Final Report for

THE CSU-CHILL RADAR FACILITY

Cooperative Agreement No. ATM-8919080

Submitted to

The National Science Foundation

Division of Atmospheric Sciences

6 May 1996

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

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NATIONAL SCIENCE FOUNDATION FINAL PROJECT REPORT

PART I - PROJECT IDENTIFICATION INFORMATION

1. Program Official/Org. Dr. Ken Van Sickle

2. Program Name Lower Atmosphere Research Section

3. Award Dates (MM/YY) **From:** 04/15/90 **To:** 04/30/95

4. Organization and Address
Colorado State University
Department of Atmospheric Science
Fort Collins, CO 80523-1371

5. Award Number ATM-8919080

6. Project Title

The CSU-CHILL Radar Facility

NSF Grant Conditions (Article 17, GC-1, and Article 8, FDP-II) require submission of a Final Project Report (NSF Form 98A) to the NSF Program Officer no later than 90 days after the expiration date of the award. Final Project Reports for expired awards must be received before new awards can be made (NSF Grants Policy Manual Section 340).

Below, or on a separate page attached to this form, provide a summary of the completed projects and technical information. Be sure to include your name and award number on each separate page. See below for more instructions.

PART II - SUMMARY OF COMPLETED PROJECT (for public use)

The summary (about 200 words) must be self-contained and intelligible to a scientifically or technically literate reader. Without restating the project title, it should begin with a topic sentence stating the project's major thesis. The summary should include, if pertinent to the project being described, the following items:

- The primary objectives and scope of the project
- The techniques or approaches used only to the degree necessary for comprehension
- The findings and implications stated as concisely and informatively as possible

PART III - TECHNICAL INFORMATION (for program management use)

List references to publications resulting from this award and briefly describe primary data, samples, physical collections, inventions, software, etc., created or gathered in the course of the research and, if appropriate, how they are being made available to the research community. Provide the NSF Invention Disclosure number for any invention.

SEE ATTACHED REPORT

I certify to the best of my knowledge (1) the statements herein (excluding scientific hypotheses and scientific opinion) are true and complete, and (2) the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or of individuals working under their supervision. I understand that willfully making a false statement or concealing a material fact in this report or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001).

[illegible]	2 May 1996
Principal Investigator/Project Director Signature	Date

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MAILING INSTRUCTIONS
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NSF Form 98A (Rev. 7/95)

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PART II - Summary of Completed Project

This award provided support for the CSU-CHILL National Radar Facility. This facility was relocated from the Illinois State Water Survey / U. of Illinois at the onset of this award, and has been improved, maintained and operated by Colorado State University since June, 1990. The Facility served a large number of field projects under this award, as detailed in Part III of this Final Report. Major improvements were carried out on the Facility, highlighted by acquisition of a new, high performance antenna (feedhorn and parabolic dish reflector). The design specifications of the antenna, resultant high data quality and performance specification are detailed in Part III. Major upgrades to the antenna pedestal, computer system, radar receiver and test equipment were also carried out. Additionally, work was started under this Award towards the development of a dual-transmitter, dual-receiver radar system. This development has been completed under our new Cooperative Agreement and is now fully operational.

The Facility has played an integral role not only in research projects, but in projects specifically related to radar engineering and radar meteorology education. Numerous projects, formal courses and other formal/informal educational activities have centered on the Facility. A large number of theses and dissertations in the Departments of Atmospheric Science and Electrical Engineering have been made possible by the relocation of this Facility to Colorado State University.

PART III - Technical Information

a) Facility Upgrades

A number of upgrades have been made to the CSU-CHILL system over the course of the cooperative agreement which ended 1 May, 1995. The radar system's fundamental measurement capabilities have been expanded by the acquisition of a new, custom-designed antenna, and by the conversion to a dual transmitter / dual receiver configuration.

The new dual-polarized antenna was delivered in late 1993 by Radiation Systems, Inc. (RSI also manufactured the original CHILL antenna). In comparison to the original system, the new antenna has much better electrical characteristics. As shown in Appendix A, the sidelobe levels are down at least 27 dB below the level of the main beam, and the pattern matching between the two polarization states is excellent. The mechanical design of the new antenna has also been improved. The individual reflector panels can be adjusted to conform to the desired parabolic shape. The excellent sidelobe and cross-polarization isolation of the new antenna increases the accuracy for polarimetric measurements, particularly any which utilize the cross-polar signal. The cost of the new antenna, ($138,000) was provided completely from cost-sharing funds contributed by CSU.

Operational experience has verified that the new antenna meets its design specifications (see Appendix A). Overall sidelobe improvements have resulted in less ground clutter contamination. The copolar correlation coefficient (ρ_{HV}) measurement has improved significantly due to a nearly constant phase difference pattern between H and V polarizations across the main lobe. This was measured at the Greeley site using a test-horn transmitting 45° slant linear polarization, with the radar alternately measuring H and V polarized returns. Also, in test data collected in snow at high elevation angles (>60°), the mean ρ_{HV} was measured to be 0.996 with standard deviation of 3.44×10^{-3}. The standard ρ_{HV} estimator was used (Doviak and Zrnic, 1993) without any interpolation of the time-series data.

The ρ_{HV} measurement is particularly useful for identifying clutter, anomalous propagation, partial beam-blocking effects, and side-lobe generated artifacts in very strong reflectivity gradients. It is also an excellent indicator of the base of the "bright-band" or melting level, and regions of rain mixed with ice (hail). Fig. 1 gives an example of a sample range profile of "raw" multiparameter variables Z_h, Z_{dr}, ρ_{HV} and ϕ_{dp} (differential phase) through a convective cell near Fort Collins known to have produced hail for approximately 30 minutes. While the well-known Z_{dr} hail signature is clearly evident between 44-49 km, a pronounced ρ_{HV} "dip" is visible centered at 49 km (and a smaller "dip" at 44 km). From theory, ρ_{HV} takes on local minima or "dips" whenever raindrops are mixed with hailstones. The rather low values of ~0.9 near 49 km are also suggestive of a wider range of non-uniformity in hail shapes. Surrounding the hail shaft, the ρ_{HV} increases to around 0.98 indicative of rain.

Fig. 2 shows a range profile of "raw" multiparameter data from a stratiform "bright-band" case very close to the radar. The "bright-band" is at range 4.25 km (altitude = 2 km agl). The ρ_{HV} "dip" centered at a range of 3.75 km (or, a few hundred meters below the "bright-band") denotes the base of the melting level and is nearly coincident with the positive Z_{dr} of 1.5-2.0 dB. Surrounding the "bright-band", the ρ_{HV} is very near to unity while ϕ_{dp} is "flat" with range as expected in very light rain. These two examples illustrate the performance of the new antenna, especially as related to the ρ_{HV} measurement.

