

**Request for T-28 Research Flight Support
(Dates: 24 April 2003 to 31 May 2003)**

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A. Identification

1. Requesting Scientists:

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2. Titles:

Straka: Associate Professor
Zrnich: Senior Scientist at NOAA/NSSL and Adjunct Professor of University of Oklahoma

3. Date of Submission: 1 June 2002

4. Address of Co-PIs:

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5. Affiliation:

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7. Other Persons and Affiliations:

V. Chandrasekar Colorado State University
Larry Carey, North Carolina State University
Jerry Straka, University of Oklahoma
Dusan Zrnica, National Severe Storms Laboratory
Mark Askelson, University of North Dakota
Steven Rutledge, Colorado State University
Don MacGorman, University of Oklahoma
Dave Rust, National Severe Storms Laboratory
Sonia Lasher-Trapp, Purdue University

8. Project Title:

Joint POLarization Experiment (JPOLE)

9. Brief Abstract of Proposed Field Program:

The Joint Polarization Experiment (JPOLE) field campaign is a multi-agency project designed to investigate the use of polarimetric radar signatures of precipitation to advance numerous NSF-related meteorological and hydrological objectives. Broadly, the objectives include improving physical understanding of polarimetric data interpretation, improving rainfall estimation and hydrometeor classification and quantification techniques, and investigating the use of polarimetric radar data in distributed hydrologic and storm-scale/mesoscale numerical weather prediction models. It will be held during a much longer NOAA-sponsored JPOLE operational demonstration, which seeks to demonstrate the utility of the first polarimetric WSR-88D radar to operational meteorologists, hydrologists, and aviation users. The JPOLE field campaign builds upon a significant program infrastructure provided by a NOAA-sponsored project.

The JPOLE field campaign is planned for central Oklahoma for 15 March 2003 through 15 June 2003. (The T-28 aircraft will be requested for five to six weeks during the middle of this period from approximately 24 April 2003 to 31 May 2003). This period is ideal to address the NSF-related objectives presented in this document. In addition to being a transitional period wherein central Oklahoma experiences precipitation events

that span a wide variety of regimes (suitable for investigating a broad range of objectives), it is also a time period wherein central Oklahoma experiences a climatological maximum in heavy precipitation events that commonly lead to flooding. Given the potential of a future network of polarimetric radars, the implications of this research promises to have a much broader and far reaching impact at a national scale for the research community.

B. General Information

10. Funding Agency: National Science Foundation

A. Contract Office (Listed in front of the pretinent proposal):

i. NSF-GEO/ATM Physical Meteorology Program

Proposal in Draft Form
Pending Negotiations
In Review
Approved

Title: Numerical Studies of Electrification and Lightning in STEPS and Other Storms (ATM-0119398)

Co-P.I.s E.N. Mansell (34%), C. Ziegler (33%) and J. M. Straka (33%)

Dates: July 2001-June 2004, Amount: \$355,293

Agency: NSF-GEO/ATM Physical Meteorology Program (lead PI is listed first, all co-PI's listed)

ii. Mesoscale and Dynamic Meteorology Program

Proposal in Draft Form
Pending Negotiations
In Review
Approved

Title: The Concentration of Vorticity at the Ground by Precipitation Processes in Supercells and Other Severe Thunderstorms (ATM-0003869)

Co-P.I.s: E.N. Rasmussen (45%), J. M. Straka (55%), and J. Davies-Jones(0%-NSSL employee)

Dates: Jan 2001-Dec 2004, Amount: \$473,274 total with increases possible

Agency: NSF-GEO/ATM Mesoscale and Dynamic Meteorology

iii. Mesoscale and Dynamic Meteorology and Physical Meteorology Programs

Proposal in Draft Form [submitted by 14 June 2002]
Pending Negotiations
In Review
Approved

Title: Radar Polarimetry for Microphysical Studies and Modeling

Co-P.I.s: J. M. Straka (40%) and D.S. Zrnice (0%-NSSL employee) A. Ryzhkov (40%), and T. Schuur (20%)

Dates: Mar2003-Feb2006, Amount: \$ 490,018

Agency: Probable split between NSF-GEO/ATM Mesoscale and Dynamic Meteorology and Physical Meteorology Programs

The following cooperative proposals are expected to be submitted or have already been submitted to the National Science Foundation as part of JPOLE. These will heavily rely on polarimetric radar observations.

iv) V. Chandrasekar:

Polarimetric Radar Observations and In-situ Measurements in Spring and Summer Storms

v) B. Vieux, L. Carey, J. Gourley:

Hydrologic Evaluation of Dual-Polarization Quantitative Precipitation Estimation

vi) A. Ryzhkov, T. Schuur, C. Duchon, G. Ciach:

Dual-Polarization Radar Rainfall Estimation and its Relation to Storm Microphysical Structure

vii) S. Lasher-Trapp:

Warm Versus Cold Rain Processes as Observed by Polarimetric Radar and In-situ Measurements

viii) D. MacGorman, D. Rust, T. Schuur:

Electrification and Lighting of Severe Storms and Mesoscale Convective Systems During STEPS and on the Southern Great Plains

ix) S. Rutledge:

Dynamical, Microphysical, and Electrical Studies of Convection

x) D. Niyogi, S. Raman, L. Carey:

Investigation of the Role of Land Atmosphere Interactions on Quantitative Precipitation Forecasts and Convective Initiation Over the Southern Great Plains

11. Location of Field Program:

Central Oklahoma

12. Start and End Dates of Field Program:

T-28: 24 April 2003-31 May 2003

Radars: 15 March 2003 - 15 June 2003

13. Number of Personnel You Will Bring to the Field:

10-15 people are likely to be in the field at any given time. No more than 3-4 should be at a radar at any given time (two for radar interpretation and two for aircraft operations).

14. Typical operations (daily ops hrs—Forecasting discussed below):

Daily operations will depend on the precipitation regime. Operations hours will typically be all day for synoptic-scale precipitation systems, late morning through mid evening for convective cases, and late evening through early morning for Mesoscale Convective Systems.

Relation of Operations Hours to Weather:

On days when precipitation is forecast.

15. T-28 provides a Scientific Project Manager for all field programs to assist in experiment design, site selection, field coordination and general liaison with Principal Investigators.

The proposed project will require the T-28 scientist resident at the field site for the duration of the experiment.

16. Describe the other observational facilities involved in your program. (e.g. aircraft, surface sensors):

CSU-CHILL Polarimetric Radar (requested concurrently)

NOAA KOUN Polarimetric Radar (prototype polarimetric WSR-88D radar)

NOAA Cimarron polarimetric radar

National Weather Service (NWS) WSR-88D radars (KTLX, KINX, KVNXX, KFDR)

SDSMT armored T-28 aircraft

NSSL Mobile Laboratory

Rain gauge data on three spatial scales:

Oklahoma Climate Survey Mesonet (115 gages, average gauge spacing of 30 km)

ARS Micronet (42 gauges, average gauge spacing of 5 km)

OU/EVAC Piconet (25 gauges, average gauge spacing of 0.65km)

USGS stream flow gages (174 gauges in the JPOLE study region)

NSSL 2D-video-disdrometer

3D-Lightning Mapping Network

C. Requirements

17. T-28 parameters needed:

HVPS:

The HVPS is needed for direct images of larger sized particles.

Hail Spectrometer:

The Hail Spectrometer is needed for particles in the 5 mm to 50 mm in size and 0 to 100 / m³ in concentration.

PMS Forward Scattering Spectrometer:

The PMS Forward Scattering Spectrometer is needed for particles up to 57 microns in size and in concentrations of 0 to 2000 cm⁻³.

Johnson-Williams Liquid Water Content Meter:

The Johnson-Williams Liquid Water Content Meter can be used for cloud contents that range from 0 to 6 g m⁻³.

