Annual Report for

THE CSU-CHILL RADAR FACILITY

Cooperative Agreement No. ATM-8919080

Submitted to

The National Science Foundation

Division of Atmospheric Sciences

1 February 1994

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

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TABLE OF CONTENTS

1. Introduction

Herein we report on the activities of the Colorado State University CSU-CHILL radar facility for 1993. In April 1990 Colorado State University was awarded a five-year cooperative agreement from the National Science Foundation for operation and maintenance of the CSU-CHILL, a 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 Colorado State University. Co-Principal Investigators for the cooperative agreement are Profs. Steven Rutledge and Stephen Cox in the Department of Atmospheric Science and Prof. V. N. Bringi in the Department of Electrical Engineering. 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. However, for projects not needing more than 20 hours of radar operational time, the Scientific Director of the CSU-CHILL facility can award the use of the radar for such projects. Radar operational costs are provided by the cooperative agreement in the case of the 20 hour projects. We have supported eight 20 hour projects in the past year, as detailed in a following section. These small projects allow investigators to conduct highly focused research with the CSU-CHILL radar. A summary of all 20 hour projects as well as formal NSF-funded projects supported by the CSU-CHILL are listed in Appendix D to this report. At the time of this writing the CSU-CHILL radar is being used in the WISP 94 program under support from the NSF.

During the past year we have continued our collection of radar data for "targets of opportunity", that is, cases describing interesting weather situations that are eventually used in formal courses in the Department of Atmospheric Science and Department of Electrical Engineering. To aid the dissemination of these data sets (internally as well as outside CSU) a user friendly, computer based, data archive was developed. This program allows users to search an extensive data base for a particular meteorological situation, provided through a list of some thirty key words representing different meteorological situations the radar has acquired data in since being relocated to Colorado. Once a particular keyword is selected (gust front, severe hailstorm, and cold frontal passage are just a few examples) the data base provides dates, times, a weather summary, a data collection summary and tape numbers of CSU-CHILL archive tapes. This data base was announced to the general meteorological community during this year, providing researchers with remote login capabilities and access to the data base. Recently, at least two universities have accessed the data base and are beginning to transfer case studies to their sites for use in radar meteorology classes.

Also during the past year, CSU-CHILL staff carefully considered the acquisition of a new parabolic, center fed reflector antenna. An Antenna Specification document was developed and bids were solicited. As a result of this action, a contract was awarded to Radiation Systems, Inc. for production of the new CHILL antenna. CSU purchased the new antenna from cost-sharing funds provided by the University under the existing cooperative agreement with the NSF. The new antenna was delivered in November 1993 and became fully operational in January 1994. Details of the new antenna are provided in a following section. The new antenna was acquired in order to: 1) provide a better match between horizontal and vertical co-polarization patterns, 2) allow meaningful meteorological measurements of the cross-polarization strength, and 3) reduce sidelobe levels. Numerous other improvements were also performed to the CSU-CHILL system in the past year including improvements to the receiver, data display systems and antenna positioning system. These improvements are again detailed in following sections.

In the coming year, we plan another major upgrade to the CSU-CHILL system. In order to take advantage of the tremendous cross-polar performance of the new antenna, we desire to develop a dual transmitter-dual receiver system at CHILL. This upgrade will involve the acquisition of a second transmitter-receiver chain. We have leads on such a system and are actively pursuing acquisition of that system. Such a system will enable us to make cross-polar measurements (L_{dr}) and perform full scattering matrix calculations. We plan to develop this dual system over the next year and focus on data collection and advanced polarimetric research with this system under a future Cooperative Agreement with the NSF. Additional details on the dual-channel system are provided in a following section. A design review of the dual-channel system will be presented to the CSU-CHILL Radar Advisory Committee during a meeting in April 1994.

2. Summary of Activities during 1993

a) NSF funded projects

No NSF - sponsored projects were supported during 1993.

b) 20 hour project support

Eight 20 hour projects were conducted at the CSU-CHILL facility during 1993. The phenomena investigated in these projects ranged from snowstorms to insect migrations. In chronological sequence the specific projects were as follows: (1) Pat Kennedy, CSU-CHILL Facility Manager, made detailed snowfall observations at the Ft. Collins - Loveland Municipal Airport while the radar collected multiparameter data over the airfield. The goal was to associate the snow characteristics, particularly in terms of potential to cause an aircraft ground icing hazard, with patterns observed in the multiparameter data. (2) Rita Roberts, an M.S. student in the CSU

Atmospheric Science Department, collected multiparameter data in synchronization with the NCAR Mile High Radar (MHR) during the WISPIT (Winter Icing and Storms and Icing Project: Instrumentation Test) program. She sought to investigate wintertime precipitation systems through the analysis of combined dual - Doppler and multiparameter radar data sets. (3) Prof. V. Chandrasekar, of the CSU Electrical Engineering Department, collected multiparameter data in close proximity to the NCAR King Air research aircraft during cloud penetrations conducted in WISPIT. His recent Ph.D. graduate, Dr. Andrew Benjamin, compared the in-situ cloud particle observations made by the King Air with the multiparameter CSU-CHILL data. (4) Mr. Larry Carey, an M.S. candidate in the CSU Department of Atmospheric Science, collected multiparameter data throughout the lifetime of several thunderstorms that occurred near the radar site. He also used supplementary instrumentation to gather data on the electrification characteristics of these storms. Mr. Carey's thesis centers on relating cloud electrification signatures to various radar-sensed aspects of thunderstorm evolution. (5) Prof. Thomas Holtzer, head of the CSU Entomology Department, directed the collection of radar data during the annual migration of Russian Wheat Aphids into eastern Colorado. Direct capture of airborne insects was made by a specially equipped helicopter operated by the University of Illinois. The radar data were designed to provide a mesoscale background to aid in the interpretation of the insect collections. (6) Prof. K. Aydin, a sabbatical visitor from the Electrical Engineering Department at The Pennsylvania State University, acquired multiparameter data in hailstorms. His objective was the correlation of multiparameter hail indications with surface hail observations made by NCAR storm chasers during the RAPS93 project. (7) Prof. V. Bringi also collected multiparameter data during hail intercepts made by NCAR personnel. (8) Prof. Bill Cotton and Mr. Ray McAnelly, both in the CSU Atmospheric Science Department, observed developing mesoscale convective complexes through CSU-CHILL scans that were synchronized with the Mile High Radar.

At this writing, initial analyses have been started by the investigators in all eight of the above-mentioned 20 hour projects. The quality of the radar data collected in these projects has generally been quite satisfactory. Evaluations of the performance of the radar system and its staff were solicited from 20 hour project investigators who were not closely connected with the facility. Copies of the solicitation and evaluation letters are included in Appendix A.

c) In-house educational projects

Selected data sets from the CSU-CHILL archives are currently being prepared for classroom use at three universities. It is worth noting that all three of these user groups took advantage of the remotely-accessible, interactive, electronic data base archive that has been developed at the CSU-CHILL facility. (This archive data base perusal system was discussed in detail in the 26 July 1993 semiannual report).

Dr. Steven Koch (North Carolina State University, NCSU) is teaching a radar meteorology class during the spring of 1994. He has identified seven dates on which potentially interesting CSU-CHILL data sets were collected. Sample Universal Format volumes from these dates are being made available for electronic transfer to NCSU. Ultimately, Dr. Koch plans to have his students work directly with the CSU-CHILL data sets.

Prof. Hans Verlinde (The Pennsylvania State University) is also interested in assembling archive radar data sets for classroom use. His initial interest focussed on cases presented in our January, 1993 BAMS article which described the educational usage of the CSU-CHILL Facility (Rutledge et al.). Prof. Verlinde is presently examining the complete data archive to identify cases of greatest potential interest.

Prof. Steven Rutledge will once again be teaching his advanced radar meteorology course at CSU during the spring semester of 1994. Seven candidate archive data sets have been selected for analysis by the students in Prof. Rutledge's class. All seven of these cases are "new"; they do not involve the same data sets that were used when this course was previously taught (Fall 1991). Several visits by the class to the radar will also be conducted.

d) Technical developments

New Antenna Position Sensing System

The CSU-CHILL system has used optical shaft position encoders to digitize the azimuth and elevation since the early 1970's. These units use an incandescent lamp which shines through a precisely etched glass disk onto an array of photocells. The output voltages from the photocells are then measured to obtain antenna position. One problem with this system is that the lamp burns out periodically and must be replaced. This can happen during a data collection period resulting in a 30-45 minute interruption. The other problem results from the fact that the photocells output levels are 150 millivolts or less. This requires DC amplifiers and comparators to produce standard logic levels. This analog circuitry is located in the rather harsh environment of the antenna pedestal. The decision levels require adjustment several times a year, and have suffered from reliability problems due to corrosion. The 12 bit output gives about 0.1 degrees accuracy which is adequate for most uses, but has been marginal for precise antenna pattern measurements.

Given the problems of the current encoder system, several alternatives were investigated. A military-spec encoder system with light emitting diode illumination and standard TTL outputs was considered. These were available with up to 16 bit outputs. However, the cost would have been over $4000 per axis. It would also be connected to a single shaft geared 1:1 with the antenna. It was suspected that backlash in getting to the 1:1 shaft would compromise the accuracy of the encoder.

A more attractive solution was to use two resolvers and a two speed converter to obtain the digital angles. This takes advantage of the high speed 36 to 1 shaft available in the CHILL data packages to make very accurate measurements (0.005 degrees) with only moderately accurate resolvers (0.11 degrees). A two axis system with spare parts could be constructed for under $4000. The resolvers used are a modern "brushless" design which do not require the slip rings which are used in traditional synchros to excite the rotor. This provides an order of magnitude improvement in life expectancy. They are driven by a 2800 Hz oscillator which allows faster tracking rates and better dynamic performance the traditional 60 Hz synchros. The converter modules (from Control Sciences Inc.) are similar to units which have been trouble free in NCAR radars for about 8 years. To limit the risk of lightning damage and loading of signals by long cable runs, the conversion electronics will be located in the pedestal close to the resolvers. Printed circuit cards are being constructed for all of the analog and most of the digital circuitry to improve performance and life expectancy in a harsh environment. The resulting digital angles will be serialized and transferred down to radar trailer over optical cable as it has been in the past.

The expected benefits from the new system are higher accuracy and greater reliability. The higher accuracy and resolution will improve the angle holding capability when the azimuth axis is in a pointing mode. This benefit will also be enjoyed while making pattern measurements where there are large amplitude changes over a very small range of angles.

New Attenuator Configuration

Over the last three years the CHILL receiver has undergone steady improvements primarily related to improving the bandwidth and settling time in the linear video channels and fine adjusting the timing of the instantaneous automatic gain control (IAGC) system. In 1993, there remained a problem in that a low level signal was getting into the system and raising the noise level slightly. The exact source of this signal was not known, but it was not the Coherent (COHO) or Local (STALO) oscilators, so it could not be filtered out with a clutter filter. The signal was found to be entering the system through the cable which controlled the switchable attenuators used in the IAGC. Overall shielding added to the cable helped somewhat, but in the Fall of 1993, the switchable attenuator box was redesigned. A printed circuit card was constructed to mount the attenuator chip on, and the control lines were converted to fiber optic cables. This eliminated all electrical connections to the attenuator box other than the IF signal, and the power supply (which was heavily filtered). This had the desired effect of completely disconnecting the noise source from the receiver. The receiver noise power dropped about 1.2 db to -111.7 dbm and the average Normalized Coherent Power (NCP) estimate now asymptotically approaches zero as the integration time is increased. These modifications are expected to provide a noticable improvement in the observation of clear air echos.

LDR Calculation

The installation of the new CSU-CHILL antenna has prompted the addition of a Linear Depolarization Ratio (LDR) Mode to the existing polarization options. This is the first field generated on CHILL to make use of a cross-polarized return. In this mode, the four pulse polarization sequence is VHXH, where V and H are copolar Vertical and Horizontal samples, and X is a transmit H, receive V sample (S_{hv} is received). This allows the calculation of all the existing VH mode fields (Z, Z_{dr}, Velocity, Phidp, RhoHV(0)) plus LDR (which is $10.0*\log(S_{hv}/S_{hh})$).

The lower limit of LDR observable by CHILL will be determined by the isolation of the ferrite polarization switch (-18 to -22 db). However, future plans call for the replacement of the polarization switch with a dual-channel rotating joint and completely separate transmitter/receivers which will reduce the LDR threshold to the isolation limit of the antenna (at least -35 db). Even with the existing switch, areas of high decorrelation which have been associated with mixed phase precipitation should be detectable. The LDR mode will be tested beginning in January 1994.