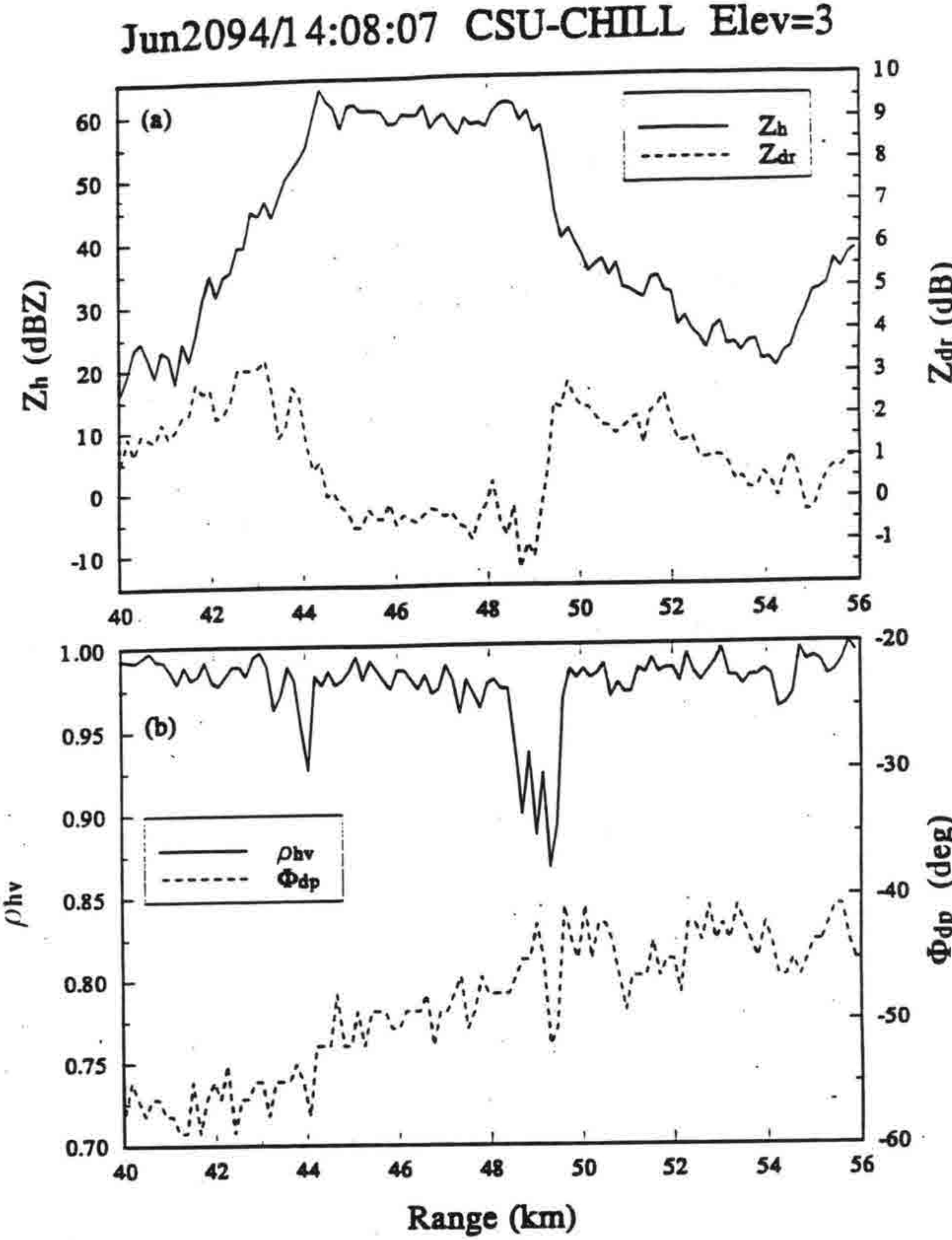


Fig. 1: Sample range profile of multiparameter variables in a hail cell located between 44 - 49 km range.

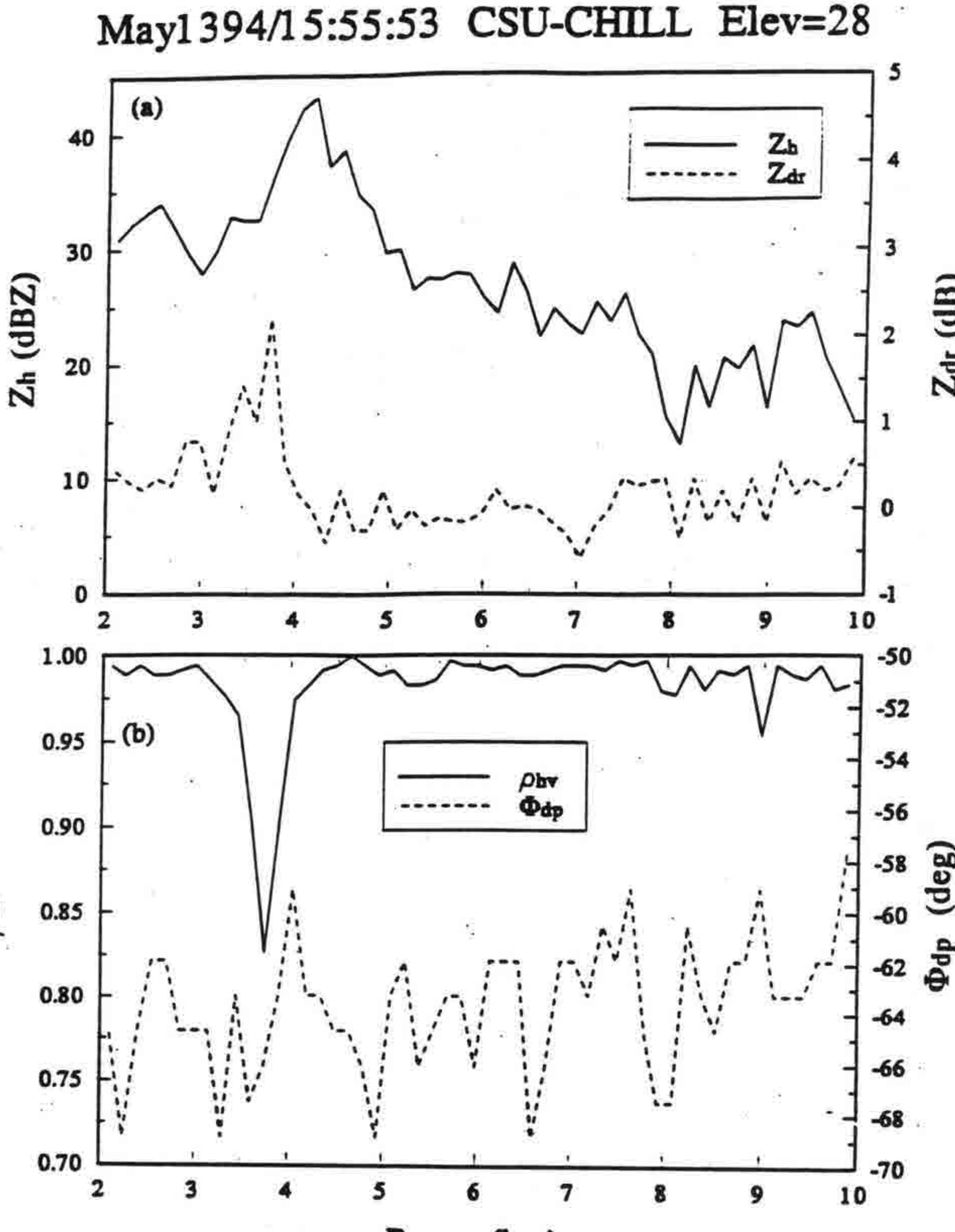


Fig. 2: Sample range profile of multiparameter variables through a bright-band located at 4 km range.

The excellent cross-polar performance capabilities of the new antenna have been borne out by linear depolarization ratio (LDR) measurements. Fig. 3 shows a Range Height Indicator (RHI) scan taken while scattered convective cells were embedded within a general area of stratiform rain. The bright band was evident at ranges of less than ~15 km at a height of 1.2 km AGL. Depolarization due to the melting snow flakes falling through this level raised the LDR to -15 to -20 dB; with localized maxima > -15 dB (X = 10.8, Z = 1.2 km; Fig. 3a). Distinct layers of >+1.5 dB Z_{dr} and <.85 ρ_{HV} (at a few gates only) (Fig. 3b) were also found in the bright band region. At greater ranges, the bright band neared the surface and was disrupted by a convective cell located near X = 28 km. Beneath this cell, ground observers reported pea sized hail. The ~-20 dB LDR values at the base of this echo core are consistent with the presence of small, wet hail stones. Finally, in the non-convective subfreezing portions of the echo system (X = 18 km, Z = 3 km), where small, completely frozen particles predominated, the LDR was typically quite small (~-30 dB).

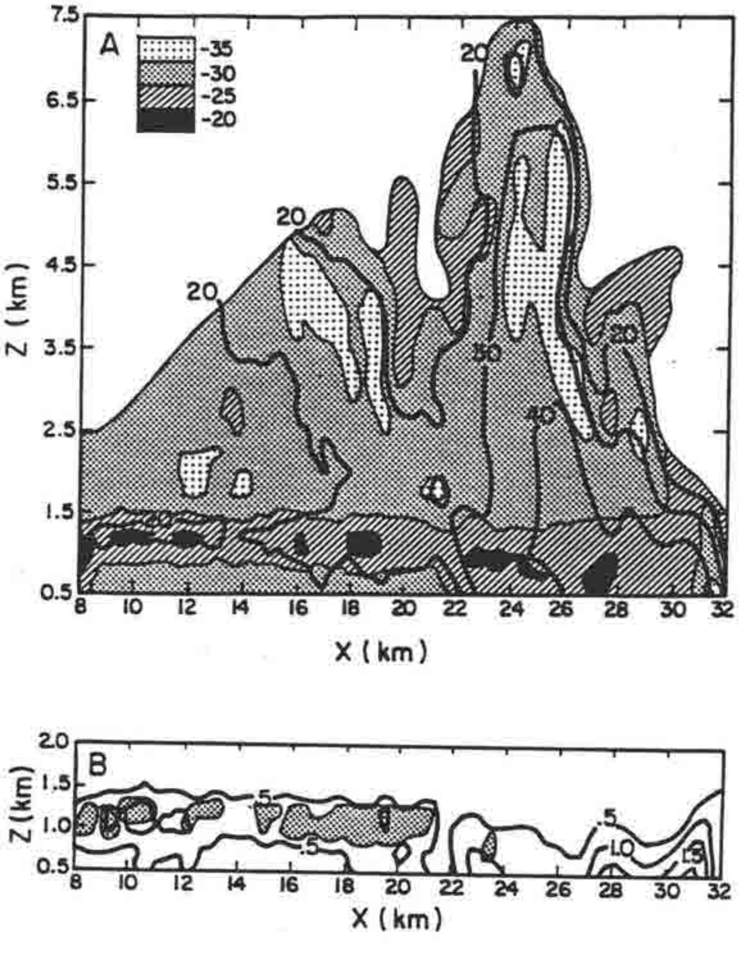


Fig. 3 a) RHI data along 227° azimuth at 1750 MDT on 4/28/95. Solid contours are reflectivity (dBZ). LDR regimes in 10 dB steps are indicated by hatching / shading. See figure inset for LDR values. b) For the same cross-section, ZDR contoured (minimum 0.5 db with 0.5 db step) and $\rho_{HV}(0)$. Shaded regions indicate $\rho_{HV}(0) < 0.96$.

