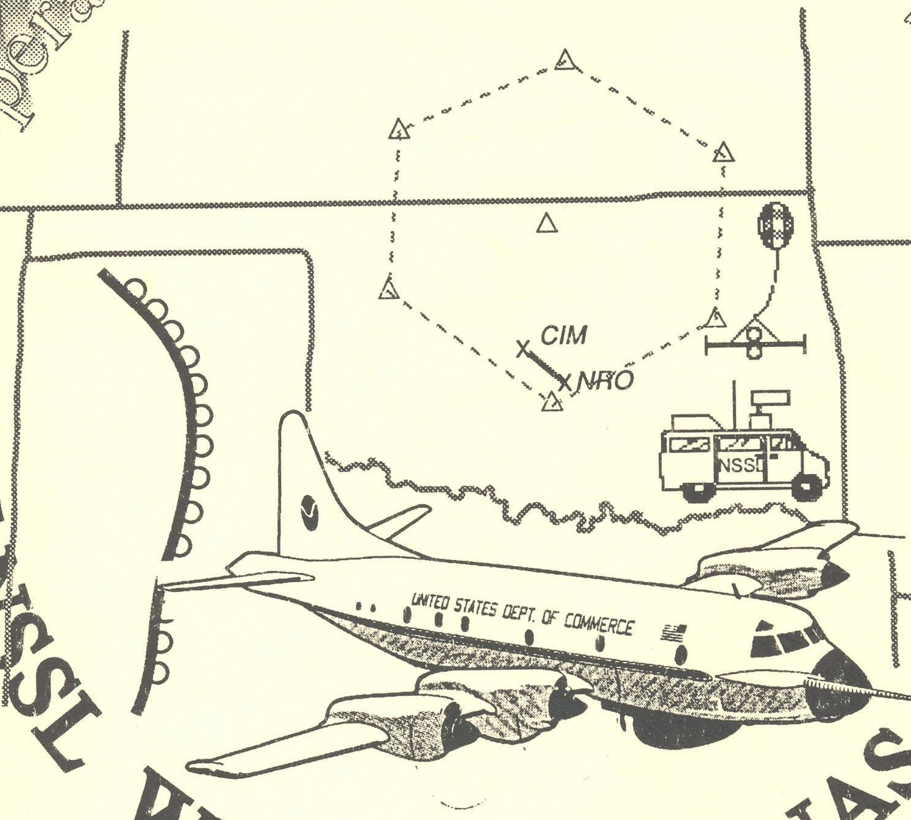
Cooperative Oklahoma Profiler Studies

1991



UM NSSL WPL OU CSU NASA SDSMT

Design & Operations Plan

National Severe Storms Laboratory

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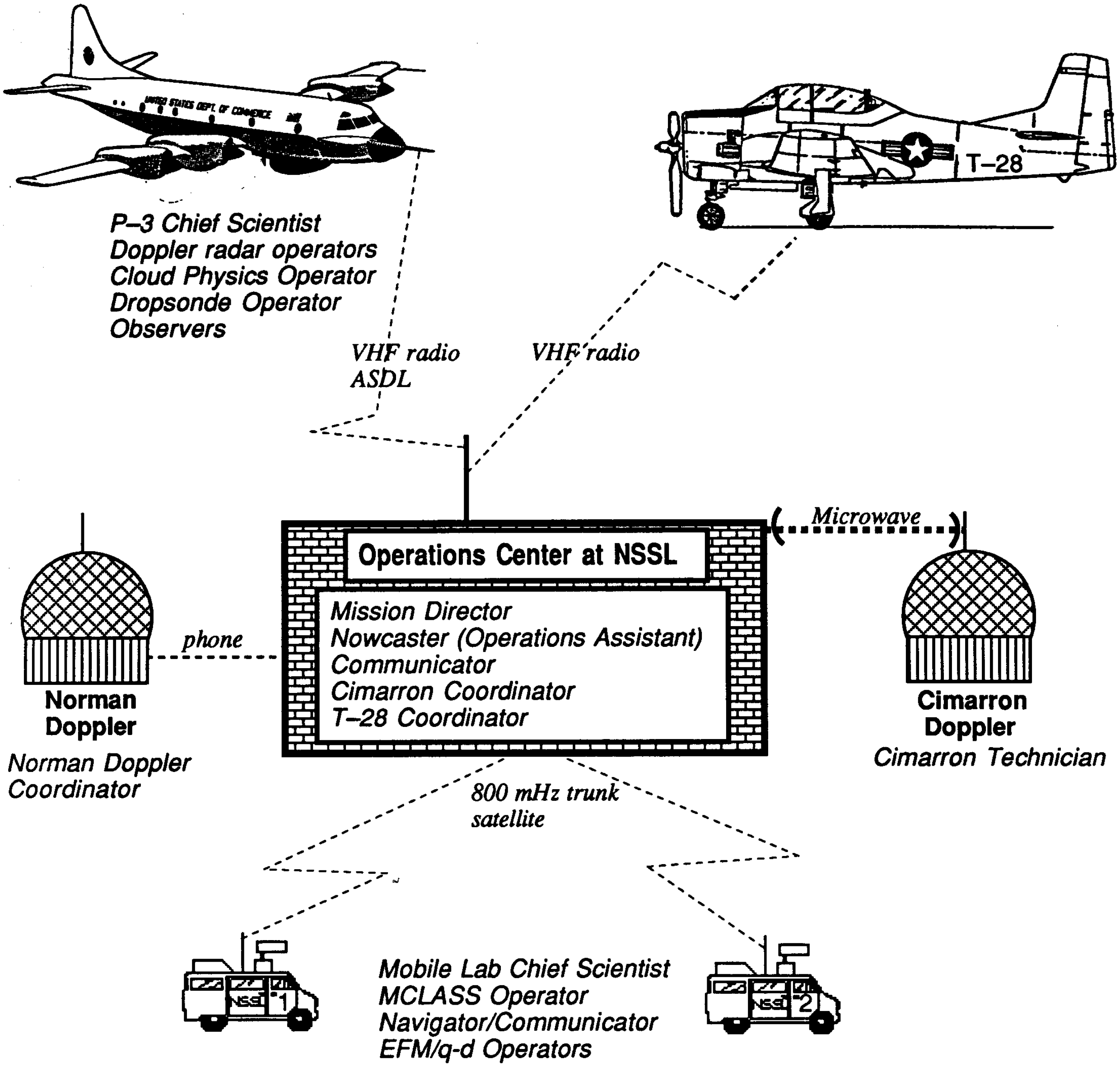
UNITED STATES DEPT. OF COMMERCE
P–3 Chief Scientist
Doppler radar operators
Cloud Physics Operator
Dropsonde Operator
Observers
T–28
VHF radio
ASDL
VHF radio
Operations Center at NSSL
Mission Director
Nowcaster (Operations Assistant)
Communicator
Cimarron Coordinator
T–28 Coordinator
Microwave
phone
Norman Doppler
Norman Doppler Coordinator
Cimarron Doppler
Cimarron Technician
800 mHz trunk
satellite
NSSL 1
NSSL 2
Mobile Lab Chief Scientist
MCLASS Operator
Navigator/Communicator
EFM/q-d Operators

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Cooperative Oklahoma Profiler Studies (COPS-91)

1. Introduction

By spring 1991, the central part of the ERL Profiler Demonstration Network will be operational. With the deployment of any new observational system, a period of assessment is required to comprehend its inherent observational strengths and limitations fully. Although comprehensive assessment will be a long-term process, an initial evaluation should be performed which involves comparison of data collected by in-situ sensors such as instrumented aircraft, dropsondes, and mobile balloon soundings in a variety of meteorological conditions. Such an evaluation will involve more than just comparison of coincident multi-sensor observed winds. We seek to determine the value of the profiler data to the determination of subsynoptic circulations and forcing for vertical motion associated with mesoscale phenomena such as Mesoscale Convective Systems (MCSs), drylines, and frontal boundaries.

The NSSL will deploy a mesoscale observational network of Doppler radars, P–3 aircraft, and mobile CLASS systems equipped with the capability to launch electric field meters and particle charge determination devices, and NCAR's Portable Automated Mesonet (PAM) surface stations for 50 days (April 24 to June 12) during the spring of 1991 to perform initial assessment activities. We have termed this project the *Cooperative Oklahoma Profiler Studies* (COPS-91).

The capabilities of the radio/acoustic sounding systems (RASS) in the plains environment will also be examined through the deployment of a 915 mHz RASS profiler near the center of the Cimarron-Norman dual-Doppler southwest lobe (near Chickasha, OK) and the installation of a RASS on the network profiler at Purcell, OK. To complement the RASS observations a multi-frequency microwave radiometer will be deployed with the 915 mHz RASS profiler near Chickasha, OK to provide temporally continuous observations of precipitable water vapor and integrated cloud liquid.

In addition to the primary goal of profiler assessment, other very specific and highly focused scientific goals will also be addressed involving the electrification and microphysical processes of MCSs, the structure and mesoscale circulations of drylines and cold frontal boundaries and their role in convective initiation. If the opportunity presents itself, we would like the P–3 to fly airborne Doppler patterns near the Cimarron Doppler radar to supplement and help validate polarization measurements made by the Cimarron radar. None of these goals were specifically addressed by previous mesoscale field experiments (*e.g.*, PRE-STORM), and are also not topics that are specifically part of the large, scale-interaction programs proposed for the late-1990s in the central U.S. (*i.e.*, STORM I). In addition, COPS-91 will complement the planned STORM-FEST experiment, which will employ new sensing systems (profilers and NEXRAD) in a wintertime setting. Thus COPS-91 will provide a valuable test of these systems, and new observing strategies, that will contribute substantially to preparations for STORM I spring/summer experiments.

2. Principal Investigators

COPS principal investigators for the various scientific sub components are listed in Table 1.

Table 1. COPS-91 principal investigators.

Subcomponent	*Principal Investigators*
Dryline	Carl Hane, NSSL Conrad Ziegler, NSSL Howie Bluestein, OU Melvyn Shapiro, WPL
MCS and Thunderstorm Electrification	David Rust, NSSL Thomas Marshall, U. Miss Steven Rutledge, CSU
MCS Dynamics	David Jorgensen, NSSL Thomas Matejka, NSSL Bradley Smull, NSSL
Frontal Circulations and Low Level Jet	Edward Brandes, NSSL Steven Koch, NASA
Experimental Forecasts & Forecast Evaluation Experiment	Chuck Doswell, NSSL Don Burgess, NSSL Harold Brooks, NSSL
Heat Fluxes from RASS Profilers	Richard Doviak, NSSL Z. Sorbjan, OU
Polarization Studies (including T-28)	Dusan Zrnic, NSSL V. N. Bringi, CSU Kultegin Aydin, PSU

3. Primary Objectives

The project has four primary objectives and a number of ancillary goals. Each of the objectives is described more fully below.

3.1 *Scientific Assessment of the Profiler Demonstration Network*

These activities will focus (1) on the interpretation of the profiler network data in the context of the other meteorological data sets, and (2) investigate the use of Radio Acoustic Sounding System (RASS) technology to determine heat flux profiles and in the analysis of mesoscale forcing fields produced by dynamic retrieval techniques based on dual-Doppler wind fields.

3.1.1 PHENOMENA OR PROCESSES TO BE STUDIED

Mesoscale convective systems, and the environments associated with severe convective storms, particularly frontal and dryline circulations and the nocturnal low level jet are the phonomena of interest. In particular, data will be collected in the stratiform regions of mesoscale convective systems since the larger spatial and temporal scales of organization should permit unquestionably reliable wind field synthesis with the airborne and ground-based Doppler radars. Also, data on the space and time structure of short wave troughs will be collected, in conjunction with the passage of such systems over the profiler array, by the P–3.

3.1.2 WHY THIS TOPIC IS IMPORTANT

The use of profilers and RASS would enable both innovative mesoscale research to be performed and afford a scientific context in which to demonstrate the capabilities of the instruments. The RASS would be exploited beyond its immediate use as a vertically remote-sensing thermometer. Specifically, RASS data would be combined with Doppler radar data for the deduction of thermodynamic fields over mesoscale domains to deduce the forces (and their evolution) that cause MCSs to evolve. Since short wave troughs are relatively poorly understood and certainly are not handled well by numerical weather prediction models, it is important to gain some insight about their nature. It is not entirely clear that winds alone will provide enough information about such systems, so the dropsondes are an essential ingredient in exploring them, as well as the detail that can be seen from the wind profilers.

3.1.3 GOALS OF THE STUDY

The profilers will be used to monitor the temporal evolution of wind shear. Those data can be related to the character of the convective storms observed by Doppler radar (both airborne and ground-based) to help understand why storms separated by short distances can sometimes have quite dissimilar structure (supercell, multicell, squall line) and why some storms evolve from one type to another, particularly near drylines, fronts, and outflow boundaries. Numerical modelling evidence indicates the sensitivity of modelled storms to convective available potential energy and wind shear. COPS-91 presents an opportunity to examine the relationships between storm structure and the mesoscale environment.

Profiler data, in conjunction with dropsondes, will be used to document the three-dimensional strucuture of wave disturbances embedded in westerly flow.

Profiler data will be used to calculate helicity, a measure of vertical wind shear available for tilting into mesocyclones and tornadoes. Calculated from sounding and Doppler VAD data, it has been shown to be useful in tornado forecasting. Profiler-estimated helicity will be compared to helicities from special mobile soundings, Cimarron Doppler data, and numerical model data to determine the added value of data from the new observational system. It is hoped that helicity from profilers or profiler data combined with NEXRAD data give better spatial and temporal resolution to forecast efforts aimed at predicting mesoscale environments suitable for tornado formation.

Profiler data will be used in experimental forecasts issued by teams of NSSL and Norman WSFO personnel. In addition, the experimental forecast teams will monitor real-time use of profiler data by WSFO Public and Aviation Forecasters. Since profiler data will become available to researchers and operational forecasters at the same time, it is important to check initial forecast contributions, correct any misusage, and develop new methods of application. As part of the profiler-usage evaluation, NSSL experimental forecasters will summarize their perceptions by filling out questionnaires on a daily basis.

The P–3 data will be used to "fill in the gaps" between profilers to help separate spatial from temporal gradients that are evident in the profiler time series, particularly if strong gradients (such as those created by dryline and frontal boundaries) exist between profiler sites. Safe dropsonde capability, proven in the earlier COPS-89 experiment, will be used to gather complementary data sets with which to compare lower tropospheric profiler analyses of vertical motions.

Improvement in understanding of the mechanisms associated with short term evolution of mesoscale weather systems will hopefully lead to improvements in prediction. Decomposing the forces and their evolution within mesoscale systems using Doppler and RASS data will help us understand the physics of system evolution and may give clues to what occurs prior to the evolution that may enable the changes to be anticipated.

3.1.4 HYPOTHESES TO BE TESTED

- Under what conditions can we trade the enhanced temporal sampling resolution of the profilers for increased spatial depiction of mesoscale weather systems?
- Can the profilers reproduce low level jet wind speed profiles?
- Can RASS profilers be used to reliably measure boundary layer heat fluxes?
- Can RASS-derived vertical virtual temperature profiles be used to complete the thermodynamic tendency analysis started by dual-Doppler retrievals?
- Can the Profiler reflectivity and spectral width data be used to estimate heat fluxes?

3.1.5 MEASUREMENT REQUIREMENTS

Data sets that are required include dual-Doppler radar, P–3 in-situ observations and dropsondes, mobile CLASS balloon flights, as well as conventional observations. Specific flight patterns will also be flown relative to the profiler network to evaluate sampling limitations. The aircraft will also fly tracks connecting the profiler sites to produce finer-scale data to check assumptions generally invoked for time variation of the winds over the profiler network.

3.1.6 DESIRED SAMPLE SIZE

Two P–3 and MCLASS deployments to examine the structure of short waves and their environments associated with baroclinic zones within the Oklahoma-Kansas hexagon of profilers.

3.2 *Electrification Mechanisms of Mesoscale Convective Systems*

3.2.1 PHENOMENA OR PROCESSES TO BE STUDIED

Mesoscale convective systems and isolated thunderstorms.

3.2.2 WHY THIS TOPIC IS IMPORTANT

Recent studies have revealed that cloud-to-ground lightning patterns in the PRE-STORM 10-11 June 1985 squall line had distinct bi-polar lightning patterns with positive cloud-to-ground flashes observed in the stratiform region with frequencies of over 100 flashes per hour. The largest positive flash frequencies occurred near in time to the maximum coverage of stratiform echo, suggesting a possible link between positive lightning and stratiform microphysical processes or advective processes from convective regions that lead to more intense stratiform echo. Furthermore, the flash rates were correlated in time with the stratiform precipitation amounts over a period of several hours. Eight other PRE-STORM and COPS-89 cases (4 June and 7 June) have been subsequently analyzed and similar results were found relating positive ground flashes to stratiform precipitation associated with MCSs.

A charge separation process was proposed by Rutledge and MacGorman (1988) to explain the presence of positive ground flashes in the stratiform precipitation regions. In this mechanism, positive charge is advected from the convective region into the stratiform region by mesoscale wind patterns. The charge is contained on small ice particles that exit the convective cells at upper levels, where positive charge normally resides in a convective storm. The advection of positive charge may then lead to the build-up of positive charge in the outlying stratiform region to the point where a lightning discharge is generated. More recently, Rutledge and MacGorman (1989) have discussed the generation of significant amounts of charge in the stratiform region through stratiform microphysical processes. They applied a simple one-dimensional model to evaluate the non-induction charging through ice-ice collisions in modest supercooled liquid water contents (0.1 g m^{-3}). They concluded that large charge densities can be generated by this process, leading to local field breakdown. This charging process is dependent upon large ice crystal concentrations (based upon observed values) and the presence of a strong mesoscale updraft which allows supercooled water to be present. Their mechanisms only provide a dipole, while our first measurements show multiple charge layers stacked in the stratiform region.

3.2.3 GOALS OF THE STUDY

Additional field measurements of electric field, particle charge, etc. are needed to allow further study of these processes. Recently, Schuur et al. (1991) and Hunter et al. (1991) have documented the existence of positive charge layers to the immediate rear of a convective line that could have resulted from the advection of positive charge by graupel particles from the convective line. In-situ charging also appears viable. There will always be questions, however, about the validity of assumptions of infinite horizontal homogeneous charge that were required to infer charge layers from soundings. Since we have identified both dynamic and microphysical mechanisms possible operating in the charging process, we need to obtain a set of measurements on multiple soundings to address this problem more completely. Another balloon-borne instrument will be flown on some flights to measure precipitation particle charge and size (called the q-d instrument). In order to test even rudimentary models, we need to measure in-situ particle q-d measurements to ascertain if the calculated (from models and EFM data) space charge densities can be explained solely by charged precipitation or whether cloud particles may play a significant role.

3.2.4 HYPOTHESES TO BE TESTED

By combining simultaneous measurements of the mesoscale circulations (by both ground-based and P-3 airborne Doppler radar) with electric field and particle charge and size from balloon-borne instruments (which yield independent estimates of charge densities), and particle concentrations and sizes/habits (from P-3 microphysical observations) a unique data set will be available with which to address these charging hypotheses. Specifically, we seek to:

- Provide the first estimates of the 3-D structure of electric charge in MCSs to evaluate 2-D assumptions used in previous studies and to provide a data base against which models can be compared.
- What extent is in-situ charging of the stratiform regions important relative to the advection of charge from convective regions?
- Are microphysical characteristics of particles revealed by polarization observations correlated to regions of charge?
- Are changes in electrical properties within squall line associated with changes in system dynamics as revealed by Doppler and polarization radar? For example, Rotunno et al. (1987) have proposed that a balance exists in the intense convection of squall lines between the horizontal vorticity in the cold, forward moving outflow air and the horizontal vorticity of the opposite sign in the environmental wind shear profile. Strengthening of the outflow vorticity upsets this balance and results in an acceleration of the outflow ahead of the convection in the line and a weakening of the squall line convection but presumably also in generation of more extensive trailing stratiform cloud and precipitation. This theory will be tested by using the P-3 Doppler to measure the strength of the outflow vorticity and P-3 dropwindsondes to measure the shear in the environmental flow ahead of the line during a time period encompassing the transition from the mature to dissipating stages.

3.2.5 MEASUREMENT REQUIREMENTS

Soundings of the electric field and particle charge and size will be obtained with NSSL's mobile CLASS facilities, which in addition to the electric field provide needed thermodynamic and wind profiles. In-situ vertical electric fields will also be provided by the T-28 aircraft. The vertical electric field from the T-28's horizontal flight paths will provide data sets with which to evaluate the homogeneity of horizontal charge distribution in large stratiform regions. Vertical profiles of precipitation will be obtained with both in-situ measurements (P–3 and T-28) and the balloon and polarimetric measurements. The polarimetric observations will be useful to determine how homogeneous is the stratiform region of MCSs.

3.2.6 DESIRED SAMPLE SIZE

Four MCSs are required to gather an adequate sample of MCS structures. Three isolated severe convective storms will be required to adequately relate electrification and polarization signatures to the storm dynamics.

3.3 *Documentation of Dryline Structure and Morphology*

3.3.1 PHENOMENA OR PROCESSES TO BE STUDIED

The dryline and its basic circulation.

3.3.2 WHY THIS TOPIC IS IMPORTANT

Convective storms that are initiated along the dryline are recognized to be of major concern to forecasters of severe weather in the Central and Southern Plains. This phenomenon has yet to be extensively observed and modelled.

3.3.3 GOALS OF THE STUDY

Of particular scientific interest are the following: Why, under weak (and sometimes strong) synoptic-scale forcing, do large storms form on some days, and fail to develop on others? Why do storms tend to form in preferred areas along the dryline, but not in others? What is the role of mesoscale dryline circulations (both two-dimensional and three-dimensional) and fluxes of heat and moisture from the surface in initiating dryline storms? How is the type of storm or storm system that forms along the dryline determined by the dryline environment? A combination of in situ observations from the P-3, serial sounding information from mobile CLASS (MCLASS) units, safe dropwindsonde releases from the P–3, and data from a regional network of surface stations (PAM) will be used to investigate the dryline environment for storm formation. When and if storms form at nearby locations along the dryline, all systems will be directed toward delineation of storm morphology and the near environment of storms.

The uniqueness of these experiments lies in the mobility of the P–3 aircraft and sounding systems, and the existence of a regional scale surface network. There have been few detailed studies of the initiation of convective storms along the dryline because the dryline is rarely located within a dense observational network. However, the dryline environment is a natural laboratory for studies of storm initiation because of its frequent occurrence in Texas and Oklahoma during the spring, the narrow zone in which it occurs, and its relatively slow movement. The mobility of the observing systems allows for the possibility of going to the area of storm formation to take measurements before storms occur, to follow the dryline by adjusting locations of flight patterns as the pre-convective dryline moves, to seek out small scale storm-producing features along the line for detailed observation, and to follow the storms once they form primarily utilizing the on-board Doppler radar.

3.3.4 HYPOTHESES TO BE TESTED

As a prerequisite to improved understanding of storm initiation, several basic questions concerning dryline structure and motion must be addressed with the aircraft and mobile CLASS data. One question is: Are virtual potential temperature contrasts present across the dryline? (Some previous studies suggest not, although data from several field experiments [*e.g.*, NSSP-62, TEXEX, COPS-89] indicate or imply that these constraints do indeed exist.) It is hypothesized that differential diabatic heating generates an east-to-west virtual temperature gradient which gives rise to a solenoidally-forced ageostrophic flow acceleration and a vertical circulation. A frontogenetic mechanism, which should be acting in such conditions, might help to explain how the discontinuity of moisture, temperature, and horizontal wind is maintained across the dryline. The frontogenetic mechanism might concentrate horizontal convergence on the moist side of the dryline. The resulting enhanced vertical motion and vertical shear of the horizontal wind might be important contributors to severe thunderstorm formation east of the dryline.

Other basic questions include the following: Does the dryline exhibit continuous eastward propagation during the daytime? What specific changes in parcel stability (*e.g.*, convective available potential energy or CAPE and negative CAPE), lifted condensation level or LFC, level of free convection or LCL, occur along the dryline on thunderstorm days? COPS-89 data suggests that moisture is injected into the layer between the shallow CBL east of the dryline and the top of the deep CBL west of the dryline, thus increasing convective instability. By what mechanism is moisture lifted east of the dryline into a layer between the tops of the external and internal CBLs? (COPS-89 data suggests that moisture is deeply mixed above the dryline, then advected eastward.)

One of the specific questions to be addressed is how small scale features along the dryline enhance the environment for storm formation. For example, mesoscale dryline low pressure areas have been hypothesized to bring about a deepening of the moisture near the dryline where it might otherwise be too shallow to allow for storm formation, and also to provide a localized vertical shear profile more favorable for storm severity. Besides these mesoscale low pressure areas, along-line features might include localized areas of mesoscale convergence, small scale dryline "bulges", or boundary layer rolls ahead of the dryline whose intersection with the line might provide preferred areas for storm formation. Larger scale features such as upper level short waves might also influence the timing and location of convective development. The high time resolution of the profiler network data will provide indications of whether upper level features such as translating short waves are influencing the development of storms, and are perhaps linked to the above-listed small scale features also.

Experience in forecasting has shown that in some cases the area near the "triple point" (point where a dryline intersects a cold front) is a favored area for the initiation of deep convection. It has been hypothesized that upward circulations associated with the cold front and dryline merge at the triple point to produce enhanced potential for initiation, as evidenced by the frequent observation of strong convective storms northeast of the triple point. If the opportunity presents itself, an experiment to examine variations of cross-dryline gradients in the along dryline direction (over approximately 200 km) will be extended to include investigation of cross-dryline, cross-frontal, and cross-(merged) frontal/dryline structure in the triple point region.

