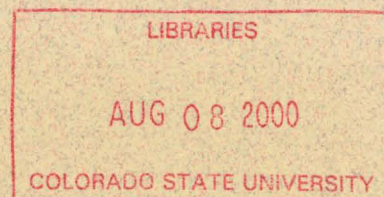


QC869.4
.U6C665
1997
ATMOS

Annual Report for



THE CSU-CHILL RADAR FACILITY

Cooperative Agreement No. ATM-9500108

Submitted to

The National Science Foundation

Division of Atmospheric Sciences

15 January 1997

Colorado
State
University

**DEPARTMENT OF ATMOSPHERIC SCIENCE
DEPARTMENT OF ELECTRICAL ENGINEERING
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO**

QC 869.4

.U6 C665

1997

ATMOS

TABLE OF CONTENTS

1. Introduction
2. Summary of Activities During 1996
 - a. Radar Operations Summary
 - b. Educational Support
 - c. Technical Developments
 - d. Atmospheric Science Activities
 - e. Electrical Engineering Activities

3. Planned Activities for 1997

- a. Project Support
- b. Facility Upgrades

4. Publications and Reports
5. Report on Cost Sharing Activities
6. Statement of Unobligated Funds
7. Changes in Project Personnel
8. Current and Pending Support

Appendix A: Status of Graduate Theses/Dissertation in 1996

Appendix B: Letters Associated with Radar Users

Appendix C: Summary of Greeley Data Collection Activities Through 01/15/97

Appendix D: 1996 CSU-CHILL Newsletter

1. Introduction

Activities at the CSU-CHILL National Radar Facility from 1 January 1996 to 31 December 1996 are summarized in this annual report. This report is the second report submitted under our second Cooperative Agreement with the National Science Foundation, which commenced on 1 May 1995. This past year marked an important milestone for the Facility as our dual channel system, consisting of two complete transmitters and receivers (which had been under development for the past year or so) provided extremely reliable operations during a nearly four month long field season during which we supported two NSF-funded projects. These projects were STERAO-A and REU96. The purpose of this new system was to achieve full polarization capabilities without using a polarization switch. Eliminating the polarization switch resulted in a highly reliable and stable system for dual-polarization data collection, and increased the dynamic range of the cross-polarization measurement (Ldr, Linear Depolarization Ratio) by more than 10 db.

The STERAO-A project involved the use of the CSU-CHILL, a 3-D lightning mapping system from France, a NOAA WP-3D research aircraft and the U. of North Dakota Citation jet research aircraft. STERAO-A was in part designed to study the production and transport of NO_x by lightning in deep convection. Many excellent cases were obtained in the field project. The second NSF-funded project, Research Experience for Undergraduates, involved ten undergraduate engineering students from a variety of universities in a two month long storm chase program. The students operated instrumented vans to collect hail and rain data in order to verify polarimetric radar signatures. The radar performed extremely well during both field programs, encountering virtually no down time. We supported three 20 hour projects in the past year, as detailed in the following sections. These projects allowed investigators to conduct highly focused research with the CSU-CHILL radar. The radar also continues to be an integral component of several courses in the Departments of Atmospheric Science and Electrical Engineering. As an example, many new case studies collected by the radar were analyzed by students in the advanced radar meteorology class in Atmospheric Science last spring.

Several radar improvements were also carried out in the past year. These improvements included pressurizing the wave guides to allow maximum transmit power levels, automated calibration techniques, and developing matched and thermally-stabilized front ends of both receiver chains (essential for minimizing errors in differential reflectivity measurements caused by even slightly mis-matched receivers). Another recent upgrade to the system was achieved by

quick changeover system to switch from commercial to backup power. In the past, the transmitters and computers had to be powered down, then brought up on diesel backup power. In doing this transfer, five to ten minutes of data were usually lost. The switchover now involves the use of a switch box and control circuitry that makes power transfer invisible to the user, with no loss of data. We will also address longer term plans in this report including development of more advanced signal processing capabilities, and continued exploratory work in pulse compression and short pulse transmission capabilities.

Recently an opportunity was presented to us to acquire the HOT 10 cm Doppler radar maintained by the Illinois State Water Survey. After careful consideration by us here at Colorado State University, in consultation with the National Science Foundation, we decided to request this radar. At the time of this writing we have received word that our request has been formally approved by the ISWS, and we expect the HOT to be transferred to CSU in the very near future. We are interested in the HOT for the primary reason of establishing a semi-permanent dual-Doppler radar observational network along the Front Range of Colorado. This network would be similar to the old NSSL Norman-Cimmaron dual-Doppler network in that S-band radars would be used to mitigate the effects of storm attenuation. However this network would have a tremendous advantage in that one radar in the pair would be a multiparameter radar (CSU-CHILL), therefore allowing simultaneous observations of storm microphysics (from multiparameter variables) in the context of dual-Doppler derived air-flow fields. Given our recent work on short pulse transmission capabilities coupled with a future signal processor upgrade, we will effectively realize a factor of two increase in scan rate at CHILL while collecting the full suite of multiparameter variables. This is important since it means that multiparameter data can be collected in a simultaneous mode with Doppler velocity data at scan rates adequate for sampling storm evolution in many situations (10-12 degrees per second).

This dual-Doppler network would provide a research capability not presently available to our community. With the mothballing of the NCAR C-band radars in the last several years, our community does not have access to a ground-based, research-quality, dual-Doppler network. Even though this dual-Doppler network would not be as portable as the old C-bands, a dual-Doppler network here along the Front Range would allow a wide variety of weather situations to be studied, including severe convection, winter storms and orographically-forced precipitation. We envision field programs gravitating toward this site, at reduced costs to funding agencies since a dual-Doppler network would already be in place.

Our plan is to bring the HOT to Colorado and operate it in a temporary mode at the CHILL site, fully checking out the radar, replacing any parts, etc. An inspection of the HOT a few months ago by B. Bowie of the CHILL staff found it to be in good condition. By summer of 1997, we intend to operate this radar in a dual-Doppler mode with the CHILL, locating the HOT radar just east of Nunn, CO (we are in the process of establishing a lease agreement with a local rancher there). The baseline would be about 42 km in length, therefore providing good resolution of convective scale features. The ability to place microphysical inferences inferred from the dual-polarized CHILL radar in the context of the high resolution three dimensional flow field would invariably lead to new insights into many problems including precipitation development and hail formation, storm electrification and storm moisture budget studies.

2. Summary of Activities During 1996

a. Radar Operations Summary: 1996

Two NSF-sponsored projects (STERAO-A and REU96), as well as three 20 hour programs were supported by the CSU-CHILL Facility during 1996. The majority of the convective season's radar operations were devoted to the STERAO-A (Stratosphere-Troposphere Experiments: Radiation, Aerosols, Ozone A: Deep Convection) project. This project was designed to study the effects of deep convection on the generation and transport of several atmospheric chemical species. Direct sampling of the air in and near convective systems was done at low and mid-levels by a NOAA P3 aircraft, and at high altitudes by the University of North Dakota Citation jet aircraft. Lightning activity in the STERAO operational area was mapped by a three dimensional VHF interferometer system installed and operated by the French ONERA research group. Supplementary lightning data were collected by a CSU Atmospheric Science Department storm chase van that was equipped to make local electric field and total lightning flash rate measurements. Realtime activities for the project were directed from the CSU-CHILL user van. The radar was scanned so as to obtain multiparameter data from the full volume of the storm of interest. These volume scans generally required a maximum of 6 minutes to complete. On a number of days storms tracked through the primary observational area, allowing simultaneous measurements to be made with the CSU-CHILL radar, the two research aircraft, and the lightning interferometer system. The STERAO-A investigators identified four days for early data analysis. CSU-CHILL data from these days have been converted to universal Doppler exchange format (UF); these tapes have been supplied to NCAR for distribution to the various investigators.

The second NSF funded project was the REU96 program directed by Prof. V. Chandrasekar of the CSU Electrical Engineering Department. Ten undergraduate students (from 5 different states) participated in this program, which was designed to give them direct experience in field research activities. The following series of day long workshops were conducted to introduce the students to the relevant engineering and meteorological principles:

Overview of Radar Hardware:	Dr. E. Mueller (CSU-CHILL)
Radar Applications in Meteorology	Mr. P. Kennedy (CSU-CHILL)
Radar Signal Processing	Dr. J. Keeler (NCAR)
Design and Development of Airborne Radar Systems	Mr. C. Walther (NCAR)
Multiparamater Radar Data Analysis	Ms. M. Gonzales (CSU EE)

Prof. Bringi, in addition, gave a series of 15 lectures on polarimetric Doppler Radar to the students. Over the course of the summer, the REU student's main field activities centered around the operation of three custom instrumented storm intercept vans. Prof. V. N. Bringi (CSU EE Department) provided the primary van which was equipped with a line scan video disdrometer built by the Joanneum Research Institute, in Graz, Austria. The disdrometer collected two orthogonal views of the precipitation particles falling through its 100 cm² sampling area. Particle size distributions were developed in real time by the disdrometer's data system. The objective was to direct the vans into the path of intense convective storm echoes that were being scanned by multiparameter radars (primarily CSU-CHILL, sometimes NCAR's S-pol system). The van measurements of precipitation particle size distributions and hail characteristics provided critical verification data for the multiparameter radar observations. Several of the students will be basing their senior year projects on data that they helped to collect during the REU96 project.