The second major upgrade to the radar has been the transition to a dual transmitter / dual receiver system configuration. The change was necessary in order to take full advantage of the new antenna's cross-pole capabilities. The horizontal (H) and vertical (V) polarization ports on the old antenna were alternately driven via a switchable ferrite circulator. This device could only achieve an isolation of ~20 dB between the two polarizations. Since the new antenna attained an isolation of ~35 dB between the H and V polarizations, the switchable circulator imposed a significant performance limitation. To overcome this problem, a second FPS-18 transmitter was obtained from surplus equipment stock at the National Severe Storms Laboratory (NSSL) in March, 1994. This allowed the ferrite switch to be removed since the new antenna's H and V ports could be driven by separate transmitters. During the transition to the dual transmitter configuration, a second receiver was built and added to the radar. This allowed both the co-polar and cross-polar return signals to be processed.

In the new configuration, there are two largely independent transmitters and receivers driven from a common frequency chain (Fig. 4). 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

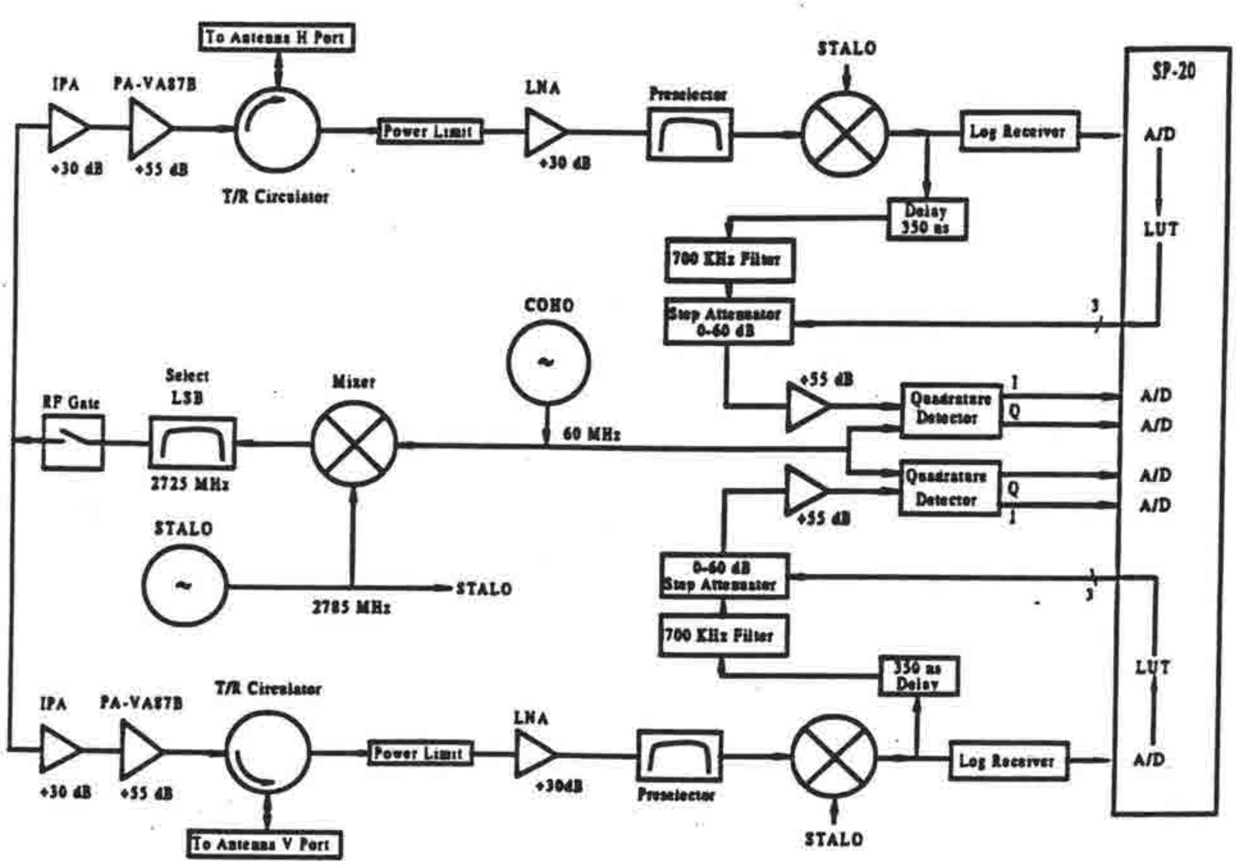


Fig. 4. Simplified CSU-CHILL Dual-Channel Block Diagram

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.

In addition to the major antenna and transmitter / receiver changes outlined above, a number of other upgrades have been made to the CSU-CHILL system over the course of the cooperative agreement.

Several improvements have been made to the antenna pedestal. The overall drive motor system has been updated. At present there are two 2.5 hp motors on each axis, horizontal and vertical. The shaft position encoders that were installed in the radar in 1972 have been replaced. The original optical encoders produced a digital 12 bit word length. Although not needed for data accuracy, four more bits were made available which permits much better antenna control. The new resolver to digital converters have proven to be extremely reliable. An automatic oiling system has been installed on the antenna, which has made operations much simpler than the manual system used previously.

A new, larger radome was acquired and installed at the beginning of the Cooperative Agreement (along with a new radome hold down ring, airlock entry system, pedestal base and concrete pad). This larger radome permits the departure angle of the radome measured to ground to be larger, thus resulting in a very stable radome in high winds. In addition, the new radome uses under-the-ground air conduits. A third inflation fan was designed, built and installed. This fan is gasoline driven, which provides redundancy to the system in case of power failure. An automatic monitoring and control system was purchased to monitor the radome. This programmable system provides recordings of pressure, temperature, winds, and status of the three fans. If abnormal conditions develop, the controller will automatically take action, such as turning on more blowers or starting the emergency generator. It is also programmed to make telephone calls to CSU-CHILL staff indicating potentially dangerous conditions.

A number of hardware and software upgrades took place in the area of signal processing. The present SP20 signal processor has been upgraded with an analog input card which digitizes the log and linear receivers, controls the attenuators in the linear channels, and generates triggers for the radar, enabling better control of the gain and DC offset in I-Q channels and a reduction in coherent interference in the receiver. Software was developed to add the VH alternating polarization mode. Initially only complex correlations were recorded in this mode, but in 1992, full Nyquist velocity, ϕ_{dp}, and ρ_{HV} were calculated and displayed in real-time. During this period, the SP20 calculation code was verified by inserting a known digital time series and observing the output. Finally, as noted earlier, a complete second receiver has been added as a part of the dual channel conversion.

The overall sensitivity of the receivers has been upgraded by replacement of the low noise amplifiers, installation of high performance bandpass filters, and various improvements in the automatic attenuator controls. The radio frequency chain and transmitter were upgraded by changing the filter in the synthesis chain which separated the STALO frequency from the transmitter frequency. The intermediate power amplifiers for both transmitters now use solid state rather than vacuum tube equipment. A phase modulator was added to the radio frequency chain to permit experimental work in pulse compression.

Four Sun workstations were added to the facility for general data processing and real time data display. They each play a role in supporting the new TITAN echo tracking and display system developed at the National Center for Atmospheric Research (NCAR). The TITAN system is used at the CSU-CHILL facility for data display (in addition to the operator console ADAGE system). This system produces a compressed 3-D grid of radar data which is stored on a data server. The viewing portion of the TITAN package requests data as needed for display. This arrangement reduces network bandwidth requirement and has allowed data to be viewed on the CSU campus and at NCAR in Boulder.