3.3.5 MEASUREMENT REQUIREMENTS

The P-3 and mobile CLASS data will document the morphology of the daytime dryline environment. From these observations, it should be possible to detect the hypothesized solenoidally-induced vertical circulation in the CBL. If thunderstorms form in the vicinity of the P-3 and MCLASS, it will be determined if the vertical circulation is accelerated (and horizontal convergence amplified) around the time of the observed convective development.

The P-3 and MCLASS soundings data will document certain specific characteristics of the mesoscale dryline environment fairly well (*e.g.* east-west moisture increase and virtual potential temperature decrease). A mesoscale numerical model will be used to provide additional information and assist in defining the physical mechanisms governing the evolution of heat, moisture content, and airflow in the dryline region. In collaboration with scientists at Colorado State University, the 2-dimensional, non-hydrostatic version of the Colorado State University RAMS (Regional Atmospheric Modeling System) is currently being run at NCAR to simulate the dryline case from COPS-89. These efforts will be expanded to include simulations of COPS-91 cases using the nested, 3-dimensional version of the CSU-RAMS. The NOAA aircraft, profiler, and mobile CLASS soundings are indispensable as a means of initializing and verifying the 2- and 3-dimensional model simulations. Hypotheses developed independently from the data and model output will be cross-validated.

3.2.6 DESIRED SAMPLE SIZE

At least three cases of drylines on days when convective storms are forecasted to develop in the dry line region.

3.4 *Documentation of Cold Frontal Circulations*

3.4.1 PHENOMENA OR PROCESSES TO BE STUDIED

Structure and dynamics of dry fronts including such features as prefrontal convergence lines, hydraulic heads, multiple frontal structures, dryline-front mergers, and transverse frontal circulations, and their interactions with the synoptic background flow.

3.4.2 WHY THIS TOPIC IS IMPORTANT

The present knowledge of dry frontal circulations is based primarily on surface measurements, cross-sections drawn with widely spaced rawinsonde observations, and theory and numerical simulations that have not been rigorously compared with observations. The manner in which the boundary layer features interact with the quasi-balanced, large-scale flow is poorly understood. Progress is hindered largely by the shortage of high resolution observations above the surface and on the mesoscale. The proposed experiment will yield observations with unprecedented spatial and temporal detail of frontal features with scales of 2-200 km. The data should prove useful for verifying numerical simulations of fronts and for increasing our understanding of dynamical processes in frontal zones. Improved understanding of the role of these mesoscale frontal circulations in the initiation of frontal and prefrontal squall lines is also of importance.

3.4.3 GOALS OF THE STUDY

To document the small scale structure of dry front (and dryline) circulations and their relationship with the larger (synoptic)-scale flow. A second goal is to assess the capabilities of new remote sensing systems. The following are subgoals.

- To determine the evolution, horizontal scale, depth, and structure of cold fronts and their accompanying transverse circulations. Temperature and pressure fields reconstructed from observations and retrieved from dual-Doppler derived wind fields will be used in Sawyer-Eliassen diagnostics of frontal circulations for comparison with the observed circulations.

- To determine the relative strengths of stretching deformation and shearing deformation in the frontal reference frame, and the combined ability of temporal information in the profiler data and spatial information in the aircraft and Doppler radar data to estimate the four-dimensional kinematic fields, including deformation and frontogenesis.
- To determine the kinematic and thermodynamic properties of prefrontal convergence boundaries. To establish their origin and role in prefrontal squall line generation.
- To use idealized frontal models and three-dimensional mesoscale numerical models to examine the interaction between the small-scale structures and large-scale forcing, to evaluate the relative importance of boundary layer processes, and to test our hypotheses.
- To determine the combined ability of the RASS and radiation-equipped PAM systems to provide reasonable sensible heat fluxes in the surface and boundary layers. These fluxes will then be related to the nature of vertical circulations derived from profiler, P-3, and dual-Doppler analyses.
- To examine the capabilities of the wind profilers (horizontal velocity, vertical velocity, and return power measurements) for frontal studies. Of particular interest is the impact of the relatively high first data gate.

3.4.4 HYPOTHESES TO BE TESTED

- Although they can be initiated by the geostrophic deformation of the large-scale flow, the transient features of the small-scale structure are largely determined by local internal dynamics.
- The cross-frontal variation in surface sensible heat flux may interact with the large-scale deformation field to produce a vertical circulation of sufficient intensity to generate post-frontal clearing of low-level clouds and frontal line convection, the latter of which culminates in the formation of a frontal squall line provided the convective available potential energy (CAPE) is adequate.
- The leading edge of some cold fronts displays dynamic similarity with gravity currents, in terms of the vertical structure, front-relative flow, and rate of advance of such fronts.
- The vertical circulation associated with the dryline-front merger process is primarily the result of the frontogenetical effect of pre-existing deformation at the dryline acting upon the newly created virtual temperature gradient provided by the appearance of the cold front at the dryline.

3.4.5 MEASUREMENT REQUIREMENTS

- Volumetric scans of radial velocity and radar reflectivity from the Norman and Cimarron Doppler radars. Measurement resolution should be 1° to 1.5° in azimuth, 0.5° in elevation, and 150 m in range. The radars should operate in expanded mode, free-run, 128 samples, rotate at 6° s^{-1}, and make full 360° sweeps. Individual scans must be coordinated to permit dual-Doppler synthesis of three-dimensional wind fields. Coordinated sequences should be taken routinely at 30 min intervals. Whenever detectable boundaries are present, the interval should be reduced to 15 min. In some instances RHI scans may be requested.
- P-3 measurements at multiple heights in cross-sections normal to the front and passing through the dual-Doppler radar network, the observations to include temperature, dew-point temperature, pressure, horizontal wind, and vertical wind.
- Serial observations from both of NSSL's MCLASS units. Soundings to be at 60-90 min intervals, both ahead of the front (or accompanying prefrontal boundaries) and well to the rear of the front.
- Surface observations from the surface nested mesonetwork, the observations to include wind velocity, temperature, wet-bulb temperature, and pressure. In addition, radiative flux measurements from several PAM sites is required.
- RASS temperature soundings, one of which should be positioned within the dual-Doppler radar area and collocated with a PAM radiative flux site.
- Wind observations from the Demonstration Network profilers and from a boundary layer wind profiler. Furthermore, 5-6 min

resolution surface data should be collected at the profiler and Doppler radar sites.

3.4.6 DESIRED SAMPLE SIZE

- Two missions with aircraft support.
- Dual-Doppler radar and soundings to be collected from all frontal passages with sufficient clear-air signal.

3.5 *Ancillary Goals*

There are five ancillary goals of COPS-91: (1) documentation of the physical characteristics of intracloud lightning, (2) validation of polarimetric parameters obtained by the Cimarron radar and comparison of these parameters with in situ electric field and particle charge and size, (3) a real-time experiment to utilize computer simulations to forecast convective development, (4) gather Cimarron radar data sets with which to test and evaluate new models and algorithms for the detection of gust fronts (FAA project), and (5) document fine scale kinematic and thermal structures of the low-level nocturnal jet. Each of these goals is addressed below.

Lightning Observations. To infer the relationships between the phases of intracloud lightning, video observations of intracloud lightning in storms nearby to Norman will be made in the whole sky mode from two locations: the roofs of NSSL and the University of Oklahoma Energy Center building. The main objective is to determine 3-dimensional dynamics in the lightning propagation processes outside the storm in relation to their electric and magnetic fields. Radiation, electric, and magnetic field measurements will be made at NSSL, while electric field sensors will be installed at OU. Special all-sky measurements with a high-speed video system will tie lightning propagation to radiation signals and provide needed data for testing theories of lightning development.

Validation of Polarimetric Parameters. The Cimarron Doppler radar is currently being modified to provide several polarimetric variables over all range gates and for the first time will be able to scan storms of interest in a time interval comparable to normal Doppler collection times. There is a need (1) to determine the effectiveness of the differential propagation constant, K_{dp}, for estimating liquid water in the mixture of rain and hail, (2) to evaluate the relationship between the correlation coefficients and hail size, and (3) to provide a better microphysical interpretation of the polarimetric data. The P–3 and T-28 will be used primarily to document basic storm structure using the airborne Doppler (on the P–3) and the microphysical probes (mounted on both aircraft). Because the P–3's Doppler radar is X–band, comparison with S-band reflectivity would allow identification of hail aloft and to some extent its size. This comparison would serve as an independent verification of polarimetric measurements. Ground truth about hail size will be provided by the T-28 hail spectrometer.

Experimental Forecast Validation Experiment. The basic idea is to begin to investigate the possible role(s) for high-resolution numerical models in forecasting deep convection. A basic tenet in the modernization of the National Weather Service is that models of all sorts (numerical, conceptual, statistical, etc.) can be used to provide a new focus on relatively short-range (24 h or less) forecasts (*i.e.*, a mesoscale emphasis). This experiment has three specific objectives:

- Determine a baseline skill level at forecasting the thermodynamic and kinematic structure of the atmosphere at a specified time and location on the order of 6 hours in advance.
- Explore the value of a numerical cloud model in near real-time to assess whether or not supercell convection is possible.
- Explore the value of a numerical weather prediction model with relatively high spatial resolution (on the order of 30 km) to forecast the detailed thermodynamic and kinematic structure of the atmosphere at a specified time and location on the order of 6 hours in advance.

The NMC has indicated their willingness to share, on a limited number of days, high-resolution (30 km grid) ETA model output. We expect to explore the use of such output subjectively, and also as a guidance tool in the first objective. We expect to verify supercells by defining supercell convection to be that which has certain Doppler-radar detectable characteristics. The cloud model output will constitute "guidance" to the forecast of whether or not supercells will occur.

Gust Front Algorithm Development. The Cimarron Doppler radar will be used to collect data for testing, enhancement, and development of a number of algorithms for both the NEXRAD and TDWR programs. The Advanced Gust Front, TVS, Velocity De-aliasing, Hail, Mesocyclone, Severe Weather, and VAD algorithms will be run in real-time. The objective of running these algorithms in real-time is to test the latest version of the algorithms on a large number of data sets in a high wind, high wind shear environment. Running these algorithms in real-time allows testing them on data sets that they would normally not be tested on, which sometimes reveals shortcomings of algorithms that would not otherwise be observed. Data will also be collected using a TDWR scanning mode for possible testing of the TDWR microburst and velocity dealiasing algorithms.

The weather phenomena of interest are: gust fronts, severe downbursts, tornadoes, strong vertical wind shear cases including low-level jets, strong frontal passages, large scale convective phenomena (to test possible C-band range folding problems) and severe thunderstorms. Also, clear-air VAD data collection, prior to deep convection, on days when mesocyclones are anticipated. These data will be used to calculate helicity and compare helicity estimates to similar estimates derived from profiler data.

The real-time system is being developed on the ConCurrent 3280 and the SUN computer network. It is planned that there will be five SUN workstations available for running the algorithms and overlaying output of the algorithms on displays of the Doppler radar data. One or two observers will monitor the algorithms when they are running.

Nocturnal Low-Level Jet. This study seeks to demonstrate the capabilities of the profilers to sample the Plains nocturnal low-level jet with sufficient detail to yield the maximum wind speed and the shape of the jet profile. The required measurements are:

- MCLASS soundings at 90 minute intervals from 1800 to 0600 CDT from Chickasha (site of the 915 mHz RASS).
- Single-Doppler radar observations from the most sensitive available radar for the period 1800 to 0600 CDT. If the NEXRAD radar is used the clear-air (long pulse) and precipitation modes (14 elevation angles) should be used. The desired interval between radar observations is 30 minutes.
- Dual-Doppler radar observations for the period 2000 to 2200 CDT.
- 915 mHz RASS profiler, Purcell RASS profiler, and other network profiler data from 1800 to 0600 CDT.
- Water vapor profiles from the multi-frequency microwave radiometer.
- Surface observations from the PAM stations.

4. Project Facilities

NSSL will bring several new observing systems to COPS-91 in addition to facilities that have proven their capabilities in past experiments, *e.g.*, OK PRE-STORM, COPS-89, and SWAMP. These facilities are:

- P-3 aircraft equipped to perform the Fore/Aft Scanning Technique (FAST) with its tail-mounted Doppler radar. Other new sensors that have been added to the P-3's complement for COPS-91 include the (a) NOAA King Air PMS probes and data system (2D-C and FSSP) to improve data quality over the older P-3 cloud physics system and the (b) NSSL-owned Loran Dropwindsonde system developed by NCAR that was very successfully used during COPS-89.
- Two NSSL mobile laboratories (designated NSSL1 & NSSL2) equipped to launch electric field meters (EFMs), particle charge and size instrument (q-d), and MCLASS soundings. These mobile labs also have capabilities for in-situ surface observations of temperature, dewpoint, and wind speed and direction as well as surface electric field and video recording of visual phenomena.
- NSSL's Cimarron and possibly Norman Doppler radars. Cimarron has been substantially upgraded in the last two years to collect a full range of dual-polarization parameters, in addition to basic moment data of radial velocity, reflectivity, and spectral width. The control of Cimarron has also been greatly improved by remoting the data via microwave link to NSSL for real time display and recording as well as remote computer-driven antenna control via commands issued from NSSL. Norman Doppler will be operated only if the OSF NEXRAD and/or Twin Lakes NEXRAD are not operational.
- NCAR PAM stations. A total of 15 stations will be installed for COPS-91. Seven will be deployed in the southwest dual-Doppler lobe in a small area to study frontal circulations (supported by NASA), while the other stations will be deployed farther west in the dryline region (supported by NSF).
- A WPL 915 mHz wind profiler equipped with RASS near the center of the Cimarron-Norman dual-Doppler southwest lobe near Chickasha, OK. This instrument was provided through support by the ERL Director's office.
- A WPL RASS system for the network wind profiler at Purcell, Oklahoma. This instrument was provided through support by the ERL Director's office.
- A WPL multi-frequency microwave radiometer for temporally continuous observations precipitable water vapor and integrated cloud liquid water. This system will be installed near the 915 mHz wind profiler near the center of the Cimarron-Norman dual-Doppler southwest lobe near Chickasha, OK. This instrument was provided through support by the ERL Director's office.
- NSF provided T-28 storm penetration aircraft for in-situ measurements of precipitation, including hail, hydrometeors, and vertical electric field.
- In order to enhance experimental convective forecasts NSSL will make occasional use of special ETA model forecast runs from NMC. Routine use will also be made of the Klemp/Wilhelmson storm scale forecast model to provide forecasts of convective storm type for selected areas.

Fig. 1 shows the likely deployment of sensors for COPS-91. Fig. 2 shows the locations of PAM stations and Table 2 shows the latitudes and longitudes of the PAM stations.

Fig. 1 Preliminary deployment of instrumentation for COPS-91. Triangles (Δ) represent the locations of network wind profilers, solid circles (•) represent the location of Cimarron and Norman Doppler radars, stars (★) with numbers represent the PAM stations, and the open circle (O) is the 915 mHz RASS wind profiler and multi-frequency microwave radiometer. National Weather Service standard SAO stations are shown as asterisks (✳) for reference.

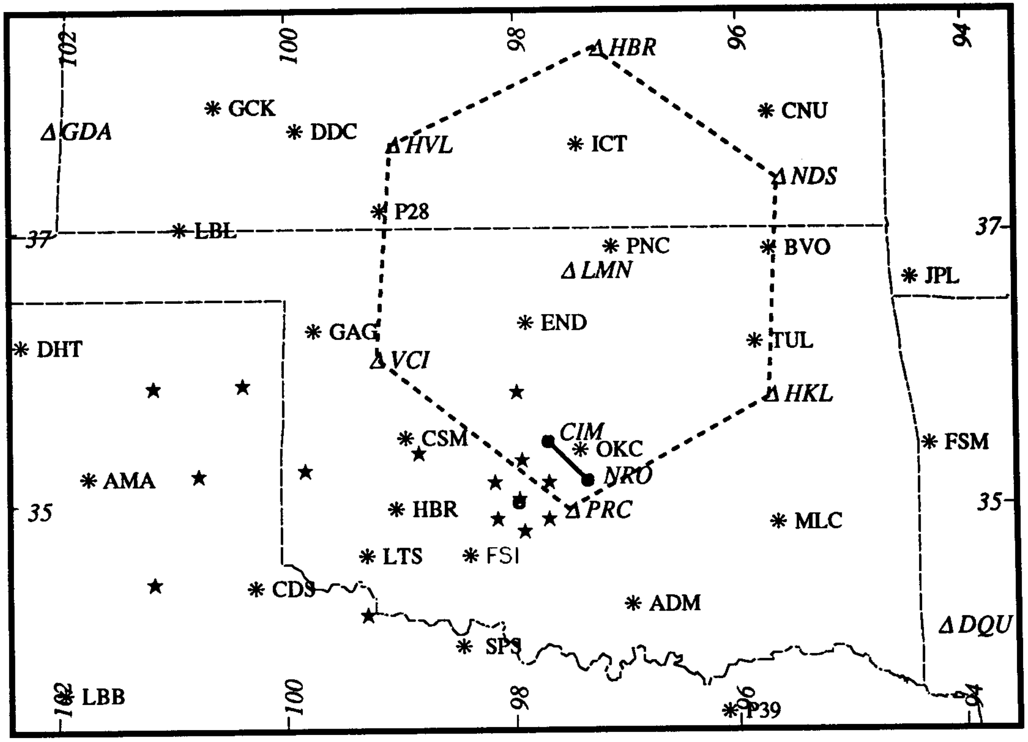


Table 2. Location of PAM stations during COPS-91

PAM Station Locations: COPS-91				
#	Station Name	Latitude (dd° mm′ ss″)	Longitude (dd° mm′ ss″)	Elevation (meters)
1	Stinnett, TX	35° 50′ 27″ N	101° 26′ 53″ W	1007
2	Quitaque, TX	34° 22′ 09″ N	100° 59′ 08″ W	738
3	McLean, TX	35° 13′ 21″ N	100° 34′ 57″ W	868
4	Canadian, TX	35° 53′ 45″ N	100° 24′ 05″ W	726
5	Erick, OK	35° 12′ 10″ N	99° 53′ 28″ W	634
6	Chillicothe, TX	34° 11′ 42″ N	99° 31′ 13″ W	429
7	Corn, OK	35° 22′ 47″ N	98° 46′ 23″ W	487
8	Watonga, OK	35° 51′ 22″ N	98° 25′ 24″ W	466
9	Union City, OK	35° 21′ 58″ N	97° 52′ 45″ W	381
10	Pocasset, OK	35° 14′ 49″ N	98° 02′ 11″ W	410
11	Chickasha, OK	35° 03′ 55″ N	98° 00′ 18″ W	337
12	Tabler, OK	35° 00′ 16″ N	97° 47′ 58″ W	351
13	Blanchard, OK	35° 06′ 24″ N	97° 37′ 04″ W	367
14	Newcastle, OK	35° 17′ 18″ N	97° 39′ 01″ W	394
15	Amber, OK	35° 10′ 35″ N	97° 49′ 44″ W	371

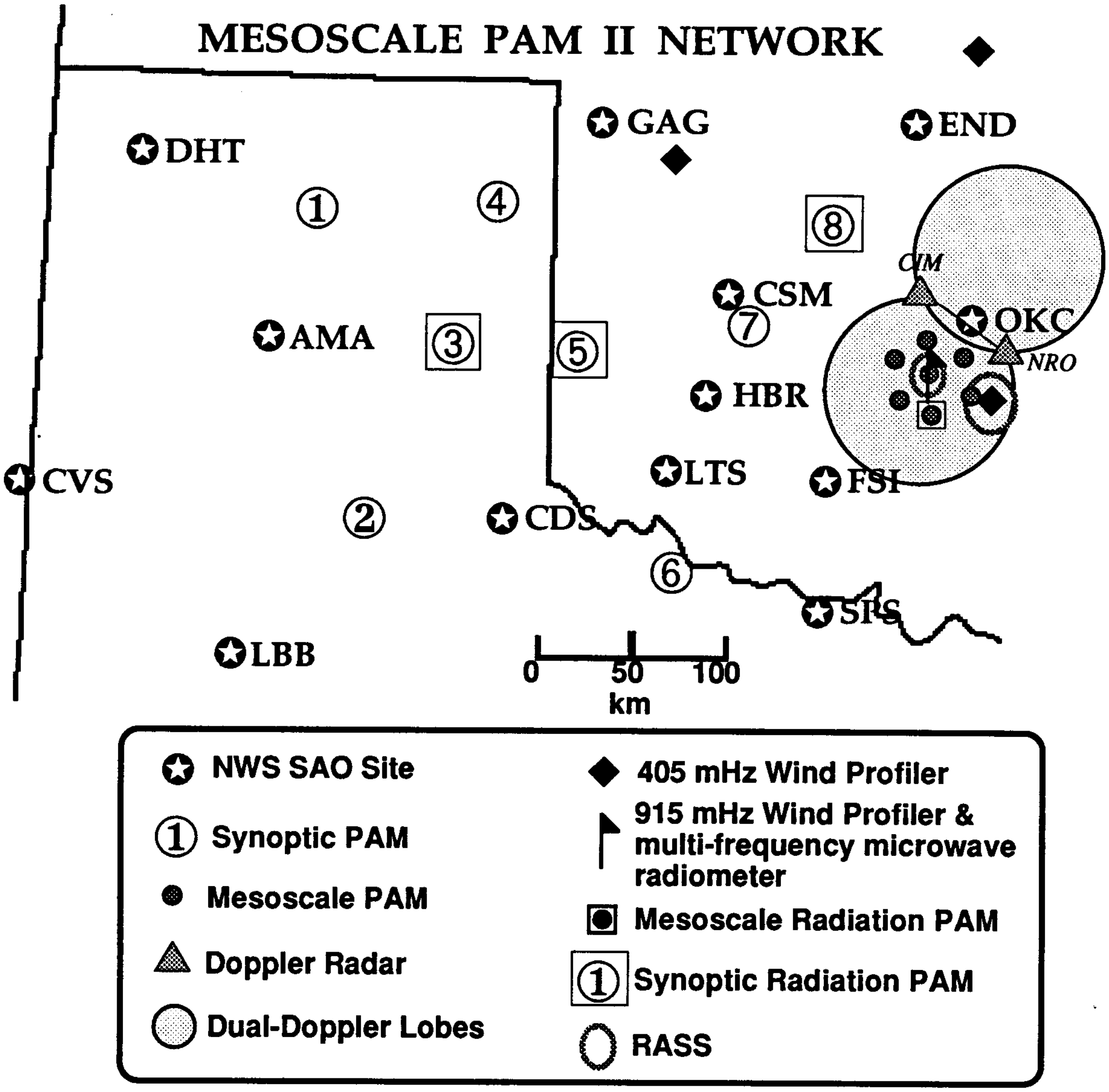


Fig. 3 Locations of primary surace facilities for COPS-91

5. Overview of Operations for Critical Observing Systems

The proposed COPS time period in April 24—June 12, 1991. This interval corresponds to the most climatologically favorable period for severe weather and mesoscale convective systems in west Texas and Oklahoma. The deployment of resources and decisions concerning specific experiments will be made following the daily noon briefing. A scientific steering committee consisting of the lead PI's, the COPS-91 Project Director, the AOC project coordinator, and the NSSL facilities coordinator will meet following the briefing to plan the specific experiment for that day *plus provide an outlook concerning the next days operations.* COPS-91 project director, in consultation with the scientific steering committee and the AOC and NSSL facilities coordinators, will make the decisions concerning choice of missions and name the Mission Director for the day. Once the mission selection is completed, the deployment schedule for the mobile labs, tentative P-3 takeoff time, and radar staffing schedules can be finalized. Operations of the primary observing components of COPS-91 are detailed below.

5.1 P-3

The amount of P-3 flight time available is 110 flight hours. The ferry and a short test flight reduces the research time available to about 100 flight hours. The distribution of flight time amongst the various scientific goals of COPS will depend on the weather, however, an ideal breakdown would be as indicated in Table 3.

Table 3. Ideal breakdown of P-3 Flight Hours.

Flight Patterns for	*# of flights*	*Flight Hours*
Short Wave Structure	2	18
Profiler Evaluations	2	10
Dryline Morphology	3	24
Cold Frontal Circulations	2	14
MCS/Convective Storms	5	30
Total	**14**	**96**

The aircraft will be based at Will Rogers Airport in Oklahoma City. There are approximately 50 Safesondes available for COPS-91.

5.2 Mobile Labs, MCLASS, EFMs, and q-d Instruments

The mobile labs will be deployed to collect both EFM and MCLASS data. Coordination with the P-3 will be achieved through radio contact with the P-3 Chief Scientist and by direction from the Mission Director via 800 mHz radio or satellite data link. There are approximately 20 EFM's, about 200 MCLASS sondes, and ~10 particle charge and size instruments available for COPS-91. The use of MCLASS sondes is dependent on the missions, however, an ideal breakdown in sonde use is indicated in Table 4.

Table 4. Ideal breakdown of MCLASS sonde use.

Mission	*# of events*	*sondes per event*	*Total Sondes*
Convective Storms	3	1	3
Dryline Morphology	3	14 or 24	52
Cold Frontal Circulations	2	12	24
MCS	6	6	36
Forecast Evaluation	21	4	84
Total			**199**

5.3 T-28

The T-28 will be available for COPS-91 from May 13 to June 12, 1991. The aircraft will be based at Westheimer Airport in Norman. Total flight time available for COPS-91 is 30 hours. The T-28 is constrained to fly during daylight hours. A T-28 coordinator will be working in the Operations Center to communicate and vector the aircraft to the proper storms for penetration.

5.4 NCAR PAMs

Fifteen NCAR PAM stations have been allocated to COPS-91. Some of these stations will be deployed in a small mesonet array within the southwest dual-Doppler lobe (Cimarron-Norman Dopplers) to study frontal and dryline circulations. The proposed layout of the PAMS is shown in Fig. 2. The remaining stations will be deployed in the dryline region to fill in the gaps between the National Weather Service (NWS) stations (SAO). A base station will also be available to examine PAM data in real time.