Beyond the two NSF sponsored projects outlined above, the CSU- CHILL was also supported three smaller 20 hour type programs.

During the February through April period, CSU-CHILL data were collected while winter season precipitation was in progress at the Ft. Collins - Loveland Airport (FNL). While the radar data were being collected, an observer was dispatched to the airport to make detailed observations of the surface precipitation characteristics (snow vs. rain, degree of particle riming and aggregation, etc.). The purpose of these efforts was to correlate multiparameter radar signatures with variations in the winter precipitation characteristics. These data are currently being analyzed by two students in the CSU EE Department. Furthermore, these studies served as

a pilot study for a larger field program under USWRP support being conducted from the CSU-CHILL radar this winter (Rutledge, Bringi and Chandrasekar are the PI's).

The second 20 hour class project was conducted on behalf of Dr. Rob Cifelli, of the University of Colorado CIRES. Dr. Cifelli sought precipitation observations made simultaneously by the CSU-CHILL radar and by the profiler systems operated by NOAA near Platteville, Colorado (30 km southwest of CSU-CHILL). The CSU-CHILL data were used to locate the melting region in two cases of stratiform, upslope-driven rain. This auxiliary particle type information (i.e. frozen vs. liquid) was used to refine various algorithms designed to retrieve particle size distributions and surface precipitation rates from profiler observations. The analyses of these data are continuing at CIRES.

The final small project of 1996 was done for Dr. Al Bedard of NOAA's Environmental Research Laboratory, in Boulder, Colorado. Dr. Bedard's work was a continuation of his explorations of generation of ultra low frequency (ULF) sound by tornadic storms. NOAA equipment to determine the direction of approach of ULF acoustical waves was installed at the CSU-CHILL site. The evolution of the acoustical signals was then correlated with rotational couplet patterns in the CSU-CHILL Doppler velocity fields. Several interesting cases were recorded. In one of these (31 July local date), a probable funnel cloud was observed visually from the radar site while acoustical measurements were in progress.

b. Educational Support

The CSU-CHILL Facility continued to provide educational support in a variety of ways during 1996. As noted in the operation summary section, another Research Experience for Undergraduates (REU) program was successfully conducted during the summer. At the graduate level, Prof. Steven Rutledge taught his Radar Meteorology course (ATS 741) during the spring semester. Twelve students were enrolled in this course. The class took a field trip to the radar and received an introduction to meteorological radar hardware and signal processing from the Mr. Dave Brunkow, the facility's chief engineer. The students also broke into pairs and analyzed 6 samples of recently-collected CSU-CHILL data sets. The topics for the analysis projects included: a flare echo, comparisons of particle types from multiparameter radar and T-28 aircraft observations, a hail "curtain" produced by a severe thunderstorm, comparison of a conceptual model of a hailstorm to CSU-CHILL observations, and tests of various radar estimates of rainfall against rain gage verification data. Prof. V. N. Bringi, (CSU EE) also taught his course in advanced electromagnetics (EE 742) in the spring semester. His class visited the radar and

were given demonstrations of various electrical engineering aspects of the radar system. Following these demonstrations, they observed in realtime one of the season's first hail-producing thunderstorms (9 May 1996). Prof. Chandrasekar arranged for two groups of undergraduate freshman students (≈ 80) to visit the radar site as part of the course EE 100 (Elec. Eng. Fundamentals) taught by Prof. Carmen Menoni. Data collected with the radar were used in the course EE 514 (Application of Random Process taught by Prof. Chandrasekar) as part of their course assignments and final exams focusing on spectral analysis of the dual-polarized radar signals.

At various times during the year, updates have been made to the CSU- CHILL Facility's world wide web homepage (<http://olympic.atmos.colostate.edu/CHILL/CSU-CHILL.html>). This web site provides numerous color examples of CSU-CHILL multiparameter data which may be useful in radar meteorology courses conducted at other institutions. Additional information pertaining to technical aspects of the radar system, archive data summaries, and applications for project utilization of the radar are also provided.

c. Technical Developments

The dual transmitter/receiver version of the CSU-CHILL system was first available during the Spring 1995 season. These major modifications left the receiver low noise amplifiers (LNA's) in different operating environments. The horizontal LNA was inside the transmitter cabinet and the vertical LNA was outside the cabinets near the ceiling of the trailer. It was suspected that these different thermal environments might be causing some of the variations in the ZDR system offset which were observed during the 1995 Spring/Summer operations. In the Fall of 1995, an electrically cooled plate was installed on top of the Horizontal transmitter channel. A waveguide assembly was fabricated which allowed both LNA's to be mounted on the cold plate along with the first mixers and first IF amplifiers. This arrangement keeps all of the critical receiver components in the radar van at the same temperature (65 degrees F). During the 1996 operational period the ZDR system offset was indeed much more stable. When shifts in ZDR calibration were observed, it was found that they were due to shifts in the transmitter timing in one or more channels which caused the transmitted spectrum to be degraded enough to shift a fraction of a dB of the transmitted power out of the bandpass of the receiver. Correcting the transmitter timing restored the ZDR offset to its standard value. This led to a fairly close monitoring of the transmitted power spectrum during the 1996 operational season. In the Fall of 1996, the trigger amplifier chassis in the Horizontal channel was replaced. This corrected much of the timing instability in the system.

During the 1995 operational season, there was an arcing condition at the new dual channel azimuth rotating joint which was solved by reducing the peak transmitter power to 300 kW. In the Fall of 1995, an air compressor/dryer was installed to pressurize the waveguide system to 9 pounds per square inch. This permitted the transmitters to be operated at 800 kW during the 1996 operational season. The transmitters could operate at 1000 kW or more, but 800 kW was selected as a level that could be achieved without overly stressing the transmitters.

A new signal processor mode was added in 1996 for project STERAO. This mode doubled the number of range gates of processed data available at the expense of the complex covariance recording. The 1995 dual receiver mode calculated reflectivity, velocity, zdr, phidp, rhovh(0), and Ldr, along with the complex covariance fields. The SP20 did not have enough computational capability to calculate all these fields for every range gate, but could calculate them for half of the the available gates. The typical operational mode would give about 150 km unambiguous range. In the VH mode, the processed data consisted of a 75 km range block which could be slid out from the radar as needed to cover echos of interest. For 1996, the new processing mode (VHL mode) re-assigned the processing tasks among the SP20 cards in such a way that all of the fields except the complex covariances could be calculated for every range gate. For many meteorological projects which need longer range operations, this trade-off is a worthwhile one.

A new automated calibration system was added and used each day during the 1996 operations. This system allowed the operator to calibrate both receivers with a single command on the antenna control terminal. The signal generator delivers a series of power levels to both receivers, while the display controller logs the processor outputs and plots the results on the Adage display. The raw results are also recorded on tape. In a similar fashion, sun scans and blue-sky noise tests can be requested and recorded by the operator.

New automatic switching gear for the diesel generator was installed in the Fall of 1996. This surplus equipment was made available though NCAR. It will start the generator and connect the radar and radome system to the generator without operator intervention. This adds an additional backup to help keep the radome inflated in the event of a power failure. This Onan system was upgraded to permit an operator instigated seamless switch-over to generator prior to power failure. Previously, this sort of switch-over would require a brief interruption in data collection. This modification was done as a senior project of one of the Electrical Engineering students.

d. Atmospheric Science Activities

Several theses and dissertations focusing on analysis of CSU-CHILL radar data have been completed in 1996 or are in-progress in the Department of Atmospheric Science. Prof. Rutledge serves as the student's advisor for these studies.

Mr. Jon Erdman completed his M.S. thesis and degree requirements in October 1996. His research, supported by a National Weather Service COMET Fellowship, focused on the use of lightning observations to provide improved nowcasts of severe storm behavior. In this work, CSU-CHILL data provided information on storm severity, including hail size/duration and outflow winds which were correlated to the observed frequency, location and polarity of cloud-to-ground lightning flashes. As a result of this work, the Denver NWS office plans to involve the use of lightning reports their nowcasting activities. In a similar view, Capt. R. Lucci of the USAF examined correlations between CG lightning characteristics and tornadic activity in severe storms (identified by the CSU-CHILL radar). Capt. Lucci completed his M.S. degree in June 1996 and has since returned to active duty with the USAF providing weather support for space shuttle operations.

Mr. L. Carey, a Ph.D. candidate continues to explore mechanisms to explain the sudden onset of positive CG flashes associated with severe storms that produce bursts of large hail. CSU-CHILL data are being used to provide detailed information on the hail phase of the severe storms. Additionally, phi dp data are being used to identify regions of high electric fields in the storm anvils, which align ice crystals in the vertical, producing negative kdp values in these regions. Two manuscripts have recently been written utilizing these datasets.

Mr. T. Lang and J. Ryan are using CSU-CHILL data collected during this past summer's STERAO-A project as part of their M.S. thesis research to examine relationship between lightning and production of NOx. Lt. C. Butler from the USAF is a first year student in the M.S. program. Lt. Butler is heavily involved in our present USWRP-funded project to explore the use of multiparameter radar to improve radar-based estimates of particle type, visibility, snowfall rate and liquid-equivalent precipitation.

e. Electrical Engineering Activities

Data collected during the summer 1995 and 1996 programs are being analyzed by a number of graduate students in EE, as well as by Post Doctoral Fellow Dr. John Beaver and Research Associate Dr. John Hubbert. A brief summary of the status of these studies is given below.