Remote Data Display

Interactive displays of real-time and archived CSU-CHILL radar data were available during 1993 at CSU's Atmospheric Sciences and Electrical Engineering Departments. The software in use is the TITAN package developed by Mike Dixon of NCAR-RAP. It consists of a Cartesianizer, cell tracker, data server, and a viewing program. The first three parts run on workstations at the radar, while the viewing program can be run anywhere on the network. The viewing program is divided into two parts; one presents horizontal and vertical cross-sections through the grid, and the second (optional) part provides three windows that present time-height views of statistics on individual cells which have been identified and tracked by the software. Online help is available for information on the numerous menu buttons available.

The grid size and location can be adjusted to suit the needs of the project. For a typical summer situation, a 230 by 230 by 15 grid has been used with a 1 km grid spacing. This provides a good overview of what the radar is observing. Furthermore, since the TITAN data sets are compact, two to four weeks of data can remain online at one time. This will be useful as a perusal mechanism to allow researchers to select cases for further study. TITAN data sets can also be converted for use by ZEB, and this form of data is being considered as a means of distributing sample CHILL data sets to researchers.

Improvements which are planned for the 1994 winter operation include the automatic switching of scan conversion lookup tables based on scan type. This will allow for high resolution RHI scans to be interleaved with standard resolution PPI scans without operator intervention. The real-time operating system which drives the TITAN Cartesianizer was ported to VxWorks during 1993. This resulted in an easier to use package and eliminated bottlenecks present in the previous operating system.

Update on New Antenna

In the last Annual report, we reported that invitations to bid on a replacement antenna were sent out to various manufacturers. Two bids were received and the lowest responsive bid was for \$126K from Radiation Systems Inc, RSI. An award was made at the end of March to RSI. Delivery of the antenna was made on November 19, 1993. The original bid of \$126K included \$20K for an increased cross polarization isolation. This more stringent requirement was not met and therefore the price of the antenna was reduced to \$106K. (The details of the antenna tests are presented in Appendix B.)

Our original intent was to have the mechanical design engineer at NCAR provide a design for the adapter plate of the antenna. This plate was necessary to mate the new antenna to the side arms of the existing pedestal. After examining the details of this design, particularly that of the antenna mounting procedure, the NCAR engineer foresaw considerable difficulty in the design and he recommended that the work be done either by RSI or some consulting engineering firm. The structure would require finite element analysis and the facilities for accomplishing this were not available at NCAR. On July 19, a proposal was received from RSI for \$28,914 to design and make the adapter. This proposal was ultimately accepted and the adapter purchase was added to the RSI contract. Hence the total antenna cost was \$106K plus \$28,914.

Testing of the antenna at the manufacturer's site indicated that it did not fully meet the specifications. The side lobe levels in the most stringent planes (phi of +/- 45 degrees) exhibit side lobe levels that appear as if they are "oscillations" as a function of the angle from boresight. The side lobes at angles from 9 to 12 degrees from boresight exceed the specifications of -33 dB to -35 dB by from 2 to 4 dB. Additionally, the preliminary patterns appear to fail to meet the cross polar ratio, CPR, specification by a few dB in 3 of the 4 planes and at the highest frequency of 2.875 GHz. The other specifications have been largely met, but a more complete discussion of the discrepancies can be found in Appendix B. Regardless of these difficulties in meeting of the specifications, it is believed that this antenna will be an outstanding antenna and will satisfactorily perform all of the desired measurements for which it was intended.

The antenna was installed on December 8, 1993. On this day the radome was removed, the old antenna removed, the new adapter plate fitted to the side arms, the new antenna installed, and the radome reinstalled. This was the first time in CHILL history that the radome was taken down and installed on a single day. An excellent no-wind day was needed for this to take place and it occurred.

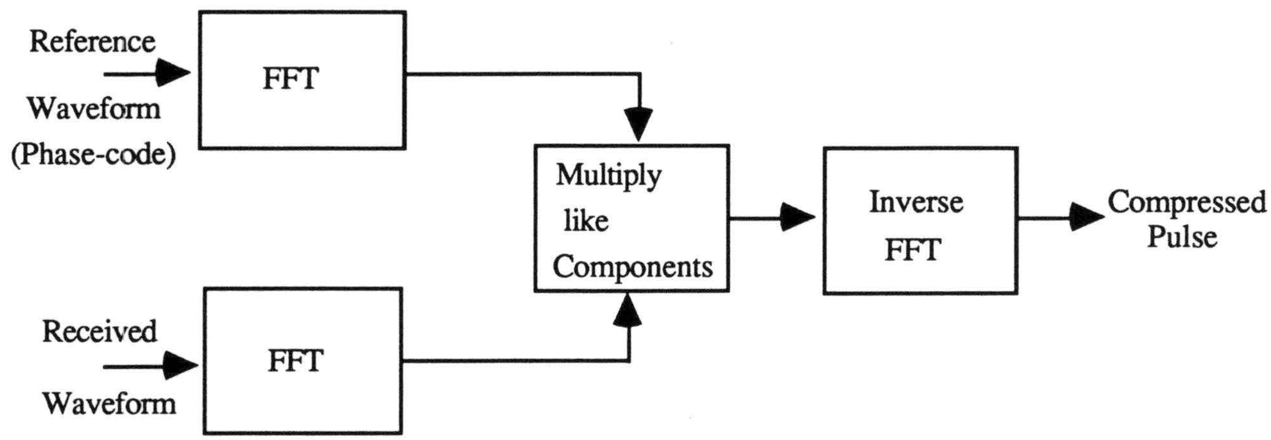
By December 17, the antenna horn, the waveguide run to the antenna, and the polarization switch were reinstalled. Measurements and design of the waveguide runs were accomplished and the design turned over to NCAR for construction on December 30, 1993. NCAR fabricated the necessary waveguide and it was delivered on January 10, 1994. Installation of the last part of the waveguide was accomplished and power applied through the bypass mode on January 12, 1994. The antenna meets the power limit that we can provide and the antenna was officially accepted on January 14, 1994.

The new antenna will make a large difference in all of the variables that depend on the polarization capability of the system. This includes the co-polar variables of differential reflectivity, differential propagation phase, and correlation between copolar horizontal and vertical returns. It will also make possible measurements of linear depolarization ratio, LDR, which until now has been seriously limited by the antenna isolation. In addition artifacts due to sidelobes will be reduced in even the copolar measurements of reflectivity and velocity. It is expected that the reduced sidelobes will permit much better measurements of height of echoes due to the reduction of the confusion due to side lobes.

To fully exploit the measurement of linear depolarization ratio, LDR, it will be desirable in the future to provide more isolation between channels which is now limited by the switchable polarization switch. Plans are being made to provide greater isolation by adding a second transmitter and a dual channel rotary joint. These plans are discussed in a following section.

Recent Developments in Pulse Compression

The following steps have been taken so far towards implementation of pulse-compression on the CSU-CHILL radar, an effort led by Prof. V. Chandrasekar in collaboration with Dr. Gene Mueller. On the transmitting end of things, the changes include a phase modulator operating at 60 MHz with phase-shifts in 90 degree increments every 200 nanoseconds. A newly acquired intermediate power amplifier with a bandwidth of 5 MHz is being used to accommodate the higher bandwidth of the receive signal. Also, on reception, the implementation of a matched filter will be accomplished through a correlation processor shown below:



The FFT, complex multiplications and inverse FFT will be performed on the IC chip, the first version of which will be available for testing in June, 1994. Meanwhile, the interfacing circuitry for sequencing the data from the SP-20 signal processor busses to the FFT chip are being designed and tested. The circuit to read off data from the output of the FFT chip and placing it back on the SP-20 bus has been designed and tested successfully. The entire circuit is being simulated and tested using Mentor Graphics tools before implementation.

Plans for Dual Transmitter System

The cross polarization isolation of the CSU-CHILL system is now limited by the isolation in the polarization switch. This device has at best an isolation of 20 dB. Thus the very high cross-pole isolation of the antenna is limited by this isolation. A solution is to implement a dual transmitter/receiver configuration. In this system one transmitter and one receiver is permanently connected to the horizontal antenna port. The second transmitter/receiver is permanently connected to the vertical port. Since at S band it is not possible to mount a high power transmitter on the antenna itself, a dual frequency rotary joint is required to connect the two transmitters to the two waveguides of the antenna. Several years ago, a manufacturer of such joints was located and discussions as to the isolation that could be obtained was determined. Isolation of at least 50 dB is attainable. With this isolation the antenna again becomes the limiting factor. Since the cross polar isolation of the new antenna is about 35 dB, meaningful measurements of the cross polarization variables in all but the case of all water clouds will be possible. Certainly it should be easy to detect and differentiate between ice crystal clouds and water cloud by using the LDR parameter. Other variables will also be possible in the dual channel configuration, such as the scattering matrices and covariance matrices.

Recently, it has come to our attention that NCAR is also interested in developing an S-band polarization radar operating with a dual transmitter/receiver system. It is our intention to join with NCAR and obtain a price discount in obtaining two rotary joints. We are actively seeking a second transmitter/receiver system. There are at least two possibilities for obtaining one at minimum cost to the contract. One would be one of the systems currently not being used at the National Severe Storms Laboratory and the other is the HOT radar system that exists at the Illinois State Water Survey. There are other options which will be explored if neither of these systems should become available. We plan a site visit to NSSL in February to determine the feasibility of acquiring one of their radar systems for us at our Facility. If the second channel is acquired in the near future, in-house funds will permit us to essentially fully develop this system during the coming year of this Cooperative Agreement.

e) Projects in the Department of Electrical Engineering

Prof. K. Aydin from Penn State spent the period July-December at CSU/EE department as part of his sabbatical. He analyzed CSU-CHILL and CP2 data from 24 June 1992 and showed excellent comparison between rainrates derived from Kdp (CSU CHILL) and X band specific attenuation (CP2) with a raingage located on the CSU campus. This was an intense rainfall event (peak R of 150 mm/h) with 0.75" hail.

As part of the 20 hour project and in coordination with RAPS '93 conducted by NCAR, Drs. Aydin and Bringi collected several days of data in hailstorms jointly scanned by CSU-CHILL and CP2 radars. In situ data from 2 hail chase teams will provide valuable confirmation of radar hail signatures. These data are being analyzed at Penn State by Dr. Aydin and one of his M.S. students in EE.

Dr. Joseph Turk and Mr. John Beaver of CSU/EE installed the NASA/ACTS propagation terminal at the CSU-CHILL site. CSU was the first of the NASA sites to acquire the ACTS 20/27 GHz beacons on 9/23/93. The terminal is working well and we look forward to collecting radar data along the slant path during WISP '94.

3. Publication and Reports

1993 CSU-CHILL Publications

1) Czys, R. R. and R. W. Scott, 1993: A simple objective method used to forecast convective activity during the 1989 PACE cloudseeding experiment. *J. Appl. Meteor.*, **32**, 996-1005.

2) Hallett, J., M. Wetzel and S. A. Rutledge, 1993: Field training in radar meteorology. *Bull. Amer. Meteor. Soc.*, **74**, 17-22.

3) Rutledge, S. A., P. C. Kennedy, and D. A. Brunkow, 1993: Use of the CSU-CHILL Radar in radar meteorology education at Colorado State University. *Bull. Amer. Meteor. Soc.*, **74**, 25-31.

4) Liu, L., A. Mudukotore and V. N. Bringi, 1993: Studies on a severe storm using the CSU-CHILL dual polarized Doppler weather radar. *Preprint, 1993 International Conference Neural Net. Signal Processing*, Guangzhou, China, November, 1993.

5) Ramamurthy, M. K., R. M. Rauber, B. P. Collins, and N. K. Malhotra, 1993: A comparative study of large-amplitude gravity-wave events. *Mon. Wea. Rev.*, **122**, 2951-2974.

6) Rutledge, S.A. and collaborators, 1993: The CSU-CHILL annual newsletter.

7) Carey, L. D., and S. A. Rutledge, 1994: Multiparameter and dual-Doppler radar study of the kinematic and microphysical evolution of lightning producing storms in northeastern Colorado. *Preprint, 1994 Global Circuit-Lightning Symposium*, AMS Annual Meeting, Nashville, TN, January, 1994.

