Annual Report for

THE CSU-CHILL RADAR FACILITY

Cooperative Agreement No. ATM-9500108

Submitted to

The National Science Foundation

Division of Atmospheric Sciences

15 January 1996

Colorado State University

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

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1. Introduction

Activities at the CSU-CHILL National Radar Facility from 1 January 1995 to 31 December 1995 are summarized in this annual report. This report is the first report submitted under our new Cooperative Agreement with the National Science Foundation, which commenced on 1 May 1995. This past year marked a major milestone for the Facility as our dual channel system, consisting of two complete transmitters and receivers, achieved full operational status. The purpose of this new system was to achieve full polarization capabilities without using a polarization switch. Eliminating the polarization switch resulted in a highly reliable and stable system for dual-polarization data collection, and increased the dynamic range of the cross-polarization measurement (Ldr, Linear Depolarization Ratio) by more than 10 db. Satisfactory testing of this new system was achieved in April and early May 1995, through examination of a variety of weather echoes, and careful scrutiny of times series data by the Department of Electrical Engineering. The system passed these tests with flying colors. From mid-May to mid-August, the new CSU-CHILL system was used in many field projects conducted at it's home base in Greeley, CO. Initial examinations of data collected in these research projects look quite satisfactory.

The projects supported this past summer included three projects supported by the NSF, and the Deployment Pool. These projects included Hydrometeor Verification, using the SDSMT T-28 aircraft to collect in-situ microphysical data in hailstorms, a Research Experience for Undergraduates (REU) project, and a project involving the NCAR Sailplane to study early microphysical and electrical development in fledgling thunderstorms. Several 20 hour projects were also conducted this past year, as detailed in the following section of this report. One of these 20 hour projects provided unprecedented ground verification data for multiparameter radar estimates such as hail size, drop shape and rainfall rate in heavy convective rain (often consisting of a mixture of hail and rain, where estimates of rain rate are contaminated by the presence of hail).

Several maintenance items and the need for system improvements in a few areas also became evident in the past few months. These items are now receiving attention. We are now moving to a pressurized wave guide system to allow us to run full power (1 Mw peak) in the multiparameter mode. Arcing has been experienced in the dual-channel rotary joint at power levels exceeding 600 kw when pressurization is not used. We have also obtained a new focus coil for one of our transmitters and will soon have this installed. This upgrade will bring both transmitters to identical levels from a component standpoint. During the past summer's operations, occasional imbalances were also noted in the receivers, introducing small errors in differential reflectivity. This problem was traced to temperature differences between the two Low Noise Amplifiers in the receiver front ends. We have now placed both LNA's on a cold plate to maintain constant temperatures, and therefore matched gains.

We will also address long term plans in this report including development of more advanced signal processing capabilities, and continued exploratory work in pulse compression and short pulse transmission capabilities.

This summer will prove to be another busy time for data collection at the radar since we will be supporting several projects. The major program we will support this summer is STERAO. This program will see the CHILL and NCAR/NSF WB-57F deployed in conjunction with a NOAA WP-3D aircraft to study the effects of deep thunderstorms on the chemistry and water vapor content in the upper troposphere and lower stratosphere. We will also support another REU project coordinated by Prof. Chandrasekar in the Department of Electrical Engineering. We also anticipate supporting several 20 hour projects, which will, as last summer, include the use of three instrumented vans to measure hail and raindrop size distributions and various lightning parameters, to continue our work in examining the use of multiparameter radar to quantify hail size convective rain rates, and diagnose stormscale microphysical processes.

A color brochure describing the technical aspects of the CSU-CHILL radar as well as information on how to access the facility has also been completed. This brochure will soon be distributed to a broad mailing list. A copy of the new brochure is attached as Appendix E.

2. Summary of Activities During 1995

a. Radar Operations Summary: 1995

The CSU-CHILL Facility supported a total of eight individual research projects during 1995. Three of these projects were funded by the NSF, while the remaining five observing programs fell into the smaller, 20 hour project category.

The first NSF-sponsored project was a Research Experience for Undergraduates (REU) effort directed by Prof. V. Chandrasekar of the CSU Electrical Engineering Department. Eleven students from four states participated in this REU project. The students played significant roles in the installation and operation of several types of hydrometeor sensors in two storm intercept vans. These instruments permitted observations to be made of number of hydrometeor parameters, including size, shape, and thermodynamic phase. The vans intercepted thunderstorm precipitation cores based upon real time guidance received from the project operations center in the CSU-CHILL user van. Several of the REU students will be basing their senior year engineering projects upon data collected by the storm intercept vans.

The second NSF project of the summer was centered on the armored T28 aircraft operated by the South Dakota Schools of Mines and Technology(SDSMT). The principal investigators for this program were Drs. D. Zrnic and J. Straka of the University of Oklahoma, along with Profs. V. N. Bringi and S. A. Rutledge of CSU. This project was designed to relate *in situ* hydrometeor observations made with the T28 to multiparameter radar measurements. Part of this effort was to evaluate the performance of the new dual-channel system at CSU-CHILL. Coordinated aircraft / radar data sets were collected in a variety of precipitation situations including a severe hailstorm (22 June), and a bright band within an upslope rain event (28 June).

The third NSF sponsored project was a study of the initial electrification of developing cumulus clouds directed by Dan Breed of NCAR's Mesoscale and Microscale Meteorology (MMM) Division, In-cloud data were collected with the NCAR instrumented sailplane. The sailplane's GPS-determined location was telemetered to CSU-CHILL in real time (as were the T28 locations). This GPS data was then transferred to the radar's antenna control computer so that the radar scans automatically remained centered on the sailplane (a T28) as it maneuvered in the cloud of interest. This technique was successfully used on a total of ~6 operational days. Notable data sets were acquired on clouds in the first echo stages (13 July), as well as in more mature cumulonimbi (10 August).

Five 20 hour projects were conducted on a non-interfering basis with the three NSF-sponsored programs. In chronological order, the first of these 20 hour projects was a storm electrification study directed by Prof. Steven Rutledge and one of his Ph. D. students, Larry Carey. Measurements of corona current and lightning-induced electric field fluctuations were made at the Greeley radar site. A field mill loaned by NASA was also installed at the CSU atmospheric science building (~40 km WNW of CSU-CHILL). A duplicate mobile corona point system was installed in a van to permit suitably close range sampling of the electrification of selected storms. Storms of interest were monitored through full volume, multiparameter data mode scanning by the CSU-CHILL. On 7 and 22 June, joint radar and mobile corona point observations were made of storms which produced large diameter (>2 cm) hailstones. Larry

Carey was awarded the Spiros Geotis Prize at the recent (27th) AMS Conference on Radar Meteorology for a paper based on the 7 June data set.

Prof. V. N. Bringi was interested in the collection of *in situ* precipitation data that could be used to verify various multiparameter radar-based methodologies for rainfall estimation. To this end, he arranged for the use of a 2D video disdrometer and two different types of portable hail samplers. (One using optical imaging, and the other designed to physically collect the falling hailstones). These instruments were installed in the two storm intercept vans operated during the REU95 program. Prof. Bringi was able to record direct observations of significant hail (7 and 22 June), as well as heavy rain (2 June and 8 August). Simultaneous dual polarization radar data were collected by CSU-CHILL during all of these events.

Drs. Al Bedard (Supervisory Physicist at NOAA's Boulder ERL Facility), Roger Pielke (Professor of Atmospheric Science at CSU), and Mel Nichols (Atmospheric Science Research Scientist at CSU) were interested in radar observations to complement their investigation of the relationship between convective storms and the production of ultra low frequency sound waves. To locate infra-sound sources, microphone networks and their associated data processing systems were installed at the CSU-CHILL site and at NOAA's Erie Colorado field site. Additionally, mobile infra-sound equipment was used during the final week of the project. During the intensive field effort period of this project in late August, convective organization varied from isolated cells to multiple thunderstorm clusters. It is expected that a similarly wide variety of infra-sound patterns were recorded during this same time.

Dr. Andy Heymsfield, Senior Scientist in NCAR's MMM division, was interested in radar monitoring of ice cloud systems that were being penetrated by his balloon-borne particle replicator. This instrument is carried aloft along with a CLASS radiosonde. During the ascent, motion picture film stock coated with liquefied formvar plastic is moved by an opening that is exposed to the passing airstream. Impacting cloud particles become embedded within the formvar layer, and ultimately leave high definition molded replicas of their shapes. After the balloon bursts at the top of the flight, the replicator package is returned via parachute for ground recovery. The most successful flight during this program took place on 19 July, when the replicator penetrated anvil debris from a thunderstorm near Estes Park.

The final 20 hour project supported during 1995 was a convective boundary layer study conceived by Dr. Keith Browning of the of the UK Meteorology Office during his visit to CHILL. Before storm development began, the radar took volume scans composed of RHI sweeps at 6 degree azimuth intervals around the entire horizon. This data acquisition mode allowed the height of the radar-observed boundary layer to be mapped over the general surveillance area. Dr. Browning's hypothesis was that convective storms would tend to initially develop in areas where the greatest boundary layer deepening had occurred. On at least two afternoons, the radar surveillance RHI's included the initiation phase of scattered thunderstorms. Tape copies of the CSU-CHILL data recorded during these cases are currently being examined by members of Dr. Browning's group.

b. Educational Support

In addition to continuing to provide data for M.S. theses and Ph. D. dissertations in Atmospheric Science and Electrical Engineering, the CSU-CHILL Facility provided several other forms of educational support during 1995. As noted above, the radar played a central role in the Research Experience for Undergraduates (REU) project directed by Prof. Chandrasekar. The REU students began their activities with introductory lectures given at the Facility by Dr. Eugene Mueller (Operating Principles of Meteorological Radars) and by Mr. Patrick Kennedy (Basic Radar Meteorology and Thunderstorm Morphology). Through their participation in data collection, the REU students were directly exposed to the challenges inherent in field operations of complex instrumentation (i.e. dual polarization radar systems, mobile hydrometeor sensors, data telemetry links, etc.). Prof. Chandra has been funded for a similar REU program in the summer of 1996.

Classroom support was provided in several ways. In October, approximately 60 undergraduate students in CSU's Engineering 100 Course were broken into smaller groups for tours of the radar facility. Emphasis was given to the multiple engineering disciplines (electrical, mechanical, computer science, etc.) that are fundamental to the overall radar operation. Additional undergraduate introductions to the CSU-CHILL system and it's observations were given by Prof. Steven Rutledge in his ATS 350 (Introduction to Weather and Climate) course taught to 70 students in the spring of 1995. Finally, approximately 20 undergraduate students enrolled in the radar meteorology course taught in the Earth Sciences Department at the University of Northern Colorado (Greeley), visited the CSU-CHILL facility on two occasions in the Spring of 1995. During their visits, these students were familiarized with both the hardware aspects of the radar system as well as replays of various example archived data sets.

The dissemination of example CSU-CHILL data via the Worldwide Web internet system was initiated late in 1995. In addition to general information regarding the facility's capabilities, the CSU-CHILL home page also includes sample multiparameter data images from recent operations. (The home page internet address is: http://olympic.atmos.colostate.edu/CHILL/CSU-CHILL.html). Preliminary responses indicate that these example images are of considerable use in radar meteorology courses taught at several institutions around the country. This web page also includes an interface to the facility's electronic data base which contains daily summaries of radar observations.

c. Technical Developments

During the last year, the dual transmitter - dual receiver configuration discussed in last year's report was completed and operated during the Spring/Summer 1995 season. The transmitters operated in an alternating horizontal, vertical sequence. The addition of the second receiver allowed the simultaneous reception of the co- and cross-polarized returns. This doubled the data rate which the signal processor (SP-20) is required to ingest. The strategy employed to process the increased data rate, given a fixed processor capability, is to process half the available range samples. With the typical pulse repetition time (prt) of 1000 usec, 75 of the available 150 km is processed. There is a provision for sliding the start of the processed data out away from the radar as needed to cover the storms of interest. The SP-20 calculates the following fields for display and archiving: Reflectivity (dBZ_h), Mean Velocity, Differential reflectivity (Zdr), Differential phase shift (Phidp), Linear depolarization ratio (Ldr), Normalized coherent power (Ncp), and Correlation (RhoHV(0)). Also archived routinely were the complex covariances at 0, 1 and 2 lags.

The system functioned reliably throughout the operational period producing generally reasonable results. A system for automatically measuring the transmit powers and correcting the Zdr calibration accordingly was implemented. In spite of this, there were still times when unaccounted for variations in the Zdr calibration occurred. This is believed to be caused by the location of one of the low noise amplifiers (LNA's) in a considerably warmer environment (inside the transmitter cabinet) than the other LNA. After the operational period ended, the receiver configuration was changed to allow both LNA's to be mounted on an electronically cooled aluminum plate. In addition, and automated technique for observing the sun and doing receiver (Zdr) calibrations has been implemented. This will allow calibrations to be done as often as deemed necessary if calibration variations are suspected. It was found that the new dual channel rotary waveguide joint would arc occasionally at 600 KW peak power levels. The immediate solution to this was to reduce the peak power to 250 KW levels. After the operational period, work was done to upgrade waveguide sections that were found to be contributing to a poor standing wave ratio. Work was also conducted to allow the entire waveguide system to be pressurized with dry air which was found to eliminate the arcing problem in tests conducted during the fall of 1995.