Dr. John Beaver and Prof. Bringi submitted an article to the Proc. IEEE Special Issue focusing on propagation results at 20 and 27 Ghz. The article is titled, "The application of S-band polarimetric radar measurements to Ka-band attenuation prediction". After the first review, the paper was revised and acceptance is imminent.

Dr. John Hubbert and Prof. Bring (together with graduate students Scott Bolen (EE) and Larry Carey (ATS)) submitted an article to *J. Appl. Meteor* titled, "CSU-CHILL polarimetric radar measurements from a severe hailstorm in Eastern Colorado". The manuscript is under review.

Scott Bolen, a Ph.D. student at the Air Force's Rome Laboratory, is in the final stages of completing his dissertation. He is focusing on polarimetric rainrate algorithms and comparison with the REU van data. So far he has completed four case studies and the results are excellent. He is also in the process of filing a patent disclosure through the Air Force on his technique of determining an optimal area (for comparing with gage) using Kdp data. A comprehensive paper is under preparation for submission to *J. Tech.*

As part of the USWRP-funded research, radar and van data collected in the summer of 1996 will play a key role in the development of rainrate algorithms. Scott Bolen's research would be directly applicable to the goals of the USWRP grant to CSU. Cumulative hourly rainfall maps using Kdp and conventional Z-R (thresholded at various Z-levels from 51-55dBZ) are being constructed for a number of severe storm episodes. Data from NCAR's S-pole radar are also being evaluated and used as part of the USWRP effort.

Mr. Ahmed Abou-El Magd is in the final stages of finishing his Ph.D. dissertation on, "Remote Sensing of Mixed Phase Microphysics Using Multiparameter Radar". He is focusing on CSU-CHILL data collected in summer 1995 and T-28 aircraft data collected with the High Volume Particle Spectrometer (HVPS).

An article titled, "Pulse Compression for Weather Radar" by A. Mudukotore, V. Chandrasekar and R. J. Keeler has been accepted for publication in *Trans. IEEE Geoscience and*

Remote Sensing. Dr. Mudukotore has joined the Research Triangle Institute in N. Carolina to work on a NASA-funded radar project.

Prof. Chandrasekar is working with NCAR and NSSL to evaluate techniques for suppression of second-trip echos as part of a NEXRAD-related research effort. The CSU-CHILL radar was modified for random phase coding of the transmitter pulses, and one data set was acquired during the summer of 1996. These data, together with simulations, have been analyzed by Li Zhao as part of his M.S. thesis (completed). The initial results are promising.

Another M.S. student, Mr. Guo-Hwang, is analyzing the polarimetric covariance matrix data collected by the CSU-CHILL radar. A careful study of system phase offsets and calibration issues are being addressed.

Mr. Ibrahim is a Ph.D. student who has started work on his dissertation which will focus on application of polarimetric data to winter storms.

Ms. Hong Ping is a Ph.D. student who has taken over Dr. Xiao's research on application of neural networks to rainfall estimation and hydrometer classification. Dr. Xiao (former Ph.D. graduate) has joined VEXEL Corporation in Boulder as a research engineer.

3. Planned Activities in 1997

a. Project Support

Currently, the CSU-CHILL Facility is scheduled to support two projects in 1997, both of which are NSF funded. Between 15 January and 31 March, a winter precipitation study under the USWRP (United States Weather Research Project) will be conducted. This project is under the direction of Profs. S. Rutledge and V. Bringi from CSU, in collaboration with Dr. R. Rasmussen and Mr. J. Wilson of NCAR. Both the CSU-CHILL and NCAR S-pol radars will make coordinated scans to collect multiparameter data under a variety of winter precipitation types. A line scan video disdrometer, precision precipitation gages, and direct manual observations will be used to collect ground truth precipitation measurements that will be correlated with the radar data. The goal of this project is to explore the degree to which the remote characterization of winter precipitation (i.e. precipitation type and / or liquid equivalent precipitation rate) can be improved through the use of dual polarization radar data.

The second upcoming project will be the REU97 program. As in the past, this June - August project will be directed by Prof. V. Chandrasekar of the CSU Electrical Engineering Department. In a similar fashion to his REU96 program, the undergraduate students in this project will operate instrumented vans designed to collect in situ observations of intense convective precipitation cores while they are being scanned by the CSU-CHILL radar. The students (most of whom will be between their junior and senior years) will thereby gain direct experience in radar meteorology field research efforts. The data collected during the summer, as well as the related instrumentation development efforts, will give the REU students a variety of topics for their senior year projects.

We also anticipate supporting several 20-hour projects during the summer of 1997 that will involve dual-Doppler and multiparameter radar data collection with the CSU-CHILL/HOT radar pair.

b. Facility Upgrades

It is anticipated that a new digital signal processing system for the CSU-CHILL facility will be ordered during 1997. The current Lassen SP20 signal processor has been in service since 1987. In recent years, the SP20's computational capabilities have been expanded to accommodate the radar system's evolution into its current dual transmitter / dual receiver configuration.

One of the next significant improvements to be made to the CSU-CHILL system will be an increase in the antenna scan rate with which dual polarization data may be collected. This increased scan rate will be achieved by shortening the transmitter pulse duration to one half to one third of its current value (1 microsecond). The resultant shortened range gates (75 m to 50 m long) can then be averaged back up to the "conventional" 150 m length. This use of spatial averaging in partial replacement of time averaging will permit the antenna scan rate during multiparameter data collection to be increased from 6 degrees per second to approximately 10 - 12 degrees per second.

However, the use of these shorter gate lengths correspondingly increases the computational load on the signal processor. Fundamental limits in the current SP20 processor prevent it from being able to effectively handle the planned short pulse / quick scan data collection scheme. Two candidate SP20 replacements have been identified: (1) The VME bus-based VIRAQ system developed by NCAR's RSF division, and (2) A next generation signal

processor currently under development at Lassen Research. The relative merits of these two signal processors are currently under evaluation. A vendor selection should be made during the first half of 1997, with delivery of the new system to take place during 1998.

A new operational mode will be added for the 1997 operational season. In this mode the Horizontal and Vertical transmitters will fire simultaneously (VHS mode). Co-polar signals will be received simultaneously on the Vertical and Horizontal transmitters. This mode has a number of advantages for polarization work. The correlation of V and H at lag 0 ($\rho_{HV}(0)$) can be measured directly, rather than extrapolated back to lag 0 from a covariance measurement taken at lag 1. The differential phase shift (phidp) can also be measured at lag 0. This field had previously been measured at lag 1, which meant that it was impacted by Doppler phase shift. Velocity measurements were also impacted by differential phase shift. Calculating phidp at 0 lag means there is no Doppler shift to contend with. Velocity calculations are also simplified since there is a high PRF (pulse repetition frequency) time series for H and V polarizations which can be used to calculate velocity and spectral width just as it is in a conventional Doppler radar. The only anticipated penalty is that the LDR field and other cross-polar measurements cannot be made when this data collection mode is selected.

4. Publications and Reports

Reviewed Publications

Beaver, J. and V. N. Bringi: The Application of S band Polarimetric Radar Measurements to Ka-band Attenuation Prediction, accepted for publication in *Proc. IEEE Special Issue on Ka-band Propagation Effects on Earth Satellite Links*.

Bedard, A.: Low-frequency atmospheric acoustic energy associated with severe weather, to be submitted to *Mon. Wea. Rev.*

Bolen, S., V. N. Bringi and V. Chandrasekar: An Optimal Area Approach to Intercomparing Polarimetric Radar Rain Rate Algorithms with Gauge Data, submitted to *J Atmos Ocean Tech.*

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. *J. Meteor. Atmos. Phys.*, **59**, 33-64.

Carey, L. D. and S. A. Rutledge: Electrical and Multiparameter Radar Observations of a Severe Hailstorm, submitted to *Journal of Geophysical Research*.

Hubbert, J., V.N. Bringi, L. Carey and S. Bolen: CSU CHILL Polarimetric Measurements from a severe hailstorm in Eastern Colorado, submitted to *J. Appl. Meteor.*

Mudukotore, A., V. Chandrasekar and R. J. Keeler: Pulse Compression for Weather Radars, accepted for publication in *Trans IEEE Geoscience and Remote Sensing*.

Other Publications

Carey, L. D. and S. A. Rutledge, 1996: Electrical and Multiparameter Radar Observations of a Severe Hailstorm, 10th International Conference on Atmospheric Electricity, Osaka, Japan.

Carey, L. D., S. A. Rutledge, and T. Lang, 1996: Positive Cloud-to-Ground Lightning in a Tornadic Thunderstorm: A Multiparameter Radar Study, AGU Fall Meeting, San Francisco, CA.

Cifelli, R., D. Rajopadhyaya, S. Avery, C. Williams, W. Ecklund, P. Johnston, K. Gage, S.A. Rutledge, L. Carey, and J. Wilson, 1997: The retrieval of hydrometeor size distributions using wind profiler and polarimetric radar measurements: Initial results from NE Colorado. Preprint volume, 13th Conference on Hydrology, 76th Annual Meeting, Amer. Meteor. Soc., February 2-7, Long Beach CA.