A new frequency synthesized signal generator improved the quality and ease of radar calibrations. Three RF power meters were acquired, two of which have digital IEEE488 outputs to aid in automating calibration procedures. A new analog plus digital storage portable scope was added to the facility. A time delay measurement circuit was built to provide an improved check on range measurements. A new 100 kVA diesel generator was also acquired to provide backup for commercial power.

To support the CSU-CHILL operations and provide office space for the radar staff, a 2300 sq. ft. building was erected at the four acre radar site near Greeley, CO (completed in December 1990). This building, in addition to providing office space, contains a conference room facility, an electronics lab, a machine shop, and visitor office space. This structure was paid for exclusively by CSU cost-sharing dollars.

b) Research Activities

i) In-House Research Summary

The in-house research conducted during the Cooperative Agreement largely centered on student projects leading to graduate degrees. A summary of in-house research conducted in Atmospheric Science follows. Dave Speltz completed his M.S. under Professor T. McKee using CSU-CHILL multiparameter data to study intense storms over the Denver urban flood district. Rainfall rates inferred from CSU-CHILL data were compared to gauge measurements over the urban area. Nick Powell completed his M.S. thesis under Professor S. Rutledge utilizing CSU-CHILL data collected during WISP91 (Winter Icing and Storms Project). Mr. Powell focused on identifying the dynamical and microphysical processes in mesoscale snowbands, and studying the role of topography in generating these features. Mr. Larry Carey completed his M.S. thesis under Professor S.

Rutledge which focused on the use of multiparameter data to infer the microphysical structure of deep convection which was then related to the observed electrical structure and lightning type. The active in-cloud lightning phase was well correlated with a mixed-phase environment near -20°C (as inferred from CSU-CHILL multiparameter data). The descent of hail, again inferred from reflectivity and differential reflectivity data, occurred close in time to the active cloud-to-ground lightning phase. The correlation of inferred microphysical states with observed lightning data demonstrate the usefulness of multiparameter data in remotely-sensing cloud and precipitation processes. A paper describing this research will soon appear in a special issue on Radar Meteorology in J. Met Atmos. Phys. Pete Clement conducted research with the CSU-CHILL radar under the direction of Professor T. McKee that resulted in the completion of a M.S. in Spring 1995. Mr. Clement's work focused on the use of CSU-CHILL multiparameter data, specifically specific differential phase, K_{dp}, in estimating heavy rain, and evaluating the contamination of reflectivity by hail (which is problematic when applying Z-R relations to infer rain rates). Professor W. Cotton and Mr. Ray McAnelly have utilized the CSU-CHILL facility during the 1992 - 94 summer seasons to study the upscale development of convective cells to Mesoscale Convective Complexes in eastern Colorado. Two additional students under the direction of Prof. S. Rutledge are presently pursuing their M.S. degrees using CSU-CHILL data to be collected in the STERAO/Deep Convection Experiment to be conducted in the summer of 1996.

In-house research in Electrical Engineering is summarized below. Mr. Ashok Mudukotore completed his M.S. under Professor V. Chandrasekar dealing with characterizing the CSU-CHILL system with a thesis focusing on signal statistics, antenna phase difference patterns, phase noise evaluation and sample data analysis. Ms. S. Mudegowda completed her M.S. under Professor V. N. Bringi with a thesis dealing with antenna errors and their effects on multiparameter radar measurements. She used measured antenna patterns for the old and new CSU-CHILL antennas in her 1D and 3D simulations. These simulations involve convolution of the antenna patterns (in 4 ø-planes) with an input reflectivity profile over a spherical surface. She also developed a theoretical framework for analyzing antenna errors. Mr. Andrew Benjamin completed his Ph.D. under Professor V. Chandrasekar's supervision. He was the first Afro-American Ph.D. to graduate from CSU's College of Engineering. He was supported by NSF and by a fellowship from the graduate school and he analyzed CSU-CHILL data obtained during WISP. Ms. Li Liu completed her Ph.D. under Professor Bringi's supervision. She studied the statistical properties of the ρ_{HV} estimator and analyzed time series data collected by the CSU-CHILL radar which were then compared with simulations. A paper has appeared in J. Atmos. Ocean. Tech. Her results have also been included in the recent edition of Doviak and Zrnic (1993).

Professor K. Aydin from Penn State spent his sabbatical at CSU and worked on a comparison of K_{dp}-based and attenuation-based estimates of rainfall with a raingage using data from a severe storm which was scanned by both the CSU-CHILL and NCAR/CP2 radars (Aydin, et. al. 1995). EE and ATS personnel collaborated on analyzing this same case focusing on storm structure and evolution of multiparameter signatures and a paper has been accepted for publication in a special issue of J. Met. Atmos. Phys.

Mr. John Beaver analyzed attenuation data at 20/27 GHz along a satellite-earth path. The CSU-CHILL radar was used to characterize the cloud vertical structure during the attenuation events. Two cases, one involving a distinct "bright band" and another a heavy convective rainfall case are being analyzed. He also tested a propagation and scattering model based on the Stoke's vector. Mr. Beaver recently completed his Ph.D. under Professor Bringi's guidance. Mr. A. Mudukotore completed his Ph.D. under Professor V.

Chandrasekar. He analyzed time series data collected by the CSU-CHILL radar in the pulse-compression mode. A tethered metallic sphere (used for absolute gain measurement) was used to test results for, (a) 1μs transmit pulse, (b) 200 ns transmit pulse, and (c) 1μs transmit pulse with length 5 biphase code (180°-0°-180°-180°-180°). Good agreement was obtained between the 200 ns pulse and the pulse compressed results. Mr. R. Xiao is a Ph.D. student working under the direction of Professor V. Chandrasekar. Mr. Xiao's research involves developing image processing algorithms to provide hydrometeor structure based on multiparameter radar measurements. In addition, Mr. Xiao is also working on correlating algorithms to compare radar and surface measurements. Fred Ogden, a Ph.D. graduate in Civil Engineering completed his dissertation on the development of water runoff models for the Colorado Front Range area. CSU-CHILL data were used to provide rain water input to the models in order to study the flow of water from various Front Range drainages.

ii) 20 Hour Projects

The CSU-CHILL facility is available to researchers via two modes. The first is the 20-hour mode where requesters apply for radar support not to exceed 20 hours of radar operation time. Twenty hour requests are reviewed by the Scientific Director of the Facility. These highly-focused projects allow relatively easy access to the Facility. The costs for the 20 hour projects (which are quite modest), are borne by the Cooperative Agreement. The 20 hour projects have led to very productive use of the CSU-CHILL over the past Cooperative Agreement. In the list of 20 hour projects that follow, we identify those projects specifically conducted to provide data for thesis/dissertation research (by initials M.S. or Ph.D.).

Investigator	Objective
1991	
Srivastava (U. of Chicago)	Remote sensing of drop size distributions
Kostinski (Michigan Tech)	Statistical properties of multiparameter data
Hartley (U.S. Dept. of Agriculture)	Multiparameter radar-rain gage comparison
Ogden (CSU, Civil Engineering)	Rainfall initialization of runoff model (Ph.D.)
Speltz (CSU, Atmospheric Science)	Multiparameter observations of storms over the Denver urban flood district (M.S.)
1992	
Srivastava (U. of Chicago)	Remote sensing of drop size distributions
Connell (CSU, Civil Engineering)	Radar and time lapse observation of thunderstorms
Cotton (CSU, Atmospheric Science)	Observations of MCS genesis
Rauber (Univ. of Illinois)	Support of tests of water collector on the NCAR Sabreliner
Dixon (NCAR)	Automated thunderstorm tracking (Ph.D.)
1993	
Kennedy (CSU, Atmospheric Science)	Characterization of aircraft ground icing
Holtzer (CSU, Entomology)	Migration patterns of Russian Wheat Aphids
Aydin, Bringi (Penn State, CSU)	Multiparameter identification of hail
McAnelly (CSU, Atmospheric Science)	Observations of MCS genesis
Roberts (CSU, Atmospheric Science)	Structure and evolution of winter storms (M.S.)
Benjamin (CSU, Electrical Engineering)	Radar-aircraft data comparisons (Ph.D.)
Carey (CSU, Atmospheric Science)	Evolution of storms and electrification (M.S.)