8) Liu, L., V. N. Bringi, V. Chandrasekar, E. A. Mueller, and A. Mudukotore, 1994: Analysis of the copolar correlation coefficient between horizontal and vertical polarizations. Accepted for publication in *J. Ocean. Atmos. Tech.*, to appear in August, 1994.

9) Aydin, K., V. N. Bringi, and L. Liu, 1994: Rainrate estimation in the presence of hail using S-band specific differential phase and other radar parameters. Submitted to *J. Appl. Meteor.*

10) Mudukotore, A., V. Chandrasekar, and E. A. Mueller, 1994: The differential phase pattern for the CSU-CHILL radar antenna. Submitted, *J. Atmos. and Oceanic Tech.*

11) McAnelly, R. L., J. E. Nachamkin, and W. R. Cotton, 1994: The development of an MCS in a quasi-tropical environment in northeastern Colorado. Submitted to the AMS Sixth Conference on Mesoscale Processes, 17-22 July 1994, Portland, OR.

12) Nachamkin, J. E., W. R. cotton, and R. L. McAnelly, 1994: Analysis of the early growth stages of a High Plains MCS. Submitted to the AMS Sixth Conference on Mesoscale Processes, 17-22 July 1994, Portland, OR.

Papers presented at the 26th International Conference on Radar Meteorology (Norman, OK 24-28 May, 1993):

Achtemeier, G. A., R.W. Scott, and P. C. Kennedy: The Champaign macroburst: a rare radar event?

Benjamin, A., and V. Chandrasekar: Polarimetric radar and aircraft observations of winter storms.

Bringi, V. N., D. Brunkow, V. Chandrasekar, S. Rutledge, P. Kennedy, and A. Mudukutore: Polarimetric measurements in Colorado convective storms using the CSU-CHILL radar.

Hubbert, J., J. Caylor, and V. Chandrasekar: A practical algorithm for the estimation of Doppler velocity and differential phases from dual polarized radar measurements.

Kennedy, P. C. and S. A. Rutledge: Combined dual-Doppler and multiparameter radar observations of a Colorado bow echo hailstorm.

Liu, L., V. N. Bringi, V. Chandrasekar, E. A. Mueller, and A. Mudukutore: Statistical characteristics of the copolar correlation coefficient between horizontal and vertical polarizations.

McAnelly, R. L., J. E. Nachamkin, W.R. Cotton: Upscale growth processes in a mesoscale convective system.

Xiao, R., V. N. Bringi, D. Garbrick, E. A. Mueller, and S. A. Rutledge: Copolar and cross polar pattern measurements of the CSU-CHILL antenna.

Manuscripts in Preparation:

1) Bringi, V. N., P. Kennedy, L. Liu, S. Rutledge, V. Chandrasekar, E. Brandes, and J. Vivekanandan: Advances in the application of multiparameter radar techniques to convective storms. Invited paper, *J. Met. Atmos. Phys.*

Ph.D. Thesis Completed:

1) Polarimetric Radar/Aircraft Observations and Modelling of Ice Crystals in Winter Storms by Mr. Andrew Benjamin.

M.S. Thesis Completed:

1) Effects of Antenna Induced Errors in Multiparameter Radar Measurements by Ms. Shanthala Mudegowda, Electrical Engineering, February 1994.

2) Image Processing Techniques to Classify Ice Crystal Images by Mr. David Garbrick.

Ph.D. Thesis (In Progress):

1) Propagation studies at K band using CSU-CHILL radar and the NASA ACTS Terminal by Mr. John Beaver, Electrical Engineering.

2) Pulse Compression and Real-Time FFT for Weather Radar Applications by A. Mudukotore, Electrical Engineering.

3) Identification of Polarimetric Radar Signatures by R. Xiao, Electrical Engineering.

M.S. Thesis (In Progress):

1) Investigation of Winter Storms with the CSU-CHILL Radar by Ms. Rita Roberts, Atmospheric Science.

2) Multiparameter Radar Studies of Electrified Convection in Colorado by Mr. Larry Carey, Atmospheric Science.

Undergraduate Project Work with CSU-CHILL Radar

1) Senior Project on CSU-CHILL radar and NASA/ACTS terminal.

2) Automatic switching from commercial power to generator by Dustin Schramm.

3) RDSS interface to CSU-CHILL field format by Dan Reinke.

4. Report on Cost Sharing Activities

The following describes cost sharing expenditures at CSU for the first four years of the Cooperative Agreement and a projection for year 5:

	Cumulative through 4/14/93	YEAR 4 4/15/93-1/1/94	Cumulative through 1/1/94	YEAR 5 4/15/94-4/14/95
Building and site prep.	$188,275	$0	$188,275	$0
Freight, Transport, ins., crane	11,975	3,965	15,940	0
Furniture and grounds	17,722	0	17,722	3,000
Materials, parts, supplies, paint	23,784	3,298	27,082	15,000
Salaries and services	98,684	27,714	126,398	32,000
Telephone and postage	5,839	0	5,839	2,000
Vehicles and fuel	2,990	0	2,990	324
Equipment	18,639	137,914 *	156,553	25,000
CSURF lease (equipment)	322,271	29,272	351,543	30,000
Indirect cost @ 45%[a]	64,473		64,473	
Indirect cost @ 44.7%[a]		15,635	15,635	23,388
TOTAL	$754,652	$217,798	$972,450	$130,712
Estimate 1/1/94 - 4/14/94	0	5,000	5,000	0
TOTAL	$754,652	$222,798	$977,450	$130,712

(a) Indirect cost base excludes building, furniture, equipment and CSURF lease.

* Antenna and waveguide procurement.

4/15/94 - 4/14/95

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
AWARD NO.		

ORGANIZATION
Colorado State University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
S. A. Rutledge and V. N. Bringi and S. K. Cox

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds Granted By NSF (If Different)
1. S. A. Rutledge, Co-PI, Scientific Director		1	1	$ 12,300	$
2. V. N. Bringi, Co-PI			1	8,412	
3. S. K. Cox, Co-PI (one month cost-sharing)	0			-0-	
4. P. Kennedy, Facility Manager	12			51,064	
5. D. Brunkow, Sr. Software Engineer	12			60,840	
6. (1) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE) F. Mueller	12			70,408	
7. (6) TOTAL SENIOR PERSONNEL (1 - 6)				203,024	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES					
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12			36,712	
3. ( ) GRADUATE STUDENTS					
4. ( ) UNDERGRADUATE STUDENTS					
5. (1) SECRETARIAL - CLERICAL				4,992	
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A + B)				244,728	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				45,194	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				289,922	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $1,000.)					
TOTAL PERMANENT EQUIPMENT				-0-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				6,000	
2. FOREIGN					
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ ___ 2. TRAVEL ___ 3. SUBSISTENCE ___ 4. OTHER ___					
( ) TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				10,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				4,783	
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER				30,000	
TOTAL OTHER DIRECT COSTS				44,783	
H. TOTAL DIRECT COSTS (A THROUGH G)				340,705	
I. INDIRECT COSTS (SPECIFY RATE AND BASE) 44.7% of total direct cost (excludes equipment and tuition)					
TOTAL INDIRECT COSTS 44.7% of $340,705				152,295	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				493,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPM 252 AND 253)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$493,000	$

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Steven A. Rutledge *Steven A. Rutledge*	10 Feb 94	INDIRECT COST RATE VERIFICATON		
INST. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - DGC
Donald W. Kelly				

NSF Form 1030 (8/90) Supersedes All Previous Editions

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPM 233)

5. NSF Budget

Budget Explanation for specific items reported on the NSF form.

A.6. Senior Personnel

Dr. Gene Mueller, CSU-CHILL Senior Engineer.

E. Travel

1. Domestic; attendance at NSF Advisory Panel Meetings and various technical meetings.

G.6. Other Direct Costs

$10,000	telephone
$11,000	utilities
$ 5,500	software/hardware maintenance
$ 3,500	machine shop

6. Statement on Residual Funds from 1993

No significant funds are anticipated from the 1993 NSF budget. A modest residual (approximately $30K) was built up over 1993 because Dr. Gene Mueller stepped down to 0.60 FTE. A full 1.0 FTE was budgeted for him in the hopes that a suitable replacement could be brought on board. A suitable replacement was not identified, but more importantly, Dr. Mueller now plans to return to nearly full-time employment this coming year to fully participate in the development of the dual-channel system. His involvement in the project at nearly a full-time level will be very valuable. Hence we request 1.0 FTE support for Dr. Mueller for the coming year. The $30K residual has been directed towards the acquisition of parts for the dual-channel system (in addition to some $35K of cost-sharing funds).

7. Statement on Cost Recovery Funds for 1993

There were no cost recovery projects supported during the past year.

8. Statement of Current and Pending Support for Key Personnel

CURRENT AND PENDING SUPPORT
Steven A. Rutledge
2/22/94

A. Current Support

Agency	Project Title	K$/ YR	Role	Period Covered	Commitment (months)
National Science Foundation	Dynamical and Electrical Studies of Mesoscale Precipitation Systems	160	PI	2/1/91 to 1/31/94	1 academic
National Oceanic and Atmospheric Administration (USTPO)	Doppler Radar Studies in TOGA/COARE	100	PI	4/1/91 to 3/31/94	1 summer 1 academic
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 12/31/96	2 academic
National Science Foundation	The CSU-CHILL Radar Facility	465	CO-PI	4/15/90 to 4/14/95	1 summer 1 academic
National Aeronautics and Space Administration	Research in Support of Micro-wave Precipitation Retrieval Algoritm for TRMM	100	CO-PI	4/15/91 to 4/14/94	1 summer
National Oceanic and Atmospheric Administration	Electrical Studies of Meso-scale Convective Systems	20	PI	8/15/91 to 6/30/94	0
Colorado State University	Resident Instruction Support				6 academic

B. Pending Support

Agency	Project Title	K$/ YR	Role	Period Covered	Commitment (months)
National Science Foundation	Dynamical and Electrical Studies of Convective Cloud Systems	170	PI	2/1/94 to 1/31/97	1 academic
National Aeronautics and Space Administration	Ground Truth Research & Algorithm Development in Support of TRMM	125	CO-PI	5/1/94 to 4/30/97	1 summer

CURRENT AND PENDING SUPPORT
V. N. Bringi
2/22/94

A. Current Support

Agency	Project Title	K$/ YR	Role	Period Covered	Commitment (months)
National Science Foundation	CAPE Radar Analysis	76	PI	4/1/91 to 3/31/94	2 months
National Aeronautics and Space Administration	Microwave Radiative Transfer	90	PI	9/1/91 to 8/30/94	3 months
National Science Foundation	The CSU-CHILL Radar Facility	465	Co-PI	4/15/90 to 4/14/95	5 months
AFOSR	CAPE Radar Analysis	43	Co-PI	12/1/91 to 1/31/94	1 month
National Science Foundation	C-band Polarimetric	80	PI	6/15/92 to 5/31/94	2 months
NASA	K-band Propagation studies using CSU-CHILL radar	115	PI	5/1/93 to 4/30/95	2 months

B. Pending Support

Agency	Project Title	K$/ YR	Role	Period Covered	Commitment (months)
NASA	Hydrometeor Profile and Rainfall Retrieval	114	PI	10/1/94 to 9/30/97	2 months

CURRENT AND PENDING SUPPORT
Stephen K .Cox
2/22/94

A. Current Support

Agency	Project Title	K$/ YR	Role	Period Covered	Commitment (months)
U.S. Department of Energy	Monitoring the Response of the Upper Troposphere/Lower Stratosphere to a Greenhouse Gas Scenario	70	PI	6/1/93 to 5/31/94	0.5 months
National Aeronautics and Space Administration	Observations of Upper and Middle Tropospheric Clouds	185	PI	12/1/93 to 11/30/94	2.0 months
National Science Foundation	The CSU-CHILL Radar Facility	465	CO-PI	4/15/90 to 4/14/95	0
National Science Foundation	Joint CSU-USSR Cloud-Radiation Climate Studies	40	CO-PI	11/01/91 to 10/31/93	0
Office of Naval Research	Observational and Modeling Studies in Support of the Atlantic Stratocumulus Transition Experiment	417	CO-PI	3/01/93 to 02/28/94	2 months

B. Pending Support

There is no pending support at this time.

Appendix A

Letters Associated with 20 Hour Projects

11 June 1993

Ms. Rita Roberts
NCAR RAP
3450 Mitchell Lane
Boulder CO 80301

Dear Rita:

The purpose of this letter is to close out our files regarding your recent winter storm data collection operations. Universal Doppler Exchange Format (UF) data have been provided to you on 8mm cartridge tape for the following three events:

7 January 1992 (NWS Blizzard warning for DEN to Loveland area)
23 November 1992 (marginal blizzard case in Greeley area)
11 March 1993 (20 hr project; WISPIT upslope event)

I trust that your analyses of these data are proceeding satisfactorily. Please contact either Dave Brunkow or me if questions about the data arise in the future.