5.5 Cimarron and Norman Dopplers

The ground-based NSSL radars will be controlled by Coordinators who will select the scanning strategies based on the weather phenomena and the objective of the experiments, in consultation with the Mission Director. Norman Doppler will be used if OSF/Twin Lakes radars are not operating routinely and recording data. This radar will also be used if needed to support NWS forecast and warning activities for severe weather situations if OSF/Twin Lakes radars are not available.

6. Forecasting and Daily Operations Schedule

The COPS-91 scientific operations base will be the NSSL operations/control room. The forecasting team will make use of WSFO facilities across the street from NSSL to prepare daily forecasts and next-day outlooks. The COPS-91 forecasting support effort will operate 7 days a week for the full operational period of the experiment.

6.1 *Nominal Daily Schedule*

The following daily chronology provides a working guide for how forecast support will operate on a day-to-day basis assuming a late afternoon or evening P-3 takeoff time (TO). **The schedule will be adjusted for earlier P-3 departures.** The typical daily schedule will be as follows:

08:00—noon CDT

The forecaster, augmented by the NWS morning forecaster, will perform analyses to forecast probability of occurrence of convective development in the COPS region (Oklahoma and Texas panhandle), and estimates of the location and speed and direction of movement of the dryline.

noon CDT

All interested staff and PIs meet to discuss the outlook for convective development for that day and to review the status of the various program elements. Based on this information the Project Director, a select subset of PIs, Project Coordinators, the AOC project manager, and the forecaster will determine if the day should be considered GO or NO-GO for T-28, mobile lab, and T-28 operations, and if it is a GO day, the observational strategies for the various instruments and platforms will be determined.

At least 4 h prior to the tentative TO, the Mission Director and Nowcaster arrives at NSSL Ops Center and begins to monitor convective development using conventional data (hourly surface maps, soundings, etc.), dial up radar and McIDAS satellite displays.

TO - 3 $^1/_2$ h

Key P-3 personnel are briefed by forecast/operations team.

TO - 3 h

Program leaders make final GO or NO-GO decision, or delay the TO.

TO - 1 $^1/_2$h

P-3 crew members go to the airport.

Following the departure of the P-3 from Will Rogers, communication is established between aircraft and nowcaster/operations team; continual updates of aircraft location, weather, movement of convective system, development of system, etc., are relayed between the operations center and the P-3. Primary functions of the nowcast/operations team are to monitor data and relay information about storm location, movement, and any significant changes in storm structure.

6.2 *Decision Responsibilities*

Due to the large number of scientific objectives and resulting competing observational strategies of COPS-91, the decision making responsibilities will be more formally established than in past NSSL projects. A small scientific steering committee consisting of the Project Director, a select subset of PIs representing the main objectives of COPS (MCS electrification, dryline, and fronts), the Facilities Coordinators (P-3, NSSL facilities), the AOC project manager, and the forecaster will meet following the noon weather briefing and discuss project priorities and observational strategies and the weather forecast. The steering committee will consider and make recommendations concerning:

- Type of mission (dryline, MCS, fronts, etc.)
- Deployment times for NSSL1 and NSSL2.
- The location and timing of MCLASS and EFM launches by NSSL1 and NSSL2.
- Crew assignments for the P-3, mobile labs, Cimarron and Norman coordinators, and operations center staff.
- Does Norman Doppler have to come up early in support of NWS operations?
- T-28 takeoff time and observational strategies. ?

The final decision about missions and deployment of facilities will be made by the Project Director following the steering committee discussion and recommendations. Note that there could be different strategies for afternoon convective storms involving the T-28 and one mobile lab and a late evening MCS involving the P-3 and both mobile labs on the same day.

Sunday	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*
		Doswell Blanchard Keller	4/24 Witt Blanchard Keller	4/25 Witt Blanchard Keller	4/26 Witt Blanchard Keller	4/27 Doswell Blanchard Keller
4/28 Doswell Blanchard Keller	4/29 Burgess Blanchard Keller	4/30 Burgess Blanchard Keller	5/1 Burgess Blanchard Keller	5/2 Crisp Blanchard Keller	5/3 Crisp Blanchard Keller	5/4 Doswell Blanchard Stumpf
5/5 Burgess Blanchard Stumpf	5/6 Burgess Blanchard Stumpf	5/7 Doswell Blanchard Stumpf	5/8 Doswell Blanchard Stumpf	5/9 Doswell Blanchard Stumpf	5/10 Doswell Blanchard Stumpf	5/11 Doswell Blanchard Stumpf
5/12 Witt Blanchard Stumpf	5/13 Witt Blanchard Stumpf	5/14 Witt Holle Vasiloff	5/15 Burgess Holle Vasiloff	5/16 Burgess Holle Vasiloff	5/17 Burgess Holle Vasiloff	5/18 Crisp Holle Vasiloff
5/19 Crisp Holle Vasiloff	5/20 Crisp Holle Vasiloff	5/21 Witt Holle Vasiloff	5/22 Witt Holle Vasiloff	5/23 Burgess Holle Vasiloff	5/24 Burgess Augustine Rhoden	5/25 Crisp Augustine Rhoden
5/26 Crisp Augustine Rhoden	5/27 Witt Augustine Rhoden	5/28 Witt Augustine Rhoden	5/29 Crisp Augustine Rhoden	5/30 Crisp Augustine Rhoden	5/31 Witt Augustine Rhoden	6/1 Witt Augustine Rhoden
6/2 Burgess Augustine Rhoden	6/3 Burgess Augustine Keller	6/4 Burgess Augustine Keller	6/5 Burgess Augustine Keller	6/6 Crisp Augustine Keller	6/7 Crisp Augustine Keller	6/8 Crisp Augustine Keller
6/9 Witt Augustine Keller	6/10 Witt Augustine Keller	6/11 Doswell Augustine Keller	6/12 Doswell Augustine Keller			

Table 5 Forecaster/Nowcaster rotation schedule. The first name is that of the forecaster, the second name is that of the 1st shift nowcaster, and the 3rd line is the name of the 2nd shift nowcaster.

6.3 *Forecaster/Nowcaster Rotation*

Assignments for forecaster and nowcaster are shown in Table 5. The first shift nowcaster comes on duty prior to the noon briefing and works until about 3 hours prior to the anticipated P-3 takeoff or 1800 CDT whichever is later. The second shift nowcaster (if needed) starts at 3 hours prior to the P-3 takeoff or 1800 CDT and works through the end of the mission day. Because of the potential for long duration operations by the Norman Doppler (severe weather usually occurs in the afternoon, while MCS's typically are more nocturnal) provisions for a second shift for the Norman Coordinator will also be made.

7. Mobile Laboratory Operations

The mobile labs (NSSL1 and NSSL2) will be used to support the COPS-91 objectives in MCSs, dryline and frontal environments, dual-polarization measurements, forecast evaluation experiment, and profiler evaluation studies. Below is a description of mobile lab deployment and MCLASS launch strategies for each of the scientific objectives.

7.1 MCS Missions

EFM Launch Strategies. To satisfy the scientific objective of documenting the horizontal variations in electric field through the MCS, two mobile labs capable of launching EFMs are required. The prime observing strategy will be to deploy both labs ahead of the system and serially launch EFMs as the system passes overhead. It is highly desirable that both labs remain in a fixed location during the launches to achieve about 1.5 hr frequency of launches, however, some adjustment in position of the labs may be required to place the launches in the optimum position. Fig. 3 illustrates two possible scenarios for the case where the baseline between the labs is oriented perpendicular and parallel to the orientation of the convective line. The mobile labs are separated by about 50–100 km. If the system motion is about 50 km hr^{-1}, then launches every 1.5 hours would achieve a time-to-space resolution of about 75 km. Due to uncertainties associated with ascent rates, the timing of the cutdown devices, and the time required for the instruments to fall back to earth, a longer time interval than 1.5 hours may be required. The next EFM will not be launched until the telemetry from the previous EFM has been lost. If launches in convective cores proves difficult to execute then EFMs can be launched in the transition zone just to the rear of the convective line. The two balloon trucks (Balloon 1 and Balloon 2) will be use to transport helium and supplies for the two mobile labs.

Manpower Requirements. Both mobile labs require 7 person crews for MCS missions. There should be ample opportunity for training of other scientists during COPS-91 to fill one or more of the key positions, therefore there should be considerable flexibility in the assignment of duties during the project. Table 6 shows initial job assignment possibilities. The actual assignments will depend on the mission and personnel availability.

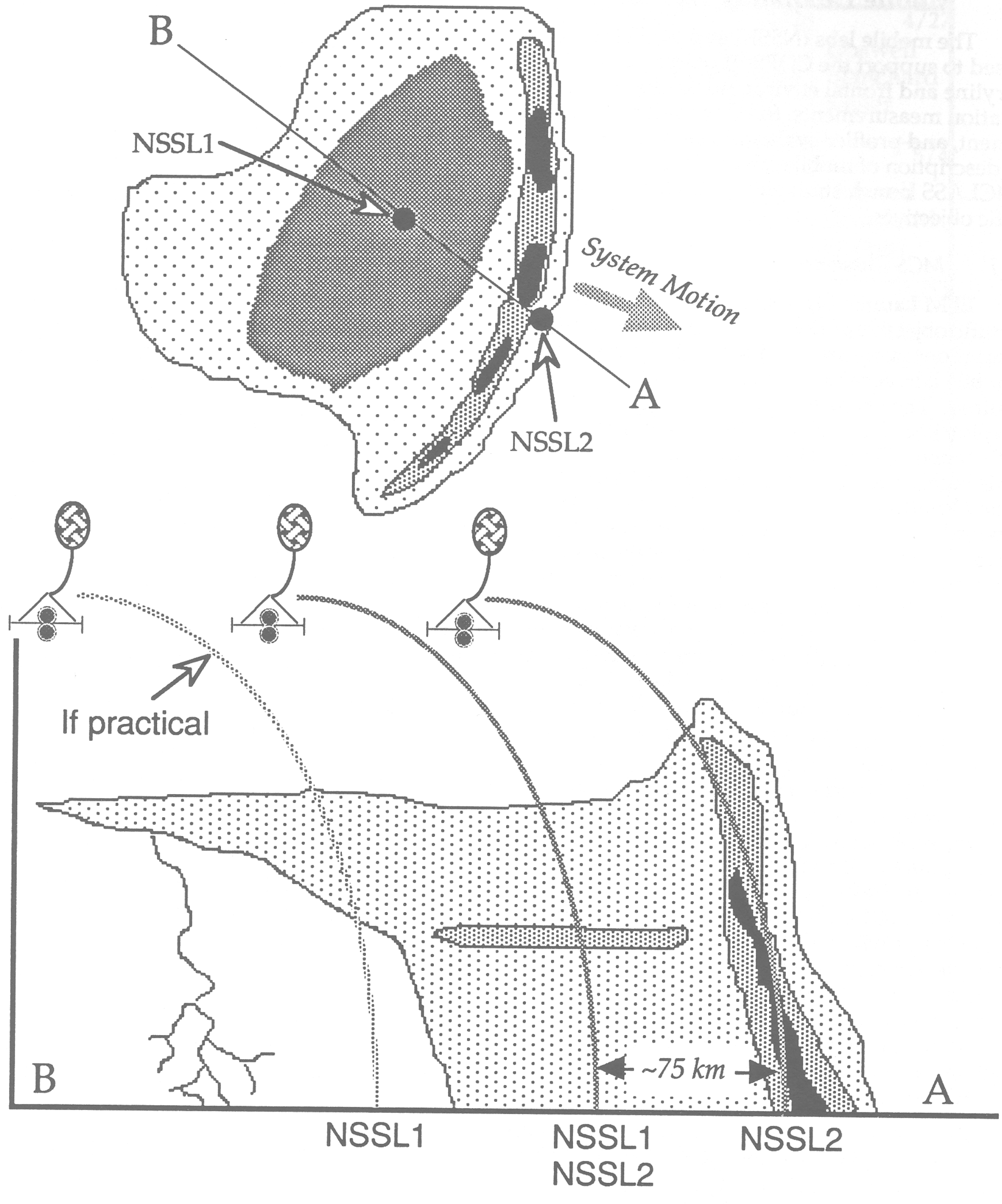


Fig. 3a Scenario for EFM flights into a well organized propagating convective line where the baseline connecting NSSL1 and NSSL2 is perpendicular to the orientation of the line so that EFM flights are taken in the core and stratiform regions simultaneously. NSSL2 then launches in the stratiform region while NSSL1 launches in the trailing anvil for a total of 4 EFM flights.

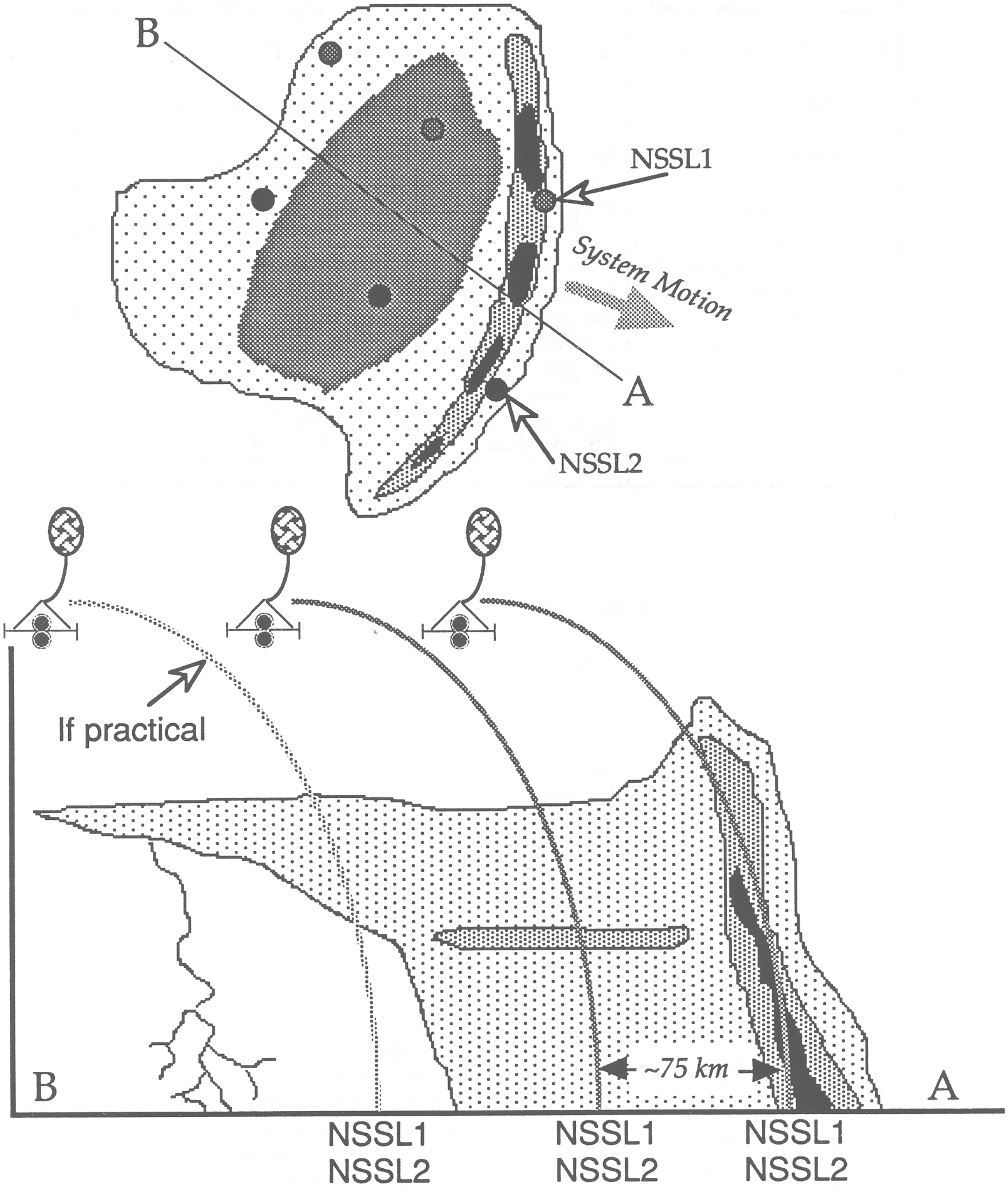


Fig. 3b Scenario for EFM flights into a well organized propagating convective line where the baseline connecting NSSL1 and NSSL2 is parallel to the orientation of the line so that two simultaneous EFM flights are made in the core, stratiform, and anvil regions. A maximum of six EFM flights are launched in this scenario.

Table 6. Possible mobile lab personnel for MCS EFM missions.

Position	NSSL1	NSSL2
Mobile Lab Chief	Rust	Showell
EFM Scientist	Hunter or MacGorman	Schuur or Marshall
Q-D Scientist	Bateman	*not required*
MCLASS Scientist	Shepherd	Fredrickson
Other Crew for NSSL1, NSSL2, Balloon 1, and Balloon 2	J. Carter Stolzenberg Keller Vasiloff Skaggs Wardius Daugherty CSU Student Martin	D. Carter Harbour Stumpf Augustine Jain Blanchard Griffin McCourry Lin Lee

7.2 Thunderstorm Electrification and Polarization Studies

Launch Strategies. When afternoon severe storms are within range of the Cimarron radar and the T-28 is penetrating those storms, EFM data will be collected through the thunderstorm cores to supplement the polarization and electrification studies. Intercept control will be exercised by the mission director at NSSL based on Cimarron radar displays to coordinate the EFM flights with the T-28 penetrations.

Manpower Requirements. Only NSSL1 and Balloon 1 are used for this study. Crew requirements are as indicated in Table 7.

Manpower Requirements. Each MCLASS should have a crew of at least three individuals. However, manpower requirements for mobile laboratory operations in the dryline environment are much reduced from those of MCS missions. Balloon 1 is required to supply helium to the mobile labs. Suggested personnel are as indicated in Table 8.

Observations Complementary to Mobile Laboratory Measurements. Regional data from SAO's, NWS soundings, profilers, and satellite images define the larger scale environment of the dryline. Considering the importance of these data and the uncertainty regarding when the dryline experiments will take place, these data should be archived throughout COPS-91. The time period of greatest interest is from 0000 UTC on the day prior to the dryline experiment, to 1200 UTC on the day following the experiment. Soundings (high vertical resolution) from NWS sites in the central U.S. at 0000 and 1200 UTC, as well as data from the profiler network at maximum time resolution, should be archived. SAO reports from Texas, Oklahoma, Kansas, New Mexico, and Colorado should be made available for later access for the duration of COPS-91.

Table 7. Crew requirements for thunderstorm core EFM missions.

Position	*NSSL1*
Mobile Lab Chief	Rust
Navigator	Davies-Jones
EFM Scientist	Marshall or Hunter
Q-D Scientist	Bateman
MCLASS Scientist	Shepherd
Other Crew for NSSL1 and Balloon 1	J. Carter Fredrickson Stolzenberg Keller Vasiloff Skaggs Wardius CSU Student

7.3 *Dryline Missions*

Launch Strategies. Dryline data should be collected during daylight hours on up to three (possibly consecutive) days on which a dryline *with a significant potential for storms* is expected to form in the COPS-91 experimental area. Examples of drylines are needed in which documentation of the potential to initiate deep convection is possible. All data collection from NSSL1 and NSSL2 will be coordinated with the P-3. Broadcast frequencies for balloon telemetry of all vehicles (including OU) should be preset to avoid conflicts as follows: NSSL1—405 mHz; NSSL2—401 mHz; OU—403.5 mHz (non adjustable). These frequency allocations in conjunction with the transmitter cutoff devices will minimize interference.

Table 8. Suggested mobile lab crews for dryline missions.

Position	*NSSL1 (west)*	*NSSL2 (east)*
Mobile Lab Chief	Showell	Hane or Ziegler
MCLASS Scientist	Shepherd	Schuur or Fredrickson
Communications	Martin	Skaggs

7.3.1 STEPPED TRAVERSE EXPERIMENT

For one of the experiments (coordinated with P-3 flight pattern C1), the teams should be pre-positioned in the field, *e.g.*, motels at Amarillo, TX and Shamrock, TX. (The decision to deploy would be made at the noon briefing on the preceding day, and teams would deploy along I-40 from Norman to staging points that afternoon. Their operational status will be updated that evening and again before the P-3 takes off.) Balloon 1 will deploy with NSSL1, carrying enough extra helium for all required soundings. A 12 UTC (0600 CDT) sounding from the eastern-most MCLASS (*i.e.*, NSSL2) is desirable. Soundings from NSSL1 and NSSL2 should be obtained by nearly simultaneous releases at 1 hr intervals beginning at 0900CST and ending at 2000 CDT. In case of interruptions, *e.g.*, burst balloon, a team should release another balloon if it can attain 500 mb before the setup time of the next release. As a last resort, the balloon can be released at the next hour. NSSL1 should launch roughly 40 km west of the dryline and NSSL2 should launch roughly 40 km east of the dryline as shown schematically in Fig. 4. Release should be within ±5 min of the hour if possible. If more time is needed, set cutdown for less than 50 min. First, middle, and last soundings of the day should go to balloon burst (no cutdown). Vehicles should adjust position according to dryline motion (largely eastward) based on dryline locations updated by the P-3 (after about 1030 CDT) and the nowcaster. For greatest mobility, teams should maneuver along I-40 between Amarillo, TX and Sayre, OK, and further east on highway 152 if needed. Teams should preposition roughly 10 min before launch, set up and launch, wait 5 min, then adjust vehicle position roughly according to dryline motion while balloon is airborne. For operations along I-40, get off on secondary road from appropriate interchange. Each balloon should be equipped with a cut-off device set for 45 minutes. In the event that a storm forms after 1700 CDT along the dryline less than 50 km north or south of I-40/U.S. 152, NSSL2 (east of the dryline) should adjust its position north-south to establish a fixed site within a radial distance of 30-40 km southeast of the storm. NSSL2 should continue the default data collection mode through 1700 CDT if a storm forms before 1700 CDT. NSSL1 would continue the default mode in the event of storms.

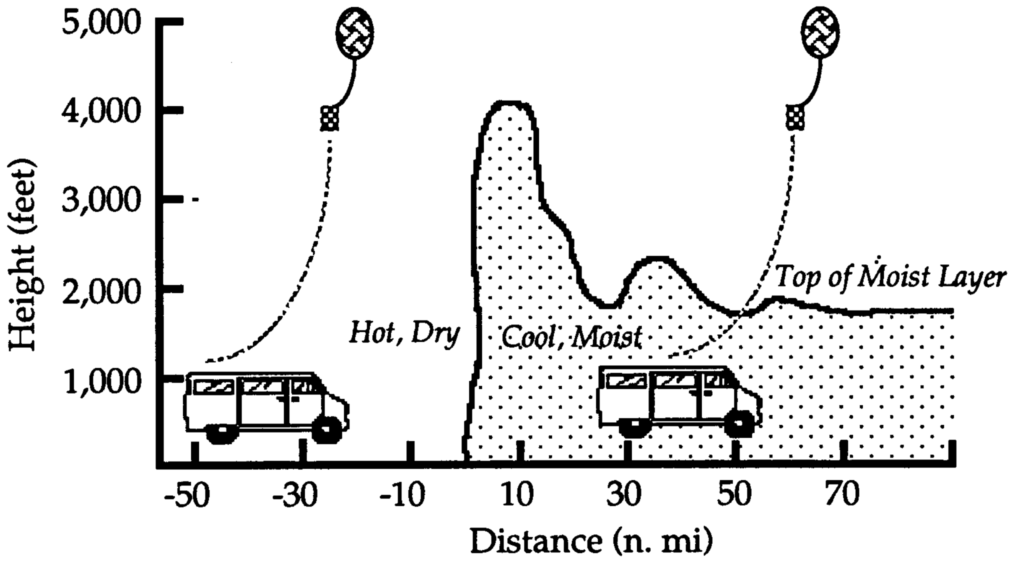


Fig. 4 MCLASS operations by NSSL1 and NSSL2 in the dryline environment. The labs should be on either side of the dryline boundary (which probably has a north-south orientation) separated by 50-80 km. Hourly soundings will allow time to space conversion of data to define dryline structure if the dryline is moving.

7.3.2 ALONG-DRYLINE VARIABILITY AND DRYLINE MESOSCALE FEATURES EXPERIMENTS

The P–3 patterns for these two experiments are shown as Patterns C3 and C4. The requirements for soundings for the options within these experiments are much the same as outlined in 7.3.1. In this case soundings will be taken from the two vehicles at the following times: 1) one sounding from each vehicle at mid-morning near the two motel sites, and 2) at one hourly intervals beginning at the P-3 take-off time and ending near the time when the P-3 leaves the dryline area (maximum of 6 launches each in this mode). These experiments will take place during afternoon and early evening hours for a period of approximately six hours. Distances east and west of the dryline and adjustments in positions along east-west roads should be as outlined in 7.3.1. In this experiment the P-3 will be flying patterns *along* the dryline rather than primarily at a single north-south location. Sounding locations along the dryline (north-south) will be at either the north or south end of the P–3 pattern (see pattern C3) and will usually remain in that position (north-south) for the duration of the experiment. The P–3 patterns will be set up so that there is a good east-west road for MCLASS operations. Redeployment to another north-south location could occur if the aircraft enters a pattern that focuses on a particular feature along the dryline (see pattern options C4), and if time and distance considerations permit. In the event that storms form in the dryline measurement area, the eastern crew will redeploy 30-40 km southeast of the storm of interest.