Foil Impactor:

The Williamson Foil Impactor would be used for particles in the 0.1 mm to 20 mm size range.

Field Mills:

The T-28 field mills would be useful for electrification studies.

Air Temperature:

Elevation:

GPS coordinates:

Vertical wind velocity:

18. List of auxiliary equipment you will bring or will be provided by OU/NSSL:

Two computers and possibly radio equipment. The computers may be used to run the WATADS (WSR-88D Algorithm Testing and Display System) and WDSS-II (Warning Decision Support System-Integrated Information).

19. Communication Requirements (including the need for sending T-28 tracking information data to a remote site for tracking on radar [KOUN]):

GPS aircraft and mobile unit locations
Remote display capability at KOUN site

20. Operation days:

Estimated number of T-28 operations (20 at 2 hrs maximum each):

Days with significant precipitation:	20
Days with MCS activity:	8
Days with Hail:	5

D. Previous Experience

21. Previous Airborne Research Experience of Requesting Scientist(s):

Most all of the requesting scientists have some to extensive experience with radars and radar programs (e.g., GALE, CCOPE, MAYPOLE, CaPE, CINDE, MIST, TOGA COARE, SWAMP, COPS, MEaPRS, MAP, STEPS, VORTEX, MIGHT, PRE-STORM, TEFLON, MCTEX, and TRMM-LBA Brazil). Dr. Zrnice is a pioneer in the area of Doppler radars and is currently conducting extensive research on polarimetric radars. Dr.

Chandrasekar has made several pioneering contributions in the area of polarimetric weather radar and rainfall estimation. Both have also published text books on Doppler radar and Polarimetric radar, respectively. The rest of the requesters have also made extensive contributions to radar meteorology, evidenced by the large number of papers published by all the requesting scientists.

List of Participant's Previous Airborne Research Experience

D. S. Zrnice: 1981, CV990 lidar, OK; 1989, P3, COPS-89, OK

C. Chandrasekar, and D.S. Zrnice: 1991, T-28, COPS-91, OK

J. M. Straka, 1994, and D.S. Zrnice: T-28, VORTEX-1994; T-28, VORTEX-1995 OK

M. Askelson, V. Chandrasekar, and S. Rutledge, J. M. Straka: T-28, MIGHT 1995, CO

S. Lasher-Trapp: 1997, Multiple Aircraft, CP-2, SCMS, FL

T. Schuur: P-3, SWAMP, COPS-91, TOGA-COARE, and MEaPRS

22. Partial list of related publications (limited for request length):

Askelson, M. A., J. P. Aubagnac, and J. M. Straka, 2000: An adaptation of the Barnes filter applied to the objective analysis of radar data. *Mon. Wea. Rev.*, **128**, 3050-3082.

Askelson, M. A., J. M. Straka, D. S. Zrnice, 1997: A study of the kinematics and microphysical evolution of a supercell from first echo using polarization diversity radar. *Preprints, AMS 28th Intl. Radar Conf.*, 9-10.

Aydin, K., T. M. Walsh, and D. S. Zrnice, 1992: Dual-polarization radar measurements in an Oklahoma hailstorm, IGARSS'92, Conference Proceedings, Houston, TX.

Aydin, K., T. M. Walsh, and D. S. Zrnice, 1993: Analysis of dual-polarization radar measurements and T-28 aircraft measurements during an Oklahoma hailstorm, Preprints, 26th International Conference on Radar Meteorology, AMS, Norman OK.

Bluestein, H. B., R. J., Doviak, M. D. Eilts, E. W. McCaul, R. Rabin, A. Sundara-Rajan, and D. S. Zrnice, 1986: Analysis of airborne Doppler lidar, Doppler radar, and tall tower measurements of atmospheric flows in quiescent and stormy weather. NASA Contract Report 3960.

Bringi, V. N., L. Liu, P. C. Kennedy, V. Chandrasekar and S. A. Rutledge, 1996: Dual multiparameter radar observations of intense convective storms: The 24 June 1992 case study. *J. Meteor. Atmos. Phys.*, **59**, 3-31.

Carey, L. D., and S. A. Rutledge, 1996: A Multiparameter Radar Case Study of the Microphysical and Kinematic Evolution of a Lightning Producing Storm. *Meteorology and Atmospheric Physics*, **59**, 33-64.

Carey, L.D., and S.A. Rutledge, 1998: Electrical and multiparameter radar observations of a severe hailstorm. *J. Geophys. Res.*, **103**, 13979-14000.

- Carey, L. D. and S. A. Rutledge, 2000: The relationship between precipitation and lightning in tropical island convection: A C-band polarimetric radar study. *Mon. Wea. Rev.*, **128**, 2687-2710.
- Carey, L. D., S. A. Rutledge, D. A. Ahijevych, and T. D. Keenan, 2000: Correcting Propagation Effects in C-band Polarimetric Radar Observations of Tropical Convection Using Differential Propagation Phase. *J Appl. Meteor.*, **39**, 1405-1433.
- Cifelli, R. W.A. Petersen, L.D. Carey, and S.A. Rutledge, 2002: Radar observations of the kinematic, microphysical, and precipitation characteristics of two MCSs in TRMM-LBA. *J. Geophys. Res.*, In Press, August 2001.
- Chandrasekar V., Abou-El-Magd, V. N. Bringi and W. Strapp, 2000: Radar and In-Situ Aircraft Observation of Graupel and Hail, *IEEE Transactions GRS*, **38**, No. 1, 570-578.
- Gorgucci, E., G. Scarchilli, V. Chandrasekar and V. N. Bringi, 2001: Rainfall estimation from Polarimetric Radar Measurements: Composite algorithms immune to variability in Raindrop-Size Relation , *J. Atmos. Ocean Tech.*, **18**, No 11, pp 1773-1786.
- Gorgucci, E., G. Scarchilli, V. Chandrasekar and V. N. Bringi, 2000: Measurement of Raindrop Shapes from Polarimetric Radar Observations, *J. Atmos. Sci.*, **57**, No. 20, 3406-3413.
- Hubbert, J., V. N. Bringi, L. D. Carey, and S. Bolen, 1998: CSU-CHILL polarimetric radar measurements from a severe storm in Eastern Colorado, *J. Applied Meteor.*, **37**, 749-775.
- Lasher-Trapp, S. G., C. A. Knight, and J. M. Straka, 2001; Early radar echos and precipitation formation from ultragriant aerosols. *J. Atmos. Sci.*, **23**, 3545-3562
- Liu H., and V. Chandrasekar, 2000: Classification of Hydrometeor Type Based on Multiparameter Radar Measurements: Development of a Fuzzy Logic and Neuro Fuzzy Systems and In-situ Verification, *J. Atmos. Ocean Tech.*, **17**, 140-164.
- Liu, Y., and J. M. Straka, 1998: The tangent linear model and adjoint model of a simple moist convective model with ice physics including implications for incorporating dual-polarimetric radar data. *Preprints, 19th Conf. on Severe Local Storms*, Minneapolis, MN, USA, Amer. Meteor. Soc. 338-341.
- Loney, M. L., D. S. Zrnic, J. M. Straka, and A.V. Ryzhkov, 2002: Enhanced polarimetric radar signatures above the melting level in a supercell storm. Accepted with minor revision, *J. Appl. Meteor*
- Ryzhkov, A.V., D. S. Zrnic, and B. A. Gordon, 1998: Polarimetric method for ice water content determination. *J. Appl. Meteor.*, **37**, 125-134.