On a related issue, feedback from users of the CSU-CHILL facility is always useful in improving radar operations. We would greatly appreciate it if you would write a short letter summarizing your evaluation of the performance of the radar and its staff during your project. Thanks in advance for taking the time to prepare your letter of evaluation.

Sincerely,

Pat Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
(303) 491-6248

11 June 1993

Prof. V. Chandrasekar
Department of Electrical Engineering
Engineering Building C, Room 105
Colorado State University
Ft. Collins CO 80523

Dear Chandra:

The purpose of this letter is to close out our files regarding the 20 hour project that you conducted during the recent WISPIT field program. The primary CSU-CHILL operations occurred on three days during WISPIT:

- 24 February 1993 (marginal 10 cm echo strength)
- 10 March 1993 (skin paints of NCAR King Air during echo penetrations)
- 11 March 1993 (evolving ZDR patterns during upslope snow event)

Andrew Benjamin has reviewed these data, and selected portions of the data have been supplied to him in both field format and Universal Doppler Exchange Format (UF). Please contact either Dave Brunkow or me if questions about these data arise in the future.

Sincerely,

Pat Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
(303) 491-6248

10 September 1993

Mr. Larry Carey
Department of Atmospheric Science
Colorado State University
Ft. Collins, Colorado 80523

Dear Larry:

The purpose of this letter is to close our files on the 20 hour project that you recently finished using the CSU-CHILL radar. According to our records, radar operations in support of your project were conducted as follows:

Date	Approx Times (MDT)	Remarks
5/18/93	1400 - 1700	Single lightning flash storm
5/19/93	1600 - 1800	Re-developing storms S of CHL
5/20/93	1530 - 1800	Only distant (SE WY area) storms
5/21/93	1430 - 1900	Storm passing S of CHL; good case
5/25/93	1620 - 1800	Scattered storms
5/26/93	1400 - 1800	Scattered storms
5/27/93	1430 - 1800	Scattered storms
5/28/93	1500 - 1930	Line passing radar, golf ball hail
6/2/93	1245 - 1630	Small storm within slow ant range
6/3/93	1115 - 1500	Organizing squall line passing radar
6/23/93	1325 - 1800	All storms remain at ranges > 75km

I believe that Dave Brunkow has already provided you with 8mm UF data tapes from the days that you have designated as being the most interesting. Please contact me if there is additional data that you would like to examine, or if questions about the data arise during your analysis.

Regards,

Patrick Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
(303) 491-6248

11 June 1993

Prof. Tom Holtzer
Head, Department of Entomology
Colorado State University
Ft. Collins, CO 80523

Dear Tom:

This letter is designed to summarize the CSU-CHILL radar data that were collected during your recent 20 hour (Russian Wheat Aphid) project. According to our records, radar operations in support of this project were conducted during the following overall time periods:

25 May	1620 - 1750 MDT
26 May	1030 - 1330 "
27 May	0830 - 1030 "
28 May	0830 - 1300 "
30 May	0800 - 0930 "
31 May	0800 - 1600 "
1 June	0800 - 1300 "
2 June	0800 - 1000 "

Preliminary discussions have already been held with Mark Carter regarding the various methods by which these radar data may be examined and processed Once the desired data format, etc. has been decided, we will generate and distribute copies of the desired data times. Any questions regarding the radar data should be directed to Dave Brunkow or me.

On a related issue, feedback from users of the CSU-CHILL facility is always useful in improving radar operations. We would greatly appreciate it if you would write a short letter summarizing your evaluation of the performance of the radar and its staff during your project. Thanks in advance for taking the time to prepare your letter of evaluation.

Sincerely,

Pat Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
(303) 491-6248

10 September 1993

Prof. V. N. Bringi
Dept. of Electrical Engineering
Colorado State University
Ft. Collins, CO 80523

Prof. K Aydin
Dept. of Electrical Engineering
314 EE East
Pennsylvania State University
University Park, PA 16820

Dear Bringi and Aydin:

The purpose of this letter is to close out our files on the joint 20 hour hail projects that you conducted with the CSU-CHILL radar during the past summer. According to our records, radar support for these projects was supplied as follows:

Date	Approx hours (MDT)	Remarks
6/21/93	1230 - 1600	Thunderstorm line in SE CHL - MHR dual Doppler lobe; hail in southern portion of this line.
6/23/93	1325 - 1800	Strong storms all at ranges > 75 km
7/8/93	1400 - 1700	IPA failure; very limited data
7/9/93	1400 - 1800	Only small size hail reported
7/12/93	1300 - 1800	Mostly rain; limited hail reports
7/13/93	1330 - 1830	NCAR hail intercepts near Ft. Collins, Boulder, and Brighton
7/14/93	1300 - 1630	Only small hail intercepted during time period of CHL recording
7/15/93	1240 - 1900	Heavy rain, but only 10mm hail reported by NCAR chasers
7/21/93	1640 - 1800	Brief NCAR intercept of 15 - 20mm size hail approx 40 km SSE CHL

To date, data copies from 21 June (in UF) and from 13 July (in field format) have been prepared. Please contact me if there are additional data sets that you would like to examine. Also, the CSU-CHILL staff is available to provide technical consultation on issues such as data quality, etc. We look forward to supporting your future research projects.

Sincerely,

Pat Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
(303) 491-6248

10 September 1993

Mr. Ray McAnelly
Atmospheric Science Department
Colorado State University
Ft. Collins CO 80523

Dear Ray

This letter is designed to close our files on the 20 hour project that you conducted with the CSU-CHILL radar during the summer of 1993. According to our records, radar operations in support of this project were done as follows:

Date	Approx hours (MDT)	Remarks
7/19/93	1218 - 1945	Developing tstm line in SE CHL - MHR dual Doppler lobe
7/20/93	1330 - 1700	Storms fail to move off foothills
7/21/93	1630 - 1900	Slow moving SE lobe storm complex; non standard antenna scans run
7/23/93	1400 - 2200	Good storm complex development in SE lobe
8/10/93	1300 - 1900	Tstm line in SE lobe with rear inflow development noted

I believe that Dave Brunkow has already provided you with 8mm UF data tapes for the 3 primary cases included above (7/19, 7/23, and 8/10).

We always find user feedback to be valuable in improving the performance of the CSU-CHILL Facility. Once you have developed an overall sense of your 20 hour project's operations and data sets, please send me a letter summarizing your impressions of our performance.

Sincerely,

Pat Kennedy
CSU-CHILL Facility Manager
(303) 491-6248

PENNSTATE

1855

(814) 865-2355 FAX: (814) 863-8457

Department of Electrical Engineering
College of Engineering

314 Electrical Engineering East
The Pennsylvania State University
University Park, PA 16802

January 5, 1993

Prof. Steven Rutledge
Colorado State University
Department of Atmospheric Sciences
Fort Collins, Colorado 80523

Dear Steve,

I'm back at Penn State now and yesterday we had our first big snowstorm, 15 inches. Friends are asking me if I brought it along from Colorado. I told them that it is mostly sunny out there and there isn't that much snow on the ground in the city. My family and I really enjoyed our stay in Fort Collins. As for my sabbatical at CSU, I can tell you that it was an excellent opportunity for me. After several years of theoretical and computational work, I was finally able to get my hands on real radar data which included parameters in addition to Z_H and Z_{DR}. Working with Bringi and his group was a special treat and proved to be very productive. I would like to thank you for your support in making this happen and look forward to a collaboration in the future on multiparameter radar related research.

Sincerely,

Kültegin

Kultegin Aydin
Associate Professor
of Electrical Engineering

PENNSTATE

(814) 865-6337
FAX: (814) 863-8457

Communications and
Space Sciences Laboratory

The Pennsylvania State University
316 Electrical Engineering East
University Park, PA 16802-2707

January 2, 1994

Dr. Pat Kennedy
CSU-CHILL Facility Manager
Colorado State University
Department of Atmospheric Sciences
Fort Collins, Colorado 80523

Dear Dr. Kennedy,

This is in response to your solicitation of my impressions of the CSU-CHILL radar facility with regard to data collection and support for my research activities. As you know, I had the opportunity to collect polarimetric radar data at your facility last summer during a 20 hour project period. I was very happy with the support and competence of your technical staff and the quality of the radar data. The radar system was always ready to go and data collection was possible practically any time of the day. During weatherwise uneventful days at this facility, it was convenient to be able to browse data that were collected earlier in the project. I was also very satisfied with your prompt production of universal format data tapes of requested events . I have one suggestion which I believe will make data collection more compatible with the multi-parameter nature of your radar system : Instead of a single display which can only show one radar parameter at a time, have at least four displays to allow for the simultaneous observation of any subset of parameters that can be selected and changed during an experiment. These displays should be linked to a common mouse so that the cursor points to the same location on each display. This will allow , in real time, the observation of interesting features that can be missed with a single display.

I would like to thank you and your staff once again for the excellent support you provided during and after my 20 hour project with the CSU-CHILL radar facility.

Sincerely,

Kultegin Aydin

Kultegin Aydin
Associate Professor
of Electrical Engineering

cc: S. Rutledge

Pat

Colorado State University

Department of Entomology
Fort Collins, Colorado 80523
(303) 491-7860
FAX: (303) 491-0564

23 July 1993

Dr. Pat Kennedy
CSU-CHILL Facility Manager
Department of Atmospheric Sciences
Colorado State University

CHILL Evaluation

The Russian wheat aphid (RWA) (*Diuraphis noxia*) has become one of the most important insect pests of small grain crops in the United States. During the period when primary hosts (e.g., small grain crops, primarily wheat and barley) are unsuitable for development and reproduction, the RWA utilizes alternate hosts (e.g., range grasses, Conservation Reserve Program grasses, volunteer grain). Dispersal between alternate hosts and small grain crops is a key component of the life history of the RWA and has a significant bearing on development of economically damaging RWA infestations. However, the dynamics of RWA dispersal are poorly understood and programs to monitor dispersal are not well developed. Without this information, management systems for RWA will remain severely limited. We are developing a comprehensive understanding of the dynamics of RWA dispersal. This research involves aerial sampling of the atmosphere to collect RWA using helicopter mounted traps and quantifying the meteorological events that are strongly associated with RWA movement.

We used the CHILL radar facility to assist our efforts to collect RWA by identifying layers in the atmosphere that may contain insects. In addition, the data collected by the CHILL radar during the helicopter flights will provide valuable meteorological data to supplement that collected using the helicopter and radiosondes.

Preparation: The CHILL staff fully explained the operation and capabilities of the system and had prepared several programs to control the CHILL radar system. These programs greatly facilitated collection of data. The staff were also extremely flexible and altered the programs as necessary to allow us to collect data and direct the helicopter during flights.

Operation: During the duration of the project the staff were available and prepared to alter their schedule to ensure the radar was available during the helicopter flights. As our schedule was highly dependent on weather conditions this required that the staff be available at all times during the two week helicopter flight period. The staff were required to work weekends and Memorial Day to facilitate our schedule. At the outset of the project, a minor problem prevented the CHILL radar from working properly. To solve this problem a member of the staff returned early from a scientific meeting to correct the problem. We experienced no appreciable loss of information due to the problem.

Data Analysis: We have not had an opportunity to analyze the data, however, preliminary discussions have been extremely positive and the staff have outlined several options to accomplish the analysis.

Sincerely,

Mark Carter
Research Associate
Entomology
491 - 7820s

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
RESEARCH APPLICATIONS PROGRAM
Mailing Address: P.O. Box 3000 • Boulder, CO 80307-3000
3450 Mitchell Lane • Boulder, Colorado 80301
Telephone: (303) 497-8422 • FAX: 497-8401

19 July 1993

Dr. Steven Rutledge
Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

Dear Steve:

I would like to express my appreciation to you and to the CHILL staff for providing me with the opportunity to collect some additional radar data on Colorado winter storms through the 20-hr proposal program. I found the CHILL staff, specifically Pat Kennedy and Dave Brunkow, responsive to my operational needs. They were ready and willing to operate the radar late into the evening, during early morning hours, or on the weekend, if necessary. Changes in radar scanning were implemented quickly and often had already been anticipated by the CHILL staff before I could reach them by phone. I was promptly informed of radar processor problems and any hardware failures during operation, including the failure in a transmitter tube. Gene Mueller was quick to locate the latter problem and soon had the radar back on line.