Future Plans:

One of the fundamental goals during this 5 year cooperative agreement is to develop the capability to collect polarization parameters at antenna scan rates faster than the current 6 degrees per second. This requires increasing the number of independent samples aquired per unit time. The proposed approach is to sample more frequently in range, and then average the (independent) range samples together after the variance calculations have been made to achieve a resulting range resolution of 150 to 400 meters. The higher resolution range samples will be achieved either via the pulse compression of a 2.5 microsecond pulse down to 200 nanoseconds, or by the transmission of a simple 200-500 nanosecond pulse.

To achieve the goal of faster antenna scanning will require the processing of about eight times as many gates as the SP-20 is currently doing. To accomplish this, the SP-20 will be replaced with a more state of the art signal processor as soon as possible. At the same time, the VAX-based data system and Adage display will be replaced. The new processor will include receivers which are digitized at the IF level. Optimal bandpass filtering and quadrature detection will be accomplished in digital electronics which will offer superior signal recovery, linearity, and dc rejection than realized in the current analog receiver design. Signal processor designs by NCAR and by commercial vendors are currently being considered for use with the CSU-CHILL system. We hope to make significant progress on the new signed processing/data display system in the next two years. However progress in this area is strongly coupled to availability of funds.

d. Projects in the Department of Electrical Engineering during 1995

In the Electrical Engineering department analysis effort is being focused on the summer '95 data obtained from the two chase vans and the T-28 penetrations. The severe hailstorm of 7 June 1995 is one case being analyzed with respect to validation of radar signatures using hail size distribution data from the "Hailstone" van (see Fig. 5 of the attached CHILL Radar News).

Several cases using the 2D-video distrometer have already been analyzed, principally related to validation of rainfall rates using various polarimetric parameters. Fig. 6 of the attached CHILL Radar News gives a figure of the Austrian instrument mounted in a van. A proposal to

NSF is being prepared to acquire this instrument as part of the overall validation effort to be used with the CSU-CHILL radar.

Mr. Scott Bolen, an Air Force Ph.D. candidate is back at Rome Laboratory after completing his course work and preliminary exam at CSU. He is working on his dissertation using CSU-CHILL radar measurements obtained from the '94 and '95 summer experiments. A paper on rainfall inter-comparisons with rain gauges in convective precipitation (with hail) is under preparation.

Mr. John Beaver just completed his Ph.D. defense. Part of his research dealt with CSU-CHILL radar measurements along an earth-satellite propagation path used for measuring beacon attenuation at 20 and 27 GHz. He was able to successfully predict attenuation at 20 and 27 GHz using the CSU-CHILL radar measurements along the slant propagation path.

The T-28 penetrations from the 22 June 1995 case are currently being analyzed. The high volume particle spectrometer (borrowed from AES, Canada) performed well on the T-28 and excellent images were obtained from a severe hailstorm event, providing valuable validation data for the radar. These data are being analyzed cooperatively with Drs. Straka and Zrnic from NSSL. Processed CSU-CHILL radar data have been supplied to Dr. Straka for this case.

Three conference presentations were given at the 1996 National Radio Science Meeting held in Boulder 9-13 January in the session titled, "Radar Remote Sensing of the Troposphere", chaired by Dr. Dusan Zrnic. These papers dealt with data from the summer 1995 experiments with the two chase vans and the T-28.

i. Pulse Compression

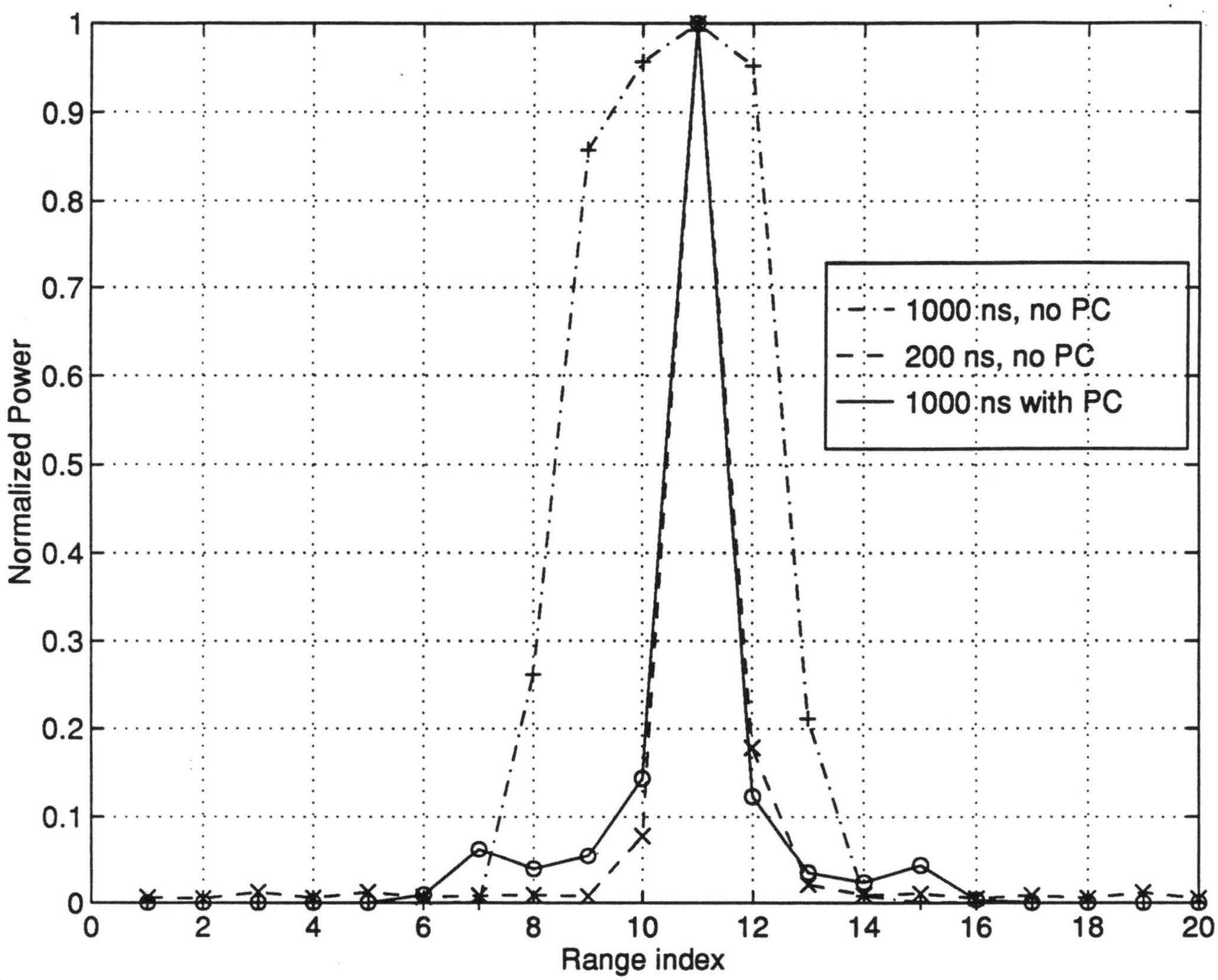
Wideband waveform techniques, such as pulse compression, allow for accurate weather measurements in a short data acquisition time. However, for extended targets such as precipitation systems, range sidelobes mask and corrupt observations of weak phenomena occurring near areas of strong echoes. Therefore, sidelobe suppression is extremely important in precisely determining the echo scattering region. Dual-polarization parameters provide valuable insight into the cloud microphysics and improved rainfall rate estimates. We have conducted extensive evaluation of pulse compression in conjunction with polarization diversity to evaluate implementation of dual polarization measurements at Nexrad scan rates. The results from our evaluation through simulation and data show that pulse compression techniques indeed provide a viable option for faster scanning rates while still retaining good accuracy in the estimates of various parameters that can be measured using a multiparameter radar. Also, it is established that with suitable sidelobe suppression filters, the range-time sidelobes can be suppressed to very low levels.

ii. Fixed point target data

Figure 1 shows the range profile of the normalized returned power from a metallic sphere target using a simple pulse and a 5-bit Barker phase-coded waveform. The dash-dot and dash pattern curves represent returns for a simple transmit pulse of duration 1 microsec and 200 nanosec, respectively. These correspond to range resolutions of 150 m and 30 m, respectively. The solid line represents returns from a 5-bit Barker phase-coded transmit pulse of width 1 microsec after matched filtering on reception. It is evident from the figure that theresolution of the compressed pulse is comparable to that of the uncoded pulse of width 200 nanosec. Also, note the presence of range-time sidelobes on either side of the main peak.

iii. Weather data

Time-series data was collected with the CSU-CHILL radar antenna pointing at the core of a thunderstorm, northwest of the radar. Figure 2 shows the standard deviation in estimates of 10log(P) as a function of number of samples used in estimate, at a fixed range bin. The different curves shown in figure represent the output of simple pulse (solid line), 5-bit Barker coded pulse with matched filtering (dotted line), 5-bit Barker coded pulse with inverse filtering (dashed line), and 5-bit complementary coding (dash-dot line). Five adjacent range samples samples were averaged resulting in a net range-sampling interval of 150 m. The standard deviation values for pulse compression output are lower than those for the simple pulse output by approximately a factor of sqrt(M) (M=5, length of phase-code). With longer code-lengths, better improvement is expected. Accuracy in estimates through range averaging translates into faster antenna-scanning rates and/or improved accuracy and sensitivity in measurements.



Normalized Power
Range index
1000 ns, no PC
200 ns, no PC
1000 ns with PC

Fig. 1

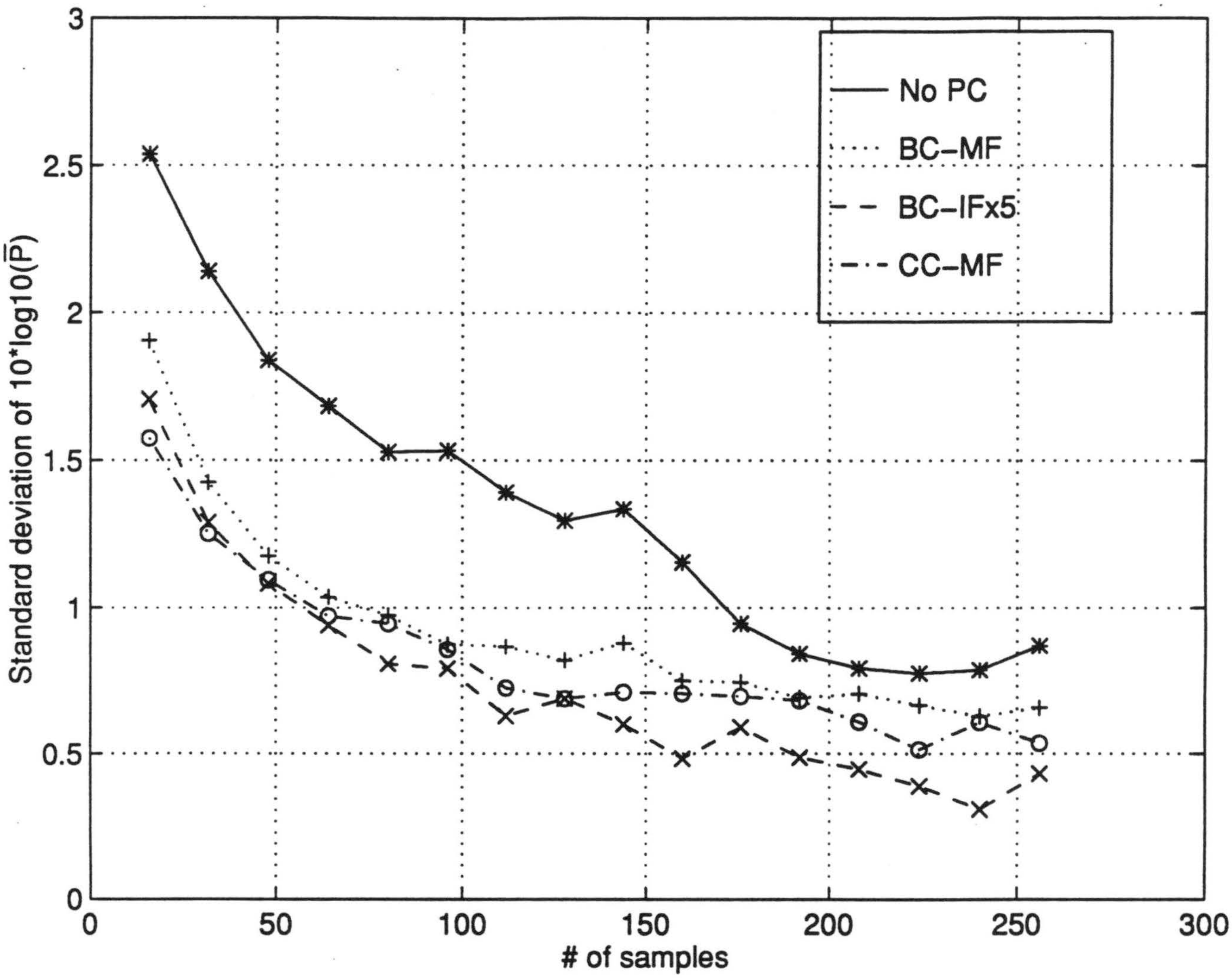

No PC
BC–MF
BC–IFx5
CC–MF
Standard deviation of 10*log10(P̄)
# of samples
0
0.5
1
1.5
2
2.5
3
0
50
100
150
200
250
300

Fig. 2

3. Publications and Reports

<u>Reviewed Publications</u>

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

Kennedy, P. C., and S. A. Rutledge, 1995: Dual-Doppler and multiparameter radar observations of a bow-echo hailstorm. *Mon. Wea. Rev.*, **123**, 921-943.