- Schuur, T. J., A. V. Ryzhkov, D. S. Zrnic, and M. Schönhuber, Drop Size Distributions Measured by a 2D Video Disdrometer: Comparison with Dual-Polarization Radar Data, *J. Appl. Meteor.*, **40**, 1019-1034, 2001.
- Straka, J.M., D. S. Zrnic, and A. V. Ryzhkov, 2000; Bulk hydrometeor classification and quantification using multi-parameter radar data. A synthesis of relations. *J. Applied Meteor.*, **40**, 1341-1372.
- Vivekanandan, J., D. S. Zrnic, S. M. Ellis, D. Oye, A. V. Ryzhkov, and J. M. Straka, 1999: Cloud Physics Retrieval Using S-band Dual-Polarization Radar Measurements. *Bull. Amer. Meteor. Soc.*, **80**, 381-387.
- Ziegler, C. L., E. N. Rasmussen, T. Shepard, A. Watson, and J.M. Straka, 2001: The evolution of low level rotation in the 29 May 1994 Newcastle, Texas storm during VORTEX: *Mon. Wea. Rev.*, **129**, 1339-1368
- Zrnic, D. S., N. Balakrishnan, C. L. Ziegler, V. N. Bringi, K. Aydin, and T. Matejka, 1993: Polarimetric signatures in the stratiform region of a mesoscale convective system., *J. Applied Meteor.*, **32**, 678-693.
- Zrnic, D. S., A. Ryzhkov, J. M. Straka, Y. Liu, R. Vivekanandan, 2001; Testing a procedure for automatic classification of hydrometeor types 'using polarimetric data, *J. Atmos. Oceanic Tech.*, **18**, 892-913.
- Zrnic, D. S., M. L. Loney, J. M. Straka, A.V. Ryzhkov, 2002: Enhanced polarimetric radar signatures above the melting level in a supercell storm. To appear IGARS
- Zrnic, D. S., M. L. Loney, J. M. Straka, A.V. Ryzhkov, 2002: Enhanced polarimetric radar signatures above the melting level in a supercell storm. To appear in *J. Appl. Meteor.*

E. Experiment Design

23. Please attach a written description of the experiment.

We request the use of the T-28 aircraft facility from 24 April 2003 to 31 May 2003 during the JPOLE 2003 field campaign. Both, earlier and later dates are acceptable, as well as a shorter period of time if necessary. The main objective of having the T-28 in Oklahoma in 2003 is to obtain in situ microphysical measurements in deep convective storms. These will be used to 1) test the collective capability of the polarimetric variables to discriminate hydrometeor type; 2) gauge the amount of ice; 3) understand the variations in drop size distribution; 4) sort hail to few size categories; 5) relate the enhanced signatures of bulk hydrometeors to storm morphology, and; 6) support a variety of scientific investigations in the JPOLE experiment.

Further, bulk hydrometeor characteristics deduced by various investigators will be used to improve microphysical parameterizations, develop microphysical retrieval schemes, and initialize moisture fields in numerical weather prediction models.

JPOLE Science Objectives:

The Scientific Overview document for JPOLE is posted at www.nssl.noaa.gov/JPOLE/ and www.jpole.colostate.edu. Parts from that document have been extracted for inclusion in this Proposal Summary. The Scientific Overview document should be consulted for more details.

The science objectives presented in this section are a collection of meteorological and hydrological objectives related to the interpretation of polarimetric signatures, use of polarimetric radar and in – situ T-28 observations to develop improved hydrometeor classification and quantification techniques, drop size distribution retrievals, and use of polarimetric radar data to initialize storm-scale prediction and distributed hydrologic models. The primary source of data for these investigations will come from the CSU-CHILL and KOUN WSR-88D polarimetric radars. With its simultaneous transmission mode, the KOUN WSR-88D radar is capable of measuring reflectivity (Z_h), the polarimetric variables differential reflectivity (Z_{dr}), specific differential phase (K_{dp}), and correlation coefficient (ρ_{hv}). With its added ability to transmit in either alternate or simultaneous mode, the CSU-CHILL radar is capable of collecting the above listed polarimetric variables, but also LDR and other cross-polar variables. Combined, these radars will provide widespread coverage of numerous river basins, as well as data that can be used to investigate the sensitivity of hydrometeor classification and quantification techniques to input variables and their use in storm-scale model simulations.

The science objectives listed here will be addressed by science proposals to be submitted by the JPOLE PIs listed in Appendices A and B in the Science Overview document. These objectives are to:

i. Improve physical understanding of polarimetric signatures.

Some of the difficulties in developing procedures to deduce dominant hydrometeor types and bulk amounts from polarimetric radar data are caused by a lack of a thorough understanding of polarimetric radar signatures. For example, there is a need for information about drop size distributions (DSDs), hydrometeor characteristics, and ambiguities associated with hydrometeor identification. (e.g., whether several or no hydrometeor types are identified). To complete rigorous validation studies, complete sets of quantitative and qualitative observations and information on the occurrence of artifacts in the data and uncertainties in radar calibration are also required. While significant insights have already been obtained, it is evident that much work remains. The future significance of this need is further magnified by the prospects for a polarimetric upgrade to existing WSR-88Ds radars in the coming decade, which promises to expose many in the community to this type of information. Research carried out under this objective will provide valuable information that will be used to understand the evidence and limitations to polarimetric radar data and products.

- ii. *Investigate the effect of natural drop size distribution variability, drop oscillations, and canting angles on conventional and polarimetric rainfall estimators.*

Natural variations in DSDs impact radar-derived rainfall estimates. Rain rate estimates are also impacted by variability in drop shape (frequently caused by oscillations) and canting angles. Though less susceptible than conventional radar methods, even polarimetric methods of rainfall estimation are affected by variability in raindrop spectra. For example, DDSs with an anomalously large number of small (large) raindrops will commonly result in an underestimation (overestimation) of rainfall. These known dependencies underscore a need to better understand natural DSD variations in precipitation events. Indeed, observations indicate that significant DSD variability exists not only from one event to the next, but even within individual precipitation events. Under this objective, high-quality DSD measurements from multiple 2D-video-disdrometers will be combined with measurements from the CSU-CHILL and KOUN WSR-88D polarimetric radars to understand the impact of DSD variability on polarimetric rainfall estimation. The data will be used to improve rainfall estimation techniques. In turn, the improved polarimetric rainfall estimates will be used as input to distributed hydrologic models, which will be used to predict the runoff associated with heavy precipitation events.

- iii. *Develop and test robust precipitation identification and quantification algorithms at long ranges. Investigate methods to account for bright band contamination in rainfall measurements.*

Since DSDs evolve significantly as they fall from cloud base, DSDs illuminated by the radar beam at long ranges (locations well above the ground) can bear little resemblance to those encountered at the surface. This can make rainfall estimation at long ranges difficult. This problem is compounded further for shallow stratiform systems, where “bright band” contamination at long ranges results in an increase in reflectivity that makes rainfall estimation by conventional methods (such as Z-R relations) almost impossible. In the past, most polarimetric radar analyses have used data collected in the 30 to 60 km range. Recent polarimetric radar and aircraft studies, however, have shown that important hydrometeor information can be obtained at distances of 90 to 120 km. Similar research needs to be conducted for rainfall estimation at long ranges, possibly out to 150 km. Two advantages of polarimetric radar measurements are their abilities to discern information about DSD characteristics and to clearly identify regions of “bright band” contamination. Under this objective, data from the CSU-CHILL and KOUN WSR-88D polarimetric radars will be compared against data from the Oklahoma mesonet. By studying rainfall estimation over large domains (the coverage area of the two radars encompasses most of the state of Oklahoma), techniques will be developed to estimate rain rate at long ranges. In addition to serving as input to hydrologic models, this information will have valuable applications in both climatological and storm-scale model validation studies.