1994

Holtzer (CSU, Entomology)	Migration patterns of Russian Wheat Aphids
Bringi (CSU, Electrical Engineering)	Comparison of WSR-88D and multiparameter based rainfall estimates
Cotton (CSU, Atmospheric Science)	Observations of MCS genesis
Breed (NCAR)	Cloud electrification; testing of new data system in NCAR sailplane
Beaver (CSU, Electrical Engineering)	Propagation effects at 20/27 GHz
Hallett (Univ. of Nevada-Reno)	Evolution of anvil airflow fields
Clement (CSU, Atmospheric Science)	Multiparameter observations of storms over Denver urban flood district (M.S.)

iii) Full Project Summary

Since the CSU-CHILL radar is an NSF National Facility, requests for full project support are reviewed by the Observing Facilities Advisory Panel (OFAP) with the award decision being made by the Facilities Advisory Council (FAC). The following OFAP/FAC reviewed projects used the CSU-CHILL facility under the Cooperative Agreement. These projects were all supported at the CSU-CHILL site near Greeley, CO. A collection of letters to/from CSU-CHILL users have been assembled in Appendix B.

Investigator	Objective
1991	
Rasmussen et al. (NCAR, CSU investigators)	Structure and evolution of winter storms (WISP91)
Hallett (Univ. of Nevada-Reno)	Graduate student field project experience
1992	
Chandrasekar (CSU)	Research experience (REU) for Electrical Engineering undergraduates
1994	
Rasmussen et al. (NCAR, CSU investigators)	Supercooled water evolution in winter storms (WISP 94)
Chandrasekar (CSU)	Research experience (REU) for Electrical Engineering undergraduates

The use of the CSU-CHILL facility for the Research Experience for Undergraduates (REU) projects are particularly noteworthy. The Electrical Engineering Department in collaboration with the CSU-CHILL facility served as an REU site in both 1992 and 1994. (This REU program is also scheduled to continue through the summers of 1995 and 1996 as well). Support for the REU students was provided by grants from the NSF Directorate for Education and Human Resources. Professor V. Chandrasekar has been the site director for this program. The program had special emphasis towards recruitment of women and minority students, and in both years the REU program had significant participation from minority and women. A total of 26 students participated in the two REU sessions, coming from states throughout the U.S. During the REU program which lasts for nearly three months during the summer term, the students were in residence in Fort Collins and worked on research projects at the CSU-CHILL Facility or on related topics. In addition several experts in the areas of radar engineering, radar meteorology, and signal and image processing conducted a sequence of lectures at the CSU-CHILL site.

During the 1992 REU program the T-28 aircraft also participated, providing students with both radar and aircraft field experience. The REU students left superlative comments about their research experience at CSU. In summary, the REU program, centered on the CSU-CHILL facility, has played a significant educational role by providing unique research experiences for undergraduate students.

iv) Data Dissemination

In addition to maintaining high quality control standards, we have made strides in disseminating data to users, and to potential users. We have developed a remote login procedure allowing scientists to peruse our complete data archive which has been summarized into a large number of meteorological situations. By selecting a key word(s) (e.g., colliding gust fronts, cyclonic upslope snowstorm), scientists can identify specific dates when such data were collected, and read a brief summary of operations. Examples of this data archive are shown in Fig. 5. Faculty from several institutions, including Penn State, and North Carolina State, have used our remote login system to select data for classroom use. We have reported on data access procedures and case study availability in each of our annual CSU-CHILL newsletters (see Appendix C).

Casebook of CSU-CHILL Operations

The CSU-CHILL Casebook contains summaries of all significant operations since the radar was moved to Colorado in 1990. If you are looking for a particular weather situation, you should try accessing the data summaries by keyword. About 70 keywords have been identified and associated with all applicable cases. The summaries can also be accessed by the date of the operation, or by the project/investigator associated with the operation.

CSU-CHILL Casebook: Known Keywords

Click on the desired Keyword for a list of available cases.

* 30M_RESOLUTION
* ANTICYCLONIC_SHEAR
* ARCTIC_FRONTAL_SNOWBAND
* BARRIER_JET
* BLIZZARD
* BOW_ECHO
* BRIGHT_BAND
* CHAFF
* CLASS_CASE
* COLD_FRONT
* COLD_SURGE
* COLLIDING_BOUNDARIES
* COLLIDING_OUTFLOWS
* DEVELOPING_THUNDERSTORM
* DEVELOPING_THUNDERSTORM_LINE
* DISTANT_THUNDERSTORM
* DISTANT_THUNDERSTORMS
* DUST_STORM
* DVLPG_MCS
* ECHO_BAND
* ECHO_TOP_ZDR
* FINE
* FINE_LINE
* FINE_LINES
* FIRST_ECHO
* FLANKING_LINE
* FLARE_ECHO
* FLOODING_RAIN
* FLOODING_THUNDERSTORM
* FRONTAL_FINE_LINE
* FUNNEL_CLOUD
* GRAUPEL
* GUST_FRONT
* GUST_FRONT_COLLISION
* HAIL
* HAIL_STORM
* HEAVY_RAIN
* INSECTS
* ISOLATED_THUNDERSTORM
* ISOLATED_THUNDERSTORMS
* LARGE_HAIL
* LIGHT_GRAUPEL
* LIGHT_RAIN

Fig. 5 Sample page from the CSU-CHILL computer-based data access guide.

c) Educational Support

i) Theses and Dissertations

The following lists theses and dissertations completed by CSU students whose research involved the direct use of the CSU-CHILL Facility.

Ph.D. Dissertations

Polarimetric Radar/Aircraft Observations and Modeling of Ice Crystals in Winter Storms by Mr. Andrew Benjamin, Electrical Engineering.

Remote Sensing of Precipitation Using Multiparameter Radar by Ms. Li Liu, Electrical Engineering.

Two Dimensional Runoff Modeling with Weather Radar by Mr. Fred Ogden, Civil Engineering

Propagation Studies at K band Using CSU-CHILL Radar and the NASA ACTS Terminal by Mr. John Beaver, Electrical Engineering.

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

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

M.S. Theses

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

Evaluation and Characterization of the CSU-CHILL Radar by Mr. A. Mudukotore, Electrical Engineering

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

A Comparison of Radar Rainfall Estimates and Rain Gage Measurements During Two Denver Thunderstorms, by David Speltz, Atmospheric Science

A Comparison of Radar-derived Precipitation and Rain Gage Precipitation in Northeast Colorado, by Peter Clement, Atmospheric Science

Radar-Based Case Study of a Northeast Colorado Snowstorm by Nicolas S. Powell, Atmospheric Science

Ph.D. Dissertations (In Progress)

Polarimetric Radar Studies of Tropical and Mid-Latitude Electrified Convection, by Larry Carey, Atmospheric Science

Rainfall Estimation Using Specific Differential Propagation, by Scott Bolen, Electrical Engineering

M.S. Thesis (In Progress)

Doppler Radar Investigation of Nonmesocyclone Tornado and Lightning Producing Storms in Northeast Colorado, by Rick Lucci, Atmospheric Science

Utility of Real-Time Lightning Data in Nowcasting: Electrical and Microphysical Observations of NE Colorado Convection, by Jonathan Erdman, Atmospheric Science

ii) CSU Classroom Support

The CSU-CHILL Facility has greatly enhanced radar meteorology and radar engineering education at CSU and other institutions. This facility has provided demonstrations to high school students and teachers, provided data for many senior projects in Electrical Engineering, and provided invaluable hands-on experience to graduate students in both Atmospheric Sciences and Electrical Engineering at CSU.

In Atmospheric Sciences, the CSU-CHILL Facility has been a focal point for students in AT741, an advanced course in Radar Meteorology. Students learn about radar engineering and signal processing methods during visits to the Facility, which follow lectures on these subjects. Students also analyze case studies collected by the radar and in doing so are exposed to a variety of advanced radar analysis software packages. The enrollment in this course normally ranges from 15-20 students. Examples of the case studies analyzed by students in AT741 were described in the article by Rutledge *et al.* (1993, BAMS). Students in AT652, Remote Sensing, also visit the radar twice per semester to receive basic knowledge on radar systems and radar operations.

The CSU-CHILL radar has been the focus of many senior projects in Electrical Engineering. Senior projects are required in Electrical Engineering, and consist of a formal write-up and presentation by the students. A list of the senior projects completed to date follows:

Student	Topic
Susan Casseday	Antenna Pattern Analysis
Dave Olson	Evaluation of Z_{dr} Errors
Dave Garbrick	Antenna Pattern and Solar Scan Analysis
Charon Shepherd	Multiparameter Data Analysis
Terry Jackson	Multiparameter Data Analysis
Dustin Schramm	Power Supply Switching
Eric Stolz	Analysis of Multiparameter Time Series Data
Dan Reinke	Real Time Display
Chad Wongwsvick	CSU-CHILL ACTS Terminal Comparison
Sam Minger	Radar Signatures of Electrification
Jeffrey Kwon	Multiparameter Radar Studies
James Haring	Radar Data Display
Matthew Deutch	Multiparameter Radar Studies

In addition there are two other undergraduate educational programs in Electrical Engineering that have used the CSU-CHILL Facility.