Mudukotore, A., V. Chandrasekar, and E. A. Mueller, 1995: The differential phase pattern for the CSU-CHILL radar antenna. *J. Atmos. Ocean. Tech.*, **12**, 1120-1123.

Kennedy, P. C., N. E. Westcott, and R. W. Scott, 1995: Reply to the comment of C. A. Doswell on Single-Doppler radar observations of a mini-supercell tornadic thunderstorm. *Mon. Wea. Rev.*, **123**, 236-238.

Bringi, V. N., L. Liu, P. C. Kennedy, V. Chandrasekar and S. A. Rutledge, 1996: Dual multiparameter radar observations of intense convective storms: The 24 June 1992 case study. *J. Meteor. Atmos. Phys.*, **58**, 3-31.

Carey, L. D., and S. A. Rutledge, 1996: A multiparameter radar case study of the microphysical and kinematic evolution of a lightning producing storm. *J. Meteor. Atmos. Phys.*, **58**, 33-64.

<u>Papers presented at the AMS 27th Conference on Radar Meteorology, Vail, Colorado, 9-13 October 1995:</u>

Bolen, S., V. N. Bringi, and L. Liu: Comparison of rainfall from specific differential phase using the CSU-CHILL radar with rain gage data: The 20 June 1994 case.

Carey, L. D. and S. A. Rutledge: Positive cloud-to-ground lightning in severe hailstorms: A Multiparameter Radar Study.

Dobaie, A. M.: Application of Tomographic Technique for the analysis of differential Propagation Phase measurement.

Kennedy, P. C., V. N. Bringi, S. Bolen, and S. A. Rutledge: An examination of dual polarization signatures associated with confirmed occurrences of large hail.

Liu, L., V. N. Bringi, and A. Mudukutore: Statistical fluctuations in multiparameter radar: Comparing radar time series measurements with simulations.

Mudukutore, A., V. Chandrasekar, R. J. Keeler: Range sidelobe suppression for weather radars with pulse compression: Simmulation and evaluation.

Mueller, E. A., S. A. Rutledge, V. N. Bringi, D. Brunkow, P. C. Kennedy, K. Pattison, R. Bowie, and V. Chandrasekar: CSU-CHILL Radar upgrades.

Rutledge, S. A., V. N. Bringi, V. Chandrasekar and P. Kennedy: Interdisciplinary educational uses of the CSU-CHILL Radar at Colorado State University.

Papers presented at the National Radio Science Meeting, Boulder, Colorado, 9-13 January 1996:

Bringi, V. N., V. Chandrasekar, J. Hubbert, R. S. Verlinde, M. Schoenhuber, H. E. Urban,and W. L. Randeu: Precipitation shaft intercepts with a mobile 2D video disdrometer: Coordinated measurements with the CSU-CHILL radar.

Chandrasekar, V., V. N. Bringi, A. Abou-El-Magd: Multiparameter radar and aircraft observations of a hailstorm.

Hubbert, J., V. N. Bringi, V. Chandrasekar, A. Abou-El-Magd, and S. Bolen: Polarimetric measurements in a severe hailstorm.

Kennedy, P. C., D. A. Brunkow, and S. A. Rutledge: Distinguishing frozen and liquid precipitation using a dual polarization radar system.

Other Publications

Mudukutore, A., V. Chandrasekar, and R. J. Keeler, 1995: Simulation and analysis of Pulse Compression for Weather radars, IGARS, Firenze, Italy, 10-14 July.

4. Report on Cost Sharing Activities

The following describes cost sharing expenditures at CSU for the first year of the Cooperative Agreement.

	YEAR 1 4/15/95- 2/1/96	Cumulative through 2/1/96
Furniture and grounds	60	60
Materials, parts, supplies, paint	915	915
Salaries and services	31,151	31,151
Telephone and postage	1,014	1,014
Vehicles and fuel	280	280
Equipment	12,517	12,517
Indirect cost @ 45%(a)	15,039	15,039
TOTAL	$60,976	$60,976
Estimate 2/1/96 - 4/30/96	27,124	27,124
TOTAL	$88,100	$88,100

5. Statement of Unobligated Funds

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

6. Changes in Project Personnel

Dr. Eugene Mueller, Senior Engineer, retired on 30 June 1995. David Brunkow, Computer Engineer, was promoted to Senior Engineer to replace Dr. Mueller. Robert Bowie, a highly experienced former NCAR technician, was hired on 1 April 1995. There were no other changes in personnel.

7. Current and Pending Support

CURRENT AND PENDING SUPPORT
Steven A. Rutledge
1/19/96

A. Current Support

Agency	**Project Title**	**K$/ YR**	**Role**	**Period Covered**	**Commitment (months)**
National Oceanic and Atmospheric Administration (USTPO)	Studies of Precipitating Cloud Systems in TOGA/ COARE Using Shipboard Doppler Radar Data	145	PI	1/1/94 to 12/31/96	1 academic
National Science Foundation	The CSU-CHILL Radar Facility	500	CO-PI	5/1/95 to 4/30/00	1 summer 1 academic
National Science Foundation	Dynamical and Electrical Studies of Convective Cloud Systems	150	PI	2/1/94 to 1/31/97	1 summer
National Aeronautics and Space Administration	Ground Truth Research & Algorithm Development in Support of TRMM	110	CO-PI	9/1/94 to 8/31/97	1 summer
Colorado State University	Resident Instruction Support				7 academic

B. Pending Support

Agency	**Project Title**	**K$/ YR**	**Role**	**Period Covered**	**Commitment (months)**
National Science Foundation	The CSU-CHILL Radar Facility	500	CO-PI	5/1/95 to 4/30/00	1 summer 1 academic

Appendix A

Status of Graduate Theses/Dissertation in 1995

Completed / in-progress graduate students:

1) Department of Atmospheric Science:

In-Progress:

L. Carey (Ph D.)	Lightning and multiparameter radar characteristics of severe hail storms
J. Erdman (MS)	Combined satellite and multiparameter radar signatures of severe thunderstorms
R. Lucci (MS)	Radar and lightning studies of tornadic thunderstorms

2) Department of Electrical Engineering:

Completed (Ph D.):

A. Mudukotore	Pulse Compression for Weather Radars
J. Beaver	Ka-band propagation studies using ACTS and CSU-CHILL multiparameter radar

In-Progress

R. Xiao (Ph D.)	Artificial Intelligence Applications for Meteorological Radar Data
S. Bolen (Ph D.)	Validation of polarimetric radar signatures
G. Hwang (MS)	Evaluation of covariance matrix measurments from CSU Chill
A. Abou-el-magd (Ph D.)	MP radar analysis of Mixed phase precipt

Appendix B

Letters Associated with Radar Users

Joint Centre for Mesoscale Meteorology

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READING, RG6 6FN, UK
Tel. (01734) 318425, Fax. (01734) 318791

Professor Steven A Rutledge
Department of Atmospheric Science
Colorado State University
Fort Collins
Colorado 80523
USA

M/JCMM/9/1

14 August 1995

Dear Steven

Thanks for your letter dated 3 August and for your continuing interest in obtaining multi-azimuth RHIs showing the evolution of the boundary-layer depth over the course of an entire day. The things to look for in obtaining a good dataset are:

- enough targets (RI inhomogeneities + bugs)
- rather weak winds in the boundary layer (so that areas of deeper b.l can remain over the same patch of favourable terrain for a long time).
- not too many outbreaks of precipitating convection (the easiest cases to analyze will be when an isolated area of thunderstorms develops in just one or two locations late in the day).

Thanks again for your hospitality last month.

Sincerely

Keith

Keith Browning

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH MMM
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1 December 1995

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

Dear Pat:

This letter concerns the 20-hour experiment we conducted in coordination with the CSU-CHILL radar during July-August 1995. We would like to request the radar data for the time periods encompassing our balloon-borne replicator flights, and would also like to provide you with feedback regarding the radar support we received during this project, as requested in your letter of 28 September (sorry this has taken so long!).

Listed below are the dates, launch times, and launch locations for the four successful replicator flights we conducted. Since our interests include looking at the development and evolution of the clouds we sampled, we would like to acquire the radar data (in Universal Format) from about one hour before launch to one hour after launch. We would also appreciate any documentation or instructions you have on the format of the data and on the parameters recorded.

Date	Launch Time (UTC)	Launch Location (lat/lon; degrees)
7-19	20:01:15	40.589 / 104.935
8-04	21:26:21	40.376 / 105.064
8-10	22:14:00	40.770 / 105.184
8-11	21:18:34	40.307 / 104.984

Regarding our impressions of the radar support during this project, they are highly favorable in all respects. Our project was a latecomer, one of at least three projects whose support needs often overlapped in time and/or conflicted in terms of the scan-location or scan-mode desired. Our work required much real-time communication and coordination while tracking storms, seeking a launch location, and, most critically, while the replicator was in-cloud. Under these demanding conditions the operations staff was adept at altering and juggling scan patterns to meet different projects' immediate needs. At one time or another we were assisted by all of the scientific, engineering, and technician staff, and are very impressed with the skill of the entire team at operating the radar and interpreting the data in real-time.

We expect that the radar data will be very helpful in illuminating the structure of the thunderstorm anvils which we sampled; we also hope to investigate correlations between radar backscatter properties and cloud microphysical properties. This type of replicator/radar coordination is potentially very scientifically valuable, and having learned much about the logistics of such coordination, we hope to make similar measurements with the CHILL radar facility in the future.

Sincerely,

Andrew Heymsfield

Andy Heymsfield

cc: Steve Rutledge

Colorado State University

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August 25, 1995

Professor Steve A. Rutledge
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado 80523

Dear Steve,

We are writing this note to communicate to you the outstanding support Pat Kennedy provided us during our Center for Geosciences field program to monitor thermally caused acoustic waves. His assistance has been instrumental in the successful completion of this effort.

Thank you for your support.

Sincerely,

Roger A. Pielke, Sr.
Professor

Melville E. Nicholls
Research Associate

Al J. Bedard
Supervisory Physicist

cc: P. Kennedy
T.H. Vonder Haar

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH MMM
MESOSCALE AND MICROSCALE METEOROLOGY DIVISION
P.O. Box 3000 • Boulder, Colorado • 80307-3000

10 January 1996

Professor Steven Rutledge
Scientific Director, CSU-CHILL Radar Facility
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado 80523

Dear Steve,

I am responding to your request for an evaluation of the CSU-CHILL support during the sailplane project (S2E2) this past summer. A brief summary of the sailplane operations is enclosed, both for the record and for your information as a possible data source for your studies.

First, I would like commend the staff of the CSU-CHILL facility for their help in setting up the sailplane ground station in the user van and in operating the radar for me. Their no-nonsense attitude in getting things done, their broad experience in solving the inevitable problems that creep into field projects, and their dedication to making the CHILL radar perform at its fullest potential were refreshing and appreciated. Your staff is first-rate, and I look forward to working with them in the future.

The project was often frustrating for me, primarily due to the sailplane side of operations. The delay in installing and debugging the new sailplane data system led to a series of other delays and problems. Thank you for being able to adjust the period of operations to accommodate us.

Based on my experience this past summer, a couple of points are worth mentioning that may be pertinent in planning similar projects in the future. Co-locating our ground station at the CHILL site was invaluable, especially in having access to the radar display with the sailplane track overlaid. Even so, the sailplane operations were understaffed. We were novices in operating our new data display hardware and software, and consequently more effort than in past projects was spent gathering and interpreting sailplane data for realtime assessment and guidance. The radar operations were left almost entirely to CHILL staff, who did an admirable job in anticipating our needs and covering the storms. But, an additional person to run the sailplane display station would have allowed me to coordinate the investigations better (e.g. evaluating the storm situation earlier for

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better sailplane guidance, fine-tuning the RHI scans, deciding earlier if and when to shift back to PPIs, assessing the impact of other project scanning strategies earlier or more easily).

The second point concerns the potential for conflicts between multiple projects. Possible conflicts were anticipated in the planning stages prior to the convective season, and were handled adequately and amicably. There were a couple of occasions when I felt a little pressured to shift to another study or project when it seemed as though sailplane investigations were over. Though not serious incidents, they made me wonder what the impact would have been if we had been operating at the same time as the T-28 (as planned but delayed because of our data system problems) or if the weather had been such that sailplane-sampled storms evolved into more severe convection. These situations are fraught with potentially serious conflicts. Anticipating possible conflicts and negotiating between PIs would be easier if the sailplane operations had an additional person (mentioned above). But, for larger multi-facility projects, it is clear that an operations director should be identified. The CHILL operations this past summer seemed to be near the threshold of such a size and complexity. The success of the projects this past summer was partly due to the experience and good-nature of the PIs involved, and also serves as another testament to the experience and dedication of the CHILL staff in making such an arrangement work.