I have received all my data requests in a timely fashion and in the format desired. Preliminary examination of the 11 March 1993 data indicates the data quality is good and will likely provide me with a nice case for winter storm analysis.

I look forward to working with you and your staff again in the future.

Sincerely,

Rita Roberts
cm

Rita Roberts
Associate Scientist
NCAR/RAP

cc: Pat Kennedy, ATS Department

Colorado State University

Department of
Atmospheric Science
Fort Collins, Colorado 80523
(303) 491-8360
FAX: (303) 491-8449

(303) 491 8341

September 14, 1993

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

Dear Pat:

This letter is in response to your letter of 10 September 1993 concerning your closing of files on our 20-h CSU-CHILL project for this year and your request for "feedback" letters. Compared to our 1992 project, the weather this year was much more co-operative: we collected data on three good cases of MCS development (7/19, 7/23 and 8/10), compared to 1992's single decent case. Dave Brunkow has provided us with the complete UF datasets on 8mm tape for these cases, from which we have completed case overview analyses.

For the 7/19 case, we have complete coverage on what radar and satellite data indicate is a nice mini-MCS life-cycle, prior to the system's explosive redevelopment (too far east, as usual) into a full-fledged MCC. For the 7/23 case, our coverage is complete for the beginning stages of a more ideal, continuous explosive development into a very nice MCC. Unfortunately, Mile High Radar shut down for the last 1.25 h of the CSU-CHILL data collection period, so we don't have as much dual-Doppler coverage into the mature MCC stage that we might have had. These two July MCCs contibuted substantially to the last week of the extreme rainy period that caused the extensive flooding on the Mississippi River and elsewhere in the Midwest.

After a relatively dry 2-week lull, the 8/10 case occurred in a more monsoon-type environment, characterized by weak southerly flow aloft and a very moist and nearly moist-adiabatic lapse rate with low CAPE. Complete life-cycle coverage was obtained on a 4-h, moderately-sized MCS, which underwent marked evolution from a primarily convective stage into a nicely developed stratiform system with no convection. Ongoing evolution between this MCS and others in eastern Colorado eventually resulted in another impressive MCC over eastern Colorado and western Kansas, but this extended development was beyond our coverage. This case helps satisfy our objective of obtaining a good "monsoon" case, since all prior cases occurred in unusually strong westerly flow aloft for this time of year.

The data collection that we requested for these three good days completely fulfilled the 20-h allottment of this year's project. We were not aware that the "stand-by" operations prior to 1700 MDT on 7/20 resulted in an archived dataset attributed to our project. The only reason we might end up analyzing this event is if we want to compare a case of strong convection (1 3/4 inch hail in Loveland) that didn't undergo upscale growth into an MCS with cases that did. The other low-priority dataset you listed, 7/21, was not requested by us, since we incorrectly forecasted MCS development to be too far east. Since the facility was fortuitously collecting data (in a scanning procedure different from ours) on convection that did develop into a decent MCS within distant dual-Doppler range, we may eventually want to analyze that case also. However, I believe that the data collection ended prior to the system's main upscale development, during which a large, well-publicized tornado north of Limon occurred. We missed only one other decent case of MCS development (7/22), but it occurred so late (midnight and beyond) that we aren't too sorry about it.

As part of our case overviews, we have performed quantitative reflectivity analyses based on the lowest sweeps of the primary volume scans and the long-range surveillance scans, at the full 6-min resolution of the data. These results indicate that the reflectivity data are quite reliable. During this analysis, a qualitative look was taken at the radial velocities and normalized coherent power, and they too look reliable. A very cursory look at the spectral width field also indicates reliable data. Combined with our satellite overview analyses, the preliminary results of our radar analyses are very promising as they relate to our scientific objective of documenting upscale transition to mature MCS stage.

We are now ordering concurrent data from Mile High Radar for these three cases in order to perform more detailed dual Doppler analyses. Also, we hope to augment the analyses for 7/19 and 7/23 with NWS WSR-88D data from Denver and Goodland in order to document ongoing development of those systems into their mature MCC stage. Unfortunately, neither radar had Stage II recorders, which record the basic fields in radar coordinates. Instead, we will be limited to Stage III data products, which I believe for our purposes would be limited to hardcopy displays of various fields. If you have any experience or advice in obtaining such WSR-88D data, we would like to hear about it — otherwise, we have made initial contacts with appropriate personnel at the NEXRAD Operational Support Facility in Norman who should be able to help us.

Although we are quite satisfied with the datasets acquired for the single 1992 case and this year's three cases, we still haven't obtained an "ideal" case of full upscale growth into a well-matured MCC within decent range — that life-cycle stage for our MCC cases has occurred too far east, which is the climatological expectation. In addition, we haven't had a case of MCS development that strongly involves any mountain-generated convection, probably due to the unusually strong westerlies aloft that dominated late July and early August in both years. Therefore, we intend to submit another 20-h mini-grant proposal for next year, in the hopes of documenting the elusive "ideal" event with some significant mountain-generated components, and also adding to our database of otherwise decent cases. Support from Mile High Radar and from the WSR-88D radars at Denver, Goodland, and (if online) Cheyenne will be sought. Although MHR has been decommissioned from routine operations, it is our understanding that with modest financial support, it could resume operations in support of such field experiments. It is also our understanding that the NWS, upon advanced request, could install Stage II data recorders at WSR-88D sites to support such experiments.

We will provide a brief update to this "feedback" letter, regarding data quality, a few months from now after some dual-Doppler analyses for the three primary cases, and prior to submitting a proposal for next year's 20-h project. As for now, we want you to know that the CSU-CHILL data look very good and the cases very promising. The data problems seen last year ("ringing", velocity scaling) have been eliminated in this year's data, and no other unforeseen problems have yet popped up. Just as last year, we found the CSU-CHILL staff to be most cooperative in all phases of our project.

Sincerely,

Ray L. McAnelly

Ray L. McAnelly
Research Associate

Appendix B

Antenna Test Evaluation

The following is a brief description of the test results for each of the specifications as set forth in the CSU new antenna Spec.

Electrical Specification

1. The antenna does have both polarizations available. Rear port is the horizontal polarization and exits the antenna on the -45 deg phi angle. Side port is the vertical polarization and exits the antenna on the +45 deg phi angle.

2. The antenna is capable of handling full power.

3. The input standing wave ratios are within specification.

Voltage standing Wave ratio

port	freq	first	second	port	freq	first	second
rear	2.725	1.24	1.22	side	2.725	1.33	1.35
rear	2.800	1.15	1.16	side	2.800	1.21	1.22
rear	2.875	1.23	1.24	side	2.875	1.12	1.16

The other comment on these measurements is that the worst case is on the side (vertical) port at our operating frequency. None of the VSWR's changed appreciatively between the two runs separated by the take down.

4. Primary feed patterns have been supplied.

5. We specified the need to meet all specs at the three frequencies of 2.725, 2.8000, and 2.875 GHz. All tests were preformed at all three frequencies.

6. The antenna directivity (one form of gain) was specified to be ≥ 44.5 dB. The gain was measured using the horn substitution method. Thus the following values would be less than the true directivity by the antenna efficiency including waveguide losses. Therefore the single measurement that did not strictly meet 44.5 (rear port 2.875) would meet the spec if the losses were considered. The following results were obtained:

Gain (as measured by horn substitution)

port	freq	first	second	port	freq	first	second
rear	2.725	45.2	45.2	side	2.725	44.5	44.9
rear	2.800	45.3	45.0	side	2.800	44.5	44.9
rear	2.875	44.0	44.0	side	2.875	44.5	45.0

7. The 3 dB beamwidths were specified as ≤ 1.1 degree. The following table lists the measured beamwidths.

Beam Widths

Phi		rear		side	
angle	freq	first	second	first	second
0	2.725	1.0	1.0	0.98	1.04
0	2.800	0.96	0.98	0.99	1.01
0	2.875	0.93	0.92	0.98	1.00
45	2.725	0.94	1.0	1.02	1.02
45	2.800	0.94	0.98	0.96	0.98
45	2.875	0.94	0.96	0.96	0.94
90	2.725	1.0	1.0	1.01	1.00
90	2.800	1.0	1.0	0.98	0.98
90	2.875	0.98	1.0	0.95	1.06
135	2.725	1.0	1.0	0.95	1.02
135	2.800	0.98	0.96	0.93	0.96
135	2.875	0.92	0.94	0.94	0.98

All values are below the specified beam width. The values for the principal plane cuts (0 and 90) were read from the analog charts. The values of the 45 and 135 cuts were interpolated from the digitized patterns.

8. Side lobe levels were within the specification except for the phi cuts of 45 and 135. On these cuts there was a far out side lobe that exceeded the specifications. The specifications called for a step from -33 dB to -35 dB at theta angle of 10 degrees. If the slope of the sidelobe specified envelope had remained constant to the -35 dB level instead of the step, the sidelobes would have nearly been within specification even at the phi angles of 45 and 135. The errors indicated below were read from the analog charts. The entries in the table are dB exceeding spec / angle of sidelobe / absolute value of side lobe (without the sign).

Sidelobe levels exceeding specs

Phi angle	freq	rear port first	rear port second	side port first	side port second
45	2.725	2.5/11/30	3.2/11/30	3.0/11/32	3/11/31
135	2.725	3.4/10.5/32	2.5/11/31	3.0/12/32	2/12/32
45	2.800	1.0/10/31	2.6/12/31	2.5/12/32	1.4/11/33
135	2.800	3.4/10.5/32	2.3/11/32	3.0/12/32	2.2/12/
45	2.875	2.5/11/32	2.0/11/32	2.2/11/31	1.6/11/33
135	2.875	4/9/31	3/10.5/32	2.4/10.5/32	2.5/10.5/32
135	2.875	3.0/11/32	2.0/11/	3.4/11/31	2.5/11/33

The worst sidelobe in this group is the single measurement at 135/2.875. This would appear to be an artifact of this particular calibration as the second run showed much better results.

9. The examination of the location and amplitude of the side lobes have been confused by the definition of the "first side lobe". If the definition is related to the distance out of the theoretical "first side lobe" there are minor discrepancies. If on the other hand the "first side lobe" is defined as a point where there is a distinct departure from the main lobe, there is no discrepancy. That is because some side lobes are completely absorbed in the main lobe while others show distinct "shouldering".

10. The cross polar ratio has been well analyzed. Values for the cross polar ratio, CPR, have been calculated by RSI, Bringi, and Mueller. We all appear to be calculating these in the same manner, which only means that starting with the same data we all can program the same equation. The results are as follows.

Cross Polar Ratios

Phi angle	freq	rear port first	rear port second	side port first	side port second
45	2.725	35.7	40.0	36.3	37.1
135	2.725	37.6	34.0	38.3	34.8
45	2.800	32.5	34.2	32.5	33.3
135	2.800	32.5	32.1	32.9	33.0
45	2.875	32.6	32.6	32.0	31.9
135	2.875	33.1	33.4	32.9	32.5

It can be noted that at our present operating frequency the CPR values are in excess of the 35 dB spec. At the higher frequencies the 35 dB spec is not met. The second attempt at 45, 2.875 was repeated in pattern measurements. The second pattern was taken because RSI was surprised to find any that did not full comply with the reduced spec of 32 dB. The third pattern did repeat almost identically the second pattern and the CPR still turned out to be 31.9. This value is still a decent value should the FCC ever force us to go to this higher frequency.

11. The specification on copolar pattern match was checked at this point only on the phi 45 and 135 cuts. There is an implicit error possible in the manner that the data were taken. The center of the chart (i.e., boresight) was aligned by eye to maximum copolar signal level. Since this is a rather broad null, it is likely that there was some error in the placement and this is reflected in the tables. When the uncorrected values were used as input to the matching program, there were 5 second run and 15 first run pattern pairs which exceeded specifications. In order to correct for this alignment error in the charts, the following was adopted. First the maximum value obtained in the digital tables was set to 0 dB. Secondly the angles which corresponded to a reduction of 1 dB was adjusted so that the angle on the minus theta was equal to minus the positive theta angle. When these corrections were made, there were only two values out of spec and both of these were at the frequency of 2.875 GHz.