The "Along-dryline variability experiment" has an extension in the event that a dryline-frontal merger is expected. In that case the MCLASS units will be deployed at the northern end of the P–3 pattern C3. After approximately three hourly releases from each unit, the orientation of the alignment of the two units may be changed if road conditions permit and as the front moves through the area.

7.4 *Forecast Evaluation Experiment*

Launch Strategies. One of the mobile labs will be used to help validate convective forecasts made by numerical simulation. A likely scenario for deployment of the mobile lab will be as follows:

- Decide this is going to be a "cloud model forecast" day following the noon briefing.
- Settle on a time and location for the forecast sounding.
- Produce a forecast sounding for that time and location and deploy one of the mobile

labs to that location as soon as possible (probably by about 1230 pm CDT)

- Upon reaching the location (*e.g.*, 1400 CDT) begin sounding releases as soon as possible, up to 100 mb (takes on the order of 90 minutes). Soundings at intervals of about 2 - 3 hours, depending on the total number available, up to the valid time of the forecast sounding made earlier in the day.
- If the forecast sounding becomes obviously invalid (*e.g.*, a front overtakes the location well before the forecast time), take a sounding documenting the erroneousness of the forecast and terminate the mission. In virtually no case, would we expect the team to stay on site beyond a sounding at or near 0000 UTC.

Manpower Requirements. Only one mobile lab is used for this study. Crew requirements are as indicated in Table 9 Because of the requirement to conduct EFM missions following a forecast evaluation mission, there should be no overlap of crews.

Table 9. Crew requirements for forecast evaluation experiments.

Position	*NSSL2*
Mobile Lab Chief	Brooks or Davies-Jones
Navigator	Doswell or Martin
MCLASS Scientist	Gold or Lasher or Spaeth

8. P–3 Operations

8.1 *Operational Constraints*

The Aircraft Operations Center (AOC) of NOAA has developed several rules regarding P-3 flight missions to ensure safe operations yet allow maximum flexibility to adjust to changing weather and multiple scientific objectives. These constraints are summarized in Table 10.

Table 10. P–3 Operational Constraints

Constraints	*Limits*
Anticipated next-day takeoff time	Must be specified at least 24 hours in advance
Crew duty day	16 hours
Minimum crew rest between duty days	15 hours
Maximum consecutive mission days	6
Minimum pre-flight preparation time	3 hours

The anticipated next-day takeoff time specifies the start of the crew duty day. The mission **must be completed within 16 hours** of this time including any delays in takeoff. A "hard-down" day must be given after the sixth consecutive mission day, or following 3 consecutive late night missions. A mission day is defined as ***an alert day whether or not the aircraft actually flies a mission***. A down day is declared at the weather briefing for the next day. *The scientific personnel will also adhere to the crew duty day and crew rest operational constraints.*

8.2 *Flight Patterns*

One of the advantages of using the P–3 aircraft to investigate weather phenomena is the ability to adjust flight patterns to fit the pattern of storms and precipitation. This ability makes precise pre-planning of specific flight patterns difficult, and what is shown below are only generic flight patterns showing what typically could be done to address each of the scientific objectives. In addition, flight safety requirements specify that the P–3 not penetrate any convective cell where the possibility exists of damage due to turbulence, strong updrafts and downdrafts, and/or damage from hail, graupel, or icing. No penetration of convective features (as evidenced on the nose radar display) will be attempted. Flight paths through extensive "stratiform" precipitation will be a priority for investigation. The flight patterns are grouped by objective and are summarized in Table 11.

8.2.1 SYNOPTIC "SHORT-WAVES" AND PROFILER EVALUATION

This experiment uses dropsondes to gather thermodynamic data on about the same spatial distribution as the Profiler winds to document the 3-D structure of short waves and baroclinic zones that may lay across the Profiler hexagon. A separate pattern is proposed to investigate the feasibility of using a triangle of profilers to calculate vertical velocity. The P-3's in-situ data will be used to validate the linear wind assumption along legs of the triangle. Patterns will also be flown to evaluate the capabilities of Profilers to observe heat fluxes.

8.2.2 MCS DOCUMENTATION

These patterns investigate the structure of the convective and stratiform parts of MCSs. Both airborne Doppler observations and in-situ microphysical data sets are important supporting documentation that is required to properly interpret the electric field measurements. If the MCS is within the CIM-NRO dual-Doppler region, then the P–3 is freer to perform patterns such as spiral descents to document the vertical profile of hydrometeor characteristics to validate polarization parameters taken by CIM. Outside the dual-Doppler lobes, the primary P–3 function is to provide dual-Doppler measurements to support EFM balloon flights. Other, more specific, flight patterns (wake low, vorticity balance studies) are also proposed for special events.

Table 11. Summary of COPS-91 P–3 mission types.

Flight Pattern	*Objective*	*Duration*	*Description*
A	Synoptic "Short-Waves" and Profiler Evaluation	9 hrs	P–3 performs dropsonde pattern from highest attainable altitude to document structure of short waves and to evaluate the capabilities of Profilers to measure heat fluxes
B	MCS Documentation	7 hrs	P–3 performs patterns to collect Doppler and microphysical data sets within MCSs.
C	Examine dryline structure	6-10 hrs	P–3 flies patterns to document the bulk structure of the dryline.
D	Examine frontal structure	6 hrs.	P–3 flies patterns to document the bulk structure of nose of cold fronts.
E	Document convective storm structure	10–12 min.	P–3 flies about 10 nm from the storm center to collect Doppler data in the FAST mode.

8.2.3 DRYLINE EXPERIMENTS: P–3 FLIGHT PATTERNS ON MISSION DAYS

Within the set of dryline P-3 flight patterns, a number of options are presented. Clearly, there are more flight patterns presented than there are mission days available for dryline flights. To clarify this situation, the following outline is presented. Total hours dedicated to the dryline experiments are ~24. It has been decided that these hours will be divided among three days as described below. There is no chronological order implied by the terminology (day 1, day 2, day 3); these are merely designations for the different mission days and these days could occur in any order (as dictated by the weather).

- Day 1. (10 hours) Dryline Cross-gradient and Evolution. Pattern C2 with Module C1.
- Day 2. (6-8 hours) Along-Dryline Variability/Dryline-frontal Merger. Pattern C3 containing module C1.
- Option A. Complete pattern C3. (6 hrs.)
- Option B. Start with C3 and break out to dryline-frontal merger extension of C3, if opportunity present (8 hrs).
- Day 3. (6 hours) Dryline Mesoscale Features
- Option A. Go directly to feature if it is identifiable by means other than aircraft. Execute C1 at location of feature followed by pattern C4 (option 1, 2, or 3).
- Option B. Start with pattern C3 and break out to pattern C4 (option 1, 2, or 3), if mesoscale feature detected.

Note that in each case, if thunderstorms form in the dryline experimental area, a decision will be made on whether they meet pre-specified criteria for concentrated observation. In the Day 2 and 3 cases above, the P-3 will go to pattern C5 if a decision is made to follow the storm with the aircraft.

8.2.4 FRONTAL PATTERNS

This pattern is designed to document the bulk frontal structure and circulations associated with the leading edge of the cold air.

8.2.5 CONVECTIVE STORM PATTERNS

This is the basic P–3 pattern to document the kinematic and precipitation structure of convective storms using the airborne Doppler "Fore/Aft Scanning Technique".

Pattern A1: Synoptic "Short-Waves"

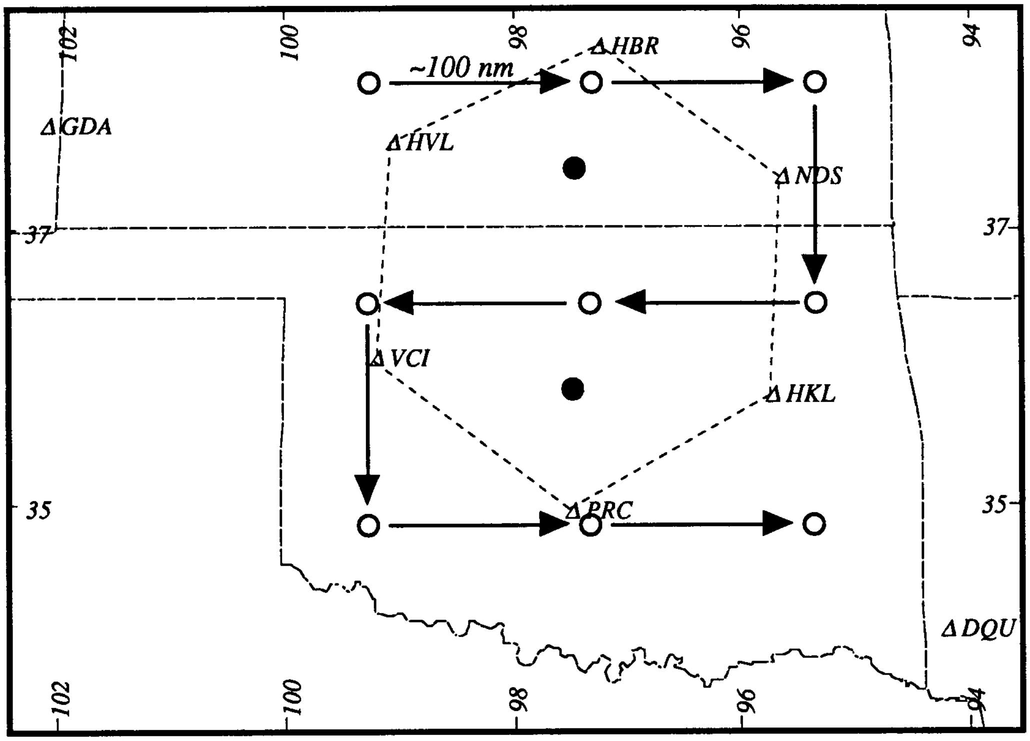
Goal: Gather data sets with which to evaluate the area-wide vertical motion kinematically derived from the profiler network.

Sequence: Aircraft flies the sequence illustrated and releases safesondes at the locations of the open circles. At the conclusion of 1 circuit reverse the track shown and complete a second circuit for a total mission duration of about 8 hours.

Mobile Labs: Both mobile lab releases hourly soundings at the location indicated (solid circles).

Nominal Takeoff Time: Morning

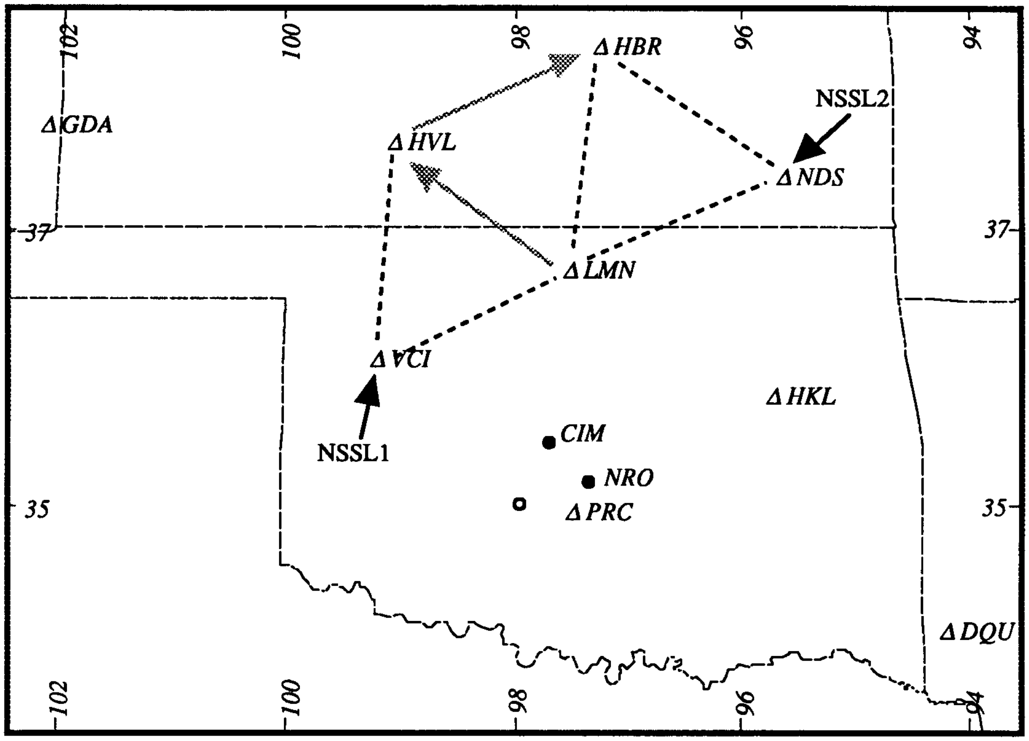
Time Required: 3.5 hours (9 drops) to complete 1 circuit. Need to perform 2 complete circuits.



Note: The P–3 will initially fly upstream to locate the short wave trough axis, collecting in situ measurements that will help establish rough temporal evolution when the system crosses the profilers. If the P–3 can't locate the trough, then the mission will be scrubbed.

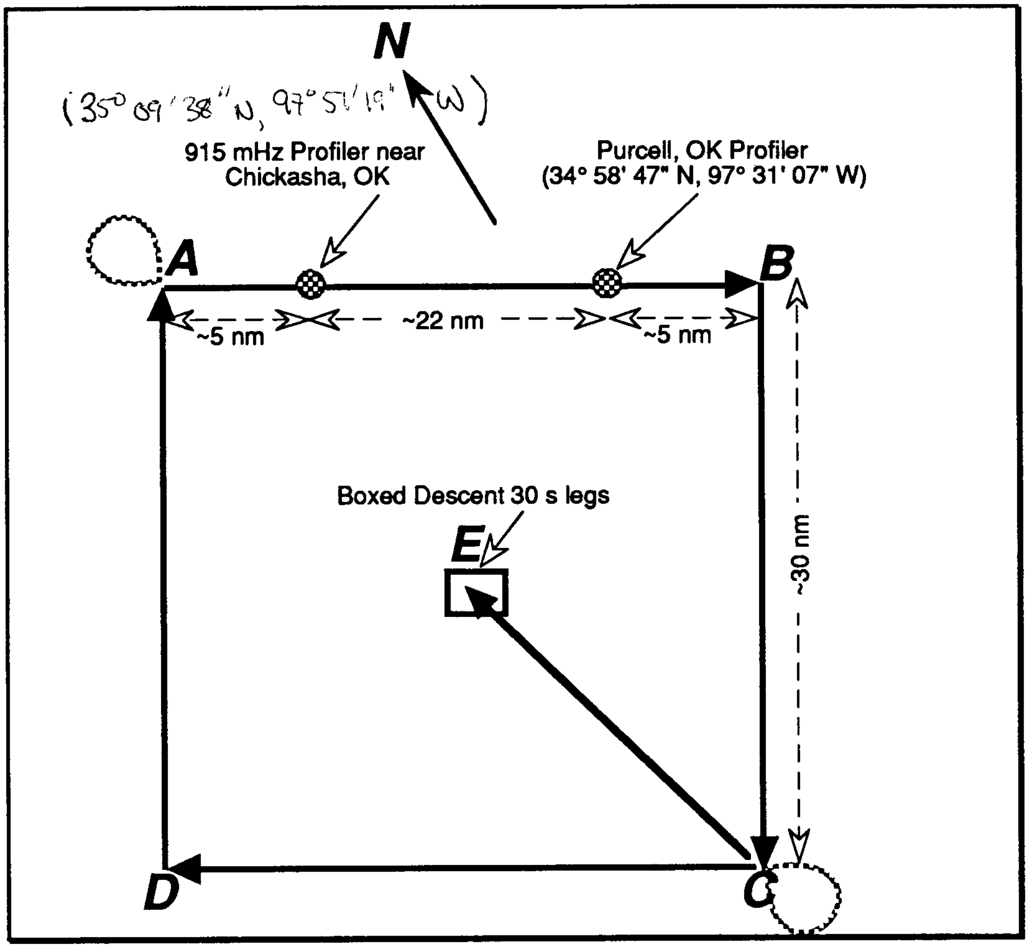
Pattern A2: Profiler Evaluation

Goal:	Gather data sets with which to evaluate the area-wide vertical motion kinematically derived by triangles from the profiler network.
Sequence:	Aircraft flies the sequence illustrated and releases safesondes at the profiler sites LMN, HVL and HBR. Repeat the circuit 4 times.
Mobile Labs:	Mobile lab releases hourly soundings at the profiler sites VCI and NDS. Repeat for 4 hours
Nominal Takeoff Time:	Morning
Time Required:	1 hour (3 drops)
Note:	Other triangles are possible using a combination of 5 sites.



Pattern A3: Heat Flux Study

Goal: To evaluate application of Profiler reflectivity and spectral width data to estimate heat fluxes.



Sequence: P–3 enters pattern at Point A. Fly A–B–C at 1,500 feet AGL. Outside turn and climb to 3,000 feet at point C. Fly C–D–A at 3,000 feet. Outside turn and climb to 5,000 feet at point A. Fly A–B–C at 5,000 feet. Outside climb and turn to 10,000 feet at point C. Fly to Point E at 10,000 feet. At point E perform boxed descent with 30 second legs with descent rate of 1,000 feet per minute to lowest practical altitude.

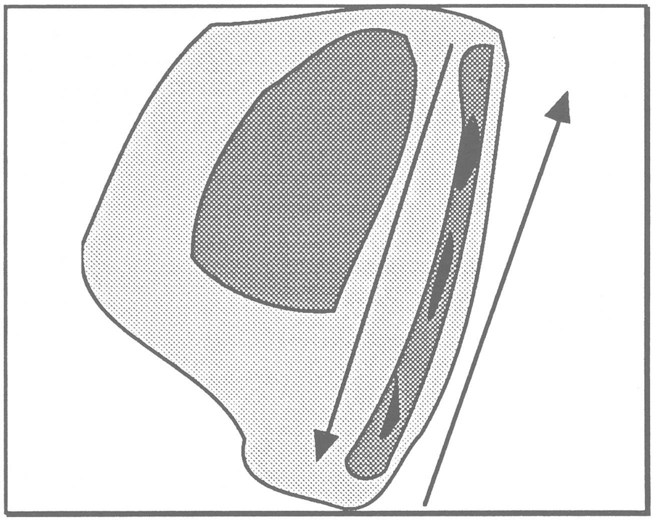
Nominal Takeoff Time: Morning

Time Required: ~1 hr 10 min to complete 1 circuit

Note: Need to perform 2 circuits of the pattern (about 2.5 hrs required). Cimarron and Norman Doppler radars need to be performing clear air scanning during mission.

Pattern B1: Document Broad MCS Kinematic Structure

Goals:	Document basic flow structure within convective line, transition zone, and toward the stratiform region.
Height:	15,000 – 23,000 ft
Sequence:	Fly pattern near convective line. Leg lengths defined by length of convective line. Airborne Doppler scans in the FAST mode. When flying on the outside of the convective line tail radar sector scans toward the line. When flying in the transition zone use continuous 360° scans.

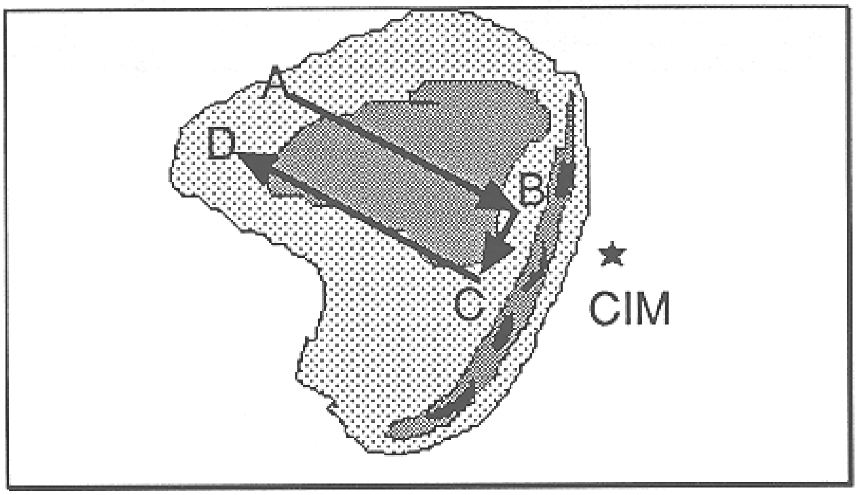


Pattern B2: Document MCS Microphysical Structure

Goals: Document spatial distribution of raindrop (Option 1) and ice (Option 2) hydrometeor characteristics within the stratiform region of the squall line system from front to rear of MCS. Airborne Doppler scans in the FAST mode using continuous 360° scans.

Extend dual-Doppler radar coverage rearward to provide better coverage of transition zone.

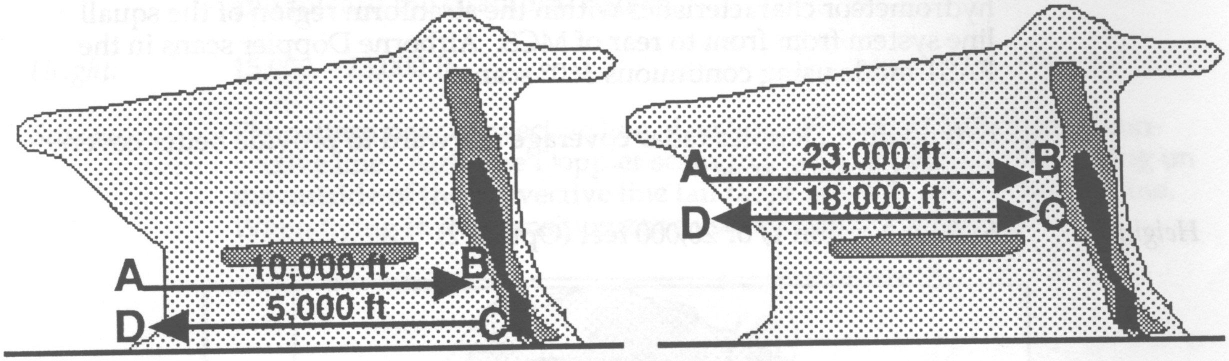
Height: 5,000 ft (Option 1) or 20,000 feet (Option 2)



Sequence: Fly A–B at the first altitude and C–D at the second altitude. Leg A–B is ~50 nm long, but could be altered depending on the size of the stratiform region and location relative to CIM.

Option 1:

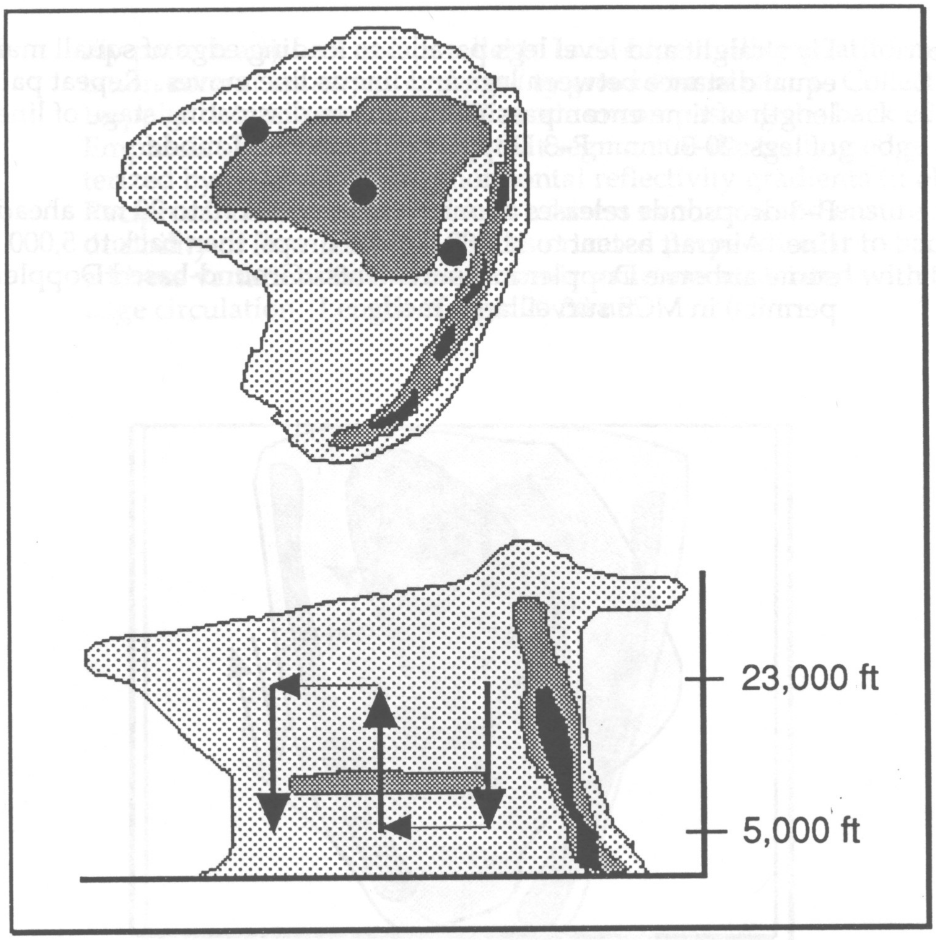
Option 2:


A
10,000 ft
B
5,000 ft
D
C
A
23,000 ft
B
18,000 ft
D
C

Pattern B3: Stratiform Region Spiral Descents

Goals: Document vertical distribution of hydrometeor characteristics in different regions of the MCS.

Height: 5,000 – 23,000 ft



Sequence: Start near the convective line and perform a spiral descent from 23,000 feet to 5,000 feet. Move to a location 20-50 km to the "rear" and perform a spiral ascent in the strongest stratiform region. Move 20-50 km farther to the "rear" and perform another spiral descent. No attempt should be made to hold the spiral over one geographic region, *i.e.,* it should drift with the wind.

Note: Guidance from the Cimarron Coordinator is essential to ensure proper placement of the soundings relative to the stratiform and transition zone region.