- iv. *Investigate how improved precipitation estimates from polarimetric rainfall measurements can be used to initialize hydrologic models.*

Recent advances in hydrologic modeling provide the capability to capitalize on improved precipitation estimates made possible by polarimetric radar. Specifically, these models are beginning to utilize spatially distributed parameters as opposed to basin-averaged, or lumped parameters. These distributed hydrologic models also take full advantage of high-resolution, gridded inputs from polarimetric radar. The quantitative precipitation estimates are

transformed to runoff on a grid cell-by-grid cell basis using physics instead of empiricism. The work proposed here will incorporate the polarimetric rainfall estimates in a physics-based, fully distributed hydrologic model called r.water.fea that was developed at the University of Oklahoma. Model-predicted stream flow will be compared to observed stream flow at USGS gauging stations. Results from this study will be used to assess the operational use of hydrologic modeling at the scales at which flash flooding occurs.

- v. *Investigate how input data uncertainties influence flood prediction, the maximum time/space scales required to accurately simulate a flash flood, and the basin characteristics that are most important in transforming rainfall into runoff.*

With improved precipitation estimates from polarimetric radar, many advances in the understanding of hydrologic processes can proceed. Specifically, basin characteristics are parameterized in the hydrologic model using proxy data sources, such as infiltration derived from soil types and Manning's roughness coefficient from land use/land cover maps. A limited sensitivity test will be conducted with these parameter sets to determine the influence of the sampled information content on stream flow predictions. These tests will improve our understanding of basin characteristics and their impacts on runoff. In addition, sensitivity tests can begin to comparatively assess how much uncertainty exists in the parameter sets, the input polarimetric rainfall estimates, within the context of the hydrologic model structure. The aim of these tests is to ascertain the amount of uncertainty associated with model-predicted stream flow. Lastly, simulations of river flow will be performed at varying frequencies and spatial resolutions to determine the maximum scales at which flash floods can be adequately modeled.

- vi. *Examine the accuracy of hydrometeor classification schemes through detailed comparisons with verification data sets. Use verification data sets to develop hydrometeor quantification schemes.*

Polarimetric-radar-based hydrometeor classification schemes are in a dire need of comprehensive verification data sets. This is especially true for widespread cold- and warm-season stratiform precipitation events that, unlike hailstorms, have received only scant attention. In-situ information from a variety of precipitation systems is therefore critical to both the refinement of current qualification/quantification techniques and to the development of new techniques. Particular emphasis will be placed on the delineation of the error modes in which classification and quantification techniques tend to fail, and the quantification of expected errors. Under this objective, T-28 in-situ aircraft data will be compared with data from the CSU-CHILL and KOUN WSR-88D polarimetric radars to improve understanding of the strengths and weaknesses of classification and quantification techniques, estimate expected errors for microphysical parameters (e.g., distribution slopes, ice-water content) that are derived from polarimetric-radar data, and identify classification/quantification failure modes and possible methods for dealing with them. They will also be used to investigate new classification/quantification techniques and provide feedback to other objectives (e.g., objectives ii, iii, vii, xi, and xii). The principal method for accomplishing these goals will be the comparison of algorithm-estimated qualitative and quantitative information (derived from polarimetric radar data) to the qualitative and quantitative hydrometeor-field properties determined by in-situ observation (derived principally from T-28 data).

- vii. *Investigate how microphysical information derived from polarimetric radar measurements can be used in cloud resolving models.*

For several years, modelers have been noting a need for improved microphysical initialization data for storm-scale models. Hydrometeor classification and quantification information derived from polarimetric radar data promises to be provide valuable information that can be used to produce short-term model predictions. Under this objective, the variational technique will be used to fit cloud models to microphysical observations for both basic scientific investigations and operational meteorological applications. Owing to the complexity of the problem, initial attention will be given deep, moist convection that includes both the liquid and ice phase and a simple ice/liquid microphysics parameterization. These data and tools also will be used to improve understanding of long-standing problems with quantitative precipitation forecasts, such as the so called moisture spin-up, microphysical/kinematical interactions, and validation of numerical models with varying microphysical representation complexities. The variational approach to this problem has several strengths. They include an ability to create complete data sets with physical conditions, assimilate observations over short periods of time, assimilate data from a variety of observation platforms even if the observed variable is missing from a model equation, and allow for ingest of inhomogeneous data in time and space. Some of the challenges of the approach include defining weights in the cost function, dealing with discontinuities or step-function processes, finding the right amount of data to ingest, and representing physical processes correctly.

- viii. *Investigate the retrieval of drop size distributions from polarimetric radar measurements.*

A long-standing goal of radar polarimetry has been the retrieval of DSD parameters using measurements of Z_h , Z_{dr} and K_{dp} . To do so requires knowledge of the relation between the axis ratio and equivalent volume diameter, which is non-linear. Nonetheless it is possible to define an equivalent linear model with slope of β_{eff} such that a correct relation between K_{dp}/N_w and D_o is preserved on average. Algorithms have been developed for retrieving rain rate (R) as well as D_o , N_w and μ using β_{eff} in combination with the pair (Z_h , Z_{dr}) (please see overview document for references) . The "effective" slope (β_{eff}) of the mean axis ratio versus D relation captures the effects of both drop oscillations and canting which vary considerably in different precipitation regimes. We will investigate thoroughly β_{eff} and reasons behind its variability. Because β_{eff} is estimated from the measurement set (Z_h , Z_{dr} , K_{dp}), and K_{dp} at long wavelengths (such as S-band) is known to be very noisy (at low rain rates), it follows that the retrieval of the DSD parameters is only practical if the radar reflectivity is sufficiently high. At low rain rates the Z_{dr} also tends to be noisy therefore a large areal average is necessary to reduce the measurement fluctuations and retrieve DSD parameters. In addition to the variability of β_{eff} (particularly in updraft/downdraft regions), an important goals of this research is to study the space-time variability of the drop size distribution over life cycles of storms. Finally, the last goal is to compare radar-derived rain rates against a network of gages to demonstrate the benefits from β_{eff} in reducing the rainfall accumulation bias.

- ix. *Examine the microphysical basis for drop size distribution variability in both cold and warm season precipitation events with particular emphasis on extreme "cold-processes" and "warm-processes".*

The adjective "extreme" is a rather subjective qualifier because it usually refers to destructive effects of rain which, depending on spatial and temporal scales, are not uniquely related to rain rate. To quantify these, accurate precipitation measurements are needed over scales ranging from those at which urban flash floods are produced to those at which major river flooding occurs. Often, it is not the extreme precipitation itself, but the associated hydrologic response at the land surface (such as flash floods, land slides, debris flow, etc.) that cause the greatest damage. The impact of extreme precipitation can be particularly severe over urban areas. Under this objective, warm and cold rain processes will be observed (and differentiated) by the polarimetric radar and aircraft measurements. It is anticipated that warm rain processes would dominate the storms earlier in their lifetime, but that gradually cold rain processes would take over. The differences in DSDs (as measured by aircraft and disdrometers at the ground) from the two types of processes will be compared. Besides enhancing understanding of rain processes, the knowledge gained will tell if polarimetric rainfall estimators should adaptively adjust to the rain type. Furthermore, it will help explain the source of typical overestimation of extreme "cold-process" rain and underestimation of extreme "warm-process" rain estimated from fixed R(Z) relations.

x. *Investigate the microphysical processes responsible for rapid changes in polarimetric signatures.*