Again, many thanks to Pat, Dave, Ken, Bob and Gene at CHILL for their work in making the sailplane project reach its fullest potential, and to you for accommodating the shift in scheduling. I look forward to future projects involving the CSU-CHILL radar.

Sincerely,

Dan Breed

Daniel W. Breed

cc: Pat Kennedy, CSU
Jim Dye, NCAR

S2E2 - 1995 SAILPLANE SUMMARY

950620 Test flight out of Jeffco; no data recorded.

950621 Test flight out of Jeffco; in and out of precipitation (snow and snow grains) NW of Boulder; under electrified clouds.

950622 Test flight out of Jeffco; climb in electrified cloud 50 km WNW of CHILL; in cloud from 221400 to 222600 UTC, max altitude 6.5 km MSL; left when pitot froze (heater failed); attempted remote CHILL coordination.

950623 Flight out of Jeffco; several short climbs in capped mountain-generated cells 50-60 km WSW of CHILL; in cloud/precip from 205500 to 214400, max altitude 5.4 km (-10°C); virga showers electrified to produce lightning (tops only about 7.5 km); CHILL collected data in same or similar cells from 213700 to 220000.

950707 Two clear-air test flights near Greeley; tested ground station operation at CHILL; no clouds.

950713 Three ascents in clouds 45 km NNW and 35 km NNW of CHILL; first two clouds (may be same cloud) were weakly electrified, third cloud was not electrified; in cloud from 220700 to 225800 (with brief breaks between clouds), max altitude 7.2 km (-16°C); well-sampled first echo cases; left clouds due to excess icing.

950714 Aborted research flight - widespread precip, low bases, strong winds; flew under reversed polarity clouds near Jeffco during return flight from Greeley (around 233000).

950804 Unsuccessful attempt to climb in weak shower 35 km WNW of CHILL; stronger convection to the west unavailable due to ATC problems; sampled E-fields over Chrisman Field from about 230000 to 230500; had several good lightning signatures below cloud base from about 230700 to 232000; no cloud penetrations, max altitude 4.4 km.

950807 Climb on the SW side of electrified storm 40-45 km W of CHILL; in cloud from 221900 past 224000, max altitude 6.8 km; lightning strike interrupted data system - no data collected after 223926.

950808 Shallow, high-based convection generating virga showers; in and out of lower portions of two clouds about 35 km W of CHILL; in and out of cloud from 233800 to 234800, max altitude 5.5 km (-4°C); several CG strokes from virga near and east of sailplane.

950809 Unsuccessful attempt to locate lift under late afternoon convection (one storm had developed earlier); towed through virga showers west of CHILL (220000-220700); no cloud penetrations.

950810 Towed under electrified cell 55 km N of CHILL, climbed in weakly electrified cell 65-70 km N of CHILL; in cloud from 220000 to 222400, max altitude 7.5 km (-17°C); cloud tops of 9.5-10.0 km.

950928 Two morning flights in less than ideal conditions (wave activity) for comparing different pressure transducers and calibrating vertical air motion calculations (polar curve); flights out of Boulder, 1344-1425 and 1526-1612.

951003 Attempted another polar curve calibration flight (1335-1415); data system failure at 134600. Afternoon flights were made for UCAR media services (filming flights).

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18 September 1995
Dr. Jerry Straka
School of Meteorology
University of Oklahoma Energy Center
100 East Boyd Street
Norman, OK 73019

Dear Jerry:

This letter serves to close out our files on the NSF-funded T28 project that you conducted during the 1995 convective season at the CSU-CHILL radar facility. According to our records, radar operations in support of this project were conducted as follows:

Date	Remarks
6/12	Initial test flight, brief CB penetration.
6/17	Several passes through fast moving cell; CHILL scans not slaved to T28 track
6/20	Multiple penetrations through small developing CB; slaved tracking working
6/22	Several penetrations of severe cell w/ large hail.
6/27	Penetrations through embedded cell.
6/28	Horizontal legs at several altitudes through bright band echo region.

Universal Doppler Exchange Format tapes from the 6/20 and 6/22 flights have already been mailed to you. UF tapes for the remaining flights are enclosed.

It should be noted that our initial replay examinations of this summer's data indicate that the ZDR field tended to became somewhat noisy on afternoons when high ambient temperatures developed the electronics van. Radar facility staff are available for technical consultation regarding the details of data collection procedures, data quality issues, etc.

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

Sincerely,

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

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28 September 1995

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

Dear Larry:

This letter serves to close out our files on the 20 hour project that you conducted during the 1995 convective season at the CSU-CHILL radar facility. I know that Dave Brunkow has already supplied Universal Doppler Exchange Format data to you for several of the more interesting case days. Additional UF data may be generated at your request from the original field recordings. Radar facility staff are also available for technical consultation regarding the details of data collection procedures, data quality issues, etc.

Best wishes for successful analyses of your data.

Sincerely,

Pat Kennedy

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

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28 September 1995

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

Dear Bringi:

This letter serves to close out our files on the storm intercept 20 hour project that you conducted at the CSU-CHILL radar this summer. I know that Dave Brunkow has already supplied field data tape copies to you for several of the more interesting case days. Copies of additional times of interest may be generated at your request. Please keep us advised of any data abnormalities that you uncover during your analyses.

Sincerely,

Pat Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
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28 September 1995

Mr. Dan Breed
NCAR/MMM
PO, Box 3000
Boulder, CO 80307-3000

Dear Dan:

This letter serves to close out our files on the NSF-funded S2E2 project that you conducted during the 1995 convective season at the CSU-CHILL radar facility. According to our records, radar operations in support of this project were conducted as follows:

Date	Remarks
6/23	Sailplane test flight through convective debris cloud.
7/7	Test flight; GPS track data not ingested into radar data system.
7/13	Sailplane spiral ascent in lower portions of developing cell.
7/14	Early landing at Greeley: no workable convective clouds.
8/4	Sailplane released near Ft. Collins showers; no lift found.
8/7	Ascent through electrified cell W of Loveland; radar data gaps.
8/8	Sailplane penetrated W fringes of cell near Loveland.
8/9	Long on tow search for lift; none found.
8/10	Ascent to ~FL250 in cell along WY CO border.

I know that you have already been supplied with a Universal Doppler Exchange Format tape from the 10 August operations. Additional UF data may be generated at your request from the original field recordings.

It should be noted that our initial replay examinations of this summer's data indicate that the ZDR field tended to became somewhat noisy on afternoons when high ambient temperatures developed the electronics van. Radar facility staff are available for technical consultation regarding the details of data collection procedures, data quality issues, etc.

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

Sincerely,

Pat Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
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28 September 1995

Dr. James Metcalf
Phillips Laboratory / GPAA
29 Randolph Road
Hanscom AFB MA 01731-3010

Dear Jim:

This letter serves to close out our files on the 20 hour project that you conducted during the 1995 convective season at the CSU-CHILL radar facility. The 2 June data were collected during your visit to the radar. The remained of the operations were in conjunction with Dan Breed's sailplane project. An overall summary is provided below:

Date	Remarks
6/2	Episode of fixed azimuth RHI's through electrified anvil near Loveland
6/23	Sailplane test flight through convective debris cloud.
7/7	Test flight; GPS track data not ingested into radar data system.
7/13	Sailplane spiral ascent in lower portions of developing cell.
7/14	Early landing at Greeley: no workable convective clouds.
8/4	Sailplane released near Ft. Collins showers; no lift found.
8/7	Ascent through electrified cell W of Loveland; radar data gaps.
8/8	Sailplane penetrated W fringes of cell near Loveland.
8/9	Long on tow search for lift; none found.
8/10	Ascent to ~FL250 in cell along WY CO border.

Unfortunately, the sailplane never operated in close proximity to a storm as intense as the one through which you directed RHI scans on 2 June. I suggest you contact Dan Breed to get a sense of the electric field data recorded during the sailplane flights. Once you have identified cases of potential interest, let me know and we can devise a suitable form of data transfer.

Finally, feedback from radar facility users is always useful. A brief summary of your impressions of the radar support for your project (i.e. conduct of operations, performance of the radar equipment and staff, data quality, etc.) will be quite useful.

Sincerely,

Pat Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
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28 September 1995

Dr. Al Bedard
NOAA/R45X7
325 Broadway
Boulder, CO 80303

Dear Al:

This letter serves to close out our files on the 20 hour project that you conducted during the 1995 convective season at the CSU-CHILL radar facility. According to our records, radar operations specifically in support of this project were conducted as follows::

Date	Remarks
8/18	Fine line approaching from the NE, only short-lived cell development.
8/21	Periodic cell development over foothills, stationary cell near Ward.
8/23	Quasi-stationary cell clusters in several areas, main group SE of CHILL
8/25	Chase vans near Wiggins. Cell development distant SE, not well scanned

General surveillance scan radar data collected on other days this summer may also be of use to you. As we have discussed before, you may schedule return visits to the radar as necessary in order to replay archived field format data tapes. Once you have identified cases of potential interest, we can devise a suitable form of data transfer.

Sincerely,

Pat Kennedy

Pat Kennedy
CSU-CHILL Facility Manager
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28 September 1995

Dr. Andy Heymsfield
NCAR/MMM
PO, Box 3000
Boulder, CO 80307-3000

Dear Andy:

This letter serves to close out our files on the 20 hour project that you conducted during the 1995 convective season at the CSU-CHILL radar facility. According to our records, radar operations in support of this project were conducted as follows:

Date	Remarks
7/14	Replicator flight aborted, balloon burst during launch
7/19	Successful cloud particle collection during anvil penetration.
8/3	Long CLASS van chase after storms in WY; ultimately no launch.
8/4	Replicator launch from south of LVE, flight through anvil debris.
8/9	CLASS van positioned near Erie, launch scrubbed when anvils miss site.
8/10	Replicator launch near Owl Canyon; no radar coordination (out of radio ctc)
8/11	Launch from Berthoud area, very thin cloud layer, LORAN data dropout.

UF data may be generated at your request from any of the operations listed above. It should be noted that our initial replay examinations of this summer's data indicate that the ZDR field tended to became somewhat noisy on afternoons when high ambient temperatures developed the electronics van. Radar facility staff are available for technical consultation regarding the details of data collection procedures, data quality issues, etc.

Finally, feedback from radar facility users is always useful. A brief summary of your impressions of the radar support for your project (i.e. conduct of operations, performance of the radar equipment and staff, data quality, etc.) will be quite useful.

Sincerely,

Pat Kennedy

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

Appendix C

Summary of Greeley Data Collection Activities Through 01/15/96

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.

1994

WISP94	Jan - March	Winter storms and icing project (NSF supported NCAR project).
ACTS	Beaver et al	Meteorological effects on microwave propagation (Ph.D.)
ANVIL	Hallett	Evolution of anvil airflow fields
APHID94	Holtzer et al	Migration patterns of Russian Wheat Aphids
DEN94	Clement and McKee	Multiparameter obs of storms over Denver urban flood district (MS)
RAIN94	Bringi	Comparison of WSR-88D and multiparameter based rainfall estimates
REU94	Chandrasekar	Research experience for EE undergraduates
MCS94	McAnelly	Observations of MCS genesis

1995

Carey and Rutledge	May-July	Combined electric field / multi-E-FIELD parameter radar observations of thunderstorms.
Chandrasekar	June-August	Exposure of undergraduate REU95 students to weather radar research project field activities.

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

Appendix D

1995 CSU-CHILL Newsletter

CHILL RADAR NEWS

from

Colorado State University

Fifth Edition
September 1995

Overview
(Steven Rutledge, Scientific Director)

This is the fifth 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 CSU. 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. Recently, we have been granted a second five year Cooperative Agreement with the NSF, which began in May 1995.

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. We supported three formal NSF projects during the summer of 1995 as discussed below. 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, without OFAP/FAC review. In these projects, radar operational costs are provided by the Cooperative Agreement. We supported five 20 hour projects in the past year, as detailed in the following section. These projects allow investigators to conduct highly focused research with the CSU-CHILL radar. The radar also continues to be an integral component of several courses in the Departments of Atmospheric Science and Electrical Engineering.

In December 1993, the new CSU-CHILL antenna, built by Radiation Systems, Inc. of Sterling, VA was installed. The antenna has performed flawlessly, and has met or exceeded all performance criteria. The new antenna has much lower sidelobes compared to the previous antenna, and matched beam patterns between horizontal and vertical polarization states, and very high cross-pole isolation. The acquisition of the new antenna was the most significant upgrade to the radar during the period covered by the first Cooperative Agreement. Over the course of the past year, we have carried out another significant modification of the radar system, by installing a second FPS-18 transmitter and another analog receiver. We used this new dual channel system this past summer with good success. One aspect of the dual channel system is the large dynamic range of the cross-pole measurement (the cross-pole isolation is limited now by the cross pole isolation of the antenna, which is -35 db). The new system does not use a ferrite switch for controlling the polarization of the transmitted signal, which for single channel systems, is usually the component of the system that limits the dynamic range of the cross-pole signal. Our new system is now capable of measuring the full covariance matrix at a non-attenuating wavelength. We are now embarking on a series of exploratory studies to investigate the additional insights into cloud microphysical processes afforded by the off-diagonal elements in this matrix.