1) Undergraduate Peer Study Group: Specifically for minority undergraduate students. Students are exposed to all aspects of CHILL. (Typical enrollment: five minority students per semester)

2) High School Days: One full day per semester, close to 150 high school students are given demonstrations on weather radar applications.

The following courses in Electrical Engineering also directly use the CSU-CHILL facility.

EE 742: Topics in Electromagnetics

Three field trips per semester, analysis of time series data, spectral analysis, description of transmitter, receiver, and signal processor by radar staff, dual-polarized radar theory, multiparameter variables and their estimators.

EE 642: Time Harmonic Fields

One field trip per semester, description of transmitter and receiver by staff, dual polarized antenna theory, radar estimators, Doppler principles and estimators.

EE 514: Applications of Random Processes

Analysis of time series data collected by CSU-CHILL with emphasis on spectral methods.

UNC Radar Meteorology Course

At the request of the Earth Sciences Department at the University of Northern Colorado (Greeley, CO), an undergraduate course in radar meteorology was designed and presented by Patrick Kennedy of the CSU-CHILL Facility staff. This was a 3 credit hour senior level course with an enrollment of 14 students. The course stressed the fundamental principles of Doppler weather radar systems, and the applications of their observations to operational meteorology. Many classroom examples were taken from the facility's data archives; the students also visited the CSU-CHILL site on 3 different occasions. Since the spring semester of 1991, a UNC faculty member has assumed the radar meteorology course. The Facility continues to support UNC's course by providing example slides of the CSU-CHILL color display and by hosting class visits.

University of Nevada-Reno/Desert Research Institute (DRI)

Professors John Hallett and Melanie Wetzel received NSF support to conduct a three-week short course on radar meteorology. Lectures were presented by Professors Bringi and Rutledge and CSU-CHILL staff. The NSF support allowed the DRI students to work at the CSU-CHILL Facility, providing them with radar field experience and exposure to data analysis studies. This course was described in the article by Hallett *et al.* (1993, BAMS).

d) Publications

The following publications acknowledged support by the Facility during the Cooperative Agreement. Publications are listed in chronological order.

Kennedy, P. C., N. E. Wescott, and R. W. Scott, 1990: Single Doppler Radar Observations of a Mini-Tornado. Preprint Volume, *16th Conference on Severe Local Storms*, American Meteorological Society, Oct 22-26, Kananaskis Provisional Park, Alberta, Canada, 209-212.

Musil, D. J., P L. Smith, and N. E. Westcott, 1990: Armored Aircraft Observations of a Severe Hailstorm in Illinois. Preprint Volume, *16th Conference on Severe Local Storms*, American Meteorological Society, Oct 22-26, Kananaskis Provisional Park, Alberta, Canada, 485-488.

Ramamurthy, M. K., B. P. Collins, R. M. Rauber, and P. C. Kennedy, 1990: Dramatic Evidence of Atmospheric Solitary Waves. *Nature*, **348**, 314-317.

Achtemeier, G .A. 1991: The Use of Insects as Tracers for "Clear Air" Boundary Layer Studies by Doppler Radar. *J. Atmos. Oceanic Tech.*, **8**, 746-765.

Bringi, V. N., E. A. Mueller, V. Chandrasekar, and A. Mudukutore, 1991: Polarimetric Measurements and Interpretation Using the S-Band CSU-CHILL Radar. Proceedings, *International Workshop on Multiparameter Radar Applied to Microwave Propagation*, September 3-6, Graz, Austria.

Changnon, S. A., R. C. Czys, R. W. Scott, and N. E. Wescott, 1991: Illinois Precipitation Research: A Focus on Cloud and Precipitation Modification. *Bull. Amer. Meteor. Soc.*, **72**, 587-604.

Huston, W. M., A. G. Detwiler, F. J. Kopp and J. L. Smith, 1991: Observation and Model Simulations of Transport and Precipitation Development in a Seeded Cumulus Congestus Cloud. *J. Appl. Meteor.*, **30**, 1389-1406.

Ramamurthy, M. K., R. M. Rauber, B. P. Collins, P. C. Kennedy, and W. L. Clark, 1991: UNIWIPP: A University of Illinois Field Experiment to Investigate the Structure of Mesoscale Precipitation in Winter Storms. *Bull. Amer. Meteor. Soc.*, **72**, 764-776.

Rutledge, S. A., V. N. Bringi, E. A. Mueller, D. A. Brunkow, P. C. Kennedy and K. Pattison, 1991: New Capabilities of the CSU-CHILL Radar. Preprint Volume, *25th International Conference on Radar Meteorology*, June 24-28, Paris, France, 852-854.

Shields, M. T., R. M. Rauber, and M. K. Ramamurthy, 1991: Dynamical Forcing and Mesoscale Organization of Precipitation Bands in a Midwest Winter Cyclonic Storm. *Mon. Wea. Rev.*, **119**, 936-964.

Westcott, N. E., 1991: The Bridging and Growing of Aggregating Echo Cores. Preprint Volume, *25th International Conference on Radar Meteorology*, American Meteorological Society, June 24-28, Paris, France, 424-427.

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

Mueller, E. A. and V. Chandrasekar, 1992: Meteorologic Radar Polimetry in North America 1950-1991. Direct and Inverse Methods in Radar Polarimetry, D. Reidel Company.

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.

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

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

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.

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.

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.

Bringi, V. N., L. Liu, P. C. Kennedy, V. Chandrasekar and S. A. Rutledge, 1994: Dual multiparameter radar observations of intense convective storms: The 24 June 1992 case study. *J. Meteor. Atmos. Physics,* in press.

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.

Carey, L. D., and S. A. Rutledge, 1994: A multiparameter radar case study of the microphysical and kinematic evolution of a lightning producing storm. *J. Meteor. Atmos. Phys.*, in press.

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. *J. Ocean. Atmos. Tech.*, in press.

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

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.

Rauber, R. M., M. K. Ramamurthy, and A. Tokay, 1994: Synoptic and Mesoscale Structure of a Severe Freezing Rain Event: The St.Valentine's Day Ice Storm. *Wea. and Forecasting*, **9**, 183-208.

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.

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.

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.

e) CSU-CHILL RAC Activities

The CSU-CHILL Radar Advisory Committee (RAC) was formed in 1990 by CSU for the purposes of reviewing the overall performance of the Facility, advising the Scientific Director on in-house research and technical enhancements, and reviewing the use of the Facility in educational activities. The RAC membership consisted of Professor Roger Wakimoto (UCLA), Professor Pierre Julien (CSU-Civil Engineering), Professor Bill Cotton (CSU-Atmospheric Science), Professor Jorge Aunon (CSU-Electrical Engineering), Dr. Jeff Keeler (NCAR), and Dr. Dusan Zrnic (NOAA/NSSL). The RAC was convened three times during the Cooperative Agreement. The RAC participated directly in the development of the electrical specifications for our new antenna, and also received detailed briefings on our plans to develop a dual-channel system. The last RAC meeting was convened on 8 April 1994 and included presentations to the RAC on the new antenna (performance, acceptance testing, initial data collections), other system improvements including improvements to the receiver and resolver-to-digital converters for antenna control, a presentation of in-house research activities, a discussion of the specific uses of the CSU-CHILL radar in education projects, and a detailed presentation and discussion of the dual transmitter-dual receiver upgrade. A formal report from the RAC on this meeting has been filed with the NSF/ATM. Recent letters from individual members of the RAC are included in Appendix D.

Appendix A

Invitation for Bid on New Antenna

Antenna Specifications
2/4/93

Introduction: Colorado State University (referred to as CSU henceforth) is considering replacement of the 28-ft diameter antenna which is now a part of the CSU-CHILL radar system, a description of which is attached. The purpose of this antenna upgrade is to permit: 1) a better match between the two co-polarization patterns, 2) meaningful meteorological measurements of the cross polarization signal strength, 3) a reduction in the magnitude of the side lobes, and 4) other heretofore impossible studies.

The first reason for upgrading the CHILL system with a new antenna relates particularly to the measurement of the differential reflectivity which has been shown to be a useful parameter in defining the state of the precipitation (e.g. hail, graupel, etc.) and precipitation intensity. The measurement of differential reflectivity has shown artifacts with the present antenna due to the mismatch of the copolar patterns (particularly of the side lobes in the presence of high reflectivity gradients). The second reason for upgrading the antenna relates to a more definitive procedure of identifying states of the individual scatterers that make up the radar return by using information from the cross polarization scattering of the hydrometeors. The new antenna must have much better cross polarization performance to make these additional measurements feasible from the stand point of the antenna. Finally, the third reason permits more confidence in all of the common observables if contamination from side lobes can be minimized.