Enhanced signatures of polarimetric variables (i.e., regions where a polarimetric variable has a distinctly different value than in its surroundings) are widely believed to be tied to specific microphysical processes. So far, several types of signatures have been observed. For example structures of K_{dp} and Z_{dr} columnar fields displaced from each other have been reported in Colorado and Oklahoma supercell storms. In ordinary storm, the Z_{dr} and K_{dp} have been collocated. Further the process of upward drop advection and subsequent freezing has been documented for ordinary storms. Very little is known about the evolution and advection of polarimetric signatures in supercell storms and squall lines. These are, of course, caused by the bulk hydrometeors; frequent observation of the signatures could help explain the processes that lead to these changes. To fully capitalize on polarimetric measurements, fast volume scans (< 1 min) to provide observations with a resolution of a few hundred meters are needed. This can be achieved with conventional radar by probing small sectors and utilizing recently proposed techniques to greatly reduce statistical errors in polarimetric radar signals. Although tested, the technique has not and will not be implemented in time for the experiment. Nonetheless, the CSU-CHILL radar can oversample (in range) the time series and record such data. JPOLE will provide an opportunity to obtain polarimetric signatures at unprecedented updates rates and with superior accuracy for several events. This information will be useful for understanding rapid microphysical changes in clouds, conducting trajectory analysis studies, and providing valuable insight that can improve model parameterizations.

xi. *Investigate the effects of electric fields on the orientation of ice crystals using polarimetric radar measurements.*

Both plate and needle like crystals naturally fall with their long axis oriented horizontally. However, vertically oriented crystals have been observed in-situ and hints appeared in polarimetric signatures. The polarimetric radar observations indicate negative K_{dp} 's of many small vertically oriented crystals. However, the orientation for the small crystals in the strong electric fields is primarily in the vertical. These electric fields are not strong enough

to reorient the larger needle or plate like crystals. As the small pristine needle crystals occur in much larger numbers they produce the negative K_{dp} signature. The signature is not indicated by Z_{dr} , which is dominated by the fewer, though much larger small crystals. Observations would require polarimetric radar and field mill measurements from equipment on board the T-28 at temperatures of around $-5\text{ }^{\circ}\text{C}$ and perhaps at temperatures colder than $-17.5\text{ }^{\circ}\text{C}$.

Importance of JPOLE-2003 and T-28 data:

JPOLE is a concentrated effort focused on scientific issues that could be resolved with a help of polarimetric measurements. Of direct interest are methodology, evolution and verification of bulk hydrometeor classification schemes, determination of ice water content, and sorting hail into size categories. Relation of bulk hydrometeors types and parameters (i.e., median size, slope of exponential DSD, type of DSD) to the storm morphology will also be investigated. Only relatively simple and mostly known (understood) phenomena have been related to bulk hydrometeor types via the polarimetric signature (i.e., Z_{dr} column above the melting layer, the LDR cap on top of the column indicating freezing, values of polarimetric variables in the melting layer). But there is much more to explain, such things as persistent increase of Z_{dr} at the leading edge of supercells and squall lines, meaning of the K_{dp} column, and the significance and relative position of various polarimetric signatures in convective storms. Ultimately three-dimensional maps of various polarimetric signatures in different convective events will emerge. For these issues the in situ measurements are indispensable.

Although there are polarimetric data from other experiments, it is only recently that a new pair of co- to cross correlation coefficients became available. Inferences from these will be verified with the T-28 penetrations. There has been no concentrated effort to unravel the microphysics of strong convection with the help of polarimetry in the Great Plains. CASES focused on proving the value of the S-Pol radar for hydrologic applications; STEPS aimed at electrification in the formative stages of MCSs. Over the years NSSL has collected a large amount of polarimetric data in Central Oklahoma. Although useful for rainfall measurements, these data are incomplete and less accurate than the ones from the newer radars that will be utilized in JPOLE.

JPOLE will offer an opportunity for several young PI meteorologists (Askelson, Carey, Gourley, Lasher-Trapp) to work with aircraft and polarimetric data and infuse these into the broader meteorological community. Given the potential of a future network of polarimetric radars, the implications of this research to have a much broader and far reaching impact on a national scale for the research community.

The existing observing systems in Oklahoma and support by the University and NOAA add a dimension hard to match in field studies. Moreover, results and findings by the investigators will influence the way National Weather Service utilizes radar for years to come.

F. Project and Analysis Plan

1. JPOLE Operation Decisions:

One of the designated scientist will call, send e-mail (and post on the web) to primary operation participants each night between 8 and 10 pm to provide a preliminary outlook for the next day.

Forecast issues at the start of each day for decisions for radar and T-28 operations will be made based on latest information from the Norman NWS forecast office (which is closely connected to this experiment, through the delivery of real-time radar data and products from KOUN radar).

If a standby is issued, a time and target will also be provided. It is hoped that the T-28 can be in the air within 30 to 45 minutes when operations are declared while on standby. We will attempt to constrain typical stand-by situations between two to four hours of possible operations.

A decision for daytime (afternoon) operations will be made if 1) towering cumulus are observed to form and first echoes are expected, 2) if first echoes develop, 3) if storms are expected to move into one or more of the radar's ranges. Typical radar coverage is out to 100 km but better radar data is possible at ranges of 25 to 75 km.

These types are essential to optimize the greatest amount of data collection given the often rapidly changing weather and periodic dry spells in Oklahoma in the spring.

2. Analysis Work:

Drs. Straka and Zrníc will co-direct the collection of microphysical data with the T-28 aircraft. They will also coordinate the aircraft /radar data analysis efforts. Their combined past experience with very similar efforts include those involving VORTEX-1994, and 1995. We also have the assistance of a wide range of expertise locally at OU and NSSL, and through collaboration with our colleagues at CSU, PSU, SDSMT, UND and other institutes.

Two new Ph. D. students directed by both Drs. Straka and Zrníc will participate in the data collection. These students will do most of the data analysis. Several other graduate and undergraduate students from OU, CSU, University of North Dakota, Purdue, and North Carolina State University will be working on JPOLE data; many will need the in situ T-28 observations. Dr. Askelson has gained valuable experience working with T-28 and radar data collected during May 1994 and 1995. He has become proficient with the SDSMT software packages (for analysis of T-28 data), and will utilize it at the University of North Dakota.

Each case study will provide an excellent opportunity for outstanding research quality radar data analyses and student education. To help interpret spatial relation between bulk hydrometeor properties and storm structure, CAPPI and RHI analyses of all multiparameter variables, and Doppler velocities will be made. Doppler data from one of the local WSR-88D's will be used for dual-Doppler analyses and similarly Cimarron radar data can be combined with the CSU-CHILL. Finally, time series of radar data along each flight path will be produced for comparison with aircraft data.

G. Proposed Flight Operations

1. Flight Period:

We request the T-28 aircraft for a period of five to six weeks. Climatologically, the best time of the year for the proposed work is from the end of April through the end of May. It would be best if the T-28 were in Norman, OK from 24 April 2003 through 31 May 2003. However, we would accept other period lengths and/or times between April and June if required by the SDSMT scientists and flight crew.

2. Number of Flights:

If we have an average year in terms of precipitation occurrence in central Oklahoma, we could have opportunities for perhaps 20 flights. With each flight lasting no more than 2 hours, and accounting for 12 hours of ferry time, we request up to 52 hours of flight time.

3. Base of Operation:

The aircraft will be based at Westheimer Field, Norman OK. *We will secure one of the aircraft hangers set aside by the OU Provost for research activities as we did in 1994 and 1995 during VORTEX.*

4. Forecast issues for operations:

For JPOLE we will rely on our own forecasts as well as nowcasts by the NWS. Decisions for T28 operations will be based on latest weather and radar information. We will have a forecast team lead by Straka. The team will forecast MCS/Squall-line events in the morning. Forecast updates and latest radar information will guide the forecaster to update current status to go, stand-by until a certain time, be ready to go after a certain time, or no operation check status after a certain time.

Forecasts for the former will be put out via phone call and e-mail one hour before sunrise, and by the same means at 10 am for the latter.