Radar Operations Summary
(Pat Kennedy, Facility Manager and Larry Carey, Ph.D. Student)

The CSU-CHILL Facility supported a wide variety of research and educational projects during the 1995 operational season. While multiparameter radar data were being collected, investigators from the various projects were obtaining companion data on storm phenomena ranging from cloud electrification to the generation of low frequency sound waves. In all cases, real time field direction of these projects was done from the CSU-CHILL user van. The following paragraphs provide a brief overview of these projects.

Three projects involved the use of instrumented chase vans which were directed to the immediate vicinity of convective storms of interest. Prof. Chandrasekar, of the CSU Electrical Engineering Department (also Co-Investigator on the present Cooperative Agreement), headed an NSF-funded Research Experience for Undergraduates (REU) program. The eleven student members of this project participated in the design, installation, and field operation of hydrometeor sensing equipment mounted in two chase vans. While the efforts of REU students were instrumental in the collection of observations of hailstone characteristics, drop size distributions, and rain rates, much of the analyses of these data will be done in a separate 20 hour project under the direction of Prof. V. N. Bringi, also of the CSU EE Department. Dr. Bringi's project is centered on verifying and improving the performance of precipitation identification and characterization algorithms used on the National Weather Service's WSR-88D radar systems. The third chase van operated during the past summer was equipped with a corona point system to record the evolution of electric fields observed near thunderstorms. This 20 hour project was conducted by Larry Carey, Jon Erdman, and Timothy Lang, students under the direction of Prof. Steven Rutledge, all in the CSU Atmospheric Science Department (ATS). This field program also employed two fixed corona points and a field mill, the latter courtesy of NASA / MSFC.

The three chase vans were generally directed towards a common storm of interest. While timely storm interception is always a challenge, the vans did make direct observations of intriguing electric field signatures along with direct observations of significant hail and rain rates on several occasions (most notably on June 7, 22, and 23).

Three other projects centered on the use of research aircraft to collect *in situ* cloud physics data. Profs. Rutledge and Bringi along with Dr. Jerry Straka of the University of Oklahoma school and Dr. Dusan Zrnic of NOAA / NSSL were the lead investigators on an NSF funded project that brought the South Dakota School of Mines and Technology armored T28 aircraft to Colorado for 3 weeks in June. This project was designed to compare the cloud particle observations made by the aircraft with multiparameter data collected by the CSU-CHILL system. The T28 sampled a variety of echoes ranging from an intense hailstorm (22 June) to a stratiform bright band situation (June 28). A second NSF-sponsored aircraft project was under the direction of Dan Breed of the NCAR Mesoscale and Microscale Meteorology (MMM) Division. Dan sought to have the sailplane ascend in the updraft of a developing cumulus cloud in its early stage of electrification. A primary point of interest was the documentation of the ice particle evolution during the cloud electrification process. CSU-CHILL data were used to monitor the overall cloud system evolution during the sailplane ascents. Successful penetrations of developing clouds were made on August 7 and 10. Dr. James Metcalf, of the Air Force's Phillips Laboratory, directed a 20 hour project that was closely associated with the sailplane effort. Dr. Metcalf sought to use multiparameter radar data to detect anvil cloud regions in which the ice particle orientation was being altered by a significant electric field. Sailplane observations were desired to monitor the electric field evolution in the anvil neighborhood. Cyclic variations in the CSU-CHILL's realtime ϕdp display strongly suggested ice particle orientations were being affected by the storm electrification / lightning discharge process in a storm observed on 2 June. Unfortunately, the sailplane was not operational during this event. Joint radar / sailplane observations taken from weaker storms later in the summer offer Dr. Metcalf some additional analysis possibilities.

The final two 20 hour projects supported during the summer of 1995 were associated with rather unique auxiliary instrumentation systems. Dr. Al Bedard, of the NOAA Environmental Technology Laboratory in Boulder, and Prof. Roger Pielke from CSU ATS, deployed specialized pressure sensors, designed to detect the passage of ultra low frequency sound waves generated by the latent heat released in rapidly growing thunderstorms. During the data analysis phase of this project, the apparent sources of the infrasound waves will be correlated with the thunderstorm locations observed in CSU-CHILL volumetric surveillance scans. Finally, Dr. Andy Heymsfield of NCAR conducted a project in which radar data were collected in coordination with the flights of a balloon-borne particle replicator. The goal was to have the replicator ascend through an active thunderstorm anvil while the radar collected multiparameter data from the vicinity of the ascent track. Initial indications are that a successful anvil penetration was made on July 19.

The severe hailstorm observations collected during the evening of 7 June 1995 provide an example of the data recorded in the course of this summer's radar operations. During this event, several storms attained supercell configurations and produced large hail, locally flooding rainfall amounts, and sporadic tornadoes. One such supercell was intercepted by both the corona point and hailstone collection vans shortly after 1800 MDT. Figure 1 shows an east - west vertical cross section through the echo core at 1818 MDT. The reflectivity contours (dashed blue lines) depict well defined echo overhang and weak echo structures, indicative of a strong updraft. The presence of liquid and/or partially melted hydrometeors within a portion of the weak echo region is evidenced by the positive Zdr column in this area (color shading; dashed line is 0^{o} C height). A cap of enhanced Ldr values (solid contours), probably due to partially frozen non-spherical ice particles, enveloped the summit of the Zdr column. As noted in other hailstorm investigations (Conway and Zrnic, Mon. Wea. Rev., v121, 2511-2528), this general echo configuration implies that conditions favorable for rapid hail growth probably existed near the upper portions of the weak echo region. The storm intercept vans were struck by numerous ~2-4 cm diameter hailstones.

Figure 2 provides a summary of the local lightning activity observed by the national lightning detection network during the 1816-1846 MDT period. The 3 km MSL CAPPI shows the sharp reflectivity gradient on the leading edge of the core (color shading) as well as the positive Zdr's in this same area (dashed contours). Locations of positive and negative cloud to ground (CG) discharges are shown by +'s and -'s respectively. Within this time period, ~80% of the cloud to ground discharges were of + polarity. Such a large percentage of + CG activity is highly anomalous for a deep convective storm in the mature phase.

Additional multiparameter-based views of the storm, prepared by Prof. Bringi's group at the CSU Electrical Engineering Department (EE), are illustrated in Figures 3 and 4. Figure 3 shows a near-surface (.75 km AGL) CAPPI at 1818 MDT. The shaded regions depict areas where the specific differential phase (Kdp) exceeded 1^{o} km^{-1}, implying rainrates in excess of ~40 mm hr^{-1}. Direct observations made by the EE hail collection van confirm that copious large hail was the primary form of precipitation in the area between the two high Kdp zones. Figure 4 is a three dimensional rendering of the storm structure based on a full CSU-CHILL volume scan. The pink shaded region is the 55 dBZ isosurface. The positive Zdr column adjacent to the maximum reflectivity core, and the Ldr enhancement near the top of the Zdr column are also evident.

Electrical Engineering
(V. Chandrasekar, Co-Investigator)

The new polarimetric matrix measurement capability of the CSU-CHILL radar is a bench mark event in radar meteorology in the U.S. especially at long wavelength (S-band). The two transmitter/two receiver upgrade of the CSU-CHILL system was successfully completed by April 95. Time series data from weather targets were analyzed to ensure the quality of the spectra from the two channels, the rms phase noise and general system stability. The radar parameter that has benefitted the most from the recent upgrades is the Linear Depolarization Ratio (LDR). The radar system limit of LDR measurement was experimentally determined to be around -32 to -35 dB. An intensive data collection effort was launched beginning 1 June 1995, and was completed on 10 August. A key objective was validation of polarimetric signatures with *in-situ* observations using instrumented "chase" vans directed into convective precipitation cores. One van ("Hailstone") was equipped with a NCAR hail catcher net for direct collection of hailstones which were immediately frozen in chilled hexane and stored in a freezer (Figure 5). This van also had an electronic "hail box" developed at CSU (modification of an earlier version from SDSM&T) as part of the REU program which measured the size and fallspeed of each particle entering its sensing area. In addition, the van was equipped with a capacitive rain gage and a wind sensor. The second van ("Austria") was instrumented with a new device called the 2D video disdrometer developed by the Joanneum Research Institute, Graz, Austria. This instrument was obtained via a cooperative research agreement with CSU and installed, for the first-time, inside a van (Figure 6). The instrument gives the front and side views of each particle entering its sensing area (10 cm x 10 cm), as well as the vertical and horizontal components of the velocity. An accurate estimate of the size distribution can thus be obtained. Having the front and side view images for each particle will enable a separation of rain and hail size distributions in mixed phase, which is critical for quantitative validation of radar signatures. The vans were directed into storm cores using GPS position information transmitted to the radar site and displayed on the radar screen. In addition, the T-28 aircraft specially

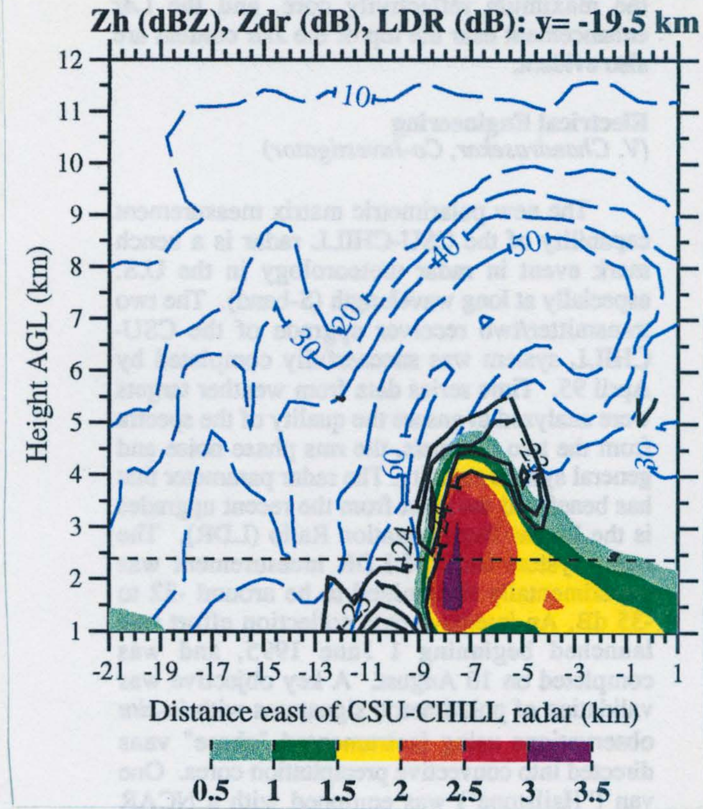


Figure 1 (See text for details)

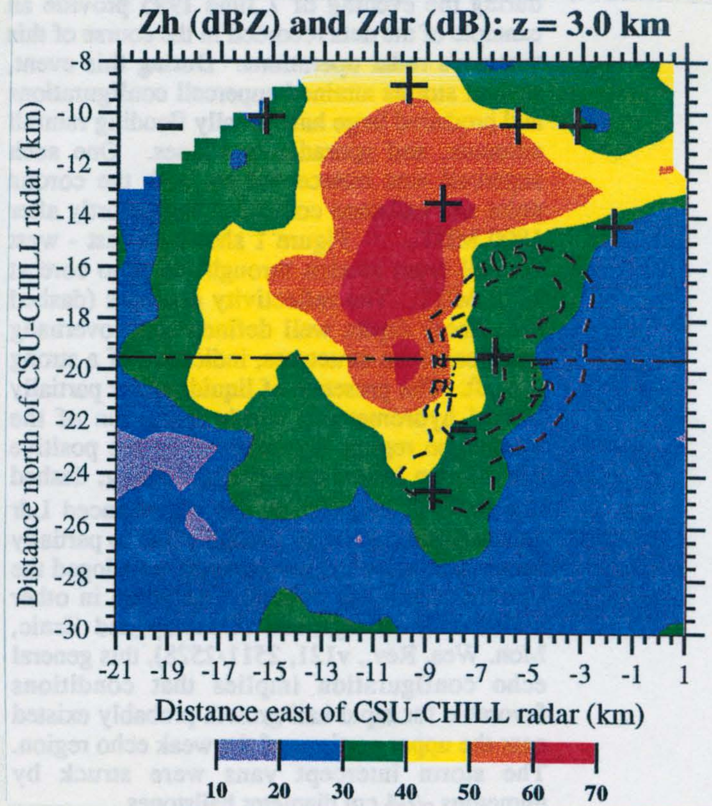
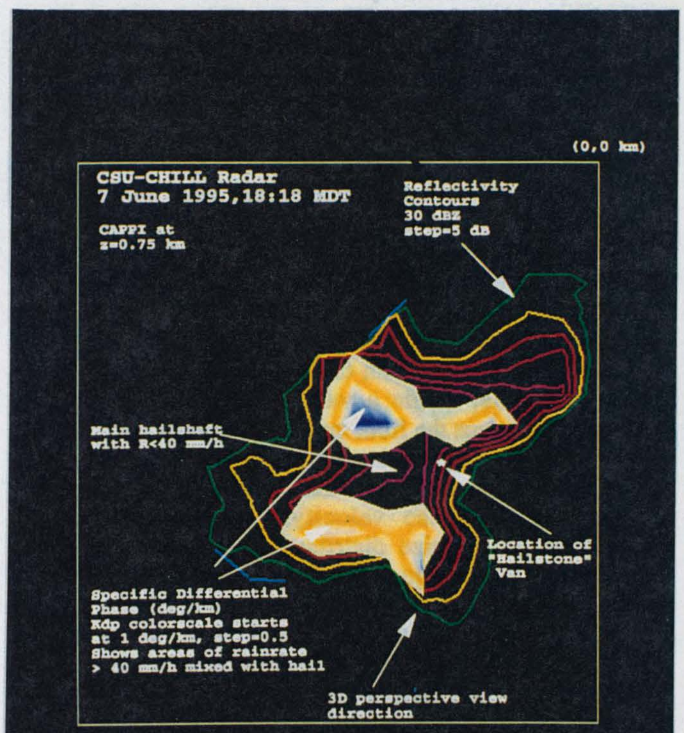