Dye, J. E., S. A. Rutledge, A. Tuck, P. Laroche, 1996: An Overview of the STERAO-Deep Convection Experiment, AGU Fall Meeting, San Francisco, CA.

Mudukotore, A. and V. Chandrasekar: Weather Radar Pulse Compression with Complementary codes, Proceedings, IGARSS 96, 574-576.

Xiao, R. and V. Chandrasekar: Multiparameter Radar Snowfall estimation using Neural Network Techniques, Proceedings, IGARSS 96, 566-568.

5. Report on Cost Sharing Activities

The following describes cost sharing expenditures at CSU through the second year of the Cooperative Agreement.

	Cumulative through 4/30/96	YEAR 2 5/1/96- 2/1/97	Cumulative through 2/1/97
Materials, parts, supplies, paint	2,271	1,198	3,469
Salaries and services	46,465	45,850	92,315
Telephone and postage	2,885	1	2,886
Vehicles and fuel	710	0	710
Equipment	14,591	950	15,541
Indirect cost @ 45% ^(a)	23,549	21,172	44,721
TOTAL	\$90,471	\$69,171	\$159,642
Estimate 2/1/97 - 4/30/97		16,558 ^(b)	16,558
TOTAL	\$90,471	\$85,729	\$176,200

a) Indirect cost base excludes equipment.

b) To be expended for acquisition, transportation, set-up and check out of the HOT radar.

6. Statement of Unobligated Funds

There will be no unobligated funds at the end of this present budget period.

7. Changes in Project Personnel

There are no changes in Senior Personnel associated with the Cooperative Agreement.

8. Current and Pending Support

A. Current Support for Steven A. Rutledge as of 01/15/97

Agency	Project Title	K\$/YR	Role	Period Covered	Commitment (months)
National Oceanic and Atmospheric Administration (USTPO)	Studies of Precipitating Cloud Systems in TOGA/COARE Using Shipboard Doppler Radar Data	145	PI	1/1/94 to 06/31/97	1 academic
National Science Foundation	The CSU-CHILL Radar Facility	500	CO-PI	5/1/95 to 4/30/00	1 summer 1 academic
National Science Foundation	Dynamical and Electrical Studies of Convective Cloud Systems	150	PI	2/1/94 to 6/01/97	1 summer
National Aeronautics and Space Administration	Ground Truth Research & Algorithm Development in Support of TRMM	115	CO-PI	9/1/94 to 8/31/97	1 summer
National Science Foundation	Improving Nexrad-based estimates of precipitating rates and hydrometeor classification	105	Co-PI	10/01/96 to 9/30/97	0.5 summer
National Aeronautics and Space Administration	Electrified Tropical Convection: Implications for use of the TRMM Lightning Imaging	22	PI	9/1/94 to 8/31/97	
National Oceanic and Atmospheric Administration	Further Analysis of the Shipboard Radar Data in COARE: Rainfall, Convective Organization and Surface Fluxes	183	PI	01/01/97 to 12/31/98	1 summer 1 academic
Colorado State University	Resident Instruction Support				7 academic

B. Pending Support

Agency	Project Title	K\$/YR	Role	Period Covered	Commitment (months)
NOAA	Analysis and Modeling of the Transport of Lightning-Generated NO _x and Other Chemical Species in Convective Cloud Systems	55	PI	05/01/97 to 04/30/98	1 summer
NASA	Validation Studies and Algorithm Refinement in Support of TRMM	143	CO-PI	09/01/97 to 08/31/98	1 summer

Appendix A

Graduate Theses/Dissertation in 1996

Completed / in-progress graduate students:

1) Department of Atmospheric Science:

Completed:

- | | |
|------------------|---|
| J. Erdman (M.S.) | Characteristics of Cloud-to-Ground Lightning Associated with Severe Thunderstorms in Northeast Colorado |
| R. Lucci (M.S.) | Doppler Radar Investigation of Tornadic and Lightning Producing Storms in Northeast Colorado |

In-Progress:

- | | |
|------------------|---|
| L. Carey (Ph.D.) | Lightning and multiparameter radar characteristics of severe hail storms |
| T. Lang (M.S.) | Relationship between lightning flash rates and polarities to microphysical processes in severe storms |
| J. Ryan (M.S.) | Lightning and NO _x production in deep convection |
| C. Butler (M.S.) | Multiparameter radar and microphysical observations in winter storms |

2) Department of Electrical Engineering:

Completed:

- | | |
|-----------------|--|
| R. Xiao (Ph.D.) | Artificial Intelligence Applications for Meteorological Radar Data |
|-----------------|--|

In-Progress

- | | |
|-------------------------|---|
| S. Bolen (Ph.D.) | Validation of polarimetric radar signatures |
| G. Hwang (M.S.) | Evaluation of covariance matrix measurements from CSU Chill |
| A. Abou-el-magd (Ph.D.) | MP radar analysis of Mixed phase precipit |
| L. Zhao (M.S.) | Weather radar signal study and random phase processing to recover second trip echo. |

Appendix B

Letters Associated with Radar Users

5 November 1996
Dr. Rob Cifelli
University of Colorado
CIRES
Campus Box 216
Boulder, CO 80309-0216

Dear Rob:

This letter serves to close out our files on the efforts to collect CSU-CHILL multiparameter radar data over NOAA's Platteville profiler site. According to our records, radar data were collected on 26 May and 16 June 1996 during stratiform rain / bright band situations over Platteville. Universal Doppler Exchange Format (UF) versions of the radar data tapes recorded during these operations have been provided to you. Please contact me if any technical questions regarding the CSU-CHILL data arise during your analyses.

Feedback from radar facility users is always useful. A brief summary of your impressions of the radar support for this project (i.e. conduct of operations, performance of the radar equipment and staff, data quality, etc.) will be quite useful. If you prefer, such a summary may be sent directly to Dr. Ken Van Sickle at NSF.

Sincerely,

Pat Kennedy
CSU-CHILL Facility Manager
(970) 491-6248

5 November 1996
Dr. Jim Dye
National Center for Atmospheric Research
P.O. Box 3000
Boulder, CO, 80307

Dear Jim:

This letter serves to close out our files on the NSF-funded STERAO-A project that was conducted using the CSU-CHILL Facility in the summer of 1996. Universal Doppler Exchange Format (UF) versions of the radar data tapes recorded during the following STERAO-A operations have been provided to you:

<u>Date</u>	<u>Remarks</u>
7/9/96	Ft. Collins storm: Widespread lightning across NW quadrant of the CSU-CHILL coverage area.
7/10/96	Kimball storm: Isolated severe storm approaching the radar from SW Nebraska.
7/12/96	Nunn storm: Intense hailstorm passing just NE of CSU-CHILL.
7/13/96	Greeley storm: Numerous strong storms moving from the radar's NW quadrant to the SE quadrant during the course of the afternoon.

UF tapes for additional days of interest will be prepared at your request. Please contact me if any technical questions regarding the CSU-CHILL data arise during your analyses.

Finally, feedback from radar facility users is always useful. A brief summary of your impressions of the radar support for this project (i.e. conduct of operations, performance of the radar equipment and staff, data quality, etc.) will be quite useful. If you prefer, such a summary may be sent directly to Dr. Ken Van Sickle at NSF.

Sincerely,

Pat Kennedy
CSU-CHILL Facility Manager
(970) 491-6248

CC: Adrian Tuck NOAA

December 19, 1996

Mr. Pat Kennedy
Colorado State Univ. - CHILL Radar Facility
30750 Wld Co. Rd. 45
Greeley, CO 80631-9603

Dear Pat:

I'm writing to give you some feedback concerning the operation of the CSU-CHILL radar during the STERAO-A project this past summer. One word can sum it up pretty well - OUTSTANDING! You and the staff bent over backwards to support the STERAO project not only with the radar operation, but also with the setup, teardown and maintenance of the ONERA interferometer. In this regard Bob Bowie deserves special thanks and Tim and Jesse for their maintenance of the interferometer after the French left. Throughout the project you, Dave, Bob and Ken were immensely helpful and tried to implement our many needs while maintaining a needed sense of balance and reality at the same time. The fact that there was only one day during the entire summer that the radar was not functioning speaks very highly of the excellent work which CHILL staff are doing in maintaining and operating the radar.

I believe this may have been the largest aircraft experiment which you have supported and in so doing both you and we learned a little about some improvements which could be made. I make the following comments with the intention of trying to be helpful in offering constructive suggestions for improvements, not criticisms.

For aircraft operations it is necessary to have an aircraft frequency radio available. While the NOAA Aeronomy Lab through Adrian Tuck and Tommy Thompson did purchase and install one for the project, I believe it would be desirable to have one readily available at CHILL and would be a reasonable piece of equipment to request for funding. I suspect you may have already made some plans in this direction.