Corrected Copolar Matching First Run

Phi angle	freq	-3	+3	-10	+10	-20	20
135	2.725	-.070	-.208	-.356	.025	-.063	-.071
45	2.725	.331	.206	.338	.140	.474	-.113
135	2.800	-.335	-.355	-.177	-.888	.445	-.595
45	2.800	-.197	.177	.337	.138	.755	-.086
135	2.875	.185	-.054	.069	-.387	1.319	-.630
45	2.875	.235	-.001	.560	-.835	1.160	-.058

Corrected Copolar Matching Second Run

Phi angle	freq	-3	+3	-10	+10	-20	20
135	2.725	.472	.124	.566	.156	1.290	-.642
45	2.725	.236	.059	-.288	.176	-.405	.450
135	2.800	-.038	.407	-.558	.620	-.347	.418
45	2.800	.016	.321	.109	.526	.313	.219
135	2.875	.120	.046	-.190	.844	-.735	.601
45	2.875	.384	-.670	1.420	-.437	2.202	-.773

12. Specification 12 was missed in several patterns but in the light of the good CPR measurements this is not considered a problem. This specification would be much more serious for point target work than distributed targets where the value of CPR is the critical parameter.

Mechanical Specifications

The only mechanical specification that is subject to confirmation is that of surface accuracy. At present the best statement that can be made is that according to RSI measurements, the surface accuracy measured 0.016 inches initially and after the take down and reassembly it measured 0.020 inches. There was some differences in all of the specifications after take down, but there is not always a degradation of the measurements on the second runs. The surface accuracy has met the specifications. CSU has been furnished with calculations that confirm meeting the strength specifications. All other mechanical and general specifications have been met.

Appendix C

1993 CSU-CHILL Newsletter

CHILL RADAR NEWS

from

Colorado State University

Overview
(Steven Rutledge, Scientific Director)

This is the third 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 activities of the CSU-CHILL facility, including research, education, and refurbishment activities. In April 1990 Colorado State University was awarded a 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 Colorado State University. Co-Principal Investigators for the cooperative agreement are Profs. Steven Rutledge and Stephen Cox in the Department of Atmospheric Science and Prof. V. N. Bringi in the Department of Electrical Engineering.

The past year has been a busy period for both research and education projects. The use of the CSU-CHILL radar is granted by the National Science Foundation after review by the NSF Facilities Advisory Committee and Observing Facilities Advisory Panel. However, for projects not needing more than approximately 20 hours of radar operational time, the Scientific Director of the CSU-CHILL facility can award the use of the radar for such projects. In these projects, radar operational costs are provided by the cooperative agreement. We have supported nine 20 hour projects in the past year, as detailed in the following section. These small projects allow investigators to conduct highly focused research with the CSU-CHILL radar. The 20 hour projects ranged from the investigation of multiparameter variables in winter storms to insect migration studies. This winter the CSU-CHILL facility will provide radar support for the NSF-supported WISP94 (Winter Icing and Storms Project) program.

In late November 1993, the present CSU-CHILL antenna will be replaced with a new antenna (reflector and feedhorn) built by Radiation Systems, Inc. of Sterling, VA. The acceptance tests presently being conducted indicate the new antenna will be superior to the existing antenna, especially in sidelobe suppression, matching of the main beam pattern between horizontal and vertical polarizations, and cross-polar isolation. The latter quantity is critical to the measurement of L_{dr} (linear depolarization ratio). The new antenna will permit L_{dr} measurements to be made to at least -32 dB.

Additional highlights during the past year included the release of a data base archive to the community (providing computer-based searches of CSU-CHILL data archives), the release of a new facility description and users guide, and the continued development of the NCAR Titan software system to enhance our real-time display capabilities.

Radar Operations Summary
(Pat Kennedy, Facility Manager)

Nine 20 hour projects were supported at the CSU-CHILL facility during the past 12 months. The target data sets sought in these projects covered a broad spectrum of meteorological conditions.

Three of the projects focused on winter precipitation events. Rita Roberts of NCAR (and M.S. candidate at CSU) directed multi-parameter CSU-CHILL scans in coordination with the Mile High Radar (MHR) operated by NCAR. This synchronized scanning was designed to permit the CSU-CHILL multiparameter data to be examined within the context of dual Doppler-derived wind fields. In conjunction with the WISPIT field project, Andrew Benjamin, a recent Ph.D. graduate in the CSU Department of Electrical Engineering, collected multiparameter data in close proximity to the NCAR King Air research aircraft while it penetrated various types of snow echoes. This allowed him to compare the radar data to the hydrometeor spectra observed by the aircraft probes. In a similar vein, Pat Kennedy made ground observations of snow characteristics at the Ft. Collins Loveland Airport while the CSU-CHILL scanned the airfield vicinity at low elevation angles. The goal was to compare variations in aircraft ground icing conditions to changes in the multiparameter radar data patterns.

Four projects sampled convective season storms. Larry Carey, a graduate student in the CSU Atmospheric Science Department (ATS), developed and installed instrumentation to monitor electric field variations near the CSU-CHILL site. The in-cloud lightning activity deduced from the electric field instrumentation is being related to graupel production within thunderstorms. As a particular example, Fig. 1 illustrates the in-cloud (IC) flash rate and graupel content (deduced from multi-parameter measurements) for a multi-cell thunderstorm on 21 May 1993. The evolution of graupel storm volume is highly correlated to the IC flash rate, especially during initial storm development when both quantities grow exponentially. Profs. Bringi (CSU Electrical Engineering) and K. Aydin (Pennsylvania State University), observed hailstorms with CSU-CHILL during the NCAR RAPS93 field project. They sought to associate various multiparameter signatures to hail encounters documented by NCAR chase vehicles. Finally, for a second season, Ray McAnelly (ATS) observed the early stages of the aggregation of individual convective echoes into mesoscale convective complexes. This process was observed through dual-Doppler observations made with the MHR and CSU-CHILL radars.

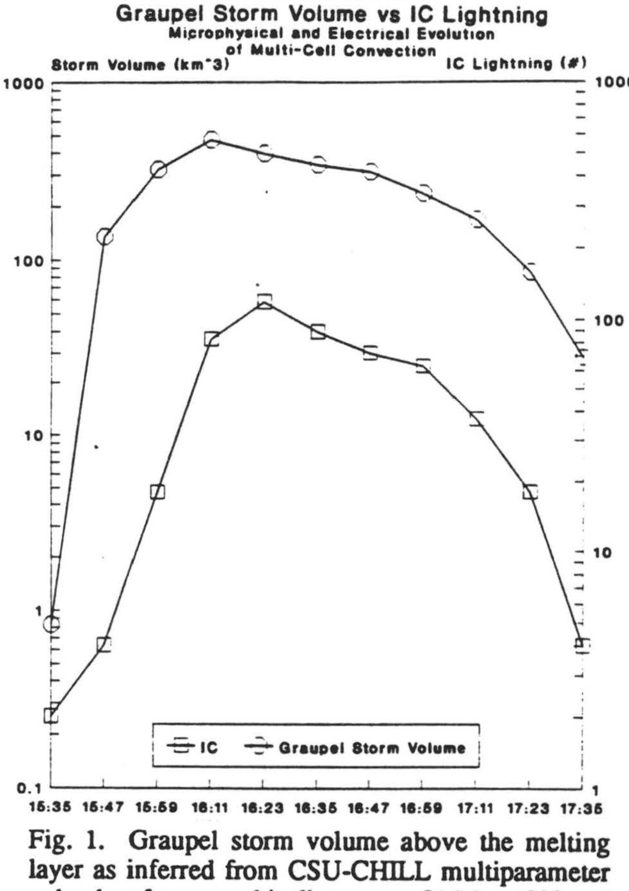


Fig. 1. Graupel storm volume above the melting layer as inferred from CSU-CHILL multiparameter radar data from a multicell storm on 21 May 1993 and number of IC flashes accompanying storm development.

The final two 20 hour projects supported research aircraft operations: Prof. Bob Rauber (U. of Illinois Department of Atmospheric Science) was involved in the testing a new instrument designed to collect cloud ice samples for subsequent chemical analysis. This instrument was being test flown on the NCAR Sabreliner. Prof. Rauber used CSU-CHILL surveillance data to document the echo systems in which the cloud ice was collected. A 20 hour project under the direction of Prof. Tom Holtzer (CSU Entomology Department), was designed to monitor the spring influx of Russian Wheat Aphids into northeastern Colorado. A helicopter equipped with collectors designed and built at the University of Illinois was used to make inflight captures of live insects. Based on transponder tracks obtained from a modem connection to the FAA's air traffic control radar system, the helicopter's real time location was plotted on the CSU-CHILL display. This permitted the collection of coordinated radar and helicopter data sets. High quality data were obtained in all of the above projects. To varying degrees, all of the 20 hour project investigators have started analyses of their data recordings.

New Antenna Update
(Gene Mueller, Senior Engineer)

Since last year's Newsletter, invitations were sent out to various manufacturers for the construction of a replacement antenna for the CSU-CHILL system that was to improve the dual polarization performance above that offered by the present antenna. The lowest responsive bid was for $126,000 from Radiation Systems Inc. (RSI). An award was made at the end of March 1993 to RSI. The original delivery date for the new antenna was 29 October 1993. This has subsequently been revised to 17 November 1993. The delay was required to permit more testing and alignment of the antenna to meet the electrical specifications more completely. The final acceptance tests began on 20 October 1993, with CSU-CHILL staff in attendance.

A new adapter plate for mounting the new antenna to the side arms of the existing pedestal was also required. The original intent was to have NCAR provide a design for the adapter plate of the antenna. After examining the details of this design, particularly that of the antenna mounting procedure, NCAR rightly foresaw considerable difficulty in the design and recommended that the work be done either by RSI or some consulting engineering firm. The structure would require finite element analysis and the facilities for accomplishing this were not available at NCAR. On 19 July a satisfactory proposal was received from RSI for $28,914 to design and make the adapter. This proposal was ultimately accepted and the adapter purchase was added to the RSI contract.

Preliminary testing of the antenna has indicated that it will probably fail in a few cases to fully meet the stringent electrical specifications. The greatest degree of difficulty in meeting the side lobe specifications occurs in the planes which contain the antenna feed horn support struts (phi angle of +/- 45 degrees). The initial antenna pattern tests show that radiation diffractions that occur from these support struts cause "oscillations" in the side lobe levels as a function of the angular displacement from the boresight direction. In the phi = +/- 45 degree planes, the side lobes at angles from 6 to 9 degrees off of boresight exceed the specifications of -33 dB by 0.5 to 1.4 dB. Additionally, the preliminary patterns appear to fail to meet the cross polar ratio, CPR, specification by just a few dB in 3 of the 4 strut planes (+/- 45 degrees, +/- 135 degrees). These differences between the specifications and the antenna performance are minor and it is believed that the new antenna will have outstanding electrical characteristics and will satisfactorily perform all of the desired measurements for which it was intended.

The modified schedule for installing this antenna is as follows. Weather permitting and assuming delivery of the antenna on 11/17/93, the antenna will be assembled on the ground during the period 11/18 to 11/23. Installation on the pedestal is scheduled to take place between 11/30 and 12/3. Following installation, the waveguide requirements will be determined and the necessary new waveguide will be procured to connect the new antenna to the existing polarization switch. NCAR will then fabricate the guide and it will hopefully be ready for installation by 12/23. The new antenna installation should then be completed by the end of December. The biggest unknown in this schedule will be delays due to the weather, which can seriously effect the schedule near the beginning. The new antenna cannot be assembled on the ground in high winds. The old antenna cannot be removed or the new one installed in anything but very light winds. Thus, slippage in these may well occur. With any reasonable luck, the system should be up and running with the new antenna by the start of the Winter Icing and Storms Project on 25 January 1994.

The new antenna will substantially improve all of the variables that depend on the polarization capability of the system. This includes the co-polar variables of differential reflectivity, differential propagation phase, and correlation between copolar horizontal and vertical returns. It will also make possible measurements of linear depolarization ratio, LDR, which until now has been seriously limited by the existing antenna's low isolation between H and V radiation. In addition, artifacts due to sidelobes will be reduced.

