. T. Fujita. April 1962. 32 p. (PB-168212)

No. 7 The vertical structure of Three Dry Lines as Revealed by Aircraft Traverses. E. L. McGuire. April 1962. 10 p. (PB-168213)

No. 8 Radar Observations of a Tornado Thunderstorm in Vertical Section. Ralph J. Donaldson, Jr. April 1962. 21 p. (PB-174859)

No. 9 Dynamics of Severe Convective Storms. Chester W. Newton. July 1962. 44 p. (PB-163319)

No. 10 Some Measured Characteristics of Severe Storms Turbulence. Roy Steiner and Richard H. Rhyne. July 1962. 17 p. (N62-16401)

No. 11 A Study of the Kinematic Properties of Certain Small-Scale Systems. D. T. Williams. October 1962. 22 p. (PB-168216)

No. 12 Analysis of the Severe Weather Factor in Automatic Control of Air Route Traffic. W. Boynton Beckwith. December 1962. 67 p. (PB-168217)

No. 13 500-Kc./Sec. Sferics Studies in Severe Storms. Douglas A. Kohl and John E. Miller. April 1963. 36 p. (PB-168218)

No. 14 Field Operations of the National Severe Storms Project in Spring 1962. L. D. Sanders. May 1963. 71 p. (PB-168219)

No. 15 Penetrations of Thunderstorms by an Aircraft Flying at Supersonic Speeds. G. P. Roys. Radar Photographs and Gust Loads in Three Storms of 1961 Rough Rider. Paul W. J. Schumacher. May 1963. 19 p. (PB-168220)

No. 16 Analysis of Selected Aircraft Data from NSSP Operations, 1962. T. Fujita. May 1963. 29 p. (PB-168221)

No. 17 Analysis of Methods for Small-Scale Surface Network Data. D. T. Williams. August 1963. 20 p. (PB-168222)

No. 18 The Thunderstorm Wake of May 4, 1961. D. T. Williams. August 1963. 23 p. (PB-168223)

No. 19 Measurements by Aircraft of Condensed Water in Great Plains Thunderstorms. George P. Roys and Edwin Kessler. July 1966. 17 p. (PB-173048)

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