A number of the specifications of the antenna are different than the typical antenna specifications because of the need to compare signals in amplitude and phase from distributed targets with different antenna polarizations. As a result of the distributed targets, these comparisons are effected not only by the boresight values but also by the integrated values throughout the entire patterns. <u>This in turn leads to specifying pattern matching</u>, which is not a common requirement for antennas. In order to formulate these specifications, it is convenient to define two angles related to the antenna. The first will be called the theta angle, θ , and represents the angle between the boresight axis and the point in question. The second angle will be called the phi angle, ϕ , and is the angle measured counter clockwise (as viewed from the back of the antenna) from the local vertical in a plane normal to the boresight when the antenna is pointing horizontally. A phi angle of zero degrees is pointing upward. The IEEE standard definitions shall apply to all variables. (IEEE Standard 145-1983, IEEE, NY)

Since this radar system is made to be moveable, all of the electrical and mechanical specifications need to withstand numerous reassemblies. On the present system assembly and reassembly was accomplished with the present antenna 29 times in the last 22 years. This number of antenna disassemblies and reassemblies is considered typical for this radar system.

All electrical tests described below are to be performed with waveguide attached to the antenna orthomode transducer. The waveguide must extend to the edge of the dish. Dummy loads if utilized for any of the tests must be attached in back of the parabola.

The following sections present the specifications for the new antenna. The order of the specifications should not be interpreted as an order of importance. All the following specifications, both electrical and mechanical, are absolutely essential. CSU will not consider any bid that does not absolutely meet these specifications.

I. Essential Electrical Specifications

1. The antenna must be capable of both horizontal and vertical linear polarization. In some of the specifications the use of horizontal or vertical port nomenclature is used. These refer to the antenna port behind the dish which when the antenna is pointing horizontally, the horizontal or vertical polarization results.

2. The antenna must be capable of a peak power of 1.5 Mw. This power specification must be met for both polarizations, for pulse widths of at least 1.5 microseconds, and for the full frequency range of 2.7 to 2.9 GHz.

3. The input Voltage Standing Wave Ratio must be less than 1.35 for both polarizations and for the full frequency range.

4. The contractor shall provide CSU with the primary patterns of the feed system. These shall consist of the copolar and cross polar patterns of the horn with the orthomode transducer attached as measured at phi angles of 0, 45, 90, and 135 degrees and for the three frequencies of 2.725, 2.80, and 2.875 GHz.

5. The antenna must meet all electrical specifications for a frequency range of 2.7 to 2.9 GHz. For this and following specifications, (electrical 6 through 12) there shall be antenna pattern measurements made at the three frequencies of 2.725, 2.80, and 2.875 GHz. These patterns shall be made at the phi angles of $\phi = 0$, 45, 90, and 135 degrees. Each of the patterns shall consist of amplitude of the received signal. If optimization is possible, it is desired that minimum side lobes and cross polarization be accomplished at a frequency of 2.725 GHz. However, specifications 6 through 12 must hold for all three measured frequencies.

6. The directivity of the antenna must be greater than 45 dB for both polarizations and within 0.5 dB of each other. CSU is willing to sacrifice up to 3 dB antenna directivity and up to 25 % in antenna efficiency for better pattern matching, cross polarization performance, and/or lower side lobes.

7. The 3-db beamwidth of the copolar patterns must be $\leq 1^\circ$ when measured at both ports and in all phi angles measured (i.e. $\phi = 0$, 45, 90, 135 degrees).

8. For both the H port and the V port and in the phi planes of $\phi = 45^\circ$ and 135°, the first sidelobe level shall be less than -27 Db with respect to the boresight value. The sidelobe levels shall be less than an envelope monotonically decreasing from the -27 dB at the location of the first sidelobe to -35 dB at 10 degrees from the

boresight. For all theta angles greater than 10 degrees the side lobe levels shall be less than -35 dB.
For both the H port and the V port and in the phi planes of $\phi=0°$ and $90°$, the first sidelobe level shall be less than -30 dB with respect to the boresight value. The sidelobe levels shall be less than an envelope monotonically decreasing from the -30 dB at the location of the first sidelobe to -40 dB at 10 degrees from the boresight. For all theta angles greater than 10 degrees the side lobe levels shall be less than -40 dB.

9. Let $F_{CH}(\theta,\phi)$ and $F_{CV}(\theta,\phi)$ be the copolar patterns of power. The subscripts H and V represent the horizontal and vertical ports. Figure 1 shows schematically the sidelobe levels of the two patterns. The difference in the amplitude of the peak signal level at each of the first two sidelobes must be less than 5 dB for each of the 4 phi angles and for both positive and negative theta angles. Further the difference in location of these sidelobes must be less than $0.25°$ in theta angle.

10. The cross polarization ratio, CPR, verification shall be as follows. Let $F_{XH}(\theta,\phi_j)$ be the cross polar power pattern when the horizontal port, H, is copolar to the radiated pattern, and let $F_{CH}(\theta,\phi_j)$ be the copolar pattern. The following ratio of summations are defined in the $\phi=45°, 135°$ planes for both the Horizontal port and the Vertical ports, where $\Delta\theta=0.2°$ and θ runs from $\theta=-10°$ to $\theta=10°$.

$$CPR_j = 10\times\log\left\{\frac{\sum_{i=-50}^{50} F_{XH}(\theta_i,\phi_j)\,F_{CH}(\theta_i,\phi_j)\ |\sin(\theta_i)|\Delta\theta}{\sum_{i=-50}^{50} F_{CH}^2(\theta_i,\phi_j)\,|\sin(\theta_i)|\Delta\theta}\right\}$$

Each of the twelve (four for each of the three frequencies) CPR values must be $\leq -32dB$. (i.e. for both H and V ports and for $\phi_j=45°, 135°$).

11. This specification is intended to demonstrate the matching of the co-polar patterns from the two ports. For the purpose of this specification let $F_{CH}(\theta,\phi_j)$ represent the co-polar power with respect to the boresight power, for horizontal port excitation at theta angle, θ, and phi angle, ϕ_j; similarly $F_{CV}(\theta,\phi_j)$ represents the copolar power for the vertical port excitation. For each phi angle there are two theta angles at which the power is reduced from boresight by 3, 10, and 20 dB (see figure 2). These theta angles will be referred to as $\theta_{i,j}$ where i is either +/- and where i=1 for the 3-dB reduction angle, 2 for the 10 db, and 3 for the 20 dB; the minus sign representing the opposite direction from the positive theta direction. Index j will run from 1 to 4 representing antenna pattern cuts at 0, 45, 90, and 135 degrees respectively. Pattern deviation, $\delta_{i,j}$ will then be defined as

$$\delta_{i,j} = |10\times\log(F_{CH}(\theta_{i,j},\phi_j)) - 10\times\log F_{CV}(\theta_{i,j},\phi_j)|$$

The deviations must meet the following criteria:

$$\delta_{i,j} \le \begin{Bmatrix} 0.5\ dB\ \ for\ i=\pm1 \\ 1.0\ dB\ \ for\ i=\pm2 \\ 2.5\ dB\ for\ i=\pm3 \end{Bmatrix}\ \ for\ j=1,2,3,4$$

12. The on-boresight cross polarization to copolarization ratio must be less than -35 dB for both horizontal and vertical polarizations.

II. Essential Mechanical Specifications

1. The surface tolerance of the antenna after assembly shall be within .020 inch root mean square. The procedure for verification of this specification shall be specified by the contractor in the bid proposal. All other factors being the same, preference will be given to the contractor proposing the minimum surface tolerance. This surface tolerance shall be demonstrated after the first disassembly and reassembly.

2. The waveguide runs between the back of the dish and the horn as well as the horn supports shall all lie in the ϕ=45° or 135° planes.

3. The antenna must have the ability to be disassembled and reassembled without destroying any of the electrical or mechanical specifications. This shall be demonstrated by disassembly and reassembly at the contractor's facility before the final electrical tests are accomplished. See item 1 in Testing Procedures with respect to the surface accuracy specification.

4. The antenna must be able to withstand repeated accelerations (i.e. normal operations) in both axes of 30 deg/sec/sec without degradation in any of the electrical or mechanical specifications. In addition it must have the ability to withstand occasional accelerations of 60 deg/sec/sec (e.g. if the antenna control system fails and drives the antenna into the hydraulic shocks) without permanent distortion of the dish.