Multiparameter Developments

(V. N. Bringi)

On June 24, 1992 an intense storm dumped nearly 3" of rain between 15:15-16:15 MDT at CSU's main campus and in Fort Collins. Observers at CSU noted that precipitation started with a few big drops followed by intense rain and then mixed with hailstones of 0.75" diameter. This storm moved SE towards the radar and the South Dakota School of Mines and Technology T-28 made several penetrations of this storm. The storm was scanned by CSU-CHILL, CP-2 and Mile High radars. In this short communication we focus on rainfall rate comparisons between radar and raingage using specific differential phase at S-band (K_{DP}, $^{\circ}$ km^{-1}) from the CSU-CHILL radar, and X-band specific attenuation (A, dB km^{-1}) from the CP-2 radar. Because rain was mixed with hail, both Z-R and Z-Z_{DR}-R methods would have failed to estimate rain intensity during most of this event. Moreover, rainrate estimates from K_{DP} and A are independent of system gain which is an important advantage over methods based on reflectivity alone. Professor K. Aydin from Penn State, who is spending a semester at CSU on sabbatical is participating in this on-going study. An overview of this storm was previously given in Bringi et al. (1993).

Figs. 2a,b show a low elevation angle PPI scan from CSU-CHILL of the storm at 15:36 MDT, (a), showing reflectivity contours (30, 45 and 60 dBZ) overlaid with Z_{DR} shown in grey-scales, and (b) K_{DP} shown in grey-scales overlaid with the same reflectivity contours. K_{DP} is obtained by adaptively filtering range profiles of ϕ_{DP} which is the differential propagation phase, and taking the range derivative, see Hubbert et al. (1993) for details. An identical procedure was used to obtain A from CP-2 range profiles of the dual-frequency reflectivity ratio at S and X-bands. The weighing-bucket raingage, which is part of the weather station located on the main campus at CSU, is at X=-37.7, Y = 15.4 km with CSU-CHILL radar at the origin. At 15:36 MDT the gauge is located within the >60 dBZ contour (when Z_{DR} is around 0 dB indicating presence of hail), and within the high K_{DP} region (indicating heavy rainfall). Since K_{DP} is proportional to the difference between the forward scattered field amplitudes at horizontal and vertical polarizations, it is responsive to the oblate raindrops while being insensitive to the quasi-spherical tumbling hail particles. On the other hand, Z_{DR} is responsive to the reflectivity-weighted mean axis ratio of the larger hailstones which is close to unity ($Z_{DR} \approx 0$ dB).

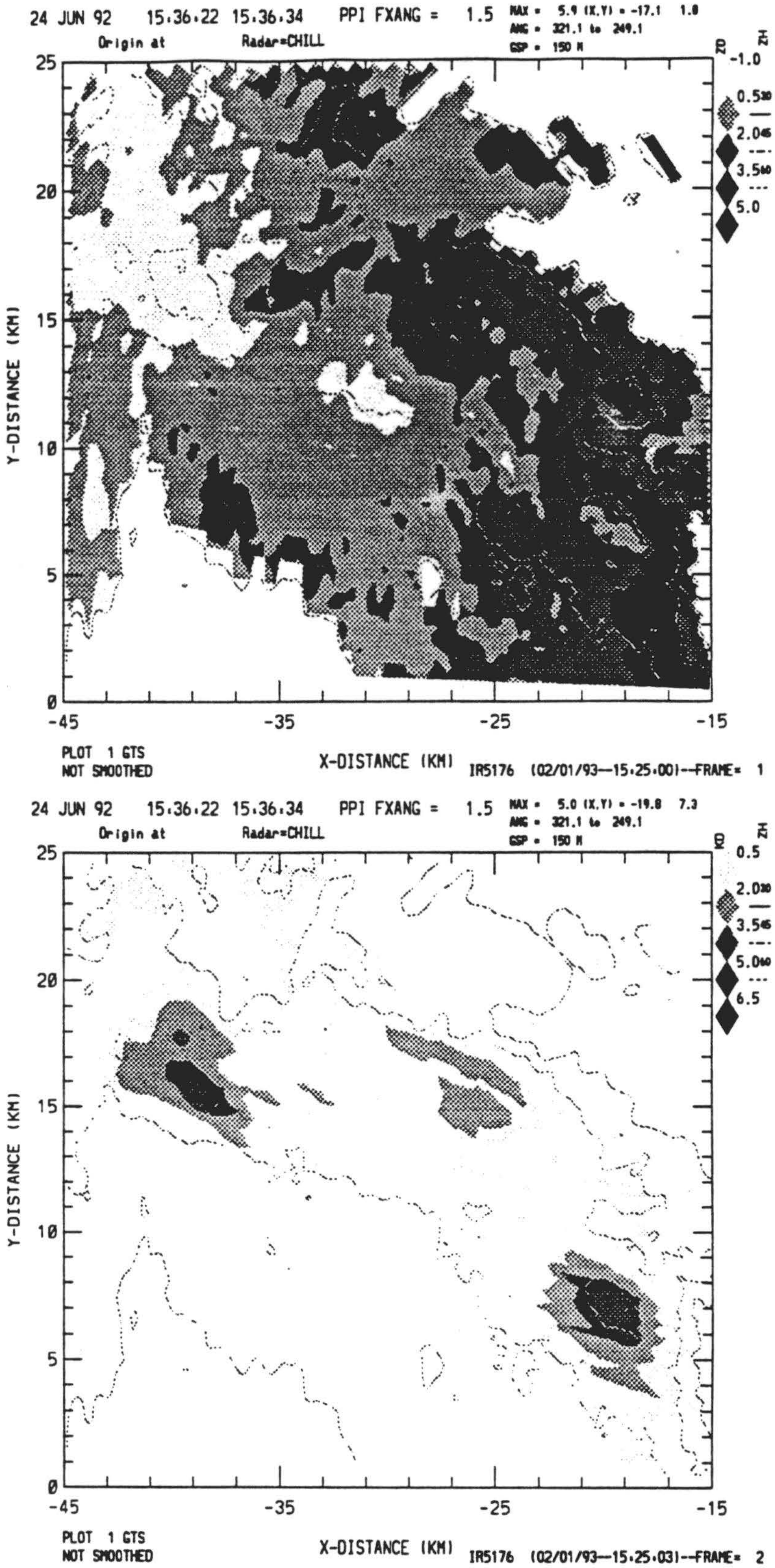


Figure 2: Overlay plot of a low elevation angle ppi showing two reflectivity cores (at 20 and 45 km). Raingage is located at X=-37.7 km, Y=15.4 km. Parameters plotted are:
(a) Z_{DR} (shown in gray-shades) overlaid with Z_H contours (30, 45 and 60 dBZ contour lines).
(b) K_{DP} (shown in gray-shades) overlaid with Z_H contours (30, 45 and 60 dBZ contour lines).

Since the K_{DP} cell identified in Fig. 2b was responsible for the gauge-measured rainfall, an estimate of its movement was obtained from successive PPI scans to be propagating nearly W to E (70° from N) at 4 m s^{-1}. The method used for comparing radar and gauge rainrates is as follows. For each low elevation angle (0.8° for CSU-CHILL and 0.5° for CP-2) PPI scan $R(K_{DP})$ and R(A) were estimated along the cell track intersecting the gauge location. The mean relationships used were $R(K_{DP}) = 40.5\,(K_{DP})^{0.85}$ and $R(A) = 54.5\,(A)^{0.845}$ mm h^{-1}. An along track section of the R-profiles between 0.2 and 1.4 km SW of the gauge location were averaged to correspond to a time period of 5 min for a cell moving at 4 m s^{-1}. This was done to match the 5 min resolution of the gauge record. Thus, for each PPI scan (a total of 8 were analyzed for each radar), an averaged $R(K_{DP}|t)$ and R(A|t) were obtained. Fig. 3 shows the comparison of $R(K_{DP}|t)$, R(A|t) with gauge rain rate (R_g) estimated every 5 minutes from the analog strip-chart rainfall accumulation record. The rainrate "pulse" is well-reproduced both in magnitude and in time by the two radars (ranges to the gauge were 40.7 km for CSU-CHILL, and 71.4 km for CP-1). Because independent data from two radars were used, and because the data processing algorithms to estimate K_{DP} and A were identical, we believe that the gauge/radar comparisons demonstrate the ability of multiparameter radar to accurately estimate the higher rainrates ($R \geq 40$ mm h^{-1}) independent of system gain uncertainties, even when hail is present.

A simpler gauge/radar comparison would directly compare $R(K_{DP}|t)$ and R(A|t) obtained from a fixed resolution volume closest to (and above) the gauge but shifted in time (~3.5 min) to match the "peak" of the gauge measured rainrate "pulse". Fig. 4 shows the comparison results which again shows the power of multiparameter radar in measuring the rainrate "pulse" both in magnitude and time.

The rainfall accumulation over a 50 min time period (20-70 min in Figs. 3 and 4) compares as follows:

Method	Rainfall Accumulation, mm	% difference relative to gauge
Gauge	73.3	0
K_{DP} (Fig. 3)	80.6	10
A (Fig. 3)	77.5	6
K_{DP} (Fig. 4)	70.3	-4
A (Fig. 4)	72.4	-1

In those regions where rainfall is accompanied by hail, the K_{DP} method appears to be the most suitable for estimating R with a single radar. Such radars can potentially serve as "ground-truth" for evaluating rainfall accumulation algorithms based on Z-R techniques, e.g., the NEXRAD precipitation algorithms.

Software Engineering

(Dave Brunkow, Software Engineer)

LDR Calculation

The arrival of the new CSU-CHILL antenna has prompted the addition of a Linear Depolarization Ratio (LDR) Mode to the existing polarization options. In this mode, the four pulse polarization sequence is VHXH, where V and H are copolarized Vertical and Horizontal samples, and the X is a transmit H, receive V sample. This allows the calculation of all the VH mode fields (Z, Zdr, Velocity, Phidp, RhoHV(0)) plus LDR (which is 10.0*log(Shv/Shh)).

With the new antenna, the lower limit of LDR observable by the CSU-CHILL radar will be determined by the isolation of the ferrite polarization switch (~ -20 dB). In the future, we would like to replace the existing polarization switch with a dual-channel rotating joint and a completely separate transmitter/receiver system. This combination will reduce the LDR threshold for the CSU-CHILL system to the cross-pole isolation provided by the antenna. Even with the existing switch, areas of high decorrelation which have been associated with mixed phase precipitation will be detectable. The LDR mode will be available for testing in January 1994 after the new antenna is installed.

Remote Data Display

Interactive displays of real-time and archived CSU-CHILL radar data were available during 1993 at CSU's Atmospheric Sciences and Electrical Engineering departments. The software in use is the TITAN package developed by Mike Dixon of NCAR-RAP. It consists of a Cartesianizer, cell tracker, data server, and a viewing program. The first three parts run on workstations at the radar, while the viewing program can be run anywhere on the network.

The viewing program is divided into two parts; One presents horizontal and vertical cross-sections through the grid, The second (optional) part provides three windows that present time-height views of statistics on individual cell which have been identified and tracked by the software. Online help is available for information on the numerous menu buttons available.

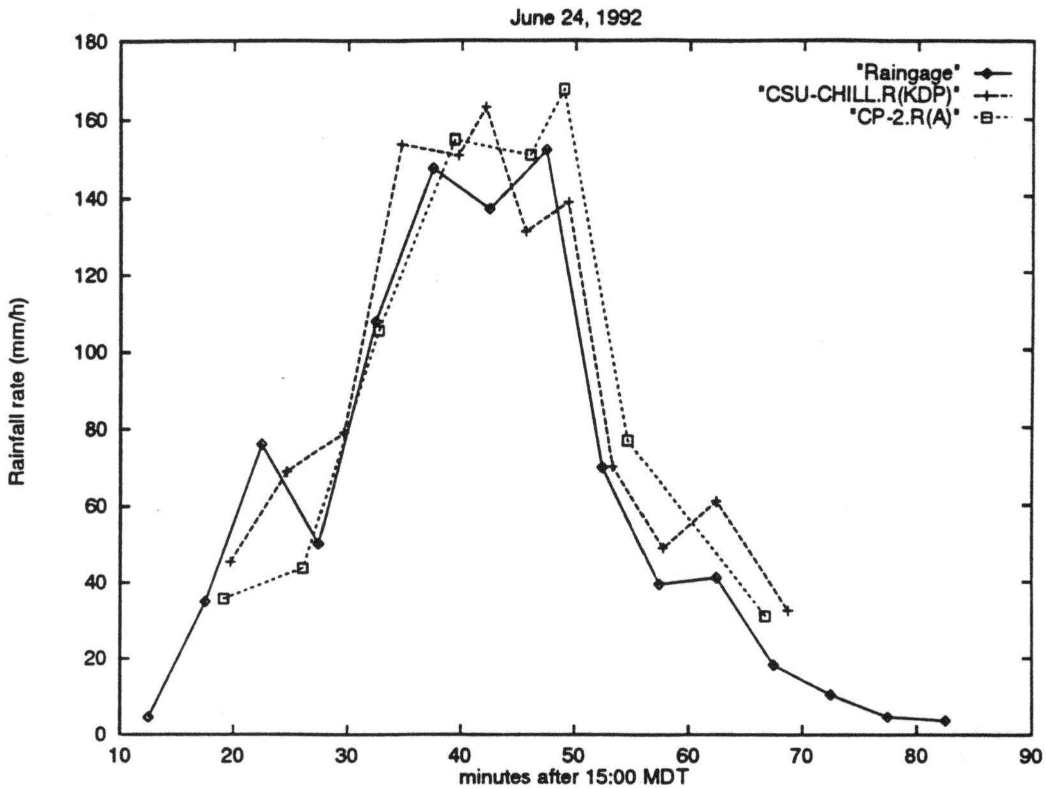


Figure 3: Rain rate comparisons from gage, R(KDP) and R(A).