The CHILL staff and Steve Rutledge and Bringi worked hard so that the CSU chase activities did not interfere with the STERAO operations and for the most part were not a problem. There were a few occasions when the congestion in the operations center was not quite optimum. If we had had the WB57F flying as

Phone: 303 497-8944 • FAX: 303 497-8181 • Telex: 989764 • EMAIL: dye@ncar.ucar.edu


*The National Center for Atmospheric Research is operated by the University Corporation
for Atmospheric Research under sponsorship of the National Science Foundation.*

intended, it would have been more confusing. I really commend the work that CSU is doing in having so many users and students utilize the facility and the storm interception work and would like to see it continue. One way to alleviate the congestion might be to have a larger area and separation of the ground and aircraft radios. If another radar is obtained for dual Doppler capability, which I hear is a possibility, it will be even more important. Of course, the priority of doing this really depends upon the number and size of aircraft and other programs which will be supported in the future and funding.

CHILL might consider trying to implement something like the NCAR ZEBRA program which would be especially nice for aircraft experiments in which both high level and low level aircraft are flying. I personally expect to see more of this in the future. The important feature is being able to easily play back radar structure and track at a couple of levels for aid in guiding the aircraft and science mission with visualization of changing storm structure. I found myself having a good idea of storm structure at mid and low levels but not so good at the anvil altitudes where the Citation was flying. CAPPIs would also help in this regard. The play back feature you have is nice, but is limited to only one level. ZEBRA allows one to customize the display for an individual user, eg. there could be low altitude CAPPIs on one display and upper level on another and also can display other sources of measurements such as soundings and surface data on the same monitor. There may be other possibilities as well.

In summary, thanks for a job extremely well done. I look forward to future involvement with you and other staff at CHILL. I'd be happy to talk to you about any of the items I mentioned above.

Sincerely,



James E. Dye
STERAO-A co-chair

cc: S. Rutledge
A. Tuck

Pat Kennedy
CSU-CHILL Facility Manager
Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523-1371

January 3, 1997

Dear Pat:

Sorry for this belated letter regarding CHILL operations during the past summer. I wanted to let you know that we really appreciated having CHILL collect data over Platteville during our field campaign. We are currently working on data collected from one of the two cases sampled with CHILL: 16 June 1996. Specifically, we are using the multiparameter data for two purposes: 1) to compare estimates of rainrate using empirical Z-R, Z_DR-R, and K_DP-R with wind profiler estimates of rainrate using a retrieval of the drop size distribution from the profiler spectra; and 2) to improve to profiler retrieval of ice and mixed phase precipitation species. Some preliminary results of this work will be presented at the upcoming Conference on Hydrology at the upcoming AMS meeting (February 1997).

In hindsight, it would have been nice to have additional data from other types of precipitation events(i.e., convective clouds); however, I think we have enough to keep us busy for quite some time and expect to produce some interesting comparisons with the NCAR S-pol radar. If interesting cases come up in the S-pol data set, perhaps I will call on you to find out if CHILL was scanning in the vicinity of Platteville at the same time (even if it's only a volume or two of data). Thanks again for helping out in our field experiment and getting us the CHILL data in a timely fashion. I hope that we will have the opportunity to do some more scanning radar - wind profiler intercomparisons using CHILL in the near future.

Sincerely,

A handwritten signature in black ink, appearing to read 'Rob Cifelli', with a long horizontal line extending to the right.

Rob Cifelli
Cooperative Institute for Research in Environmental Sciences (CIRES)
University of Colorado
CB 216, Boulder, CO 80309-0216

Department of Electrical Engineering
Fort Collins, Colorado 80523-1373
(970) 491-6600
FAX: (970) 491-2249

October 14, 1996

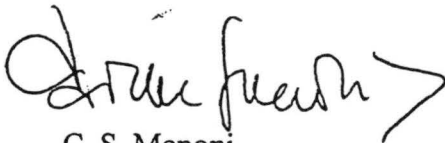
Mr. Pat Kennedy
Facility Manager
CSU-CHILL Radar Facility
30750 Weld County Road 45
Greeley, CO 80631

Dear Pat:

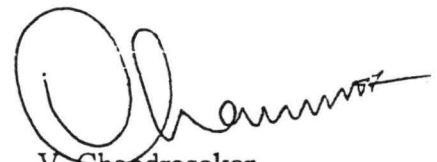
The EE100 class and us would like to thank-you all for the effort you devoted to show the students the CSU CHILL Radar facility. The way you organized yourselves this year was excellent, as it allowed us to have smaller groups and more individualized attention. Thanks to David Brunkow for describing the processor, to Bob Bowie for sharing with us the details of the transmitter, to Ken Pattison for the tour of the Radome and description of the radar capabilities, and to you Pat for showing us how you process and interpret the signals.

Experiences such as the one you offer students, greatly contribute to enhance their education.

Sincerely,



C. S. Menoni
Asst. Professor



V. Chandrasekar
Assoc. Professor

cc Dr. V. N. Bringi
Dr. S. Rutledge

Appendix C

Summary of Greeley Data Collection Activities Through 01/15/97

<u>Project</u>	<u>Period</u>	<u>Outcome</u>
<u>1991</u>		
WISP91 (NSF)	January-March	Nick Powell - CSU Atmospheric Science M.S. thesis completed.
Kostinski (20 hr)	April	Subsequently funded NSF proposal.
Srivastava (20 hr)	April-June	Profiler-radar intercomparison.
University of Nevada-Reno/ DRI (NSF)	May	Summary to appear in BAMS.
Julien (20 hr)	May-July	Fred Ogden CSU Ph.D. Civil Engineering dissertation completed.
McKee (20 hr)	June-August	Dave Speltz CSU Atmospheric Science M.S. thesis completed.
Hartley (20 hr)	May-August	Summary in Ag. Res. Svc. article.
(Rutledge; Classroom cases)	January-August	Data base for CSU Atmospheric Science radar class, summary to appear in BAMS. Antenna patterns, sphere calibrations, etc., for Ashok CSU Electrical Engineering (M.S. thesis completed).
<u>1992</u>		
Turk (20 hr)	March	Support of NASA ER2 over flights.
Srivastava (20 hr)	April-May	Continuation of 91 program.
Dixon (20 hr)	May - June	Ph.D. dissertation in progress.
Chandra REU (NSF)	June-August	Several senior year electrical engineering projects in progress.
T-28 tests (NSF)	June	Support data during T-28 test flights.
Cotton 92 (20 hr)	July-August modeling study.	Observational data for NSF funded
Connell (20 hr)	July-August	Exploratory data.
Rauber	October Sabreliner.	Cloud water sampler test on
<u>1993</u>		
Kennedy	Feb - April	Aircraft ground icing study.

Chandra (WISPIT)	Feb - March	In-situ aircraft / multi-param radar comparison.
Roberts (WISPIT)	Feb - March	Combined dual-Doppler and multi-param radar analyses.
Carey	May - June	Multiparameter radar and storm electrification study.
Holtzer	May - June migration.	Radar observations of insect
Aydin	June	Multi-parameter radar hail detection.
Bringi	July	" "
McAnelly	July - August	Upscale evolution of mesoscale convective systems.
<u>1994</u>		
WISP94	Jan - March	Winter storms and icing project (NSF supported NCAR project).
ACTS	Beaver et al propagation (Ph.D.)	Meteorological effects on microwave
ANVIL	Hallett	Evolution of anvil airflow fields
APHID94	Holtzer et al	Migration patterns of Russian Wheat Aphids
DEN94	Clement and McKee	Multiparameter obs of storms over Denver urban flood district (MS)
RAIN94	Bringi	Comparison of WSR-88D and multiparameter based rainfall estimates
REU94	Chandrasekar	Research experience for EE undergraduates
MCS94	McAnelly	Observations of MCS genesis
<u>1995</u>		
Carey and Rutledge	May-July	Combined electric field / multi-E-FIELD parameter radar observations of thunderstorms.
Chandrasekar	June-August	Exposure of undergraduate REU95 students to weather radar research project field activities.

Straka, Zrnic et. al	June	Aircraft collection of in-situ T28 cloud observations to validate multiparameter radar data.
Bringi	June-August	Use of mobile hydrometeor PRECIP VAN95 measuring systems to verify multiparameter radar data.
Breed	June-August	Sailplane observations of the SAILPLANE 95 early electrification stages of cumulus clouds.
Metcalf	June	Radar detection of cloud ICE ORIENTATION electrification through ice particle orientation signatures.
Bedard et. al.	June-August	Correlations between low LF SOUND frequency sound waves and convective storm life cycle.
Browning	July-August	Relationship between boundary PBL95 layer echo evolution and later convective development.
Heymsfield	July-August	Multiparameter radar REPLICATOR observations of convective cloud systems penetrated by a balloon-borne particle replicator.

1996

Kennedy and Chandrasekar FNL	Feb-April	Combined multiparameter radar and surface observations of winter season precipitation.
Cifelli PLATTEVILLE	May-June	Joint CSU-CHILL / NOAA profiler study of precipitating cloud systems.
Chandrasekar and Bringi REU96	June-August	Exposure of undergraduate students to weather radar research project activities.
Rutledge, Dye, and Tuck STERAO-A	June-July	Coordinated multiparameter radar, aircraft, and lightning study of deep convective storms.
Bedard LF SOUND	July-August	Correlations between low frequency sound waves and convective storm life cycle.