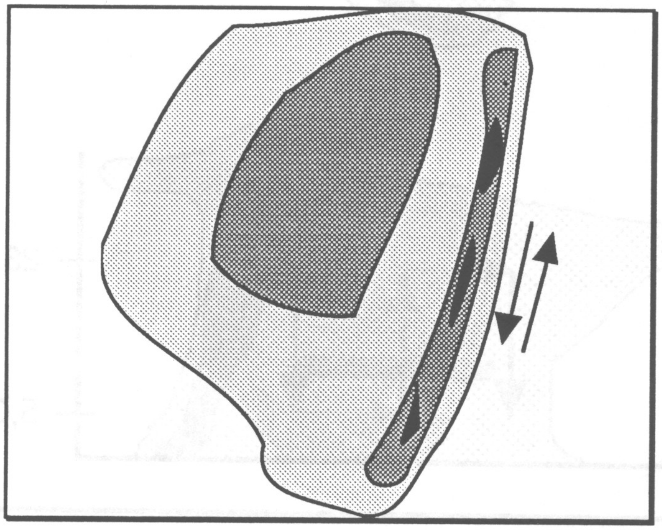
Pattern B4: Vorticity Balance along Squall Line Leading Edge

Goal: Measure the horizontal vorticity in squall line outflow and in environmental shear ahead of the line to evaluate the squall line evolution theory.

Height: 5000 ft to 11,000 ft.

Sequence: Fly straight and level legs parallel to leading edge of squall maintaining equal distance between legs and line as line moves. Repeat pattern over length of time encompassing mature to dissipating stage of line. Length of legs: 20-30 nm. P–3 Doppler radar in FAST mode.

Notes: P–3 dropsonde releases at one hour intervals 10 to 20 nm ahead of the line. Aircraft ascent to 11,000 feet for drops, then back to 5,000 feet to resume airborne Doppler measurements. Ground-based Doppler (if range permits) in MCS surveillance mode.

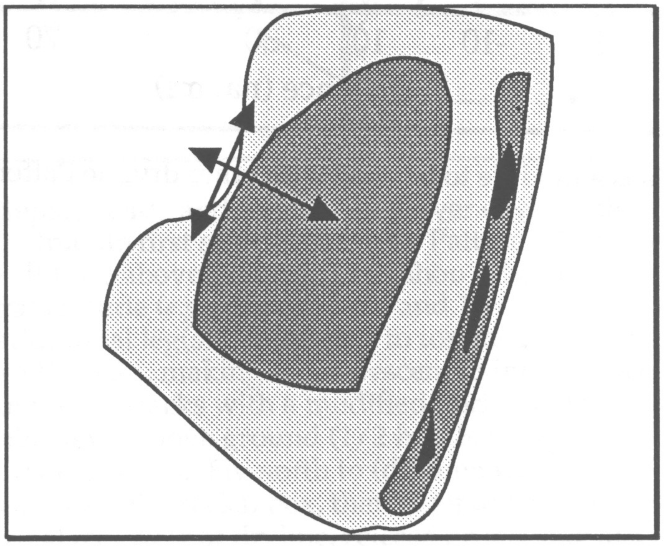


Pattern B5: Wake Low Kinematic and Precipitation Structure

Goal: Document basic airflow and reflectivity structure along back edge of trailing stratiform region, especially in vicinity of surface "wake low" pressure center.

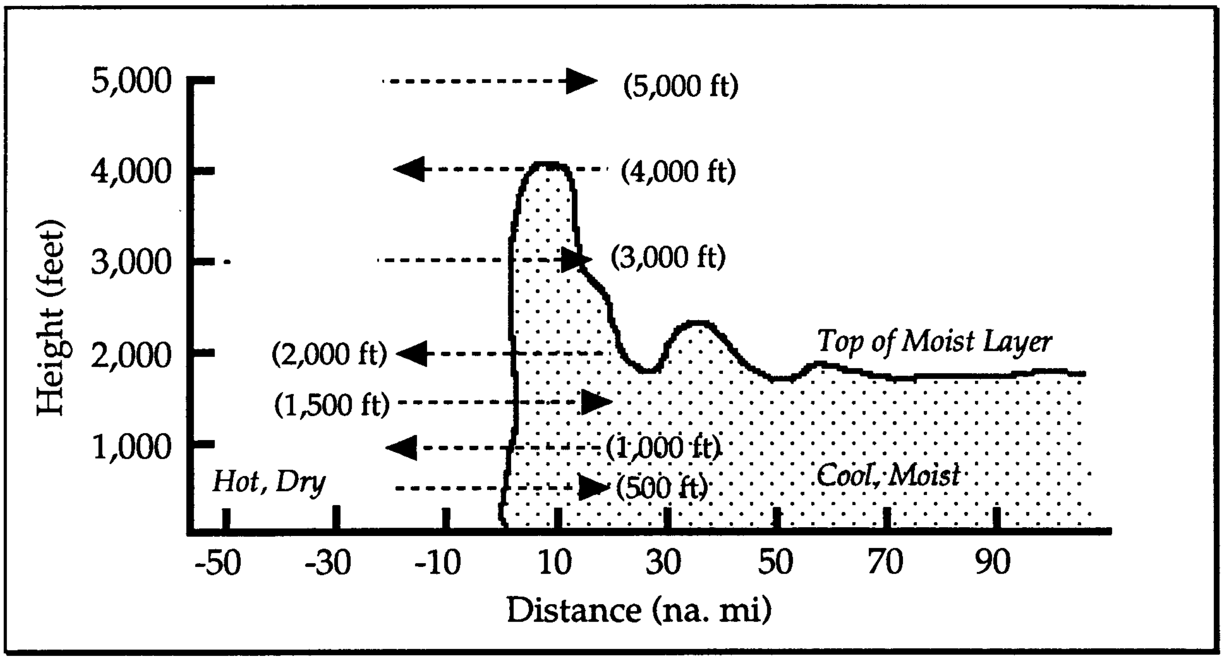
Height: 5000 ft

Sequence: Fly pattern adjacent and parallel to back edge trailing stratiform precipitation zone *at the surface as defined by ground-based radars.* Collect dual-Doppler data in sectored-FAST mode encompassing the back edge. Emphasis should be placed on that segment of the trailing edge characterized by relatively strong horizontal reflectivity gradients (if observed). Reciprocal tracks are desirable to address evolution and ensure reproducibility of flow features. Tracks oriented perpendicular to back edge address variations in thermodynamic structure associated with trailing-edge circulation. Length of legs: 20-30 nm.



Pattern C1: Stepped Traverses

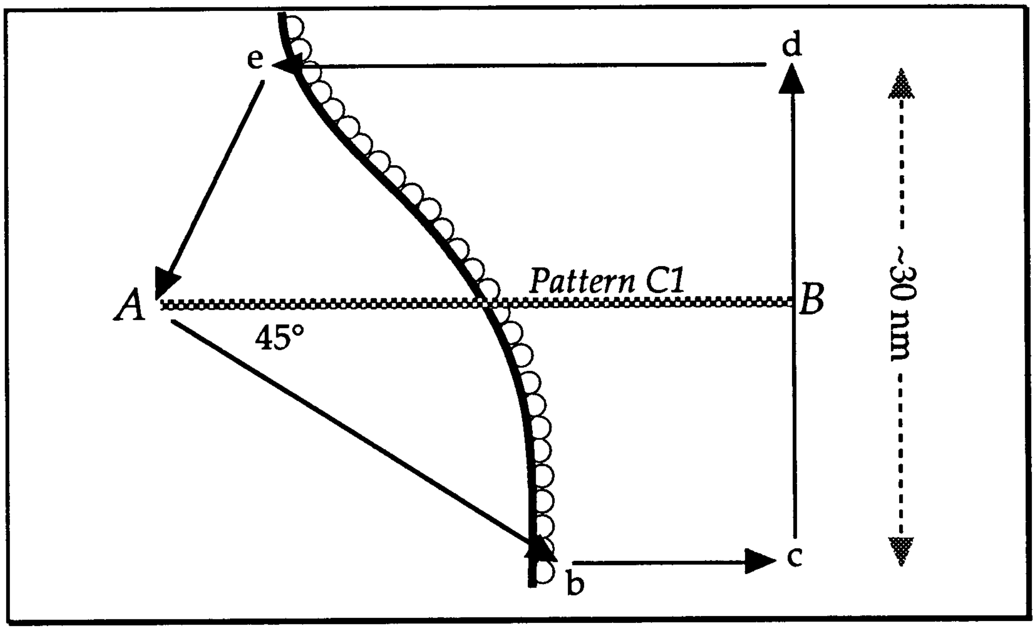
Goal: Document the two dimensional structure of the dryline.



Note: This is a module to be used with other dryline Patterns.

Pattern C2: Variations of Structure Normal to the Dryline

Goal: Document evolution of gradients in a vertical west-east cross-section centered on the dryline. Estimate orientation of dryline in vicinity of vertical cross-section.



Sequence: P-3 departs OKC and transits west over dryline, then perform box descent. Initiate first stepped traverse Pattern C1 at lowest possible pressure altitude above ground. Legs should be oriented east-west at a fixed central latitude (*e.g.*, close to I-40) and 15 nm either side of the dryline. Fly additional leg(s) if necessary to top the moist layer. Fly a sequence of three (3) stacks, making rapid descent to initiate each new stack (3 hr). Follow set of stacks with a modified horizontal box pattern at lowest possible level above ground (1/2 hr). Starting at A, fly SE to dryline (b), then fly east to (c). Fly north to (d), then west to dryline (e), then to (f). Repeat multiple stacks/box, then complete mission with stacks. Climb to 18,000 feet west of dryline, release dropsonde just east of dryline, then return to OKC.

Other measurements: MCLASS hourly soundings 40 km west and 40 km east of dryline near central latitude of multiple stacks/box. Doppler data should be collected if dryline storms develop within 50 km of P-3.

Nominal takeoff: 0900 CDT

Time required: 10 hours

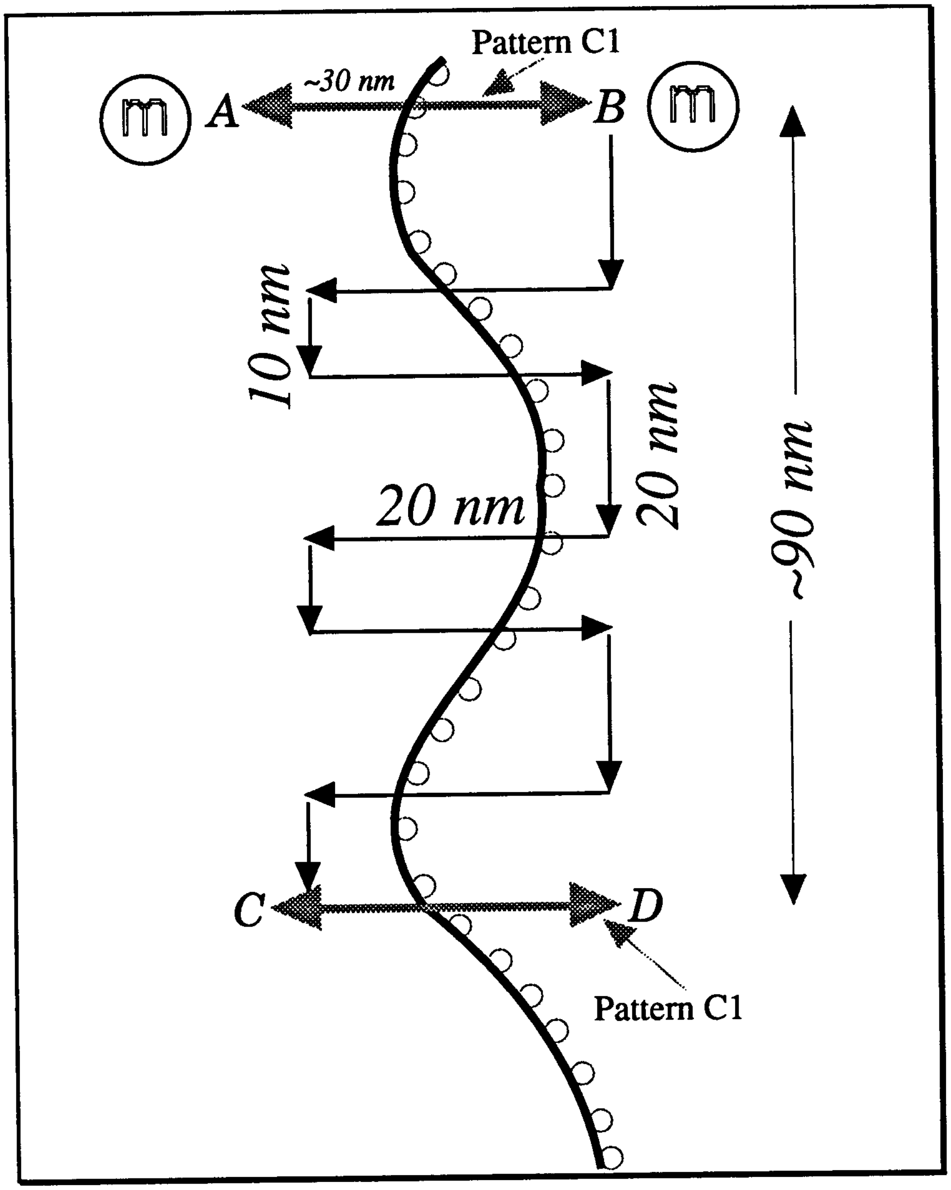
Note: Dryline must be roughly centered in each stack. To allow for wind shear or evolution, P-3 must fly 15 nm AFTER EACH DRYLINE

PENETRATION. The Dryline Mission Scientist is responsible for noting time of penetration and updating AOC Flight Director. Dryline mission scientist should update NSSL1 AND NSSL2 of the ROAD MAP LOCATION/TIME of the dryline roughly every 1/2 hour.

Pattern C3: Along Dryline Variability

Goal: Examine across-line gradients at two different locations along the dryline and compare. Locate and identify mesoscale features in the along-dryline direction that can concentrate the initiation of convection in favored areas. Examine across-dryline/frontal gradients in the vicinity of the triple point as frontal-dryline merger occurs, if opportunity presents itself.

Height: 500 ft — 16,000 feet

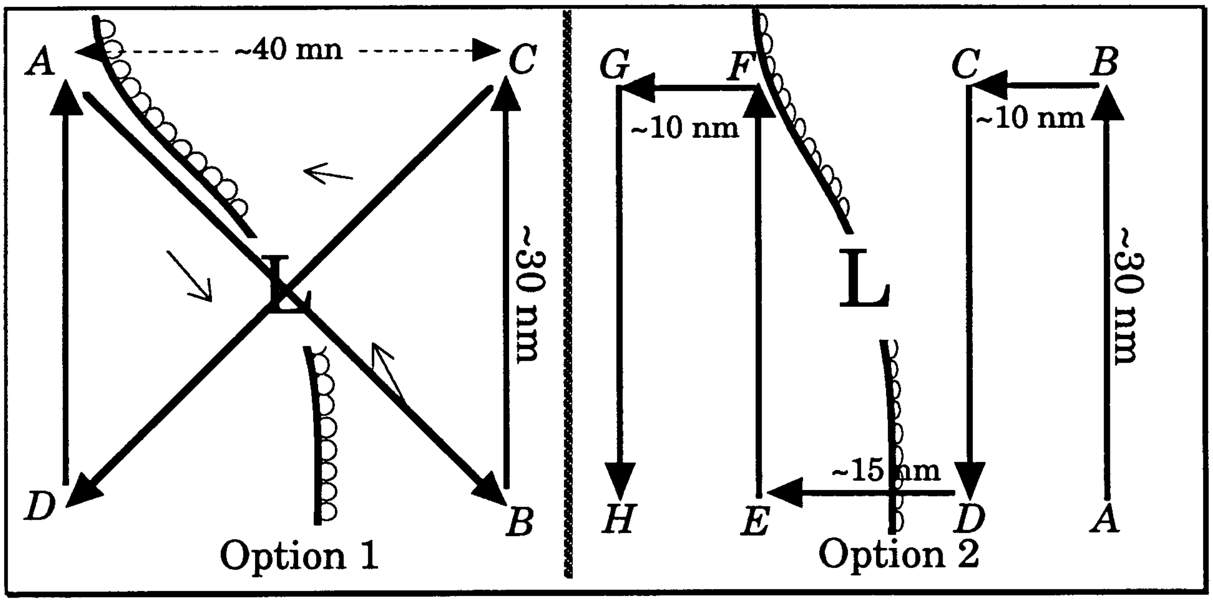


Sequence: P-3 depart OKC in early to mid-afternoon. Proceed westward toward dryline at 16,000 feet and deploy dropsonde 40-60 nm east of point B. Proceed westward to point A and descend to 500 ft to enter stacked traverse A-B (Pattern C1). More legs than indicated in Pattern C1 may be necessary to top moisture plume at dryline interface. Descend at B to 500 ft and initiate square sawtooth pattern, maintaining constant altitude and finishing at point C. At point C begin stacked traverse C–D (pattern C1). At completion of stacked traverse descend to 1500 ft and begin square sawtooth pattern back to point B, maintaining constant altitude. Descend to 500 ft after completing sawtooth and begin another stacked traverse B–A. At completion of stacked traverse ascend to 16,000 ft, deploy dropsonde 40-60 nm east of point B, and return to OKC.

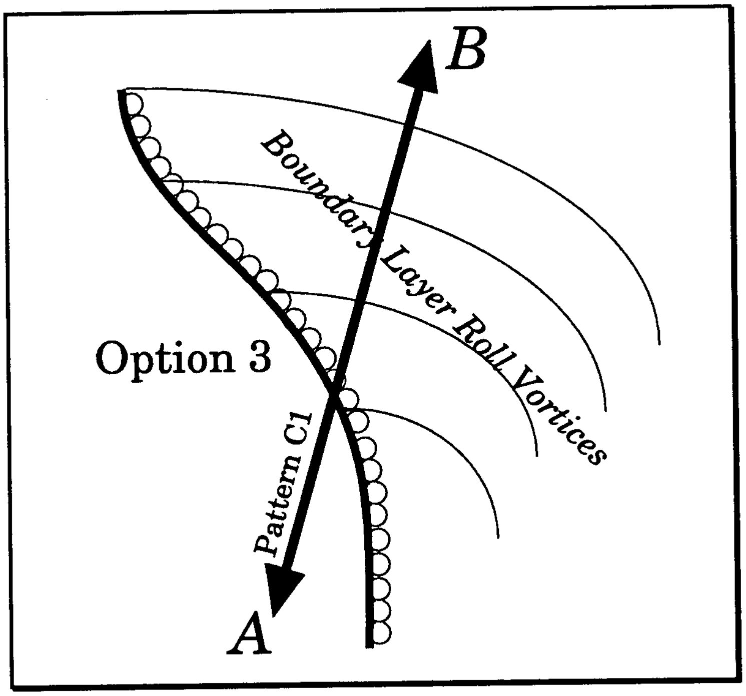
Notes: MCLASS hourly soundings 40 km west and 40 km east of dryline/traverse A-B intersection (circled M's in the above figure). An adjustment in north-south position of western MCLASS will be made if the frontal-dryline merger experiment is entered and if roads in the area permit; locations for units are noted in the frontal flight pattern section. In the event that a storm or storms form along the dryline in the area the P–3 Doppler observations (FAST scanning mode) of the storm will be begun using pattern C5.

Pattern C4: Dryline Mesoscale Features

Goal: Document the structure of mesoscale features such as low pressure areas, vorticity centers, enhanced convergence regions, and boundary layer rolls that may concentrate convective initiation along the dryline.



Sequence: Identify features in the sawtooth portion of pattern C3 that may be investigated in more detail. Break out of Pattern C3 into one of the options of C4. Option 1 or 2 are suited for investigation of suspected circulation features, while 2 may better measure along line changes such as near an area of enhanced convergence. Option 3 is a vertically stacked pattern designed to observe the structure of boundary layer rolls ahead of the dryline. Enter Option 1 at 500 ft and complete butterfly pattern A–B–C–D–A at constant altitude. Repeat pattern at 1500 ft. If mesoscale feature is still evident, repeat pattern again at 500 and 1500 ft. For Option 2 enter pattern at point A at 500 ft and execute A–B–C–D–E–F–G–H, then repeat pattern at 1500 ft. If feature is still evident, repeat at 500 and 1500 ft. The presence of boundary layer rolls might be identified by data from the sawtooth east-west legs, by satellite visible imagery, or visually from the aircraft. Option 3 is a stacked set of legs beginning at point A and ending at B with altitudes identical to the lower portion of the cross section shown in C1. Each of these patterns takes approximately 40 minutes to complete (single altitude in Option 1 and 2 and single stacked pattern in Option 3).

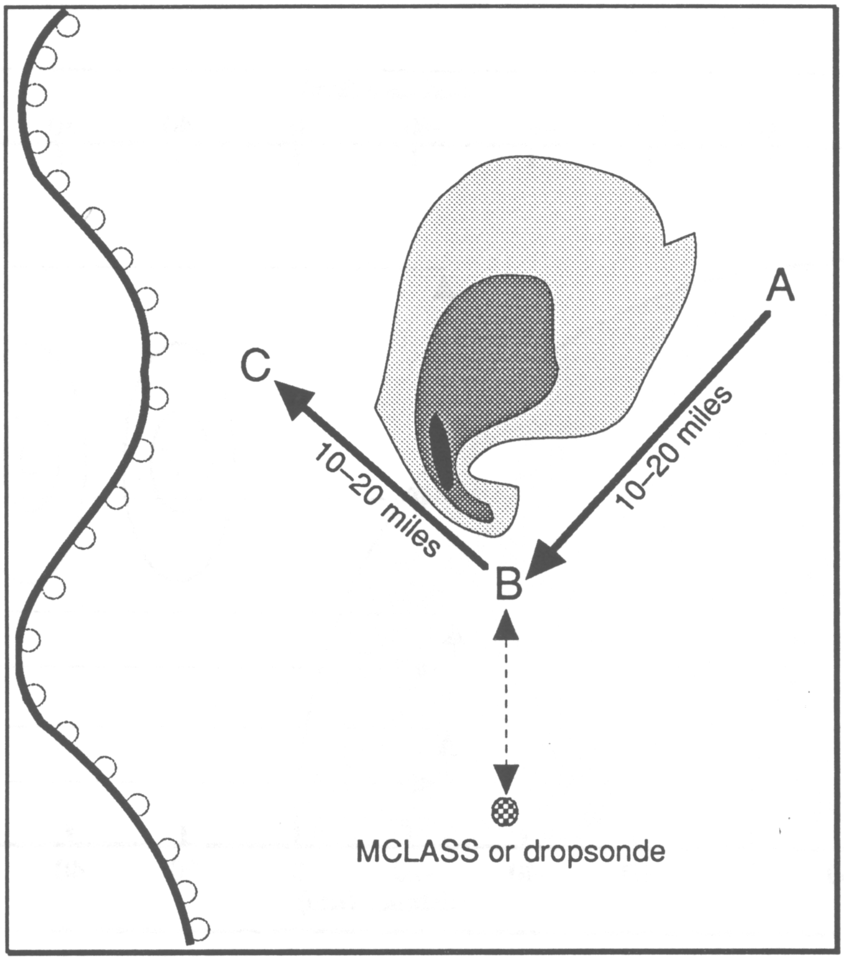


Other Measurements: If mobile labs can reach region of mesoscale features in reasonable time from their locations noted in C3, they will deployed east and west of area of interest. Real time readout from PAM network, satellite imagery, and visual appearance of clouds (if present) from aircraft will be used to help identify suspected mesoscale features along line. In the event that a storm or storms form along the dryline in the experimental area, P–3 Doppler observations (FAST scanning mode) of the storm will be begun using pattern C5.

Pattern C5: Dryline Storm

Goal: Document the structure and evolution of thunderstorms that form on the dryline and relate to measured dryline environment characteristics.

Height: 10,000—20,000 ft

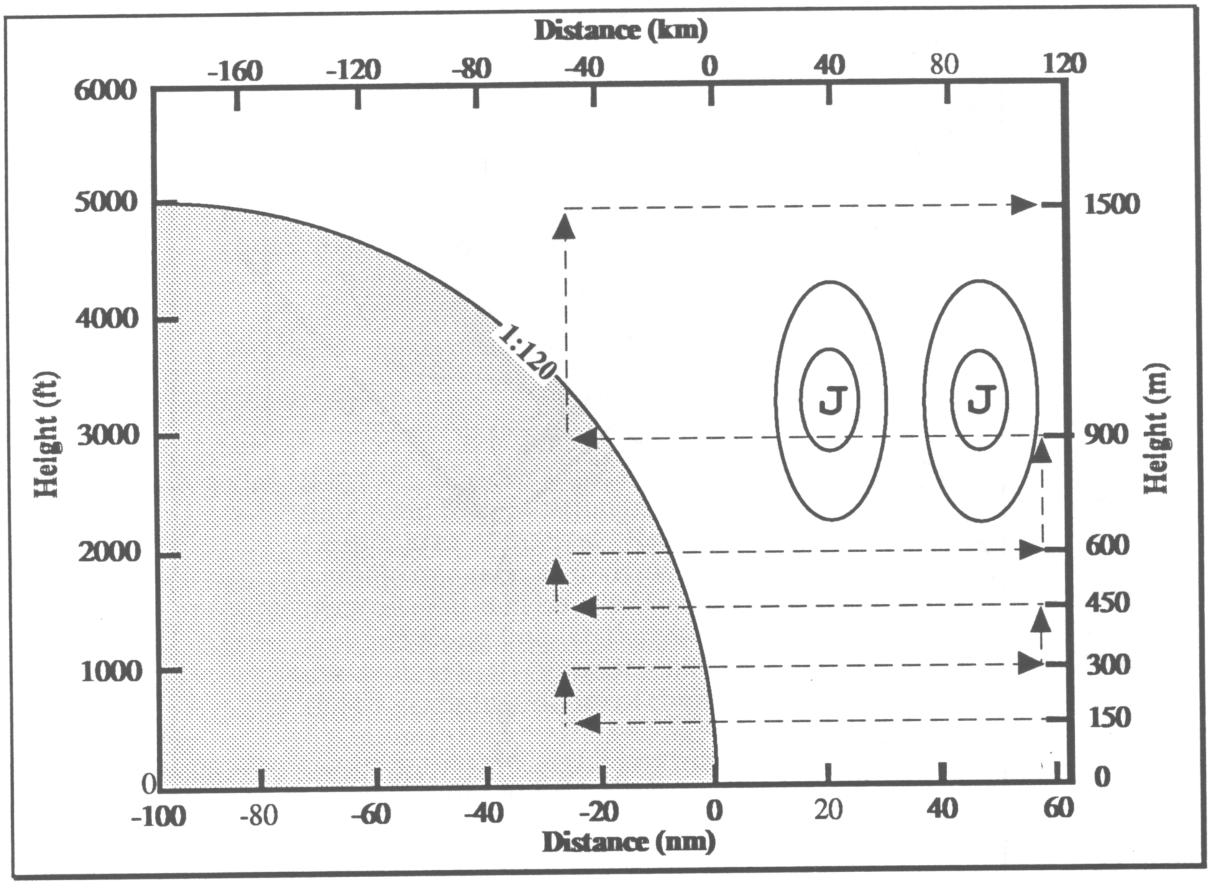


Sequence: Break from dryline pattern as thunderstorms form on the dryline and when pre-specified criteria are met. Climb to 10,000 feet and fly straight legs A–B–C and repeat in opposite direction.