Figure 2 (See text for details)



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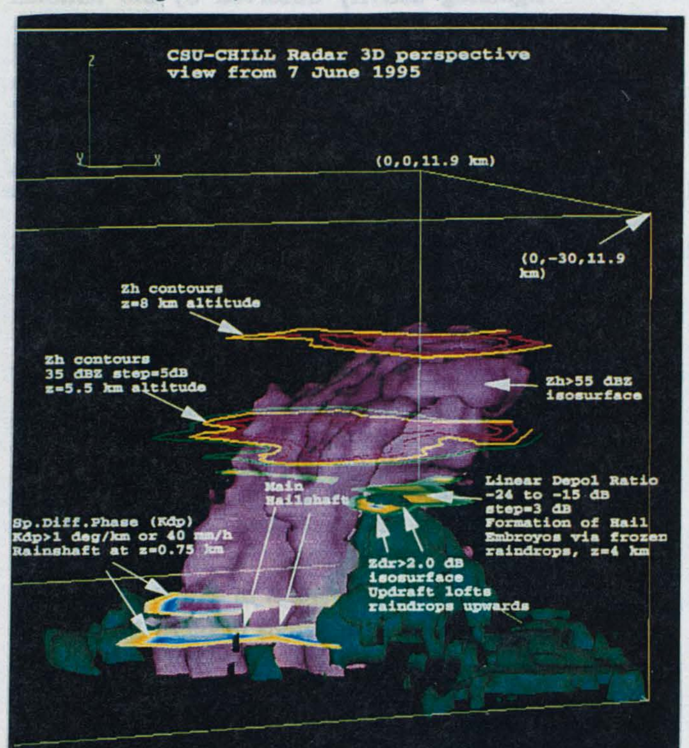

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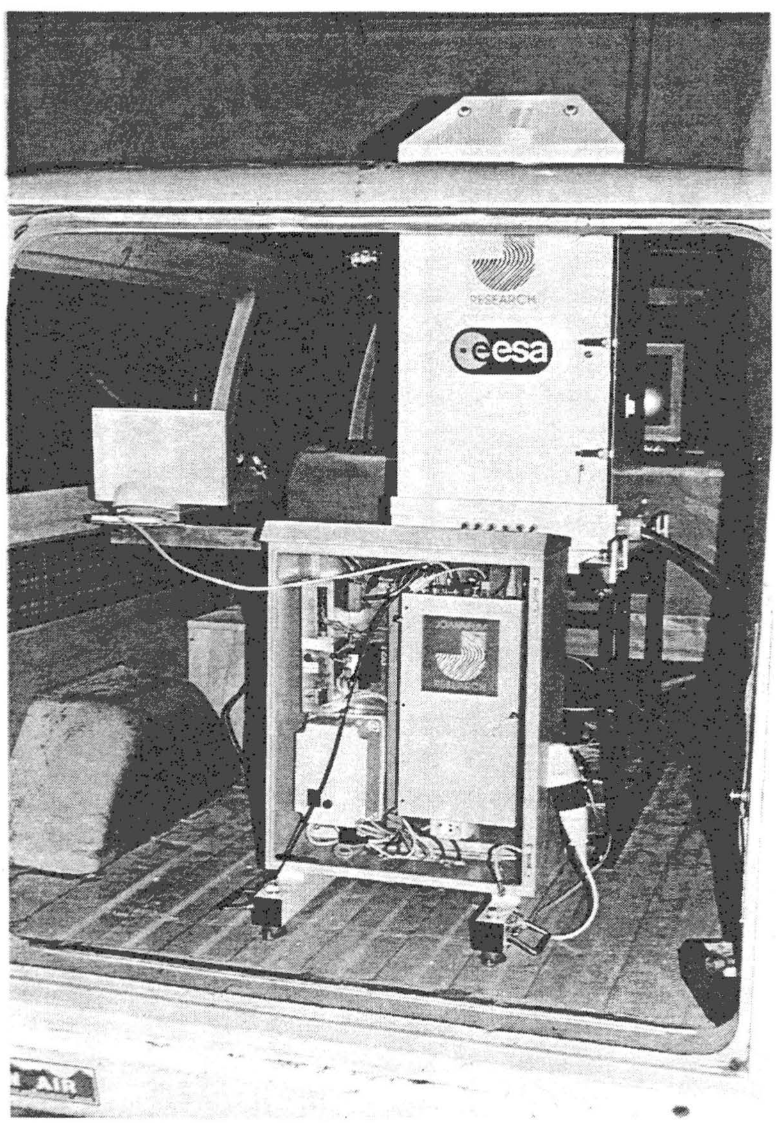

Figure 5 ↑
The "hailstone" van. Falling hailstones are collected by the NCAR designed roof-top mesh funnel. Collected hail samples are then directed into a refrigerated hexane bath for storage.

Figure 6 ←
Video disdrometer installed in the rear of the "Austria" van. Line scan video cameras record two orthogonal views of precipitation particles falling through the sampling opening at the top of the instrument.

equipped with a High Volume Particle Spectrometer, was deployed to collect coordinated measurements with CSU-CHILL during the period 12 June-1 July 1995.

The REU program (Research Experience for Undergraduates) was a significant part of our activity this summer. There were a total of 11 students supported by the program who spent the summer semester (10 to 12 weeks) in residence at CSU. The students came from different states such as New Mexico, Texas, Louisiana, Kansas and Colorado. The students actively participated in the field program phase. They were also involved in the instrumentation development for the two chase vans that were part of the summer field program. At the end of the program the students presented their research results in a seminar series at CSU.

In other engineering developments, a 5 bit pulse compression system using a phase coding scheme was implemented in the RF synthesis circuit to generate a phase coded 1 microsecond transmit pulse. Time series data were collected under phase coded transmit mode, and pulse compression algorithms were implemented to obtain radar returns at 200 ns intervals. Preliminary data analysis indicates that all elements of the pulse compression system are working. More extensive evaluations, including real time pulse compression processing, are planned in the near future.

Dual Channel Upgrade
(Dave Brunkow, Senior Engineer)

During the Fall of 1994 a major upgrade of the CSU-CHILL radar was begun. The primary focus of the work was the addition of a second transmitter, receiver, and dual channel rotating joint. This system will allow full utilization of the new RSI antenna. This antenna has superior isolation of the two orthogonal linear polarizations. Previously with the switchable ferrite circulator it was only possible to maintain about 20 dB of isolation between channels. In this new system the channel isolation exclusive of the antenna will be on the order of 60dB and thus the realized isolation will be limited only by the antenna itself to approximately 35 db. During the summer of 1995, linear depolarization ratios (LDR) of ~-35 db were observed which indicates a considerable improvement in crosspolar isolation.

The second transmitter like the first is from an FPS-18 military radar. This transmitter was acquired from the National Severe Storm Laboratories (NSSL). This channel has been modified by changing the high voltage rectifier tubes to solid state devices. A high power circulator duplexer has replaced the original FPS-18 system of ATR/TR duplexers. The transmitter focus coil will be replaced in the Fall of 1995 with a newly built unit. The second receiver has been installed and is a clone of the existing Instantaneous Automatic Gain Control design previously used on the CSU-CHILL system. In addition the low noise amplifier, first mixer, intermediate frequency amplifiers, and second detectors are new components. A new input board for the SP-20 processor has been purchased and modified to provide the attenuator setting for the second receiver as well as digitize the second receiver's I/Q video channels.

To provide space for the second transmitter and receiver, the area previously devoted to the signal processing and control computers has been vacated. The computers have been moved to a new trailer which also houses a 28 foot operations control room.

A new dual channel rotary joint was purchased in conjunction with NCAR who also bought the same joint for the S-pol radar under development. The old rotary azmuthal axis joint has been removed and was used for the new elevation axis joint.

The SP20 signal processor code was modified to control both trasmitters and digitize two receivers. One processor was dedicated to buffering the input by ingesting it at two samples per microsecond and putting it back out at one sample per microsecond. This allowed much of the remaining code to be used with little or no modification. The system operated in an alternating H V transmit mode for 1995 and the traditional polarization parameters (Z, Zdr, Vel, Ldr, $\rho HV(0)$, ϕdp) were calculated. Additionally, the complex covariance matrix terms were recorded.

Acknowledgments:
The CSU-CHILL facility is supported by NSF Cooperative Agreement ATM-9500108, supplemented by cost sharing funds from the state of Colorado. This newsletter was skillfully assembled by Kristy Rouault.

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Appendix E

1996 CSU-CHILL Brochure

The CSU-CHILL National Radar Facility

at

Colorado State University

1. Introduction

The CSU-CHILL is a transportable research weather radar system funded by the National Science Foundation (NSF) and Colorado State University (CSU). The radar is jointly operated by the CSU Departments of Atmospheric Science and Electrical Engineering. The radar was originally developed by the Universities of CHicago and ILLinois, thus the CHILL acronym. The purpose of this facility is to provide a state of the art radar system that can be used for both research and educational activities by the community (Fig. 1).

Figure 1: CSU-CHILL Facility at Greeley, Colorado

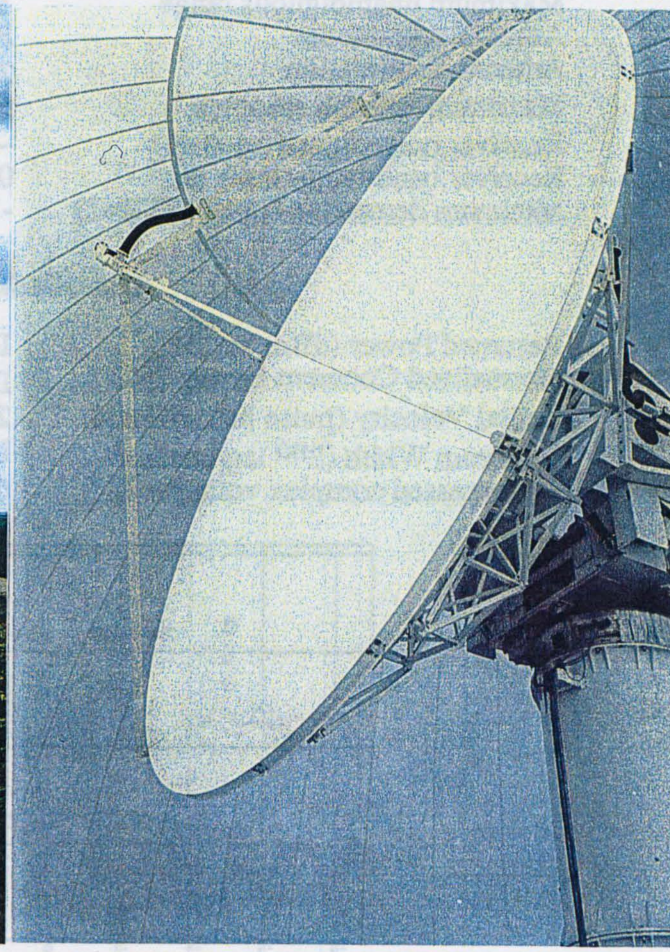

Figure 2: CSU-CHILL dual polarization antenna

2. System Description

The radar is an 11 cm wavelength Doppler system with dual linear polarization capability. The custom designed 8.5 m diameter parabolic antenna (1.1° half power beam width) has suppressed sidelobe levels, and achieves excellent matching between the horizontal (H) and vertical (V) polarization beam patterns (Figs. 2 and 3). To maximize the isolation between the transmitted polarization states, the antenna's H and V feeds are separately driven by a pair of identical transmitters. Two matched receivers handle the co- and cross-polarized signal returns. The received signals are digitally processed in real time. Processed data are presented on an interactively controlled display system which drives a network of four color monitors (one master and three slaves). All data fields are archived at full resolution on magnetic tape for post analysis. The radar's operational control system is highly flexible, readily allowing real time modification of data acquisition parameters. Summaries of the radar system's general capabilities are shown in the following tables.