H. Proposed Flight Patterns and Radar Scan Strategies

1. Flight Plans:

Flight patterns are developed to best observe hail-graupel-rain mixtures, hail-graupel mixtures, snow-graupel mixtures, and pure rain in squall lines and isolated convective storms. The details of the proposed flight paths are provided below in section H.5. Efforts will be made to fly patterns at only one or two flight levels to obtain as much data as possible (given a certain storm configuration). We are aware that changing altitude costs time. Also, we will attempt to make all flight level changes from lower to higher altitudes to prevent problems with condensation on instruments. Flight paths will need to deviate from those planned to avoid 55 dBZ cores.

2. Radar Scan Strategies:

The Polarimetric Sector Volume Scan strategies are designed to collect polarimetric data over small volumes through the depths of squall lines, MCSs, and isolated convection. These scans consist of a number of sector sweeps at various elevations. A dwell time of 64 or 128 ms and a modest antenna rotation rate between 6 and 12 degrees per second will be used. The entire scan strategy would take on the order of 3-6 minutes, and be coordinated with the WSR-88D of choice. These scans will be pre-programmed by Drs. Chandrasekar and Zrnica as follows;

- Example elevations, in degrees, for storm distances of 30 to 60 km
0.5, 1.0, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 8.0, 10.0, 12.0, 14.0, 17.0, 20.0, 23.0, 26.0, 29.0
- Example elevations, in degrees, for storm distances of > 60 km
0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0

Specific, very rapid (< 60 s), single or several elevation sector scans will be made to capture rapidly changing polarimetric signatures.

Polarimetric Survey Volume Scan and RHI Volume Scan

Survey Volume Scan strategies and RHI Volume Scan strategies are designed to collect polarimetric data over broad regions through the depths of squall lines, MCSs, and isolated convection. These scans consist of a number of 360 degree sweeps at various elevations. The entire scan strategy would take on the order of 3 to 6 minutes, and be coordinated with the WSR-88D of choice. These scans will be pre-programmed by Drs. Chandrasekar and Zrnica.

3. Provisions for Directing Flight from the Ground:

Flight control will use the CSU-CHILL radar. Ground-to-air radio will be provided by the T-28 Facility, which will also supply, via telemetry, the radio coordinates from the GPS system. These will be displayed on the reflectivity data from the CSU-CHILL radar. Coordination of this effort at NSSL will be done by Drs. Straka, Chandrasekar, Zrnica, and Schuur.

4. Data Recording and Processing Requirements:

For particle data analysis, 9-track, IAS and PMS data tapes in standard formats will be acceptable. The Foil Impactor data reduction (for selected cases) may be more appropriately done in collaboration with personnel from SDSMT. Analysis of air motion data to derive wind speeds also might be done at SDSMT. We have recently loaded some of the SDSMT software on the OU and NSSL computers to analyze data from the T-28.

5. Flight Patterns:

The following flight patterns are highly idealized plans for intercepting isolated deep convective cells, and squall lines with and without stratiform regions. These are only for planning purposes. Deviations from these are certain owing to many factors including, but

not limited to, flight conditions, air traffic control, time remaining in flight, and storm location relative to the radar location and aircraft base.

5.1 Squall Line without Significant (<40km) Stratiform Region - Cold Regions (SL.C)

5.1.1 Objective:

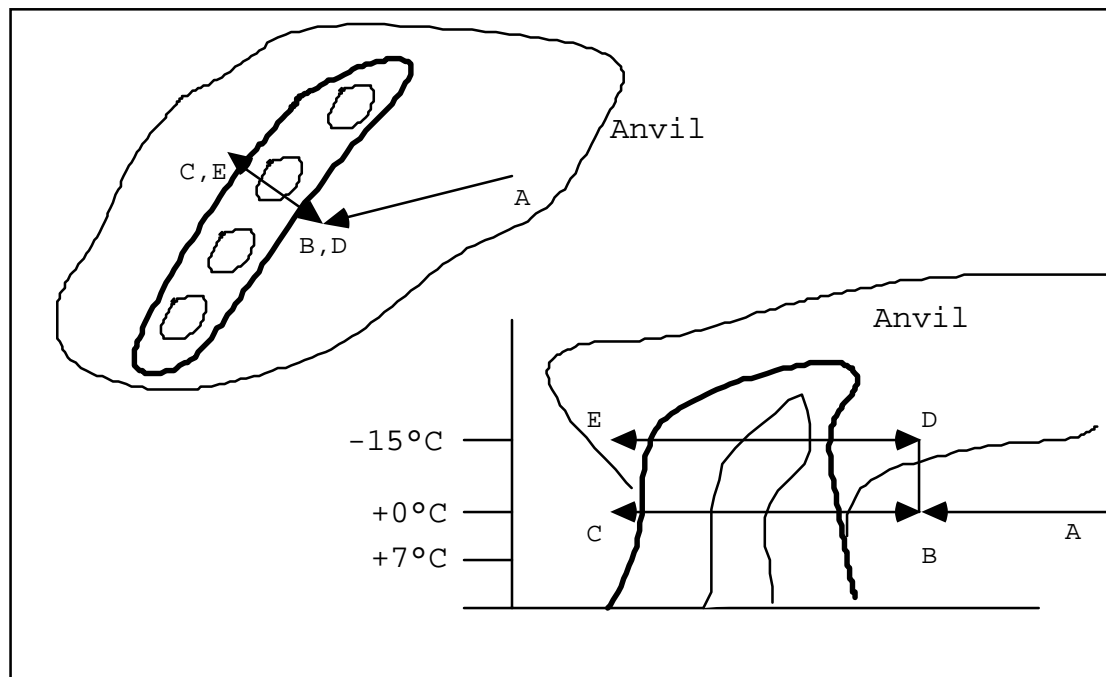
Document polarimetric signatures and associated microphysical characteristics of squall lines that do not have extensive stratiform regions. Flights at -15°C (20,000 ft) might be in regions of mixed ice phase particles. Flights at 0°C (14,000 ft) might be in regions of mixed ice and liquid phase particles.

5.1.2 Flight level:

Flights are at -15°C (20,000 ft) and 0°C (14,000 ft).

5.1.3 Flight legs:

Fly all legs, in decreasing order of preference, along radar radial (CSUCHILL or Cimarron), normal to the squall line orientation, or along the shear vector. Penetrate a convective element along line segment BC at the 0°C level. Upon exiting the convective cell, turn 180 degrees and reenter the storm at the 0°C level fly line segment CB (same as segment BC). Repeat this pattern (fly line segment BC/CB) for a second time. After exiting the front of the convective cell for the second time, turn 180 degrees and ascend to the -15°C level and reenter the storm. Fly line segments DE/ED as was done before for BC/CB. If time permits, repeat the flight along DE/ED at -15°C . Return to home base after completion of flight legs.



5.2 Squall Line without Significant (<40km) Stratiform Region - Warm Regions (SL.W)

5.2.1 Objective:

Document polarimetric signatures and associated microphysical characteristics in warm regions of squall lines that do not have extensive stratiform regions. Two flight patterns a) and b) are requested. Flights a) at 0°C (14,000 ft) and +7°C (10,000 ft) might be in regions of mixed ice and liquid phase particles. Flights b) at +7°C (10,000 ft) and +20°C (2,500 ft or lowest level allowed by the ATC) to sample the region of enhanced Z_{dr} observed below 1 km.

5.2.2a Flight level:

Flights are at 0°C (14,000 ft) and +7°C (10,000 ft).