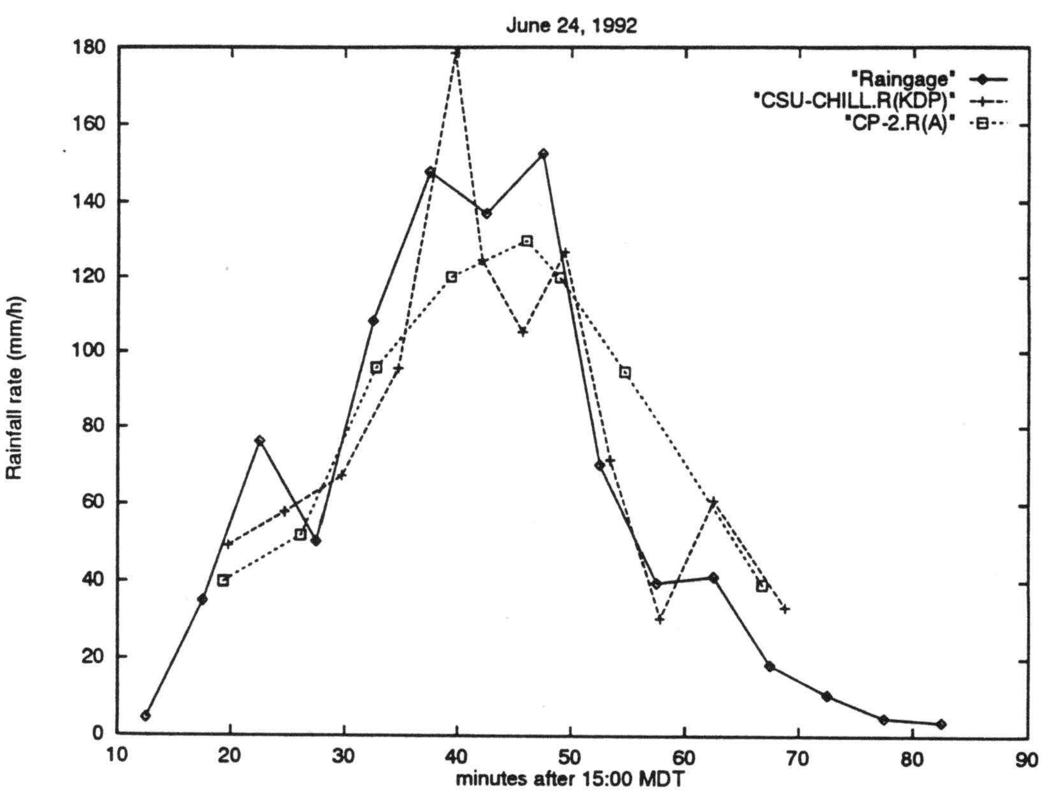


Figure 4: Rain rate comparisons from gage, R(KDP) and R(A).

The grid size and location can be adjusted to suit the needs of the project. For a typical summer situation, a 230 by 230 by 15 grid has been used with a 1 km grid spacing. This provides a good overview of what the radar is observing. Furthermore, since the TITAN data sets are compact, two to four weeks of data can remain online at one time. This will be useful as a perusal mechanism to allow researchers to select cases for further study. TITAN data sets can also be converted for use by ZEB, and this form of data is presently being considered as a means of distributing sample CSU-CHILL data sets to researchers.

A sample of a monochrome (postscript) plot of a TITAN CAPPI section is shown in Fig. 5. The CAPPI also displays the current position of a cell, its past (30 min) history, and an extrapolation of its future position.

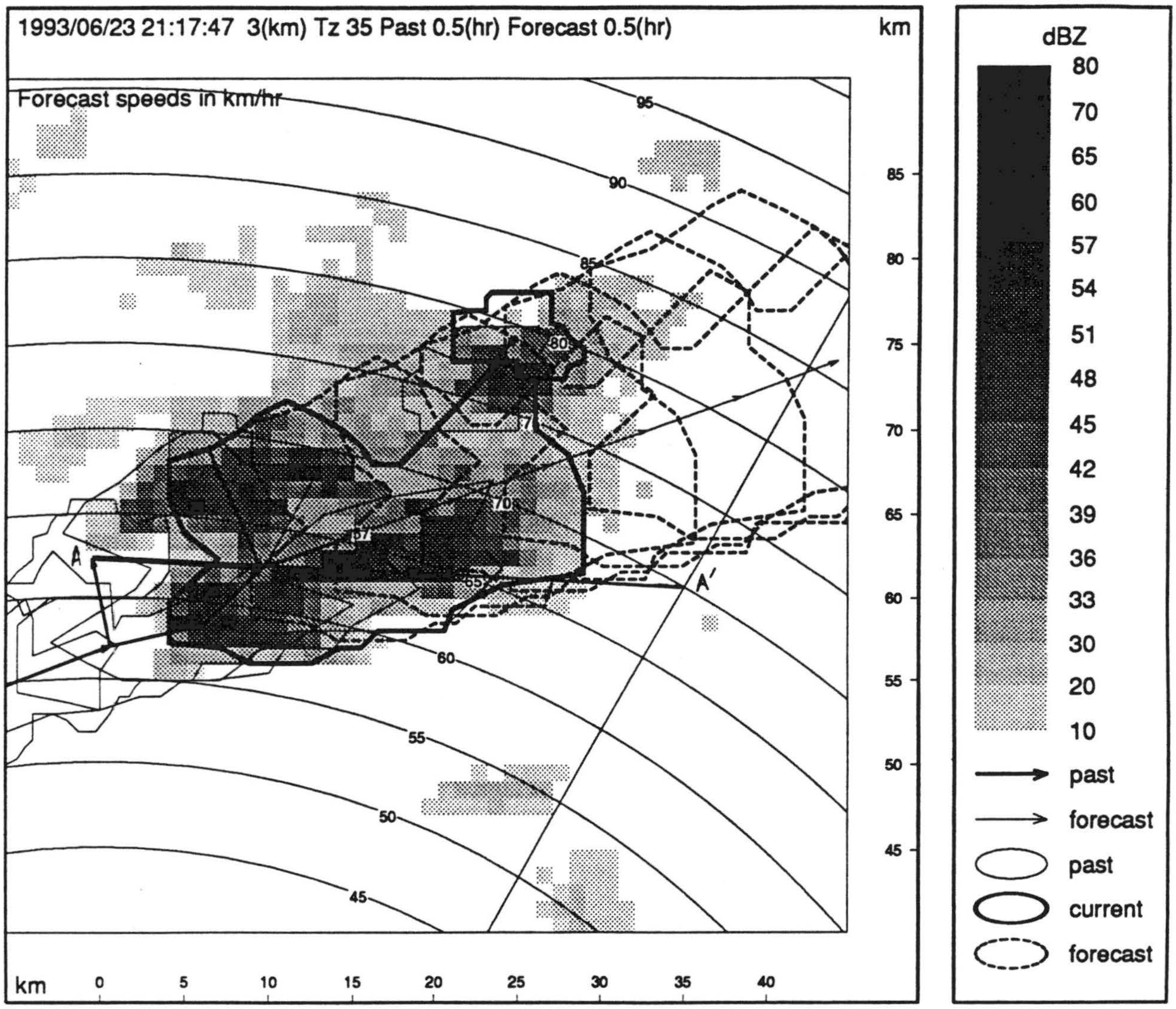


Figure 5: CAPPI - CHILL Reflectivity

List of Publications Using CSU-CHILL Data

CHILL Publications

1992-1993 CHILL Publications

In this section, all publications for the period 1992-1993 which used data collected by the CSU-CHILL radar are listed. Studies by both CSU and non-CSU researchers are included.

Reviewed publications:

Changnon, S. A. 1992: Temporal and spatial relationships between hail and lightning, *J. Appl. Meteor.*, **31**, 587-604.

Czys, R. R. and R. W. Scott, 1993: A simple objective method used to forecast convective activity during the 1989 PACE cloudseeding experiment. *J. Appl. Meteor.*, **32**, 996-1005.

Hallett, J., M. Wetzel and S. A. Rutledge, 1993: Field training in radar meteorology. *Bull. Amer. Meteor. Soc.*, **74**, 17-22.

Kennedy, P. C., N. E. Westcott, and R. W. Scott, 1992: Single Doppler radar observations of a tornadic mini-super cell thunderstorm. *Mon. Wea. Rev.*, **121**, 1860-1870.

Liu, L., V.N. Bringi, V. Chandrasekar, E.A. Mueller and A. Mudukutore, 1993: Analysis of the copolar correlation coefficient between horizontal and vertical polarizations. Submitted to J. *Atmos. Oceanic Tech.* (under review).

Rasmussen, R., M. Politovich, J. Marwitz, W. Sand, J. McGinley, J. Smart, R. Pielke, S. Rutledge, D. Wesley, G. Stossmeister, B. Bernstein, K. Elmore, N. Powell, E. Westwater, B. Stankov, and D. Burrows, 1992: Winter Icing and Storms Project. *Bull. Amer. Meteor. Soc.*, **73**, 951-974.

Rutledge, S. A., P. C. Kennedy, and D. A. Brunkow, 1993: Use of the CSU-CHILL Radar in radar meteorology education at Colorado State University. *Bull. Amer. Meteor. Soc.*, **74**, 25-31.

Papers presented at the 26th International Conference on Radar Meteorology (Norman, OK 24-28 May, 1993):

Achtemeier, G. A., R.W. Scott, and P. C. Kennedy: The Champaign macroburst: a rare radar event?

Benjamin, A., and V. Chandrasekar: Polarimetric radar and aircraft observations of winter storms.

Bringi, V. N., D. Brunkow, V. Chandrasekar, S. Rutledge, P. Kennedy, and A. Mudukutore: Polarimetric measurements in Colorado convective storms using the CSU-CHILL radar.

Hubbert, J., J. Caylor, and V. Chandrasekar: A practical algorithm for the estimation of Doppler velocity and differential phases from dual polarized radar measurements.

Kennedy, P. C. and S. A. Rutledge: Combined dual-Doppler and multiparameter radar observations of a Colorado bow echo hailstorm.

Liu, L., V. N. Bringi, V. Chandrasekar, E. A. Mueller, and A. Mudukutore: Statistical characteristics of the copolar correlation coefficient between horizontal and vertical polarizations.

McAnelly, R. L., J. E. Nachamkin, W.R. Cotton: Upscale growth processes in a mesoscale convective system.

Xiao, R., V. N. Bringi, D. Garbrick, E. A. Mueller, and S. A. Rutledge: Copolar and cross polar pattern measurements of the CSU-CHILL antenna.

Appendix D

Summary of Greeley Data Collection Activities through 2/1/94

Project	Period	Outcome
1991		
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; Class-room 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).
1992		
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	Observational data for NSF funded modeling study.
Connell (20 hr)	July-August	Exploratory data.
Rauber	October	Cloud water sampler test on Sabreliner.

1993:

Kennedy	Feb - April	Aircraft ground icing study.
Chandra (WISPIT)	Feb - March	In-situ aircraft / multi-parm radar comparison.
Roberts (WISPIT)	Feb - March	Combined dual-Doppler and multi-parm radar analyses.
Carey	May - June	Multiparameter radar and storm electrification study.
Holtzer	May - June	Radar observations of insect migration.
Aydin	June	Multi-parameter radar hail detection.
Bringi	July	" "
McAnelly	July - August	Upscale evolution of mesoscale convective systems.
WISP94	Jan - March	Winter storms and icing project (NSF supported NCAR project).

Appendix E

Recent letters from CSU-CHILL Radar Advisory Committee Members