Appendix D

1996 CSU-CHILL Newsletter

CHILL RADAR NEWS

from

**Colorado
State**
University

Sixth Edition
October 1996

Overview

(Steven Rutledge, Scientific Director)

This is the sixth edition of the Colorado State University (CSU)-CHILL newsletter which we distribute on an annual basis, near the start of the academic year. The newsletter is intended to provide information to the community regarding research, education, and refurbishment activities of the CSU-CHILL facility. In April 1995 Colorado State University was awarded a second five-year Cooperative Agreement from the National Science Foundation for operation and maintenance of the CSU-CHILL, a 10 cm, dual polarized Doppler radar. The radar is presently operational near Greeley, CO (located approximately one mile north of the Greeley-Weld County Municipal Airport), situated on an eighty acre agricultural site owned by CSU.

The use of the CSU-CHILL radar is granted by the National Science Foundation after review by the NSF Facilities Advisory Council and Observing Facilities Advisory Panel. We supported two NSF-reviewed projects during the summer of 1996, the STERAO-A project involving the use of the CHILL, a 3-D lightning mapping system from France, a NOAA WP-3D research aircraft and the U. of North Dakota Citation jet research aircraft. STERAO-A was in part designed to study the production and transport of NO_x by lightning in deep convection. Many excellent cases were obtained in the field project. The second NSF-funded project was a Research Experience for Undergraduates, where ten undergraduate engineering students from a variety of universities participated in a two month long storm chase program, operating instrumented vans to collect hail and rain data to verify polarimetric radar signatures. The radar performed extremely well during both field programs, encountering virtually no down time. For projects requiring less than about 20 hours of radar operational time, the Scientific Director of the CSU-CHILL facility can award the use of the

radar for such projects, without OFAP/FAC review. In these projects, radar operational costs are provided by the Cooperative Agreement. We supported four 20 hour projects in the past year, as detailed in the following sections. These projects allow investigators to conduct highly focused research with the CSU-CHILL radar. The radar also continues to be an integral component of several courses in the Departments of Atmospheric Science and Electrical Engineering. Many new case studies collected by the radar were analyzed by students in the advanced radar meteorology class in Atmospheric Science last spring.

During the last two to three years, numerous improvements have been carried out at the Facility, including the acquisition of a new high performance antenna, installation of a second FPS-18 transmitter and a second analog receiver (thus eliminating the need for a polarization switch), temperature stabilization of the front end's of both receivers (to improve estimates of differential reflectivity), and development of automated calibration procedures. These improvements and advances, coupled with regularly scheduled maintenance, have brought the facility to a high level of readiness and reliability.

Radar Operations Summary

(Pat Kennedy, Facility Manager)

The STERAO-A program (Stratosphere-Troposphere Experiments: Radiation, Aerosols, Ozone A: Deep Convection) was designed to explore the primary mechanisms by which thunderstorms effect the concentrations of several chemical species in the troposphere and lower stratosphere. The wind fields in these storms can cause significant exchanges of air to occur between the troposphere and stratosphere. Also, lightning discharges in thunderstorms attain temperatures high enough permit a variety of oxygen - nitrogen chemical reactions to occur.

To better understand these processes, observations of deep convective precipitation systems were made from a variety of platforms during the STERAO-A program.

Airborne measurements were made by instrumentation carried aboard a NOAA P3 (a 4 engine turboprop transport aircraft), and by the University of North Dakota Citation (a twin engine jet). The P3 obtained air chemistry samples at altitudes below 25,000 ft MSL, and also used its tail-mounted radar system to collect dual Doppler data sets. The Citation focused on in-situ observations at higher altitudes in and near storm anvils.

Figure 1 shows an overview of a typical STERAO-A operation on 12 July 1996. On this date, isolated, intense thunderstorms developed near the town of Kimball in southwestern Nebraska. The CSU-CHILL reflectivity data have been interpolated to the 11 km MSL height level. The aircraft tracks are based on transponder data recorded in real time from the FAA Air Route Traffic Control Center at Longmont, CO. In Fig. 1 the Citation is sampling conditions in the anvil while flying at 39,800 ft MSL near the echo summit. At the same time, the NOAA P3 is setting up for another airborne dual Doppler flight leg along the southwest flank of the storm at an altitude of 11,600 ft MSL.

Regional lightning activity was monitored by a two station VHF interferometer system provided by the French ONERA group. This system determined and displayed real time X, Y locations of lightning discharges with respect to CSU-CHILL. To aid project direction, the realtime plan view color display of the discharge locations was installed in the CSU-CHILL user van. Also, the full three dimensional path of the lightning discharges can be resolved from post analysis of detailed data archived at the interferometer antenna sites.

Additional storm electrification data were collected by graduate students from Prof. Rutledge's group in the CSU Atmospheric Science Department. They instrumented and operated a van equipped to measure and record time variations in the local atmospheric electric field. The van was directed from the CSU-CHILL operations center to locations from which optimal electrification data could be obtained from passing thunderstorms. This group also operated fixed field change meters at the CSU-CHILL site (near Greeley, CO), and at the Ft. Morgan, CO municipal airport.

Significant thunderstorm activity occurred on a number of days during the STERAO-A project. At least 4 high priority days have been identified when coordinated ground and airborne observations of severe thunderstorms within the STERAO-A network were made. Analyses of these data sets are currently underway.

The REU96 project, under the direction of Prof. V. Chandrasekar of the CSU Electrical Engineering Department, was designed to introduce a group of 10 undergraduate students to the various challenges of field research programs. A primary focus of this research was the collection of in-situ precipitation observations suitable for use as ground truth verification for dual polarization measurements made by the CSU-CHILL radar. To this end, three custom instrumented vans were developed and operated by the REU students. (Further information about the van equipment and the REU program are provided in the Electrical Engineering Department's section in this newsletter).

In addition to the above mentioned large, NSF sponsored projects, the CSU-CHILL facility collected data for several smaller programs. During the early spring months, a joint CSU Atmospheric Science / Electrical Engineering snow study was conducted. During this project, the radar scanned over the Ft. Collins - Loveland Airport while snow was falling there. Surface weather and precipitation observations made at the airport are being compared with the multiparameter radar data in an effort to characterize winter season precipitation based on dual polarization signatures. During the late spring months, CSU-CHILL data were collected in two episodes of stratiform, upslope-driven rain over NOAA's 404 MHz wind profiler located at Platteville, CO. Dr. Rob. Cifelli, of the NOAA's Boulder laboratory, hopes to use the multiparameter radar data to test several schemes for deriving hydrometeor classifications from profiler data. Finally, for the second summer, Dr. Al Bedard of the NOAA Aeronomy Laboratory installed ultra low frequency sound wave sensing equipment at the CSU-CHILL radar site. During the 1995 field season, this equipment detected acoustical signatures that appeared to have been generated by a tornadic mesocyclone. The 1996 data sets are currently being checked for additional occurrences of acoustical signatures associated with confirmed tornadoes. A case of primary interest was recorded on the evening of 31 July 1996 when a tornadic supercell thunderstorm, accompanied by

a visually impressive wall cloud, passed within 15 km of the CSU-CHILL site.

Numerous additional examples of recent CSU-CHILL radar observations are available on the facility's world wide web site. (See D. Brunkow's radar engineering section of this newsletter for the web site address.)

Electrical Engineering

A. REU 96 Project

(V. Chandrasekar, Co-Investigator)

The CSU Electrical Engineering Department conducted a Research Experience for Undergraduates (REU) project for a group of 10 students during the summer of 1996. These students came from 5 different states, and spent the summer in residence at CSU. A series of day-long workshops were conducted on the following topics to familiarize the students with radar meteorology:

- 1) Overview of radar hardware - Dr. Eugene Mueller.
- 2) Radar Applications in Meteorology - Mr. Pat Kennedy.
- 3) Multiparameter radar techniques - Dr. V. N. Bringi.
- 4) Radar Signal Processing - Dr. R. J. Keeler.
- 5) Design and Development of Airborne Radar Systems - Mr. Craig Walther.
- 6) Multiparameter Radar Data Analysis - Ms. M. G. Gonzales.

The primary field research activity for these students was the operation of three chase vehicles instrumented to collect in-situ precipitation measurements. Figures 2 a - c present views of the three storm intercept vans. The vans were directed into the storm cores using GPS position information transmitted to the radar site and displayed on the radar screen. In addition the van positions were also displayed at the advanced weather lab at NCAR for possible guidance from S-Pol Radar. The van observations of the rain / hail composition of the precipitation, as well as particle size distributions and instantaneous rainfall rates, are being compared to CSU-CHILL dual polarization radar data.

In addition to the REU program, two other radar engineering developments have been under study in 1996: (1) pulse compression and (2) random phase coding. A 5 bit pulse compression system using a phase coding scheme was implemented in the RF synthesis circuit to generate a phase coded transmit pulse. Radar

data were collected under phase coded transmit mode in precipitation echoes. Pulse compression algorithms (with inverse filtering) were applied to the data. The pulse compressed radar returns were then averaged over 1 μ s to study the reduction in the standard deviation in the estimates of reflectivity. The standard deviation in the estimates of reflectivity was reduced by a factor of 2.2, demonstrating the potential to increase the scan rates by a factor of 2. Based on the initial success of the pulse compression efforts plans are under way to implement a 13 bit Barker code-pulse compression scheme for fast scan applications.