CSU-CHILL Basic Operational Characteristics:

Peak transmit power (each channel)	800 kW
Pulse width	0.1-1.0 μs in steps of .1 μs
Range gate depth	15 - 150 m
Pulse repetition time	800-2500 μs
Maximum unambiguous range	375 km
Antenna scan modes	PPI, RHI, V pointing, coplane
Antenna acceleration	$20^{\circ}\ s^{-2}$
Maximum antenna scan rate	$25^{\circ}\ s^{-1}$
Receiver noise figure (each ch)	~4.3 dB
Receiver bandwidth (each ch)	0.75 - 5.0 MHz
Minimum detectable signal (SNR=1)	-115 dBm (-15 dBZ at 30 km ra

Available data fields:

Returned Power (dBm or dBZ)	Differential Reflectivity (ZDR)
Normalized Coherent Power (NCP)	Differential Propagation Phase (ϕdp)
Radial Velocity (pulse pair method)	Zero Lag HV Correlation (ρHV(0))
Spectrum Width (2nd lag method)	Linear Depolarization Ratio (LDR)
Unprocessed complex voltages (I,Q)	Complex Correlations (RHV1, etc.)

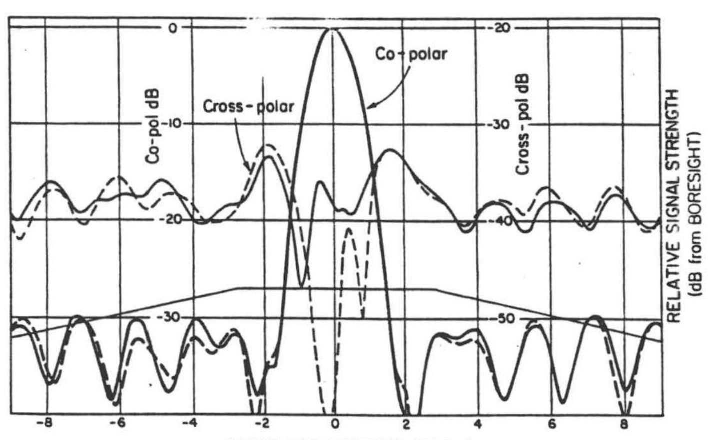

Figure 3: CSU-CHILL co-polar and cross-polar antenna pattern plots. The patterns were taken in the plane of the feed horn support struts (worst case).

Block Diagram Discussion: There are two largely independent transmitters and receivers driven from a common frequency chain. The frequency chain consists of two crystal controlled oscillators; a 60 MHz coherent reference oscillator (COHO) and a 2785 MHz stable local oscillator (STALO). These signals are mixed and the lower sideband is selected to provide the 2725 MHz transmit frequency. This is gated through a fast solid state switch to the solid state intermediate power amplifiers (IPA) and on to the high power Klystron transmit tubes (VA87B). Not shown on the diagram are the triggers that come from the signal processor to control the rf gate and the power applied to the IPA and the VA87's. These triggers determine whether the H, V, or both transmitters will fire. The high power pulse passes though the transmit/receive circulators and out to the antenna. A dual-channel waveguide rotating joint is used to maintain signal separation all the way to the ortho-mode transducer on the feed horn. Power received at the antenna returns along the same waveguide system and passes through the transmit/receive circulators, through the ionizing power limiters to the low noise amplifiers (LNA's). Not shown on the diagram is a high frequency solid state transfer switch located just after the LNA's. This allows the power from either channel to be routed to either receiver for maximum flexibility. A preselector filter limits the bandwidth to 5 MHz. The signal is then mixed with the STALO to down-convert to 60 MHz. The signal is split at this point to drive the log and linear receivers. The log receiver is digitized by the signal processor, and used to set the gain of the linear channel on a gate by gate, pulse by pulse basis. The linear signal passes through a ~700 kHz bandwidth matching filter and is delayed slightly to allow the step attenuator to be set for each gate based on the sample from the log receiver. This prevents the saturation of the following IF stages and allows for approximately 90 dB dynamic range in the linear receiver. The quadrature detector provides in-phase (I) and quadrature (Q) base-band video signals that are digitized and combined with the step attenuator setting to produce floating point samples that are used in the signal processor to generate the various meteorological moments.

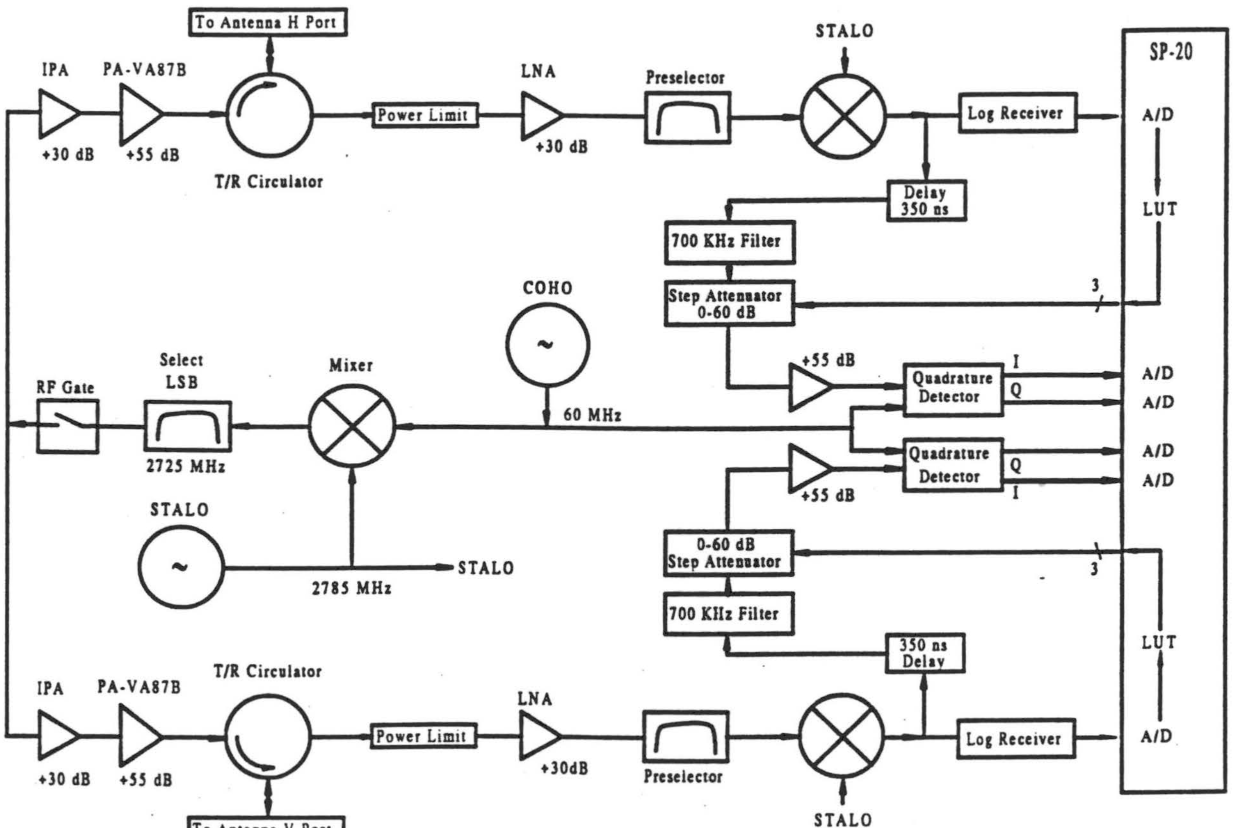

Figure 4. Simplified CSU-CHILL Block Diagram.

3. The Physical Facility

The home base of the CSU-CHILL Facility is located one mile north of the Greeley, CO Weld County Airport. This site is equipped with a permanent building which provides office space for staff as well as visiting radar users (Fig. 1). The building also has auxiliary computer workstations and is connected to the main CSU campus via a T1 data line. These computer capabilities permit access to a wide variety of on-line meteorological information to aid in making realtime refinements to radar data collection strategies.

For remote deployments, the CSU-CHILL system is transported on 5 full sized semitrailers. Installation of the antenna and radome at a remote site requires the construction of a 21.3 m (70 foot) diameter reinforced concrete pad. During operations the radar needs 75 kW of 3 phase 120-volt electrical power. This can be supplied either by suitable commercial electrical service or by an on site diesel generator transported as a part of the CSU-CHILL system.

4. Example Data

Samples of standard Doppler weather radar data available from the CSU-CHILL system are illustrated by observations of a tornadic thunderstorm. This storm passed within ~15 km of the Greeley radar site shortly before the tornado developed. Fig. 5a shows reflectivity data collected in a 9.6^o elevation angle PPI scan made at 1901:09 MDT. The strongest reflectivity was located in the 5 - 10 km range interval. Curving southeastward from the main core was a line of strong echo, evidently associated with hail. The pre-tornadic circulation was forming where a reduced reflectivity "eye" appeared, centered at 162^o azimuth and 10.4 km range. The radial velocity pattern showed that this small scale circulation was located on the leading (right) side of the larger mesocyclone (Fig. 5b). The smooth, uncontaminated nature of these short-range data demonstrate the suppressed sidelobe levels achieved by the CSU-CHILL antenna.

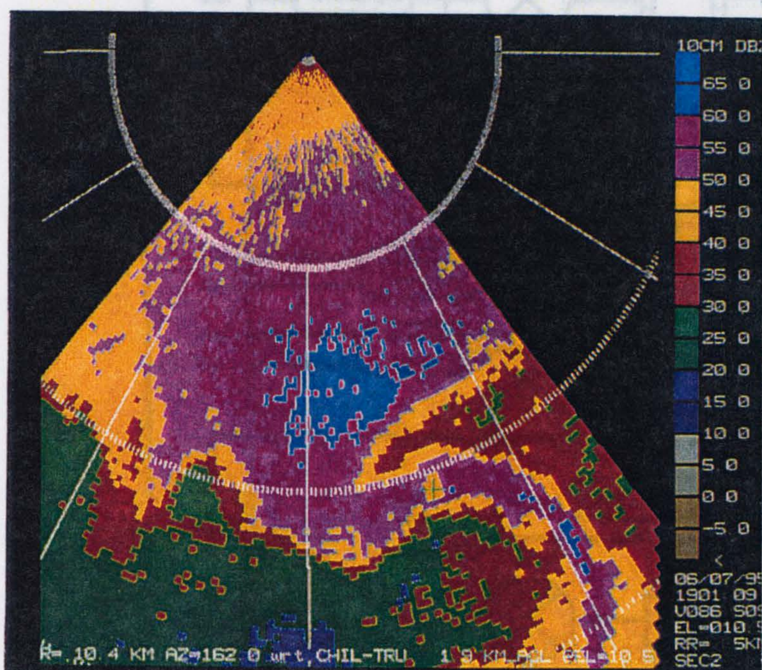

Figure 5a: Pre-tornadic thunderstorm reflectivity PPI at 1901:09 MDT

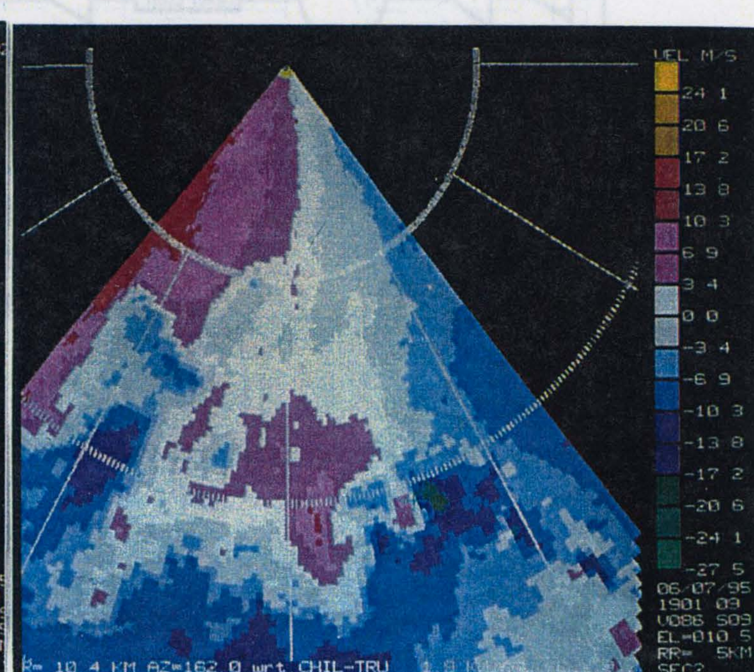

Figure 5b: As in 5a, except data field is radial velocity

Examples of multiparameter data from the CSU-CHILL system are shown by RHI scans made through a hailstorm. The reflectivity pattern contained an echo overhang that extended above the inflow region on the far-range side of the storm (Fig. 6a). A positive ZDR column (centered at a range of 23 km) that penetrated into the overhang was probably the result of a strong updraft that lofted partially frozen drops above the freezing level (Fig. 6b). (The height of the freezing level was marked by the horizontally oriented ZDR gradient region in the weaker echo intersected by the 10 km range ring). Near 0 dB ZDR values due to hail were found in the intense echo core (21 km range). Concurrent observations made from a storm intercept van confirmed that copious amounts of 10 - 15 mm diameter hailstones, mixed with moderate rain, were present in this low ZDR shaft.