Notes: MCLASS or dropsonde on west side of dryline in the low level inflow to the storm. For dropsonde climb to 20,000 feet while performing A–B–C pattern. At point B track south for 10 miles, release sonde, and return to pattern.

Pattern D1: Prefrontal Boundaries and Low-Level "Jetlets"

Goal:	Examine kinematic and thermodynamic properties of prefrontal convergence boundaries. Establish their origin and role in prefrontal squall line generation. Determine position and strength of prefrontal low-level jet (s).
Height:	500 ft-5000 ft

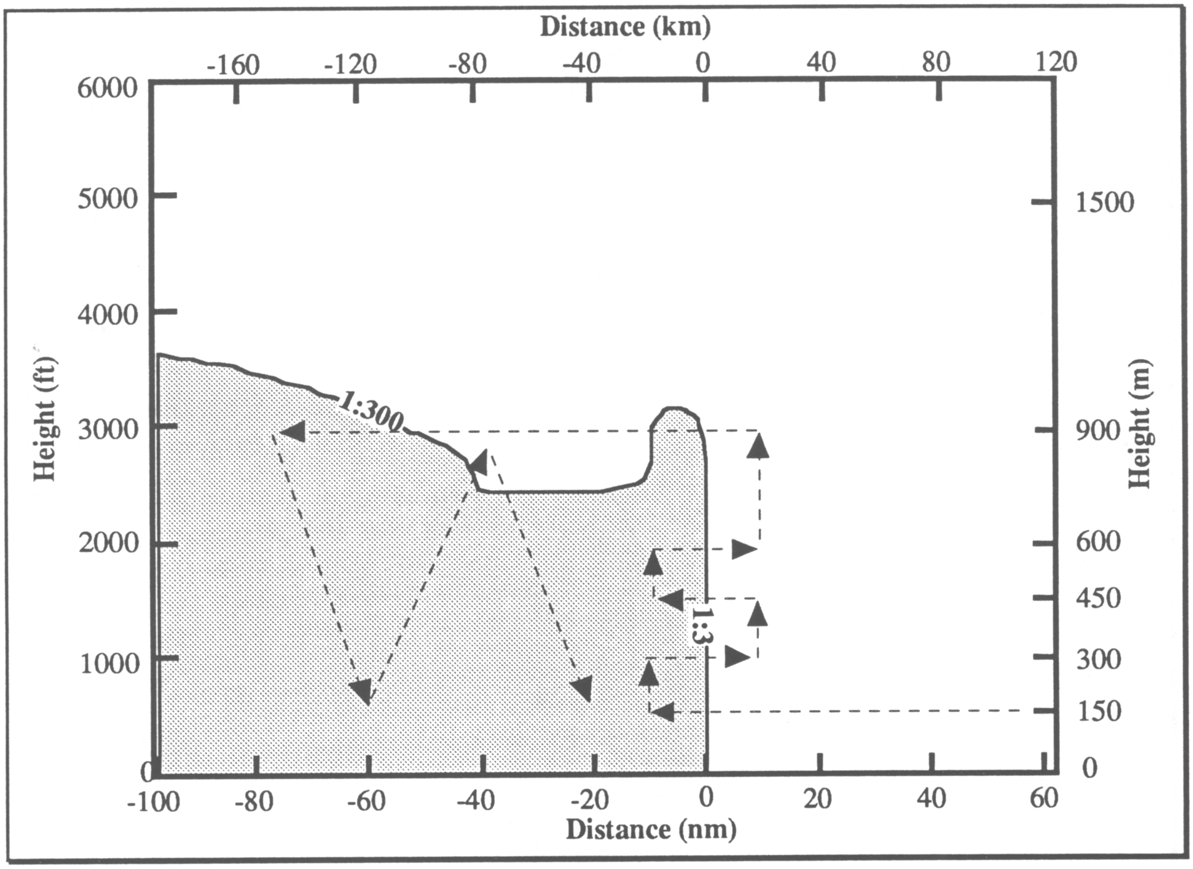


Sequence:	P-3 departs OKC and proceeds southwestwards at 500 ft to cold front approaching inner mesonetwork in dual Doppler area. Enter stacked traverse in direction normal to cold front as determined from ground control. Proceed into cold air a short distance (~25 n mi), only enough to ensure that frontal boundary has indeed been crossed. Exit stacked traverse at 5000 ft and proceed 60 n mi ahead of surface frontal location. Descend back down to 500 ft and repeat entire sequence one more time.
Mobile Labs:	Mobile lab releases hourly soundings at distances of 25 n mi (45 km) on either side of cold front. Repeat for 6 hours (total of 12 sondes).
Takeoff Time:	Early morning (06-09 CDT)

Time required:	4-6 hours
Note:	The Frontal Mission Scientist is responsible for noting time of frontal penetration, and updating both the Field Operations Director and NSSL1 and NSSL2 of frontal location at the beginning of every stacked traverse (~2 hour intervals). Doppler data collection must be coordinated with P-3 flight patterns.

Pattern D2: Line Convection/Clear Zone Phenomenon

Goal:	Measure the evolving vertical circulation and structure of cold frontal systems characterized by post-frontal stratus-type cloudiness, pre-frontal clear skies, and satellite evidence of frontal line convection (LC).
Height:	500 ft-3000 ft



Sequence:	P-3 departs OKC and proceeds southwestwards at 500 ft to LC location only if front is approaching dual Doppler area. Enter stacked traverse in direction normal to cold front, and proceed into cold air a distance of 10 n mi. Exit stacked traverse at 3000-5000 ft and proceed to conduct porpoise-type sampling of cold air in search of secondary cold surge at distances ≤100 n mi from surface front. Descend back down to 500 ft and repeat entire sequence twice more.
Mobile Labs:	Mobile lab releases hourly soundings at distances of 25 n mi (45 km) on either side of cold front. Repeat for 4 hours (total of 8 sondes).
Takeoff Time:	Late morning or early afternoon (10-13 CDT)

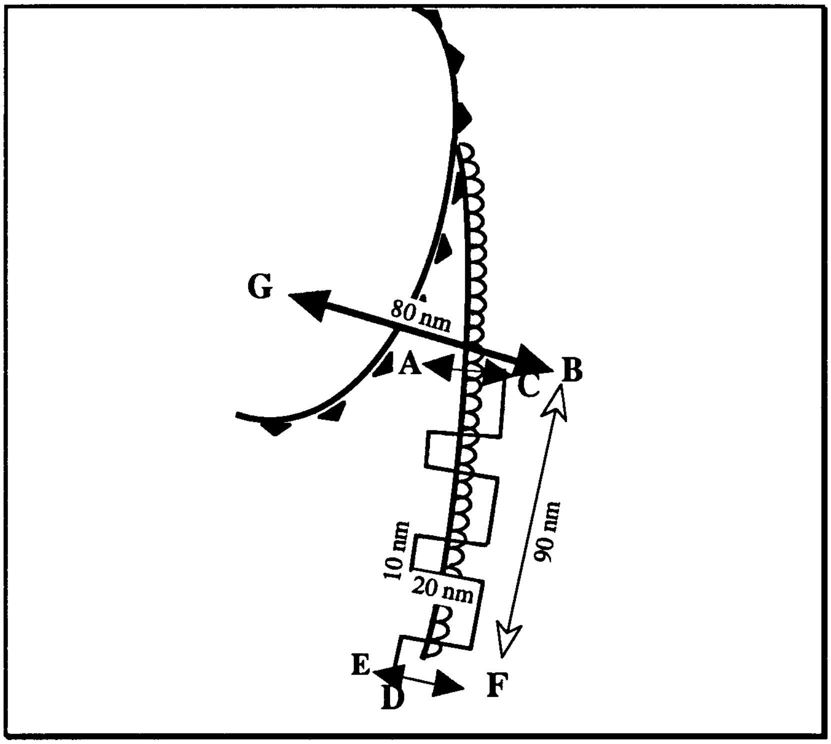
Time required: 4-5 hours

Note: The Frontal Mission Scientist is responsible for noting time of frontal penetration, possible existence of frontal hydraulic head and multiple frontal structures and updating personnel just as in Pattern D1. Multiple Doppler data is also to be collected in close coordination with aircraft measurements.

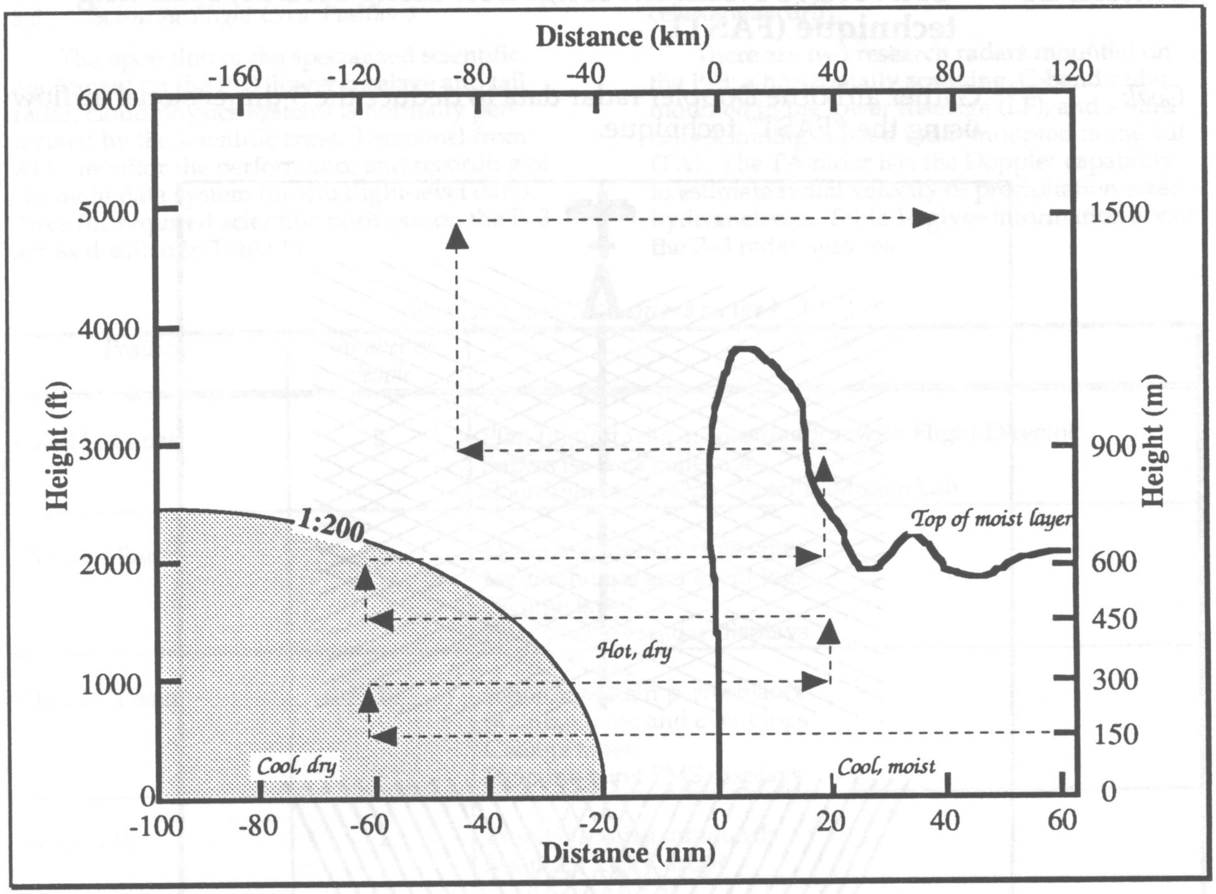
Pattern D3: Dryline/Front Merger

Goal: Determine vertical circulations and structures of both the dryline and an approaching cold front, using flexible sampling strategy that accounts for increasingly small distance between the two phenomena.

Height: 500 ft-5000 ft



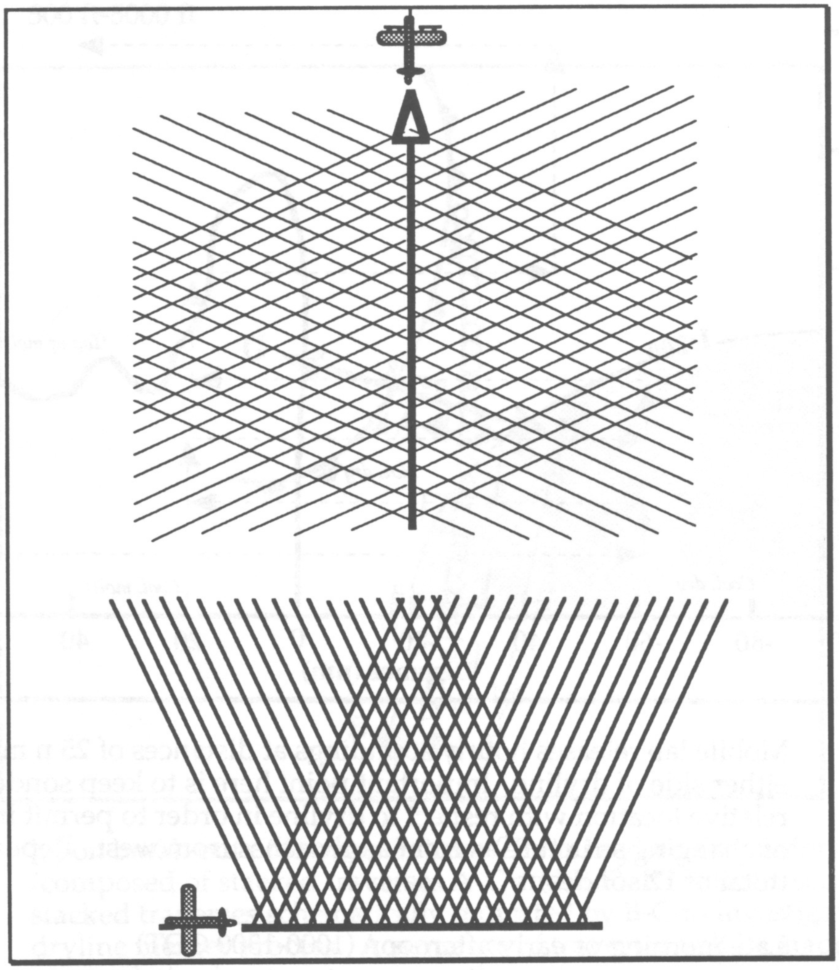
Sequence: Upon break-out of Dryline Pattern C3 for Dryline-Front Merger Study (composed of stacked traverses A-C and E-F), P3 enters a series of stacked traverses schematically indicated by B-G to investigate front-dryline merger process. A sequence of traverses will be made at the same relative location to capture the entire merger process. As shown below, traverses must be sufficiently wide to encompass both the dryline and frontal circulations. It is proposed to make flight legs that pass 40-80 nm into the cold air prior to actual merger, which is much longer than the flight leg of the dryline C3 pattern.



Mobile Labs:	Mobile lab releases hourly soundings at distances of 25 n mi (45 km) on either side of dryline. Important point here is to keep sondes at same relative location with respect to dryline in order to permit investigation of changing structure as front approaches from west. Repeat for 6 hours (total of 12 sondes).
Takeoff Time:	Late morning or early afternoon (1000-1300 CDT)
Time required:	4.5 hours
Note:	The Frontal Mission Scientist is responsible for noting time of dryline and cold frontal penetrations, possible existence of vertical circulations, and updating the Operations Director and Mobile Lab crews. Multiple Doppler data is also to be collected in tandem with aircraft measurements.

Pattern E1 Convective storm investigation using fore/aft scanning technique (FAST).

Goal: Gather airborne Doppler radar data to deduce the 3-dimensional airflow using the "FAST" technique.



Note: The top figure illustrates the scanning pattern when using full rotation FAST scans. The horizontal data density is about 2 km for typical P–3 true air speeds and a rotation rate of 10 rpm. The bottom figure illustrates a sector scan to one side of the aircraft. For sector scans the horizontal data density can be ~1 km.

8.3 *Scientific Flight Crew Positions*

The operation of the specialized scientific equipment on the P-3 (lower fuselage and tail radar, cloud physics system) is normally performed by the scientific crew. Personnel from AOC monitor the performance and recording of the main data system (in-situ flight-level data). Thus the required scientific positions on the P-3 are as detailed in Table 12.

Table 12. Scientific positions on the P-3.

Position	*Number of People*	*Duties*
Chief Scientist	2	Plan flight tracks in coordination with Flight Director Supervise data collection Coordinate with Ops Center & Mobile Lab
Doppler Radar	2	Monitor system performance Maintain tape and event logs Change tapes Help interpret radar displays
Cloud Physics	1	Monitor system performance Maintain tape and event logs Change tapes Help interpret PMS displays
Safesonde	1	Prepare sondes for launch Maintain log of drops
Observers	2 (or more)	Help interpret meteorology and assist Chief Scientist in mission planning Maintain scientific logs

8.4 *Instrumentation*

There are four basic data systems on the P-3. These systems include the main data system for the in-situ data, the radar data system, the safesonde data system, and the cloud physics data system. Table 13 lists the instrumentation on the P-3 for COPS-91, its accuracy, resolution, and manufacturer. The sensors that are serviced by the main data system are sampled at a rate of 40 Hz, and then are averaged to yield 1 sample per second.

Derived parameters (such as wind) are calculated in post-processing once calibrations and biases are determined and removed. The INE accelerometers are bounded with Omega and LORAN navigation position estimates (for horizontal position) and radar altitude observations (for vertical position) to remove the effects of accelerometer drift.

There are two research radars mounted on the P-3: a horizontally scanning, C-band radar mounted in the lower fuselage (LF), and a vertically scanning X-band radar mounted in the tail (TA). The TA radar has the Doppler capability to estimate radial velocity of precipitation-sized hydrometeors. Table 14 gives information about the P-3 radar systems.

Table 13. Characteristics of in-situ (main data system) sensors on the P-3.

Parameter	*Instrument*	*Manufacturer*	*Accuracy*	*Resolution*
Positioning	Inertial Navigation Equipment (INE)	Northrop/Delco	1.5 km (after post-processing)	$8.3\text{x}10^{-8°}$
Temperature	Platinum resistance	Rosemount	0.2° C	0.03° C
Dewpoint	Cooled Mirror	General Eastern	0.5° C	0.03° C
Static pressure	Transducer	Garrett	0.2 mb	0.1 mb
Dynamic pressure	Transducer	Garrett, Rosemount	0.1 mb	0.1 mb
Attack pressure	Transducer	Rosemount	0.15%	0.1 mb
Sideslip pressure	Transducer	Rosemount	0.15%	0.1 mb
Absolute altitude	Radar Altimeter	Stewart-Warner (APN-59)	0.01%	1 m
Cloud water	Hot Wire	Johnson-Williams	0.2%	0.1 g m^{-3}
In-cloud temp.	CO_2 radiometer (14 µm)	Barnes/AOC	0.2° C	0.1° C
Sea surface temp.	CO_2 radiometer (9.5-11.5 µm)	Barnes	0.2° C	0.1° C
Ground speed	INE accelerometers	Northrop/Delco	0.5 m s^{-1}	0.06 m s^{-1}
Track angle	INE accelerometers	Northrop/Delco	0.2°	0.005°
Heading angle	INE accelerometers	Northrop/Delco	0.1°	0.005°
Pitch angle	INE accelerometers	Northrop/Delco	0.06°	0.005°
Roll angle	INE accelerometers	Northrop/Delco	0.06°	0.005°

Table 14. Characteristics of the P-3 airborne radars.

Parameter	*LF Radar*	*TA Radar*
Transmitter frequency	5370 ± 6.7 mHz	9315 ± 11.6 mHz
Transmitter wavelength	5.59 cm (C-band)	3.22 cm (X-band)
Transmitter pulse width	1800 m	150 m
Pulse repetition frequency	200 s^{-1}	1600 s^{-1}
Peak transmitter power	70 kW	60 kW
Receiver dynamic range	80 dB	80 dB
Gain, main beam	37.5 dB	40 dB
Gain, first side lobe	23 dB down	23 dB down
Horizontal beam width	1.1°	1.35°
Vertical beam width	4.1°	1.9°
Antenna stabilization range	± 10°	± 25°
Antenna stabilized against	pitch and roll	pitch and drift
Maximum range	384 km	76 km
Nyquist velocity		12.89 m s^{-1}
Antenna rotation rate	4 RPM	8 RPM

The Knollenberg Particle Measurement System (PMS) records the output from their 2-D imaging probes and the Forward Scattering Spectrometer Probe (FSSP) on a separate data system. The cloud probe (2D-C), FSSP, and data system are special equipment which are on loan from the AOC King Air aircraft. The characteristics of the 2-D probes are given in Table 15 The FSSP detects the cloud droplet spectrum for 0.5 µm to 45 µm with the data recorded in 2 s intervals on the same tape as the 2D data.

Table 15. Characteristics of the PMS probes.

Parameter	*2D-P*	*2D-C*
Size range	6.4 mm	1.6 mm
Resolution	200 microns	50 microns
Ice/water discrimination	No	Depolarizer

8.5 Communications

One of the most important aspects of coordinated observational platforms is good reliable scientific communications between the P-3, the mobile labs, Doppler radars, and the Operations Center. When the P-3 is within line-of-sight distance, the VHF radio will be used on the AOC frequency of 122.925 MHz. Beyond line-of-sight range, communications will be by air-to-ground telephone or HF radio. Both mobile labs are equipped with VHF, HF, and 800 mHz radios capable of receiving and transmitting on the AOC's frequencies. In addition, the mobile labs are equipped with a satellite communications and tracking system that allows them to communicate with a base station at the Operations Center. VHF radio will be used between the Operations Center and Cimarron radar and direct communication lines exist between the Norman Doppler and Operations Center. Balloon One will communicate with an 800 mHz radio. O.U. will also be provided a 800 mHz system for use in coordination of use of radiosonde frequencies. The T-28 will have their own VHF radio system for communications.

8.6 *Scientific Personnel*

The scientific positions on the P-3 will normally be filled by personnel from NSSL. There should be ample opportunity for training of other scientists during COPS-91 to fill one or more of the key positions, therefore there should be considerable flexibility in the assignment of duties during the project. Table 16 shows initial job assignment possibilities. The actual assignments will depend on the mission and personnel availability.

Table 16. Possible P-3 personnel.

Position	*MCS Missions*	*Dryline/Frontal Missions*	*Short Wave & Profiler Missions*
Chief Scientists (1)	Smull or Watson	Smull or Watson	Smull or Watson
Assistant Chief Scientist (1)	Skaggs or Hane	Ziegler, Hane, Brandes, Bluestein or Koch	Skaggs or Hane
Radar Scientists (2)	Bartels or Schuur Brandes, Ziegler, or Fredrickson	Bartels or Schuur Brandes, Ziegler, or Fredrickson	Bartels or Schuur
Cloud Physics (1)	Ziegler, Hunter, Brandes, or Daugherty	*Not Required*	*Not Required*
Dropsonde (1)	Meitín or Fredrickson	Meitín or Fredrickson	Meitín or Fredrickson
Observers (2 or 3 will be selected from persons available for each mission)	Stumpf Hermes Mitchell Maddox? Forsyth??	Shapiro Ziegler Hane Brandes Bluestein Koch	Ziegler Hane Brandes Bluestein Koch Shapiro

9. T-28 Operations

9.1 *Operational Constraints*

The T-28 has a maximum endurance of about 2 hours. No night penetrations will be attempted for safety reasons. Flights in the evening within the stratiform region of an MCS are possible. Only regions of storms with reflectivity factors less than 55 dBZ at or above the flight level will be penetrated. Crew constraints call for only a single flight per day with a minimum time between flights of 10 hours. It will take about 2 hours from first call to takeoff if the crew is not at the airport. If the crew is at the airport then the time from decision to takeoff is about 30 minutes.

1, Conflicts with P-3, separation

The climbing speed of the T-28 is 1000 feet per minute up to 15,000 feet, 700 feet per minute from 15,000 feet to 20,000 feet, and 500 feet per minute above 20,000 feet.