Random phase coding of transmitter pulses with alternately polarized pulsing scheme has been implemented in order to improve the suppression of 2nd trip echoes using a combination of polarization and phase coding. The data collected under this mode is currently being evaluated.

B. CSU-ACTS Propagation Experiment Results *(J. Beaver, Electrical Engineering)*

Colorado State University is currently involved in an ongoing satellite propagation experiment sponsored by NASA. The Advanced Communications Technology Satellite (ACTS) program began in September 1993 and is currently in its third year of data collection. The ACTS system supports both communications and propagation experiments at the 20/30 GHz frequency band. The satellite is deployed into a geostationary orbit and employs two propagation beacons, one at 20.185 GHz and the other at 27.505 GHz. The purpose of the propagation experiment is to obtain high quality attenuation measurements in order to construct a data base so that the attenuation effects at Ka-band frequencies can be statistically characterized. Colorado State and six other sites located in the United States and Canada are conducting the propagation studies. Each site is located in a different climatic zone and is equipped with the ACTS propagation terminal (APT), and a receive only Earth station that is continuously measuring the beacon power levels. In addition to constructing a statistical data base, each site is applying its own expertise to secondary studies. CSU's contribution is the application of polarimetric radar data for attenuation prediction at Ka-band frequencies. For this purpose, the CSU-CHILL radar is being utilized to gain a greater understanding of the microphysical processes that are responsible for Ka-band attenuation that occurs along the ACTS slant path. The radar data is also used to

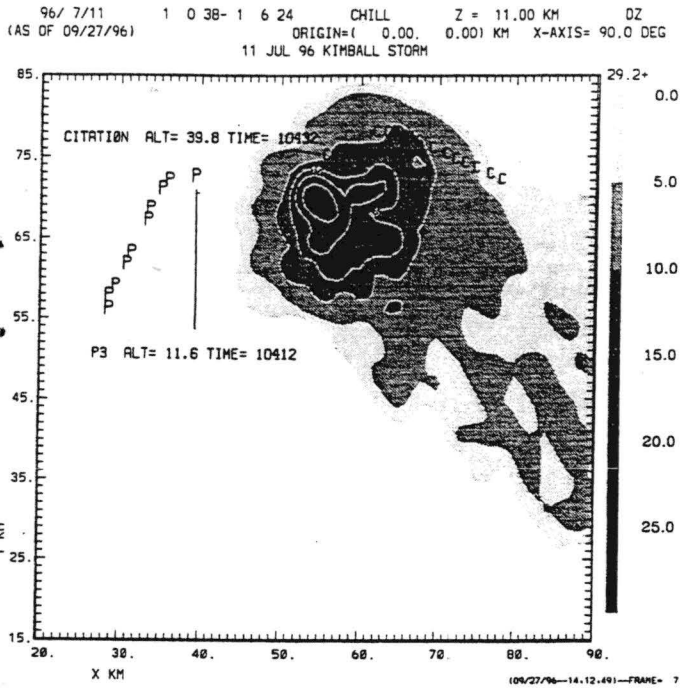
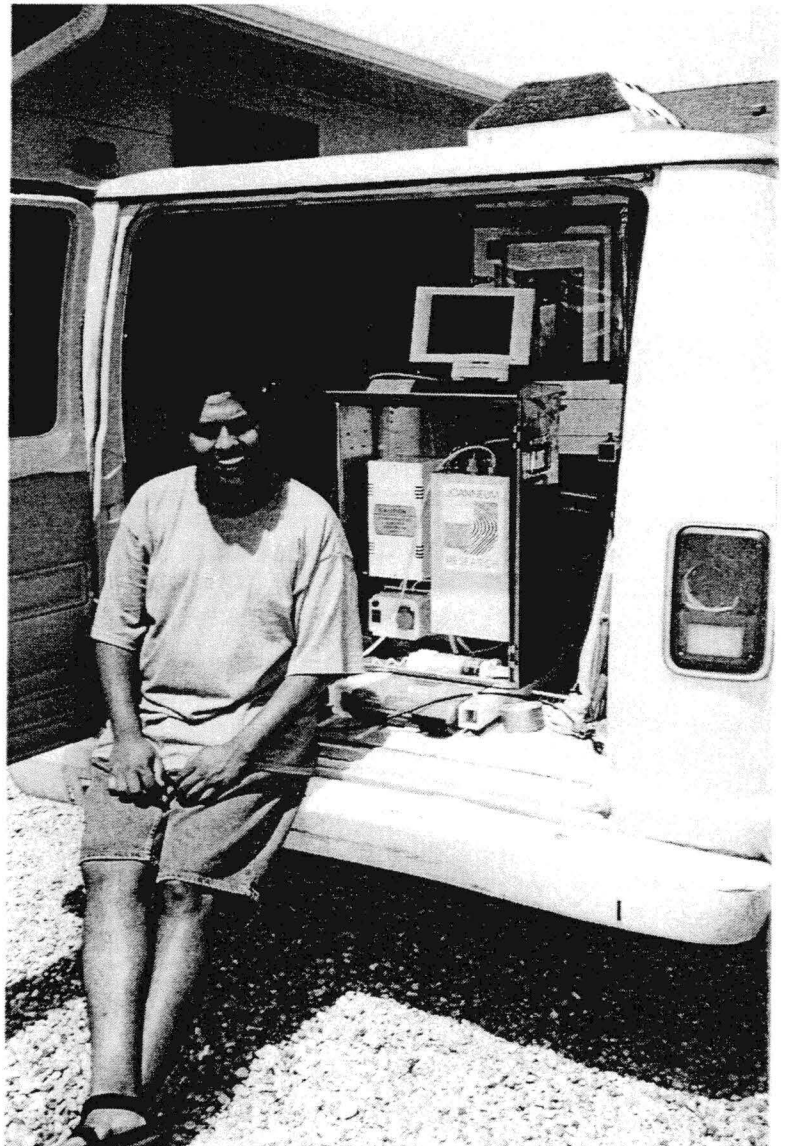


Figure 1: Constant Altitude PPI (CAPP) plot of CSU-CHILL radar reflectivities at 11 km MSL. Volume start time is 0100:38 UTC on 11 July 1996. Plotted reflectivities start at 0 dBZ and are contoured in 5 dB steps. Research aircraft tracks are shown by series of C's (UND Citation), and P's (NOAA P3).



Figure 2a) Two dimensional video disdrometer installed in the "Austria" van.





2b) Optical hail sampler (4 legged box on the ground) and van-mounted capacitive raingauge.



2c) Hail collection funnel and capacitive raingauge mounted on the "Hailstone" van.



July 6, 1996 Convective Case

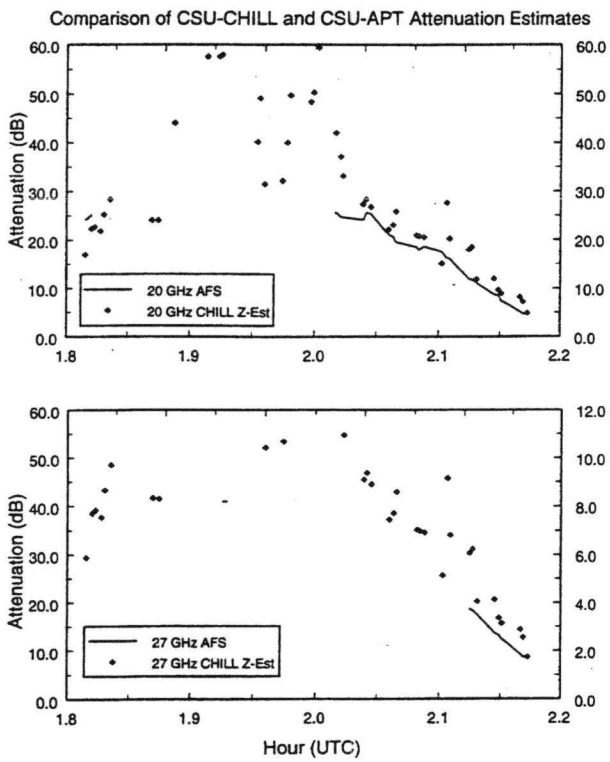


Figure 3) Comparison of measured CSU-APT attenuation at 20 and 27 GHz (solid lines) with attenuation estimates derived from CSU-CHILL S-band reflectivity data. For the July 6, 1996 convective case.