5.2.3a Flight legs:

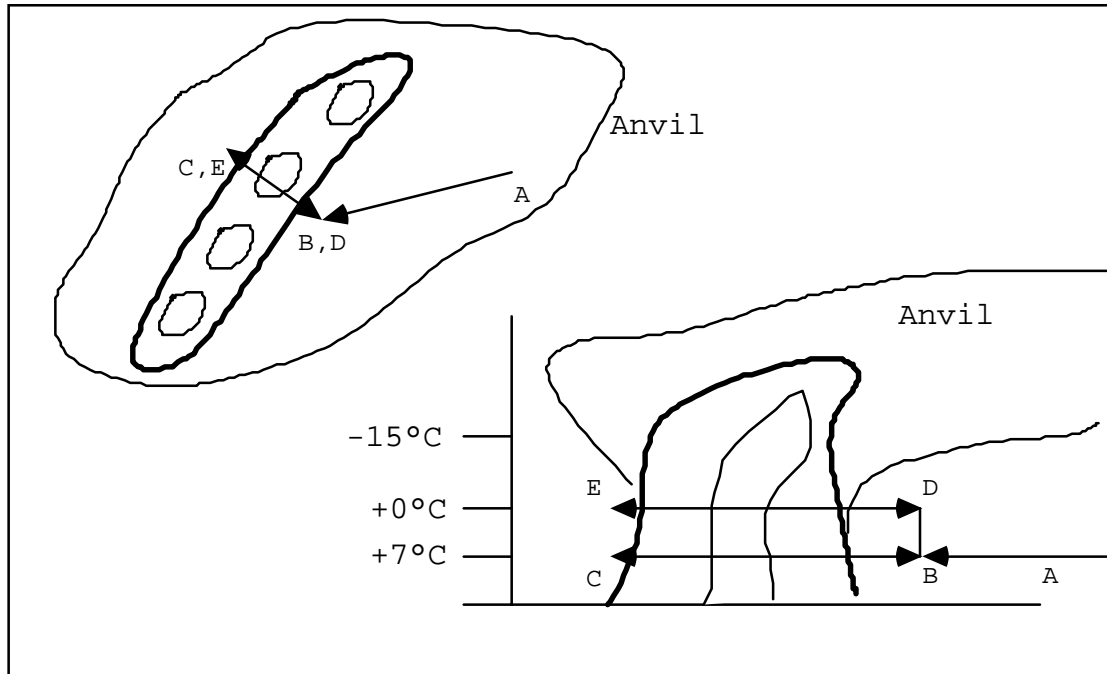
Fly all legs, in decreasing order of preference, along radar radial, normal to the squall line orientation, or along the shear vector. Penetrate a convective element along line segment BC at the +7°C level. Upon exiting the convective cell, turn 180 degrees and reenter the storm at the +7°C level fly line segment CB (same as segment BC). Repeat this pattern (fly line segment BC/CB) for a second time. After exiting the front of the convective cell for the second time, turn 180 degrees and ascend to the +0°C level and reenter the storm. Fly line segments DE/ED as was done before for BC/CB. If time permits, repeat the flight along DE/ED at 0°C. Return to home base after completion of flight legs.

5.2.2b Flight level:

Flights are at +7°C (10,000 ft) and +20°C (2,500 ft).

5.2.3b Flight legs:

These are the same as in 5.2.3a except the two heights are lower.



5.3 Squall Line with Stratiform Region - Cold Regions (SLSR.C)

5.3.1 Objective:

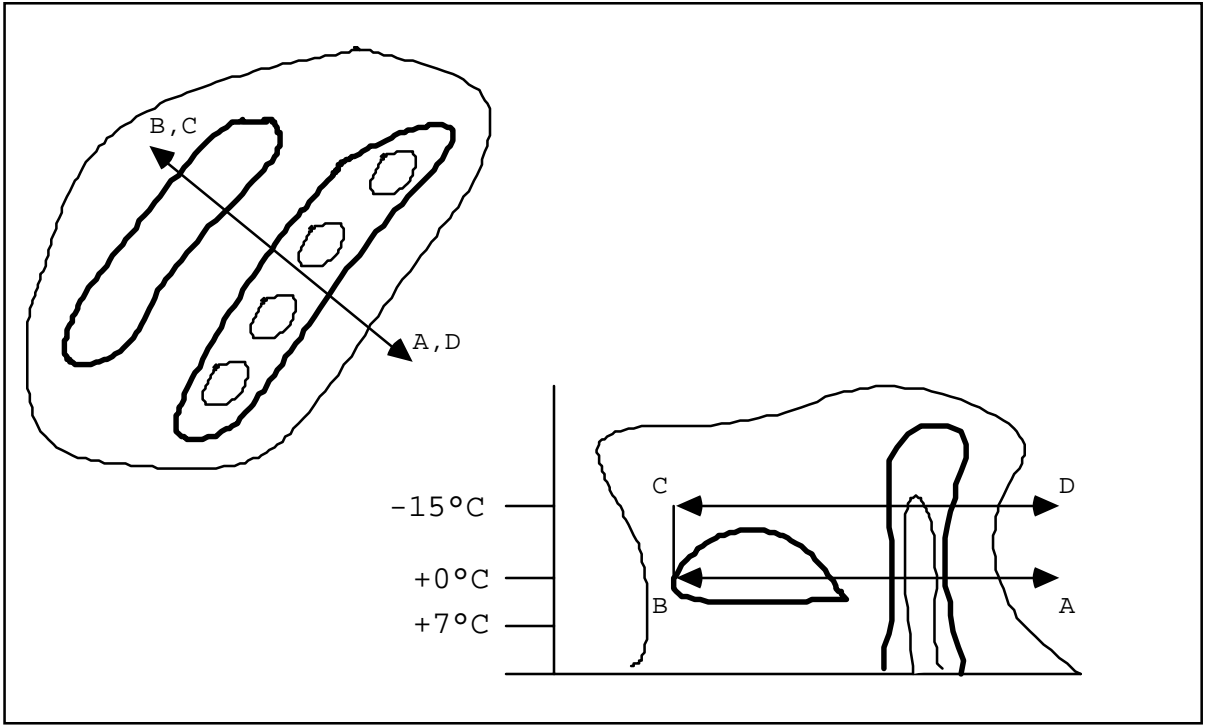
Document polarimetric signatures and associated microphysical characteristics in the lower trailing anvil regions and in convective cells. Flights at -15°C (20,000 ft) might be in regions of mixed ice phase particles. Flights at 0°C (14,000 ft) might be in regions of mixed ice and liquid phase particles.

5.3.2 Flight level:

Flights at -15°C (20,000 ft) and at 0°C (14,000 ft).

5.3.3 Flight legs:

Fly all legs, in decreasing order of preference, along radar radial, normal to the squall line orientation, or along the shear vector. Fly line into convective element along line segment AB at the 0°C level, and continue through to the core of stratiform region. Turn 180 degrees to left or right, ascend to the -15°C level, and fly line segment CD above line segment AB. If time permits, repeat penetrations through the convective regions along segment CD. Return to home base after completion of flight legs.



5.4 Squall Line with Stratiform Region - Warm Regions (SLSR.W)

5.4.1 Objective:

Document polarimetric signatures and associated microphysical characteristics in the lower trailing anvil regions and in convective cells. Two flight patterns a) and b) are requested. Flights a) at 0°C (14,000 ft) and +7°C (10,000 ft) might be in regions of mixed ice and liquid phase particles. Flights b) at +7°C (10,000 ft) and +20°C (2,500 ft or lowest level allowed by the ATC) will sample the region of enhanced Z_{dr} observed close to the ground.

5.4.2a Flight level:

Flights are at 0°C (14,000 ft) and +7°C (10,000 ft).