9.2 *Flight Patterns*

Specific T–28 flight patterns have been developed for (1) a squall line system with little or no trailing stratiform rain; (2) a squall line system with a trailing stratiform region; and (3) an isolated convective storm. Each of these flight patterns are detailed below. If RHIs are executed for polarization study, modification of flight legs to lie along the RHI radial to Cimarron would be desirable.

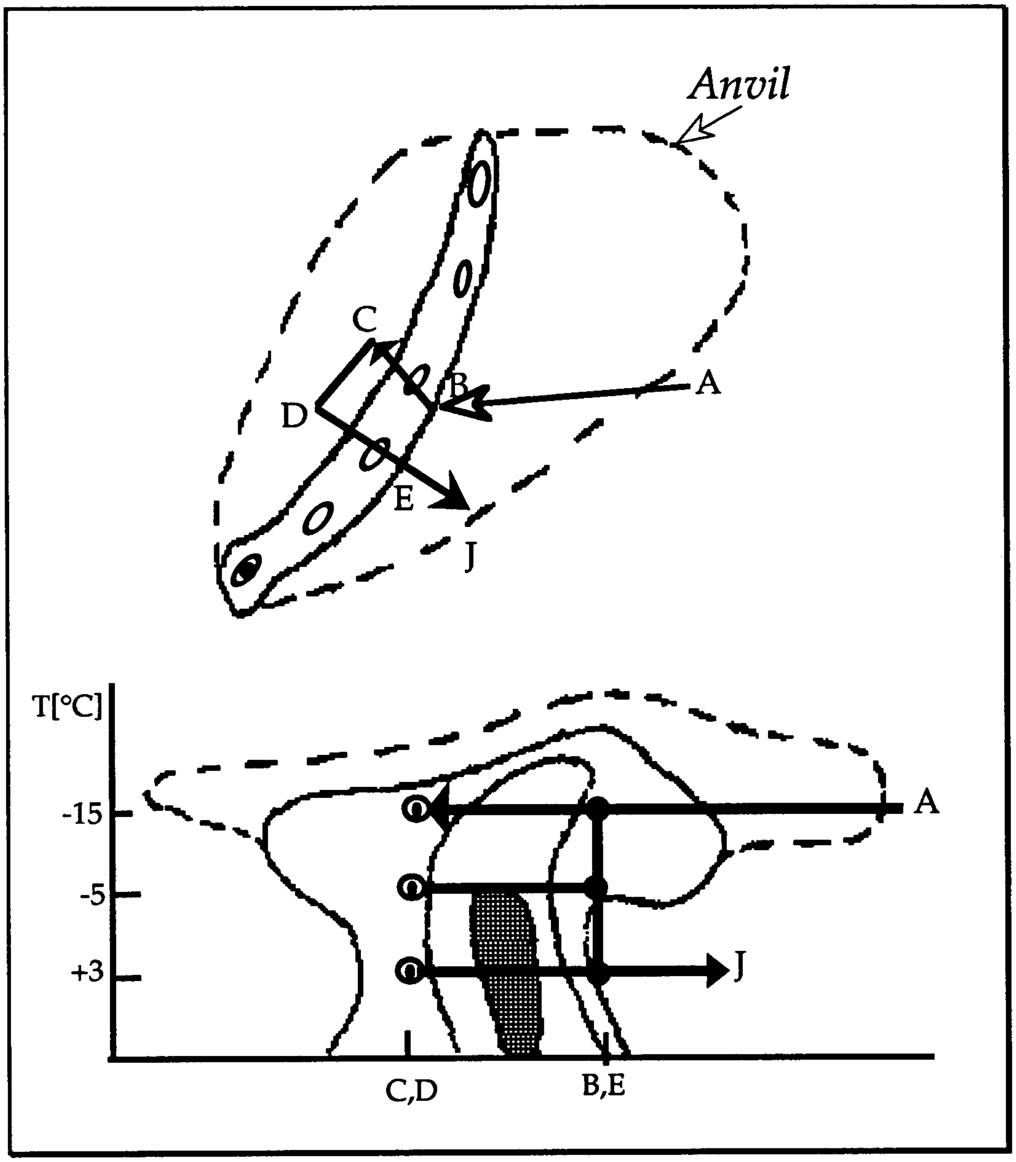
9.3 *Instrumentation*

The basic cloud physics instrumentation for the T-28 consists of the PMS 2D-P (0.2 mm to 6.4 mm size range), a hail spectrometer (5 mm to 5 cm), the PMS forward scattering spectrometer (max size 50 microns), the Johnson-Williams liquid water content meter, and a foil impactor (0.2 mm to 3 cm).

T–28 Pattern MCS 1: Squall Line with no Trailing Stratiform Region

Goal: Document microphysical characteristics and electric field in and to the rear of convective cells and in the near anvil region.

Height: -15° C to +3° C (~23,000 to 13,000 feet)

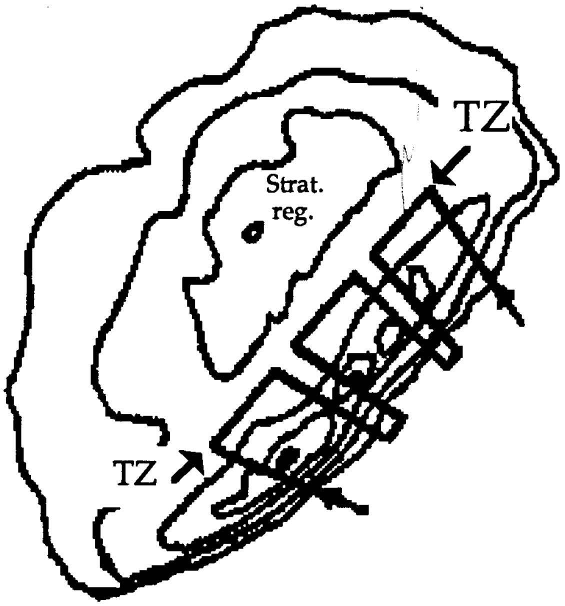


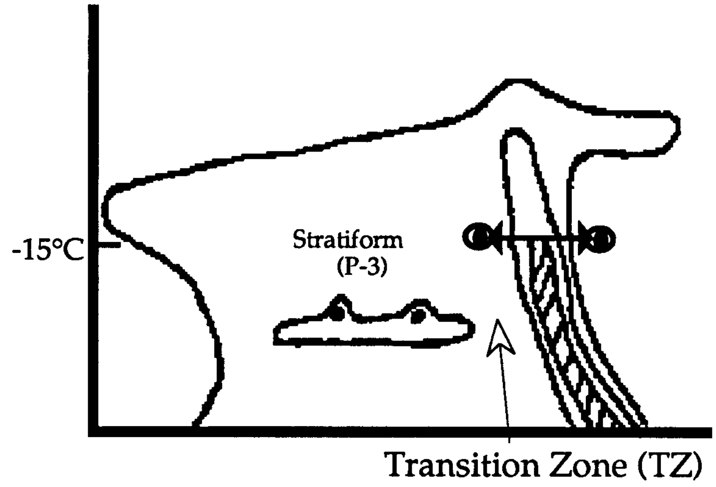
Sequence: Fly into downshear anvil at -15°C level (if anvil is higher, proceed to convection). Penetrate along BC. Turn left and follow CD. Turn left and penetrate along DE. Descend along EB to -5°C level. Repeat race-track BCDE. Descend again along EB to +3°C level. Repeat BCDE and continue back to home base along EJ.

T–28 Pattern MCS 2a: Squall Line with Trailing Stratiform Region

Goal:	Determine microphysical characteristics (particle spectra, state variables, liquid water content etc.) and E field of upper convective cores and transition zone.
Height:	-15° C (~23,000 feet)

?



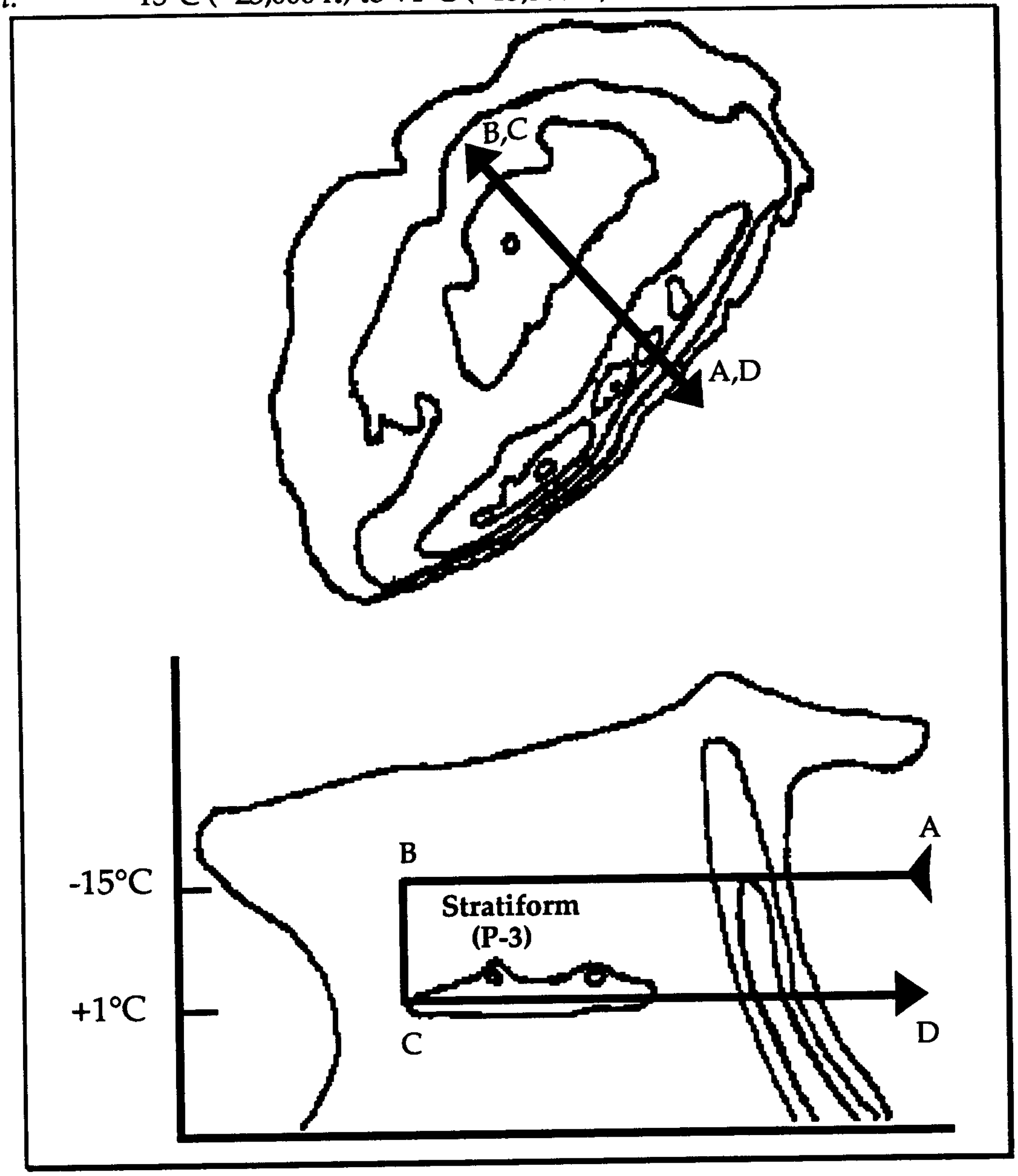


Sequence: Fly square wave pattern at -15°C level, penetrating convective line and turning to fly long legs (tops of square waves) parallel to and in the middle of transition zone. Make short-radius turns in advance of leading convective line. Qualifiers: If no leading line/trailing stratiform structure , modify to fly between main convection and stratiform regions, according to their arrangement; do spiral descent/ascent in general area of EFM launch if time permits. ?

T–28 Pattern MCS 2b: Squall Line with Trailing Stratiform Region

Goal: To study microphysics and electrification of the main convective region, transition zone, and stratiform region along a line through middle of MCS, at two levels.

Height: -15°C (~23,000 ft) to +1°C (~13,500 ft).



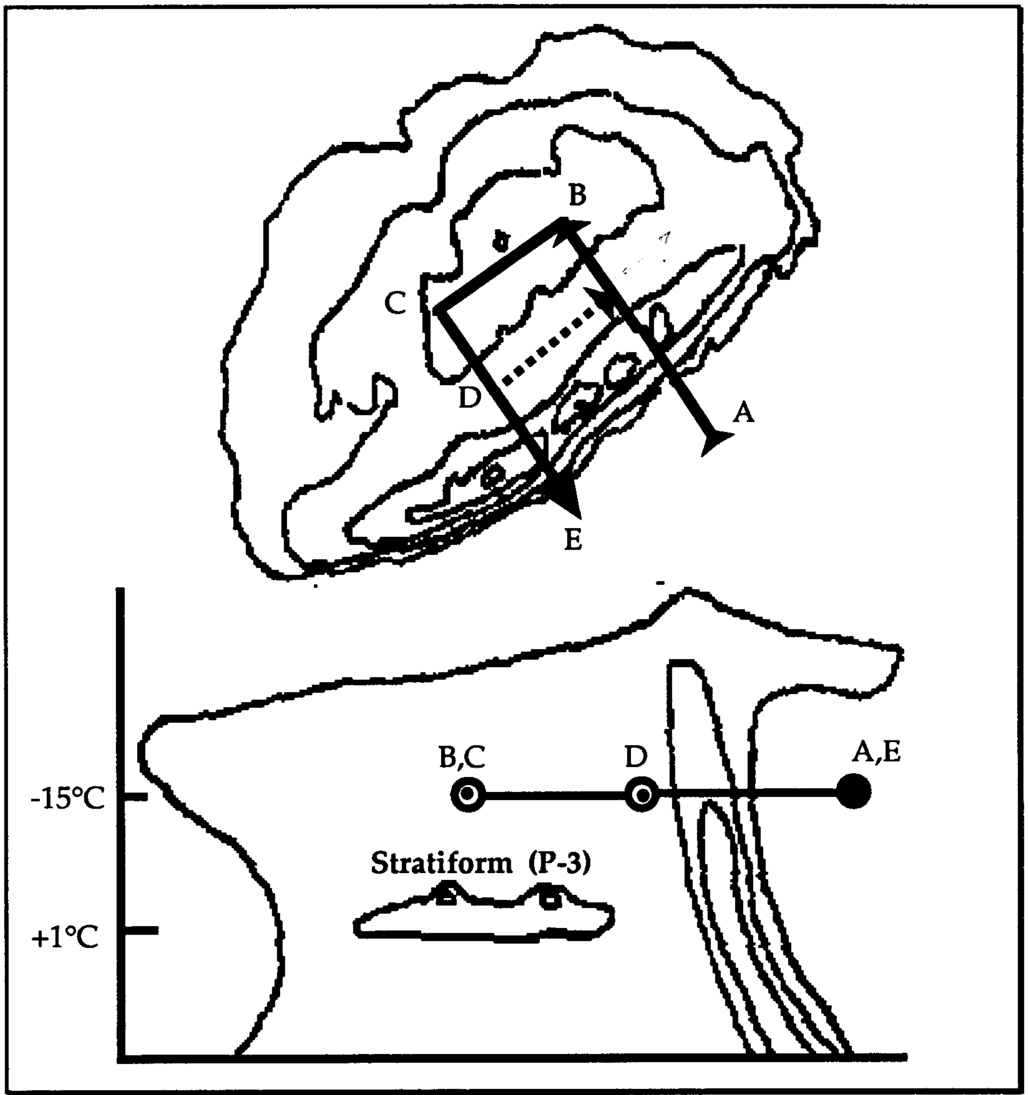
?

Sequence: Penetrate MCS near line of symmetry, or line through center of convective line and stratiform region (AB), at -15°C level. If P-3 is in stratiform region, coordinate with P-3 maintain horizontal separation. Descend to +1°C level and return through stratiform bright band along CD. Qualifiers: Same as 2a.

T–28 Pattern MCS 2c: Squall Line with Trailing Stratiform Region

Goal: To document upper-level advection and charge pattern from main convective zone to the stratiform region.

Height: -15°C (~23,000 ft) to +5°C (~12,000 ft).

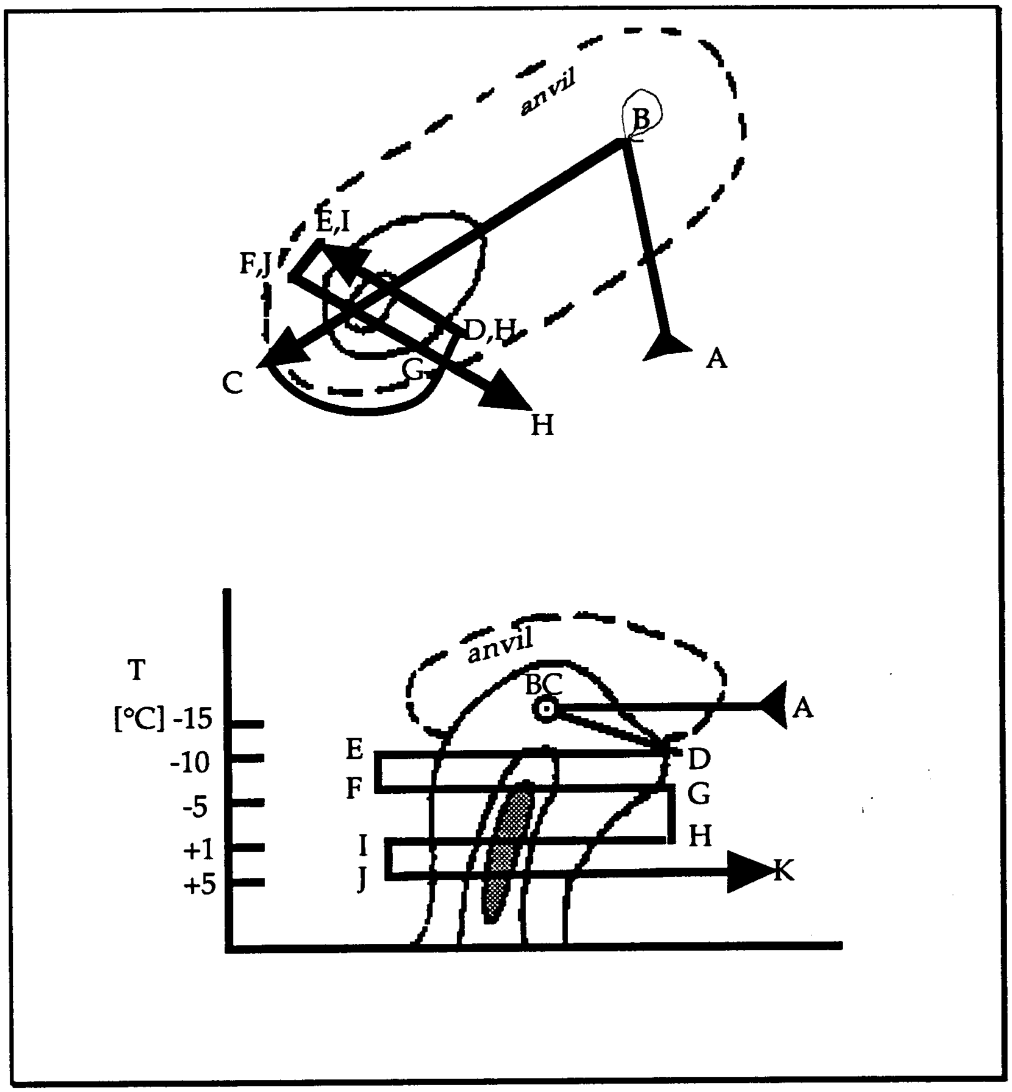


Sequence: Penetrate main convection at -15°C level and proceed toward middle of stratiform area at B. Turn 90° to fly over stratiform area along BC. Turn again and proceed along CD. If time permits, fly one or more square waves (pattern 2a) through transition zone and convection. If not, continue to E and home base. Qualifiers: Same as 2a.

T–28 Pattern 3: Isolated Convective Storm

Goal: To observe the microphysics and E field in the main convective cell or anvil of a supercell or multicell hail storm.

Height: -15°C (~23,000 ft) to +5°C (~12,000 ft).



Sequence: Penetrate anvil at -15°C level along AB. Continue at this level in anvil toward main cell along BC. Exit upshear anvil descend outside storm along CD to -10°C level. Penetrate main cell along DE. Descend along EF to -5°C level and penetrate along FG. Descend along GH to +1°C level and repeat racetrack HIJ with step down to +5°C level between I-J. Penetrate and exit along K.

10. Ground-Based Doppler Radar Operations

10.1 *Fundamental Operating Modes*

The Cimarron and Norman Doppler radars will be operated in three fundamental modes: synchronized, non-synchronized, and independent.

In *synchronized mode*, the operation of the two radars will be highly coordinated. Synchronized mode will be used to obtain dual-Doppler data for the determination of air motions. It will be the preferred mode in studies of the convective and stratiform regions of MCSs and in studies of frontal circulations. The air motions obtained from this mode are required to satisfy objectives related to profiler assessment; MCS dynamics, electrification, and microphysics; and frontal dynamics.

In *non-synchronized mode*, the two radars will still be operated cooperatively but with looser coordination. Non-synchronized mode will be used during the intensive collection of polarimetric measurements by the Cimarron radar in thunderstorms and the convective regions of MCSs, especially when the T-28 aircraft is performing penetrations of convective cores. This mode will provide the flexibility necessary to switch between a polarimetric radar configuration at the Cimarron radar and scans providing rapid updates of echo intensity that are necessary for planning safe T-28 penetrations. The dual-Doppler coverage, although not synchronized, will still enable air motions to be deduced.

In *independent mode*, the radars will be operated singly or with no coordination. Independent mode will be used in several situations: (1) When severe weather is in the vicinity, the Norman radar may be dedicated to supporting NWS forecast and warning operations.
(2) The Cimarron radar may be dedicated to performing simulated, continuous TDWR scans.
(3) If the Norman radar is unavailable, the Cimarron radar can be used independently to collect data in the vicinity of research aircraft or soundings, to collect data for EVAD analysis, to collect continuous polarimetric data, or for surveillance.

10.2 *Synchronized Operating Mode*

The synchronized operating mode will consist of volume scans executed by the Norman and Cimarron radars. To reduce errors in determining air motion fields, scans at each radar will be started simultaneously. In the synchronized operating mode, scans will be run on one of two clock cycles. During periods in which the primary goal is to study mesoscale circulations (such as those associated with the stratiform region of MCSs or with fronts), scans will have a period of 7.5 min. During periods in which the primary goal is to study convective circulations over mesoscale areas (such as those associated with the convective regions of MCSs), scans will have a period of 5 min.

Scans in synchronized mode will be run in blocks of two (see Fig. 5). The first of the two scans in each block ("A" in Fig. 5) will always consist of azimuthal sector sweeps at a series of elevations. They will be referred to as *mesoscale volume scans* or *convective-scale volume scans*, depending on whether the scan period is 7.5 or 5 min. These scans are designed for the deduction of three-dimensional air motion fields. "A" scans should be consistent in design and should cover the same part of a weather system as much as possible for at least three consecutive blocks and preferably longer. This will provide the data set required for mesoscale, electrical, microphysical, and profiler assessment research. Determination of airflows for these objectives will therefore be guaranteed every 15 min for mesoscale circulations and every 10 min for convective-scale circulations. The insistence on design consistency for the "A" scans in at least three consecutive blocks will enable thermodynamic fields to be deduced.

The azimuthal sector of the 7.5-min mesoscale volume scans will be 150° and will cover either the entire northeast or the entire southwest lobe of dual-Doppler coverage. The azimuthal sector of the 5-min convective-scale volume scans will be 110° or less. Mesoscale and convective-scale volume scans will use a pulse repetition period of 768 ms for velocity data (giving a maximum unambiguous range of 114.4 km) unless a longer pulse repetition period is needed to reduce contamination from range folding of distant echoes. 64 pulses per estimate will be used.