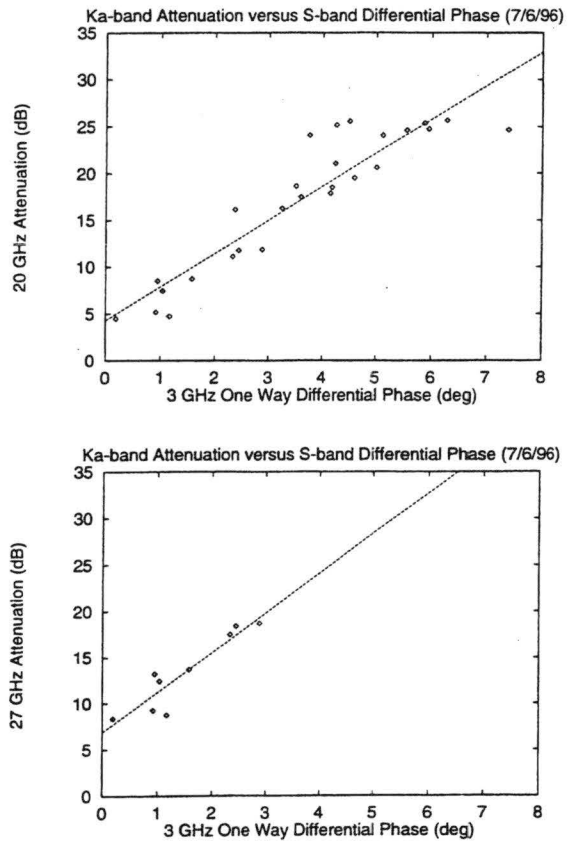


Figure 4) Attenuation for 20 and 27 GHz versus one-way differential phase at 3 GHz, for the July 6, 1996 convective case. Dashed line shows (least squares) straight line fit.

initialize a radar-based attenuation model that has been developed at CSU. Results from the attenuation model for one recently obtained case study are shown here.

The radar-based propagation model uses S-band reflectivity data measured by the CHILL radar, along the ACTS propagation path, to obtain Ka-band attenuation estimates. Polarimetric parameters such as differential reflectivity, specific differential phase and the complex cross-correlation coefficient are used to subjectively determine the effective length of the attenuation path. Results from a convective event that occurred on July 6, 1996 are shown in Figure 3. For a large portion of this event the ACTS beacon signals were not being received due to attenuation from rain. The digital receivers employed by the APT system have a dynamic range of approximately 25 to 30 dB. For the portion of the event where there is concurrent ACTS and CHILL data available there is good agreement between the predicted Ka-band attenuation estimates derived from S-band reflectivity data and the measured Ka-band attenuation obtained by the CSU-APT. For the most part the differences are on the order of 1-2 dB. A scatter plot of Ka-band attenuation versus S-band one-way differential phase for this event is shown in Figure 4. As expected there is very good correlation between Ka-band attenuation and S-band differential phase. The y-intercept of the fitted lines shown in Figure 4 is 4.3 dB for 20 GHz and 6.9 dB for 27 GHz. During a rain-only event it is expected that the y-intercept for the fitted curves would ideally be close to zero. Therefore, it is likely that precipitation in this event was composed of predominantly raindrops mixed with pea-marble sized hail. This was observed at the surface by CSU personnel in mobile chase vans who intercepted the storm cell about 10-20 km west of the APT site.

Several case studies have been obtained where concurrent CHILL and CSU-APT data are available. These include stratiform events where there is a well defined 'bright band' and several convective events. Very good results have been obtained for each case study that has been examined thus far.

Radar Engineering

(Dave Brunkow, Senior Engineer)

A. 1996 Radar Improvements

The entire waveguide system is now pressurized with dry air to 9 pounds per square inch. This improvement cured an arcing problem in the Horizontal channel of the Azimuth rotating

joint. This allowed the two transmitters to be operated at 800 KW peak power versus the 300 KW limitation which existed during the 1995 season. Higher power operation is possible, but 800 KW was chosen as a level which can be achieved with a transmitter high voltage of under 10 KV.

The receiver low noise amplifiers, first mixers, and first IF amplifiers were placed on a temperature controlled "cold-plate". These items are located in the radar trailer which is not air-conditioned. The cold plate kept these components at a constant 65 degrees F which significantly improved the tracking of the horizontal and vertical receivers. This improvement allowed one ZDR correction to be used throughout the season and the ZDR fields generally showed no shift throughout each day's operation. When shifts were observed, it was found that the transmitter voltage pulse timing had drifted on one channel or the other. This shift would degrade the transmitted spectrum enough to shift a fraction of a dB of transmitter power outside of the bandpass of the receivers. The wide-band power meters used to correct for power differences between the two transmitters were oblivious to the spectrum shift and consequently the ZDR correction would be off. After the timing was corrected, the ZDR field would return to a reasonable appearance on the display. Reasonable appearance means that there were broad areas above the freezing level that had a zero ZDR, and that rain areas below the freezing level showed a positive ZDR. The cold plate resulted in a much more stable receiver system.

A new mode for the SP20 signal processor was developed. This "long range LDR mode" overcame the 50% duty cycle imposed by the dual receiver VH mode used last year. Last year only half of the available range gates could be processed and recorded. This limitation was imposed by the additional computational load of the second receiver which permitted for the first time cross polar products to be calculated from a VH sequence. The 1995 mode allowed the calculation and recording of many of the complex covariances, but the operator typically had to choose where to locate the 75 KM of processed data was to be placed in the 150 KM unambiguous range interval. The new long-range LDR mode allowed the recording of all of the co-polar fields plus LDR out the full 150 KM range limit. This was done at the expense of complex covariance recording, but for many projects such as STERAO, this is a desirable trade-off.

A new transfer switch was installed which automatically starts the backup diesel generator and transfers the load to the diesel when the commercial power fails. This surplus unit was obtained from NCAR. It provides another tier of protection of the radome, should there be a power failure when the site is unattended. A modification of the transfer switch is being developed as an CSU Electrical Engineering student project. This will allow a seamless transfer of power from line to generator prior to power failure. This mode would be used when the radar site locale is threatened by thunderstorms or heavy winter storms and a manual transfer to generator is desired.

An automated receiver calibration system was developed and used daily during the 1996 season. This allowed the operator to do a complete calibration on both receivers with a single command on the antenna control console. The results are plotted on the display, terms recorded on disk, and raw data recorded on tape. A similar command was used to initiate sun scans which are used to check the az/el calibration and the LDR calibration.

The CSU-CHILL Web page has been established at:

<http://olympic.atmos.colostate.edu/CHILL> It contains examples of radar data, articles of interest to CSU-CHILL users, as well as request forms to apply for radar time. The interactive casebook function has been transferred to this web page and is available to assist in selecting case study days from the catalog of recent years operations.

B. Future Plans

A plan to stabilize the transmitter high voltage pulse timing is underway. It will involve adding a feedback path to adjust for delay changes in the FPS-18 trigger amplifier. This should mitigate the occasional transmit spectrum lapses mentioned in part 2) above.

A simultaneous H and V transmit mode will be developed and tested. This has a number of advantages for polarization work. It allows the direct measurement of $\rho_{HV}(0)$ (the HV correlation at zero lag) rather than the current method of using the lag 1 and lag 2 covariances and extrapolating back to lag 0. It also allows the measurement of ϕ_{dp} at lag 0. This separates the ϕ_{dp} and velocity measurements and doubles the unambiguous range of the measured ϕ_{dp} . Full Nyquist velocity measurements and filtering are

also simplified in this mode. The only anticipated penalty is that the LDR field cannot be measured. LDR would still be available by transferring back to our current mode of operation.

A new rotary power regulator will be installed. This will provide more power to facilitate the simultaneous H and V transmit mode and protect more of the radar equipment i.e. the computer systems.

Acknowledgments:

The CSU-CHILL facility is supported by NSF Cooperative Agreement ATM-9500108, supplemented by cost sharing funds from the state of Colorado.

Publications Between October 1995 and October 1996

Aydin K, V. N. Bringi and L. Liu, 1995: Rain rate estimation in the presence of hail using S-band specific differential phase and other radar parameters, *J. Appl. Meteor.*, 34, 404-410.

Bolen, S., V. N. Bringi, and L. Liu, 1995: Comparison of rainfall from specific differential phase using the CSU-CHILL radar with rain gage data: The 20 June 1994 case. AMS 27th Conference on Radar Meteorology, Vail, CO, 9-13 October.

Beaver, J. and V. N. Bringi: The Application of S band Polarimetric Radar Measurements to Ka-band Attenuation Prediction, submitted to *Proc. IEEE Special Issue on Ka-band Propagation Effects on Earth Satellite Links*.

Bolen, S., V. N. Bringi and V Chandrasekar: An Optimal Area Approach to Intercomparing Polarimetric Radar Rain Rate Algorithms with Gauge Data, submitted to *J Atmos Ocean Tech*.

Mudukutore, A. and V. Chandrasekar: Weather Radar Pulse Compression with Complementary codes, *Proceedings, IGARSS 96*, 574-576.

Xiao, R. and V. Chandrasekar: Multiparameter Radar Snowfall estimation using Neural Network Techniques, *Proceedings, IGARSS 96*, 566-568.

Lucci, R. 1996: Doppler Radar Investigation of Tornadoic and Lightning Producing Storms in Northeast Colorado. M.S. Thesis, Atmospheric Science, Colorado State University, Fort Collins, Colorado. (Advisor: Prof. S. A. Rutledge).

Carey, L.D., S.A. Rutledge, and T.J. Lang, 1996: High Percentage Positive Cloud-to-Ground Lightning in a Tornadoic Thunderstorm: A Multiparameter Radar Study. AGU 1996 Fall Meeting, San Francisco, CA, 15-19 December.

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

Erdman, J.P., 1996: Characteristics of Cloud-to-Ground Lightning Associated with Severe Thunderstorms in Northeast Colorado. M.S. Thesis, Atmospheric Science, Colorado State University, Fort Collins, Colorado. (Advisor: Prof. S.A. Rutledge).