5.4.3a Flight legs:

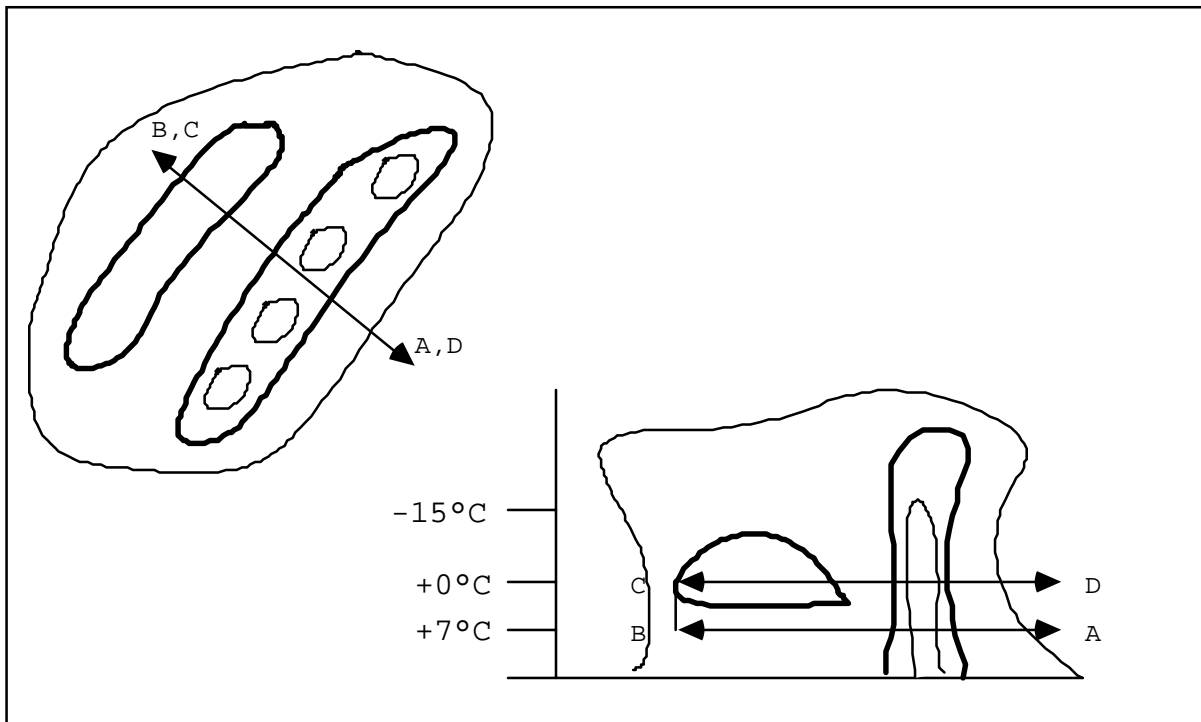
Fly all legs, in decreasing order of preference, along radar radial, normal to the squall line orientation, or along the shear vector. Fly line into convective element along line segment AB at the +7°C level, and continue through to the core of stratiform region. Turn 180 degrees to left or right, ascend to the +0°C level, and fly line segment CD above line segment AB. If time permits, repeat penetrations through the convective regions along segment CD. Return to home base after completion of flight legs.

5.4.2b Flight level:

Flights are at +7°C (10,000 ft) and +20°C (2,500 ft).

5.4.3b Flight legs:

These are the same as in 5.4.3a except the two heights are lower.



5.5 Isolated Convection - Cold Regions (IC.C)

5.5.1 Objective:

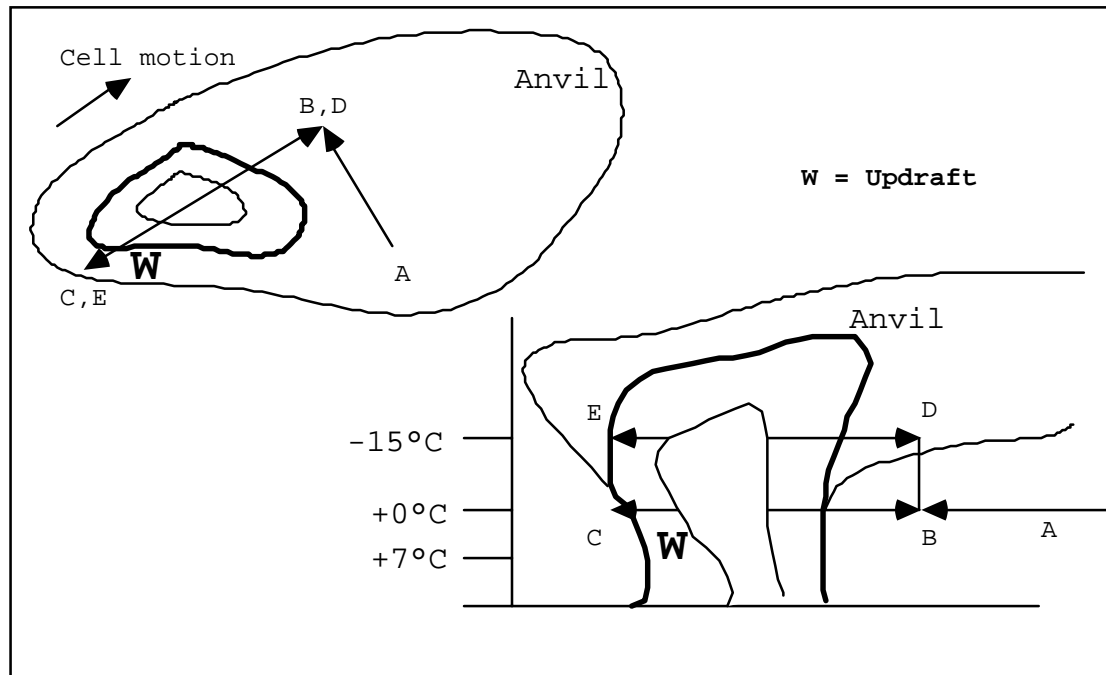
Document polarimetric signatures and associated microphysical characteristics in cold regions of isolated convection. Flights at -15°C (20,000 ft) might be in regions of mixed ice phase particles. Flights at 0°C (14,000 ft) might be in regions of mixed ice and liquid phase particles. All flights should be attempted in updraft or down shear regions of the updrafts.

5.5.2 Flight level:

Flights at -15°C (20,000 ft) and 0°C (14,000 ft).

5.5.3 Flight legs:

From in front of the storm path, enter the precipitation region at the 0°C level and fly along the line segment BC. After exiting the storm core (20 dBZ), turn 180 degrees and repeat this path. Upon completion of the second storm penetration, ascend to the -15°C level and fly down the storm movement vector through the updraft core along DE. Upon exiting the storm updraft, turn 180 degrees, and reenter the storm along line segment ED. Return to home base after completion of flight legs.



5.6 Isolated Convection - Warm Regions (IC.W)

5.6.1 Objective:

Document polarimetric signatures and associated microphysical characteristics in warm regions of isolated convection. Two flight patterns a) and b) are requested. Flights a) at 0°C (14,000 ft) and +7°C (10,000 ft) might be in regions of mixed ice and liquid phase particles. Flights b) at +7°C (10,000 ft) and +20°C (2,500 ft or lowest level allowed by the ATC) will sample the region of enhanced Z_{dr} observed below 1 km. Some flights should be attempted in updraft or down shear regions of the updrafts.

5.6.2a Flight level:

Flights at +7°C (14,000 ft) and 0°C (14,000 ft).

5.6.3a Flight legs:

From in front of the storm path, enter the precipitation region at the +7°C level and fly along the line segment BC. After exiting the storm core (20 dBZ), turn 180 degrees and repeat this path. Upon completion of the second storm penetration, ascend to the 0°C level and fly down the storm movement vector through the updraft core along DE. Upon exiting the storm updraft, turn 180 degrees, and reenter the storm along line segment ED. Return to home base after completion of flight legs.

5.6.2b Flight level:

Flights are at +7°C (10,000 ft) and +20°C (2,500 ft).

5.6.3b Flight legs:

These are the same as in 5.6.3a except the two heights are lower.