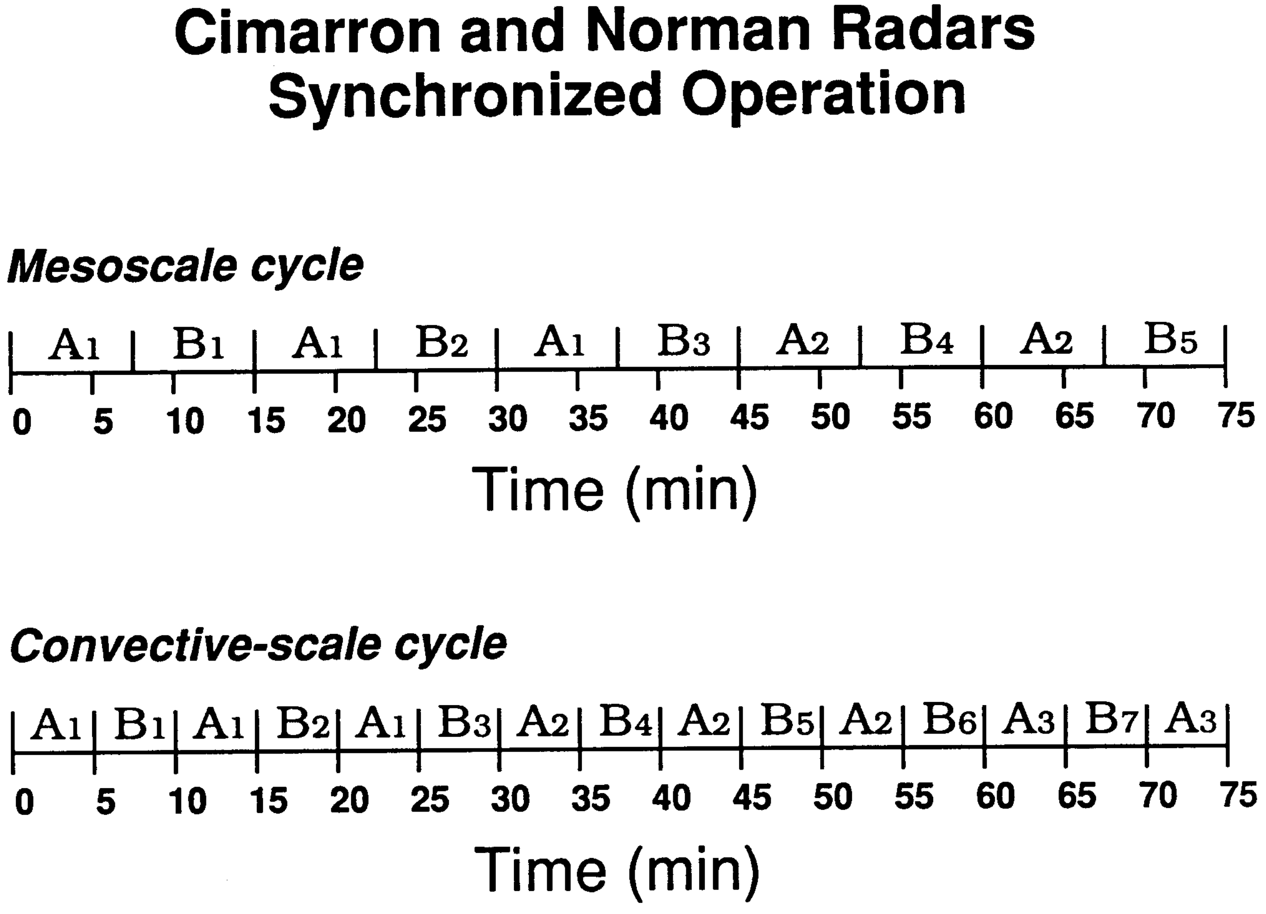


Fig. 5. Radar scan sequences in the synchronized operating mode. "A" and "B" refer to possibly different radar scan designs to satisfy different objectives. "A" scans with the same subscript should be identical.

The second of the scans in each block ("B" in Fig. 5) will be chosen from several options. The selection of these scans will depend on the meteorological situation and the research objectives announced by the Mission Director. Options for the "B" scans are:

(1) *A repetition of the previous "A" scan.* This will double the temporal resolution of the airflows. This increase in temporal resolution should be especially beneficial to studies of convective-scale circulations.

(2) *A convective-scale volume scan different from the previous "A" scan.* This may be performed whether the scan cycle is 5 or 7.5 min. This option could allow convective-scale data to be collected in a different region from that being documented by the "A" scans. Alternatively, it could enable convective-scale data to be collected within the region whose mesoscale motions are being documented by the "A" scans. It could also be used to collect data in the vicinity of research aircraft and soundings when they are not in the region being documented by the "A" scans. In particular, this scan could be used to collect data in the same region as the Doppler radar on board the P-3 aircraft.

(3) *A mesoscale volume scan different from the previous "A" scans.* This may be performed if the scan cycle is 7.5 min. This option could allow mesoscale data to be collected in a region that is different from that being documented by the "A" scans, for example, in the other dual-Doppler lobe. It could also be used to collect data in the vicinity of research aircraft or soundings when they are not in the region being documented by the "A" scans. In particular, this scan could

be used to collect data in the same region as the Doppler radar on board the P–3 aircraft.

(4) *A polarimetric sector volume scan.* This scan, executed with the Cimarron radar, is designed to collect polarimetric data over a small volume within an MCS or in a thunderstorm. It will consist of a series of sector sweeps at various elevations. A pulse repetition period of 768 ms, a slow antenna rotation rate (4 deg s^{-1}), and 256 pulses per estimate will be used. When this scan is being performed, the Norman radar should perform a mesoscale or convective-scale volume scan of the same region.

(5) *A polarimetric RHI volume scan.* This scan, executed with the Cimarron radar, is designed to collect polarimetric data over a small volume within an MCS or in a thunderstorm. It will consist of a series of sweeps through elevation at various azimuths. A pulse repetition period of 768 ms, a slow antenna rotation rate (4 deg s^{-1}), and 256 pulses per estimate will be used. When this scan is being performed, the Norman radar should execute a mesoscale or convective-scale volume scan of the same region.

(6) *A polarimetric survey volume scan.* This scan, executed with the Cimarron radar, is designed to collect polarimetric data over a broad region. 360° sweeps at various elevations will be performed. The antenna rotation rate will be 10 deg s^{-1}, and 128 pulses per estimate will be used. When this scan is being performed, the Norman radar should execute a survey volume scan, (8) below.

(7) *An EVAD scan.* This scan, executed with the Cimarron radar, will be used to collect data for Extended Velocity-Azimuth Display analysis. The scan will consist of rapid 360° sweeps covering elevations from near 0° to near 90°. It can be performed in the stratiform region of MCSs when noncellular echo surrounds or nearly surrounds the radar out to a horizontal range of at least 15 km. EVAD analysis is useful for obtaining highly accurate vertical profiles of horizontal divergence, vertical air velocity, and vertical hydrometeor velocity in stratiform precipitation. When this scan is being performed, the Norman radar should execute a survey volume scan, (8) below.

(8) *A survey volume scan.* This scan will consist of 360° azimuthal sweeps at a limited number of elevations. It will be used to obtain low-resolution data over a large area. Mesoscale convective systems are usually much larger than the region covered by mesoscale or convective-scale sectors. This scan can enable a larger context for the higher-resolution data to be obtained occasionally.

The design of the synchronized mode scan structure in blocks of two guarantees a data set that is both consistent and varied. The "A" scans provide a basic, consistent data set that will document the time-dependent airflows and the enable thermodynamic fields to be deduced. The interleaved "B" scans support specialized or complimentary objectives.

10.3 Non-synchronized operating mode

The non-synchronized operating mode will be used primarily when the T–28 aircraft is performing penetrations of convective cores. The Cimarron radar will execute volume scans of the convective cores of interest to provide real-time information for planning safe flight paths. These scans will have a period of 2.5 min. Periods of running these scans will be alternated with periods during which polarimetric data will be collected in the convective features of interest (using the polarimetric sector volume scan or polarimetric RHI volume scan described above for the synchronized mode).

In non-synchronized mode, the Norman radar will continuously execute convective-scale volume scans (as described above for the synchronized mode) of the region of interest. Because of the impossibility of timing the scans in this situation, the starts of scans will not be synchronized at the two radars. Data from the Norman radar can be incorporated into the planning of T–28 flight paths.

The non-synchronized operating mode can also be used when the T–28 is not being used if the uninterrupted collection of polarimetric measurements is the preferred research strategy.

10.4 Independent operating mode

When the Norman radar is dedicated to supporting NWS operations, it will perform whatever scans are requested by NWS personnel. These will usually consist of 360° azimuthal sweeps or azimuthal sectors that are stepped through the storm in elevation.

When the Cimarron radar is supporting FAA algorithm tests, it will perform repeated simulated TDWR scans, which have a period of 5 min. The algorithms to be tested are designed to detect downbursts within 30 km from the radar, detect vertical wind shear within 30 km from the radar, detect fronts within 60 km from the radar, detect mesocyclones and tornadoes within 100 km from the radar, perform range unfolding in cases of extensive or distant echoes, and dealias velocities in cases of strong winds or strong horizontal wind shears.

When the Norman radar is unavailable, the Cimarron radar may collect measurements in the vicinity of research aircraft, balloon soundings, or profilers. The scans should be selected from the mesoscale volume scans and convective-scale volume scans described above for the synchronized operating mode. When the Norman radar is unavailable, the Cimarron radar may collect polarimetric data using the polarimetric sector volume scan or polarimetric RHI volume scan described above for the synchronized operating mode. When the Norman radar is unavailable, the Cimarron radar may collect data for EVAD analysis using the EVAD scan described above for the synchronized operating mode. When the Norman radar is unavailable, the Cimarron radar may be used for surveillance using the survey volume scan described above for the synchronized operating mode.

10.5 *Scans for testing the "Advanced Gust Front Algorithm"*

Each of the scans for the Cimarron radar, except scans for collecting polarimetric data, will include 360°sweeps at elevations of 0.5° and 1.0° to provide input for testing the Advanced Gust Front Algorithm. These two sweeps will be inserted in the scans so that they occur at intervals of 5 min. Therefore, two versions of each scan having a period of 7.5 min will be required: one in which the two sweeps are inserted at the start of the scan and at 5 min into the scan, and another in which the two sweeps are inserted at 2.5 min into the scan.

10.6 *Logistics*

The decision to dedicate the Norman radar to NWS operations will be made by NWS. Otherwise, the decision of whether to operate in coordinated mode, non-synchronized mode, or independent mode depends on assigning priorities to research objectives and therefore will be made by the Mission Director.

In synchronized mode, the Cimarron Coordinator will be responsible for deciding whether mesoscale or convective-scale scan periods will be used, for selecting the region that will be documented systematically by the "A" scans, for selecting the category of "B" scans that will be used, and for selecting and tailoring the scans at each radar. These decisions will take into consideration the announced research objectives from the Mission Director; the deployment of research aircraft, mobile soundings, and other instruments; and the guidance of investigators who are assisting the Cimarron Coordinator. The Cimarron Coordinator will coordinate the starts of scans at the Cimarron and Norman radars.

In non-synchronized mode and independent mode, the Cimarron Coordinator will select the scans as required by the experimental objectives.

Because scans will be run on a strict schedule, scans will, as much as possible, be designed in advance and, at Cimarron, preprogrammed. Scans will be designed for various minimum and maximum echo ranges, for various maximum echo heights, and for various azimuthal sector sizes. The antenna rotation speed and the elevation sequence will, in general, vary with each design.

The Cimarron Coordinator should be especially vigilant (1) that the pulse repetition period is raised when range aliasing is contaminating the area of interest, and (2) that sweeps are performed to high enough elevations so that data is collected clearly above the echoes throughout the area of interest. The area of interest should not extend to within about 35 km of a radar for mesoscale volume scans, to within about 25 km for convective-scale volume scans, and to within about 40 km for survey volume scans.

10.7 *CIM & NRO Coordinator Staffing Schedule*

From April 24 to May 7 the Cimarron Coordinator will be Thomas Matejka. From May 8–18 the job will be filled by Mike Eilts. For the period May 19–26 Thomas Matejka will be the Coordinator, and from May 25 through the end of the project the Coordinator will be Steven Rutledge.

Specific assignments for the Norman Doppler Radar Coordinator are undefined at this time due to the uncertain status of the OSF WSR-88D. It may be necessary for the Norman Doppler radar to support NWS warning activities which would necessitate expanded Norman radar activities. The primary personnel to perform the NRO coordinator role are: Don Burgess, Arthur Witt, Rodger Brown, Laurie Hermes, Mike Eilts, Jerry Wardius, and Ed Brandes, with backup by Kevin Kelleher, Mike Jain, and the staff of the WSFO and OSF.

11. Job Descriptions of Key Personnel

11.1 *Mission Director*

This individual has overall responsibility for the execution of the experiment for the day and will normally be stationed at the Operations center at NSSL. He will monitor the McIDAS, dial-up radar, NWS products, and lightning mapping displays to direct the mobile lab and P–3 aircraft to the best weather system for study, consistent with the goals for the particular experiment. Once the weather target is selected and the experimental strategies are decided upon, the Mission Director would normally turn the responsibility for the execution of the specified experiment over to the P–3 Chief Scientist, Mobile Lab Chief Scientist, and the Cimarron Coordinator (*e.g.*, coordination of specific flight patterns with CIM, timing of balloon releases, etc). This individual would continue to monitor the exercise to ensure that the data gathering is proceeding smoothly and will resolve problems that arise.

11.2 *P–3 Chief Scientist*

This person has overall responsibility for scientific data gathering by the P–3 aircraft. He will choose specific targets for investigation (usually after radio coordination with the Mission Director, Cimarron Doppler radar, and the mobile lab), work with the AOC flight director in planning specific patterns to be flown, and will supervise the scientific crew to ensure proper data gathering by the airborne Doppler radar and cloud physics data systems.

11.3 *Cimarron Radar Coordinator*

This individual has overall responsibility for the scientific data gathering by the Cimarron Doppler radar and is stationed at the Operations Center at NSSL. Activities include coordination of scans with the P–3 tracks and MCLASS releases, selection of specific scans to be executed, and insuring proper data recording. Major changes in scanning strategy (such as would be required when changing basic data gathering strategies) will normally be made by the Mission Director.

11.4 *Norman Radar Coordinator*

This individual has overall responsibility for the scientific data gathering by the Norman Doppler radar. He/she coordinates scans with the Weather Service Forecast Office if the radar is being used to support warning activities. Coordinates dual-Doppler scans with the Cimarron Radar Coordinator.

11.5 *Mobile Lab Chief Scientist*

Has overall responsibility for the scientific data gathering of the mobile lab (*e.g.*, MCLASS launches). Will coordinate launches (if possible) with the Mission Director, Cimarron Coordinator, and P–3 Chief Scientist.

11.6 *Forecasting Support Coordinator*

This person has overall responsibility for preparation and delivery of the daily weather briefing. He/she will work with an assigned WSFO person in the morning on the preparation and coordination of that briefing. The briefing will be at noon local time. The Forecaster will work with the Nowcaster during the afternoon to assure that needed products (surface maps, special soundings, experimental model output, etc) from the WSFO are made available in the Operations Center. Some experimental forecasts will be made at the WSFO during the morning and the afternoon. The forecaster's shift will end at 1800 local time.

11.7 *Nowcaster or Operations Assistant*

This individual will assist in the Operations Center during COPS-91 experiments. Duties include bringing weather information during a mission from the WSFO over to NSSL in order to update the Mission Director with the latest information. He/she will also assist the Mission Director with the operations of the dial-up radar equipment, McIDAS, and radios. During potentially long operations there may be a need for a second shift Nowcaster.

11.8 *Data Manager*

This person will be responsible for coordinating the archive and quality control after each operation of all specialized data sets produced by the P–3, mobile labs, and the ground-based Doppler radars. He/she will also have the responsibility of insuring that all data logs are entered into the NSSL data log file.

11.9 *COPS Project Director*

This person has responsibility for the overall operations in COPS. In consultation with the PI scientific steering committee, NSSL Facilities Coordinator and the AOC Project Manager, the COPS Project Director will decide on the mission for the day, the Mission Director, and the tentative time for the start of the operations.

11.10 NSSL Facilities Coordinator

This person has responsibility for the overall management of NSSL facilities during COPS. These facilities include the mobile laboratories, the operations center, and Cimarron and Norman Doppler radars. The NSSL facilities coordinator is Doug Forsyth.

11.11 Operations Center Communicator

This person has responsibility for operations of the communications equipment in the operations center at NSSL. This equipment includes the 800 mHz trunk radio for voice communication to the mobile labs, the aircraft radio for communications to the P–3, and the satellite data link to the mobile labs.

12. Data Management and Dissemination

The general philosophy for COPS-91 will be to disseminate all calibrated data sets freely to interested Principal Investigators as soon as the data sets are validated. The data management procedures that will be followed for each main data set are detailed below. The P–3 and MCLASS data sets will be checked and archived at NSSL/MRD in Boulder, CO. The COPS-91 data manager is José Meitín. A mission summary and data inventory document will be prepared within 3 months of the project's completion.

12.1 P–3

The P-3 flight-level data set will be processed at AOC to produce an archived data set (called the AOC "standard tape") that will reside at NSSL/MRD. Copies of the flight level data for selected cases will be made available on an ASCII tape to interested scientists. The Doppler radar, cloud physics, and Safesonde data sets will not be routinely processed to produce an archived data set due to the high volume of data produced. The original tapes will be stored at NSSL/MRD. A data processing facility exists at NSSL/MRD for complete processing and analysis of all P–3 data and will be made available to all COPS-91 investigators.

12.2 MCLASS

The MCLASS soundings will be routinely processed to provide an archived data set on the NSSL VAX in the NSSL sounding format. The archived data set will reside at NSSL/MRD in this standard format and will be made available to all interested investigators. Post-processing should be completed within 3 months of the conclusion of COPS-91. NSSL will provide a reprocessing facility for more detailed examination and potential optimization of the LORAN signals to improve the quality of the winds of selected soundings.

12.3 Cimarron and Norman Doppler Radar

The Cimarron and Norman Doppler radar data will be archived at NSSL/SSD. Copies of Universal Format tapes will be made available to interested researchers on a case-by-case basis. The data manager will be Mike Jain and Jerry Wardius. A data inventory document consisting of log sheets and scientists notes will be available for distribution within 6 months from the completion of the project. Scan summaries from individual tapes will be made available on a case-by-case basis.

12.4 Electric Field Meter

The balloon-borne EFM and meteorological soundings and ground-strike lightning data will be examined and validated by NSSL/SECPR personnel prior to general release. SECPR will also archive the EFM and ground-strike data sets. Copies of data tapes will be made available to interested researchers on a case-by-case basis. The data manager will be Dave Rust. A data inventory document consisting of log sheets and scientists notes will be available for distribution within 6 months from the completion of the project.

12.5 T–28

Data from the T-28 will be archived on a PC-based system at South Dakota School of Mines and Technology. Andy Detwiler is the data manager. The format and medium of data distribution will be defined based on user requirements. The user will be charged for the cost of the recording medium. Foil impactor data is not digitally processed, thus the user would need to either process it or compensate the South Dakota School of Mines and Technology for processing.

12.6 PAM

PAM data will be post-processed and validated at NCAR prior to release to the principal investigator (Howie Bluestein). Copies of validated PAM data will be available from the PI at nominal cost.

12.7 RASS Profilers

Data from the RASS systems will be archived at MRD following delivery by WPL. The 915 mHz profiler data will be provided by William Neff of WPL to NSSL at the conclusion of the project. The RASS data from the Purcell profiler will be transmitted to the Profiler Data Control Center and archived on NSSL computers. The data manager is José Meitín.

12.8 Microwave Radiometer

Data from the multi-frequency microwave radiometer will be archived at MRD following delivery by WPL. The data will be provided by Ed Westwater of WPL to NSSL at the conclusion of the project. The data manager is José Meitín.

Appendix

PROJECT FORMS

The following forms should be filled out by the P–3 radar crew during COPS-91 missions. They will become part of the permanent data archive.

COPS-91

P-3 CHIEF SCIENTIST CHECKLIST

Flight Number____________________

Flight Crew:

Scientific Crew	*AOC Crew*
Chief Scientist__________	Flight Director __________
Doppler Radar __________	AC Commander __________
Cloud Physics__________	Pilot __________
Observer __________	Data Tech __________
Observer __________	Sys Engineer __________
Others __________	
__________	
__________	
__________	

Mission Briefing (including proposed flight plans):

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Mission Summary:

*Takeoff Time:*__________UTC *Landing Time:* __________UTC
Official Mission Duration: __________hr (from Flight Director)
Number of Magnetic Tapes Used: Radar: __________ Cloud Physics: __________
*Number of Sondes Dropped:*__________

COPS-91

P-3 RADAR OPERATOR CHECKLIST

Flight Number ____________________

Operator(s): ______________________ ______________________

Confirm Software Settings:
TA: 32 pulses Fastest RPM Tilt 0° (non FAST mode) Threshold on dBm
LF: 32 pulses Fastest RPM Threshold on dBm

Equipment status prior to takeoff:

Brief description of problems encountered during flight:

Radar Data System Tape Log

Tape #	*Time On*	*Time Off*	*Mode (FAST or Cont)*	*Comments*

COPS-91

P-3 CLOUD PHYSICS OPERATOR CHECKLIST

Flight Number________________________

Operator(s):________________________ ________________________

Confirm PMS Settings: FSSP range 4. Recording rate MAX.

Equipment status prior to takeoff:

Brief description of problems encountered during flight:

PMS Data System Tape Log

Tape #	*Time On*	*Time Off*	*Mode*	*Comments*

COPS-91

P-3 SAFESONDE OPERATOR CHECKLIST

Flight Number ____________________

Operator(s): ____________________ ____________________

Number of sondes onboard: __________

Equipment status prior to takeoff:

Brief description of problems encountered during flight:

Safesonde System Log

Drop #	*Drop Time (GMT)*	*Location*		*Altitude (m)*	*Comments*
		Lat	*Lon*		

COPS-91 Phone List

Operations Center .... ?
Message Phone.. ?
AOC Operations .... ?

Visiting Scientific Personnel

Name	*Affiliation*	*Dates*	*Hotel*	*Room*	*Phone*
D. Bartels	NSSL (Boulder)	5/19-6/12	Residence Inn		
D. Carter	University of Mississippi				
D. Jorgensen	NSSL (Boulder)	4/24-6/12	Residence Inn		
T. Marshall	University of Mississippi				
J. Meitín	NSSL (Boulder)	4/24-4/27, 5/7-6/12	Residence Inn		
T. Schuur	NSSL/CIRES (Boulder)	4/24-5/18	Residence Inn		
B. Smull	NSSL (Boulder)	5/19-6/12	Residence Inn		
I. Watson	NSSL (Boulder)	4/24-5/18	Residence Inn		
T. Matejka	NSSL (Boulder)	4/24-5/7, 5/19-5/29	Residence Inn		
J. Daugherty	NSSL (Boulder)	5/16-5/31	Residence Inn		
J. Augustine	NSSL (Boulder)	5/24-6/12	Residence Inn		
D. Blanchard	NSSL (Boulder)	4/24-5/13	Residence Inn		
R. Holle	NSSL (Boulder)	5/14-5/23	Residence Inn		
S. Rutledge	CSU	5/25-6/12	Residence Inn		
W. Peterson	CSU (student)	5/25-6/12	Residence Inn		
S. Randell	CSU (student)	5/25-6/12	Residence Inn		

Beeper Numbers

Name	*Dates*	*Beeper Number*
Glen Anderson	4/24-6/12	791-6239
Monte Bateman	4/24–6/12	791-6344
Don Burgess	4/24-6/12	671-4748
Mike Eilts	4/24-6/12	671-0192
Doug Forsyth	4/24–6/12	671-5314
Sherman Frederickson	4/24-6/12	791-6246
Paul Griffin	4/24-6/12	791-6241
Steve Hunter	4/24-6/12	791-6346
Mike Jain	4/24-6/12	686-8951
Dave Jorgensen	4/24–6/12	791-6244
Kevin Kelleher	4/24-6/12	686-8783
Robert Maddox	4/24-6/12	671-5343
Tom Marshall		791-6347
Tom Matejka	4/24–5/7, 5/19–5/29	791-6240
Jose Meitín	4/24–4/27, 5/7–6/12	791-6248
Dennis Nealson	4/24-6/12	686-9552
Jack Parrish	4/24–6/12	791-6242
Steve Rutledge	5/25–6/12	791-6240
Dave Rust	4/24–6/12	671-4343
Terry Schuur	4/24–5/18	791-6339
Tom Shepherd	4/24-6/12	791-6343
Les Showell	4/24-6/12	686-9753
Maribeth Stolzenburg	4/24-6/12	791-6342
Mike Schmidt	4/24-6/12	791-6238
Gary Skaggs	4/24-6/12	686-8123
Brad Smull	5/19–6/12	791-6245
Greg Stumpf	4/24-6/12	791-6351
Kevin Thomas	4/24-6/12	791-6350
Irv Watson	5/24–5/18	791-6245
Arthur Witt	4/24-6/12	791-6247
Allen Zahrai	4/24-6/12	686-9815
Dusan Zrnic	4/24-6/12	671-6667

AOC Personnel

Name	*Title*	*Room*	*Phone*
Jack Parrish	AOC Project Coordinator		
Barry Damiano	Flight Director		
Howard Ticknor	Aircraft Commander		
Phil Kennedy	Pilot		
George Player	Pilot		
Nelson Fleury	Flight Engineer		
Stevan Wade	Flight Engineer		
Steve Nokutis	Navigator		
Greg Bast	Crew Chief		
Ted Hines	Avionics Technician		
Jim Roles	Electronics Engineer		
Terry Lynch	Electronics Technician		
Juan Pradas-Bergnes	Electronics Technician		
Jack Hanchett	Alternate El Tech		
Courtenay Starck	Supply Tech		

Motel Addresses

AOC Personnel
Residence Inn of Oklahoma City?
4361 West Reno
Oklahoma City, OK 73107
(405) 942-4500
FAX: (405) 942-7777

NSSL & Other Personnel
Residence Inn of Norman
2681 Jefferson
Norman, OK 73072
(405) 366-0900
FAX: (405) 360-6552

LIST OF PARTICIPATING ORGANIZATIONS

AOC	*Aircraft Operations Center*
CSU	*Colorado State University*
NASA	*National Aeronautics and Space Administration*
NCAR	*National Center for Atmospheric Research*
NSSL	*National Severe Storms Laboratory*
OU	*University of Oklahoma*
SDSMT	*South Dakota School of Mines and Technology*
UM	*University of Mississippi*
WPL	*Wave Propagation Laboratory*

LIST OF ACRONYMS

AGL	*Above Ground Level*
COPS	*Cooperative Oklahoma Profiler Studies*
CSU-RAMS	*CSU Regional Atmospheric Modeling System*
EFM	*Electric Field Meter*
EVAD	*Extended Velocity-Azimuth Display*
FAST	*Fore/Aft Scanning Technique*
MCLASS	*Mobile Cross-Chained Loran Atmospheric Sounding System*
MCS	*Mesoscale Convective System*
NWS	*National Weather Service*
PAM	*Portable Area Mesonet*
PRF	*Pulse Repetition Frequency*
q-d	*Particle Charge and Size Device*
RASS	*Radio-Acoustic Sounding System*
VAD	*Velocity-Azimuth Display*
WSFO	*Weather Service Forecast Office*