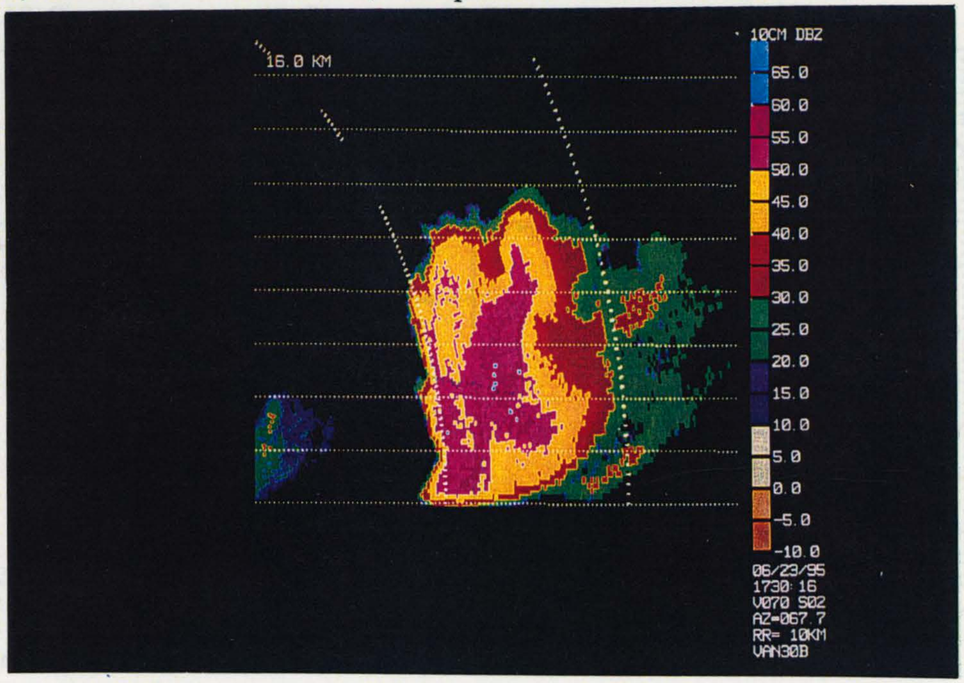

Figure 6a: Hailstorm RHI: reflectivity; range rings are at 20 and 30 km

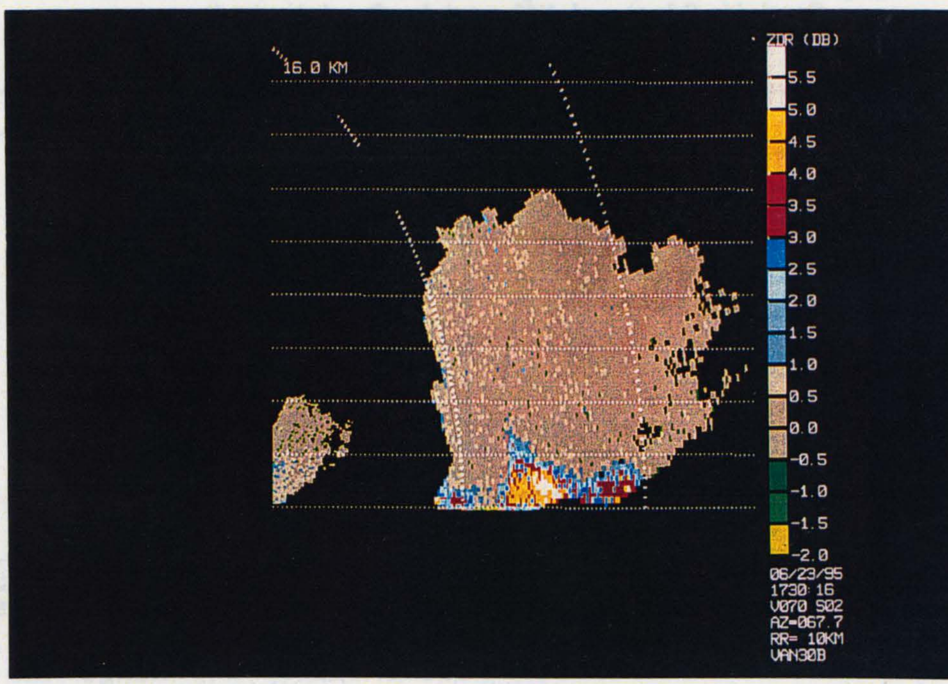

Figure 6b: Differential reflectivity, range rings are at 20 and 30 km

Detailed range profiles of data values along the 2.34° elevation beam in this RHI sweep are shown in Figure 7. Reflectivities of 45 - 55 dBZ were present in the 19 - 25 km range interval (Fig. 7a). ZDR values varied significantly within this high reflectivity echo. In the hail shaft (~19.5 - 22 km) ZDR's were near 0 dB, while in the rain region (beyond 23 km) they reached 3 - 4 dB (Fig. 7a). The hail - rain boundary zone (22.6 km) was marked by a local reduction to .~90 in ρHV(0) trace (Fig. 7b). A kink in the smoothed LDR curve also occurred at the rain - hail interface, with LDR values generally being 3 - 4 dB higher in the hail region (Fig. 7b).

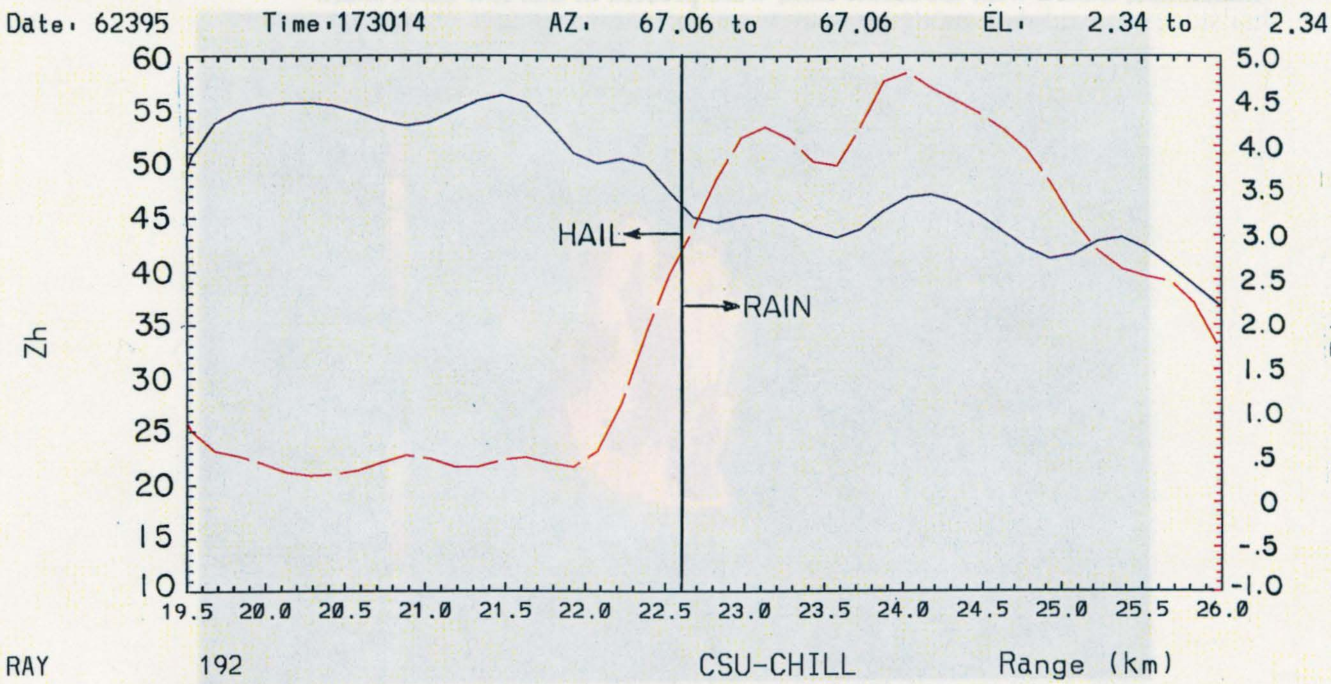

Figure 7a: Ray plot of data values along 2.34° elevation beam within the hailstorm RHI. Curves are reflectivity (blue) and differential reflectivity (red).

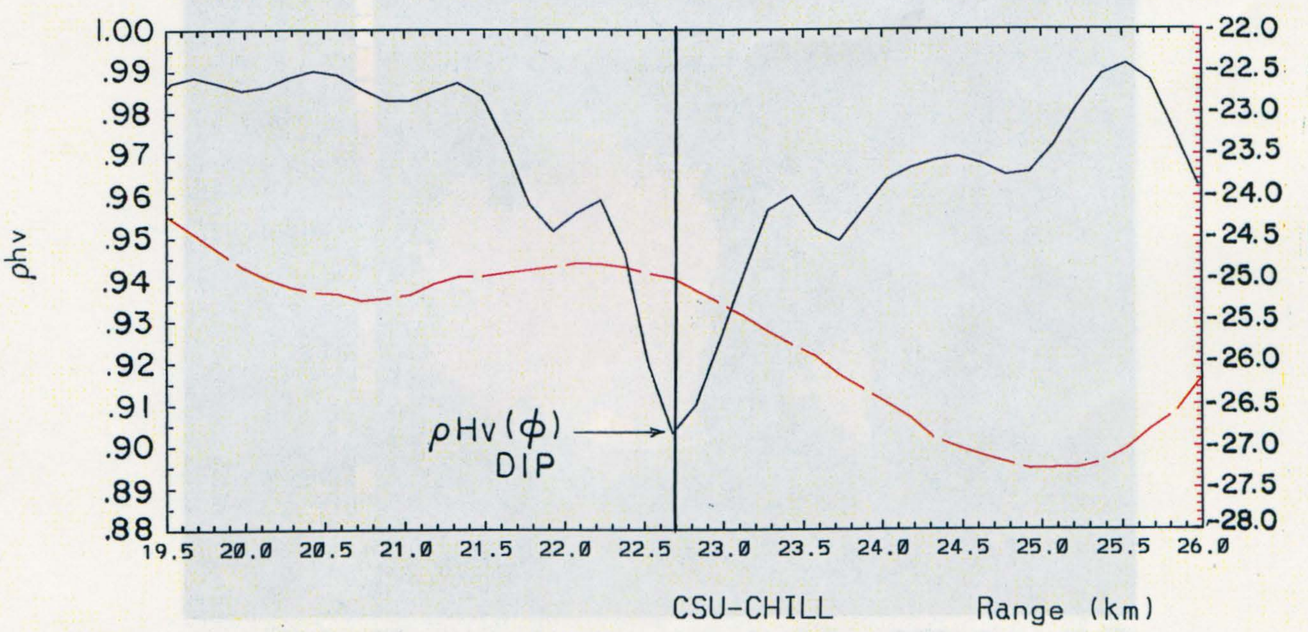

Figure 7b: As in 6a except curves are ρHV(0) (blue) and LDR (red).

These are just two examples taken from the CSU-CHILL field tape recordings. All such field tapes are retained in the facility archives. These archived data are available for educational use, typically as classroom case studies, as well as for specific research investigations. Narrative summaries for most of the radar operational days included in the data archives may be perused via the CSU-CHILL's World Wide Web home page described below.

5. Procedures for Obtaining use of the CSU-CHILL Facility

Allocation of the CSU-CHILL radar facility for use in field projects is done by the Facility Advisory Committee (FAC), based upon input from the Observing Facilities Advisory Panel (OFAP). This panel convenes twice a year (generally in October and April) to review facility use requests. For those projects requiring OFAP/FAC approval, proposals (sent to NSF), and Facility requests (sent to the Scientific Director), are due on 15 June (for review at the October meeting) and on 15 December (for review at the April meeting). The fall OFAP/FAC meeting considers projects that are scheduled to start in the last six months of that fiscal year. The spring meeting considers projects with scheduled starting dates in the first six months of the next fiscal year. Allocation of radar support for smaller projects needing less than 20 hours of data time, and conducted at the radar's home base in Greeley, Colorado, is done upon approval by the Scientific Director of the facility. Applications for both large and small projects are available from the CSU-CHILL Facility (see contact information below). Costs for use of the CSU-CHILL facility in field projects with NSF funding are supported by the ATM Deployment Pool. Projects that are not funded by the NSF, and which require more than 20 hours of radar operations, are charged a daily radar use fee of approximately $2000 in addition to out of pocket expenses. Costs for smaller projects at the Greeley site, requiring less than 20 hours of radar time, are borne by the CSU-CHILL facility budget.

Prospective users are encouraged to contact the Scientific Director of the Facility, Prof. Steven A. Rutledge (970 491-8283, rutledge@olympic.atmos.colostate.edu), or the Facility Manager (Pat Kennedy: 970 491-6248; pat@lab.chill.colostate.edu) for consultation on specific usage of the radar. Current information regarding the CSU-CHILL facility (as well as numerous examples of radar data) is available through the following World Wide Web home page: http://olympic.atmos.colostate.edu/CHILL/CSU-CHILL.html

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Revised 18 January 1996