5. The entire antenna must be capable of disassembly and packing on flat bed trailers for transport. If a single "center spinner" is a part of the antenna, it must be less than 8 feet in diameter. Any special mounting packaging or holding frames required for safe transportation shall be furnished by the contractor. These items must be reusable since the system is required to move, and they must withstand normal truck transportation.

6. The weight of the entire antenna shall not exceed 3000 pounds.

7. The supporting interface between the antenna and the pedestal shall not be greater than can be attached to a rectangular plate 10.5 by 5 feet. This interface will be provided by CSU. The contractor shall provide drawings to CSU within one month of the contract date showing the details of the antenna mounting, so that CSU can proceed

with the design of the interface.

8. The size of the antenna must be such that it shall fit inside of the present radome and permit "over the top" operation without coming closer than 2 feet to the structure. This requires that from the geometric center of the 10.5 by 5 foot supporting structure to any point on the dish or on the horn or waveguide shall be less than 17.5 feet.

9. Any special rigging, spreaders, or other devices for lifting of the assembled antenna with a crane in order to attach to the existing pedestal shall be furnished by the contractor.

10. Complete assembly and disassembly instructions shall be included in a maintenance manual. Two copies of this manual shall be supplied with the antenna.

11. The assembled dish when pointing vertically must have sufficient strength to permit two people to be located side by side at any point within the dish with the exception of the center spinner. This load shall be considered to be a weight of 380 pounds distributed over 4 square feet. The dish must support this load without damage to the dish or reducing its surface accuracy.

12. All parts shall be marked by metal stamping in such a manner that the reflector and center spinner and any other critical part may be reassembled in the same relative location.

13. The location of the horn relative to the dish must be adjustable by at least plus or minus 1 inch along the boresight axis. This will allow the refocusing for optimizing of other parameters than the critical ones in this specification. This adjustment must not be effected by the normal dismantling and reassembly procedures.

14. All the waveguide and the horn must be capable of pressurization to a pressure of at least 5 pounds/inch/inch.

15. All waveguide and horn components shall be constructed of aluminum alloy. The exterior of all parts shall be painted to prevent corrosion. Only stainless steel bolts, nuts, and washers of grade 18-8 steel shall be used.

16. The waveguide ports shall be in back of the reflector and shall be of type RG-75/U with standard UG-584 / UG-585 flanges.

17. In event of radome failure the antenna must withstand 90 mph winds when in a stowed vertical position. It should be operative in 50 mph winds.

III. Testing Procedures

1. A means of verifying the surface accuracy of the dish must be agreed upon by both the contractor and CSU personnel before contract signing. As a part of the bid the contractor shall describe the procedure that is recommended to verify this specification. The surface accuracy must be verified after assembly, disassembly and reassembly. If the procedure for verifying this specification is portable, the final check shall be made at CSU's radar facility at Greeley CO.

2. All of the Electrical Specifications must be demonstrated on the completed at the Contractors facility. The antenna shall then be disassembled and reassembled at the contractors location and all electrical specifications re-tested. Representatives of CSU shall be present for all these tests.

3. Adequate calculations on the strength of the antenna shall be submitted to CSU to demonstrate the adequacy of the strength of the antenna to withstand the accelerations specified. Likewise the calculation of adequate strength of the antenna when statically loaded at any point within the dish by 380 pounds (2 people) shall be submitted to CSU.

IV Additional Bid for Higher Performance in CPR

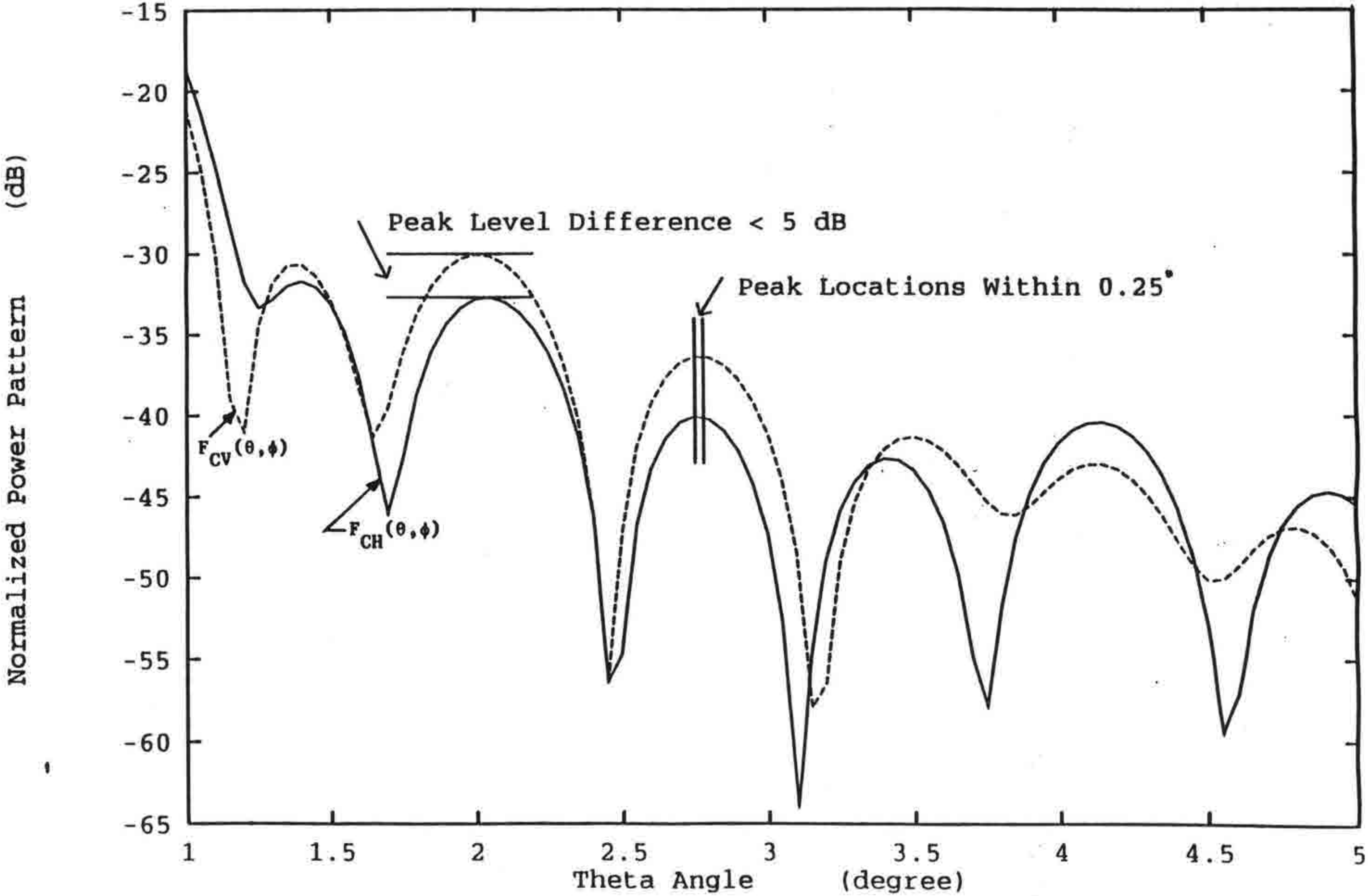
Specification 10 in Section II refers to the minimum specification for the twelve CPR values being $\leq$ -32 dB. It is desirable that all of the CPR values be $\leq$ -35 dB. Hence CSU requests a quote for the cost increment for an antenna that meets or exceeds the -35 dB criteria. This desirable specification can be stated as follows, and is referred to as specification 10 a.

10a. The cross polarization ratio, CPR, verification shall be as follows. Let $F_{XH}(\theta,\phi_j)$ be the cross polar power pattern when the horizontal port, H, is copolar to the radiated pattern, and let $F_{CH}(\theta,\phi_j)$ be the copolar pattern. The following ratio of summations are defined in the $\phi = 45°, 135°$ planes for both the Horizontal port and the Vertical ports, where $\Delta\theta = 0.1°$ and θ runs from $\theta = -10°$ to $\theta = 10°$.

$$CPR_j = 10\times\log\left\{\frac{\sum_{i=-100}^{100} F_{XH}(\theta_i,\phi_j)\, F_{CH}(\theta_i,\phi_j)\ |\sin(\theta_i)|\Delta\theta}{\sum_{i=-100}^{100} F_{CH}^2(\theta_i,\phi_j)\,|\sin(\theta_i)|\Delta\theta}\right\}$$

Each of the twelve (four at each of three frequencies) CPR values must be $\leq -35dB$ (i.e. for both H and V ports and for $\phi_j = 45°, 135°$).

Fig. 1 Sidelobe Matching Specification 8



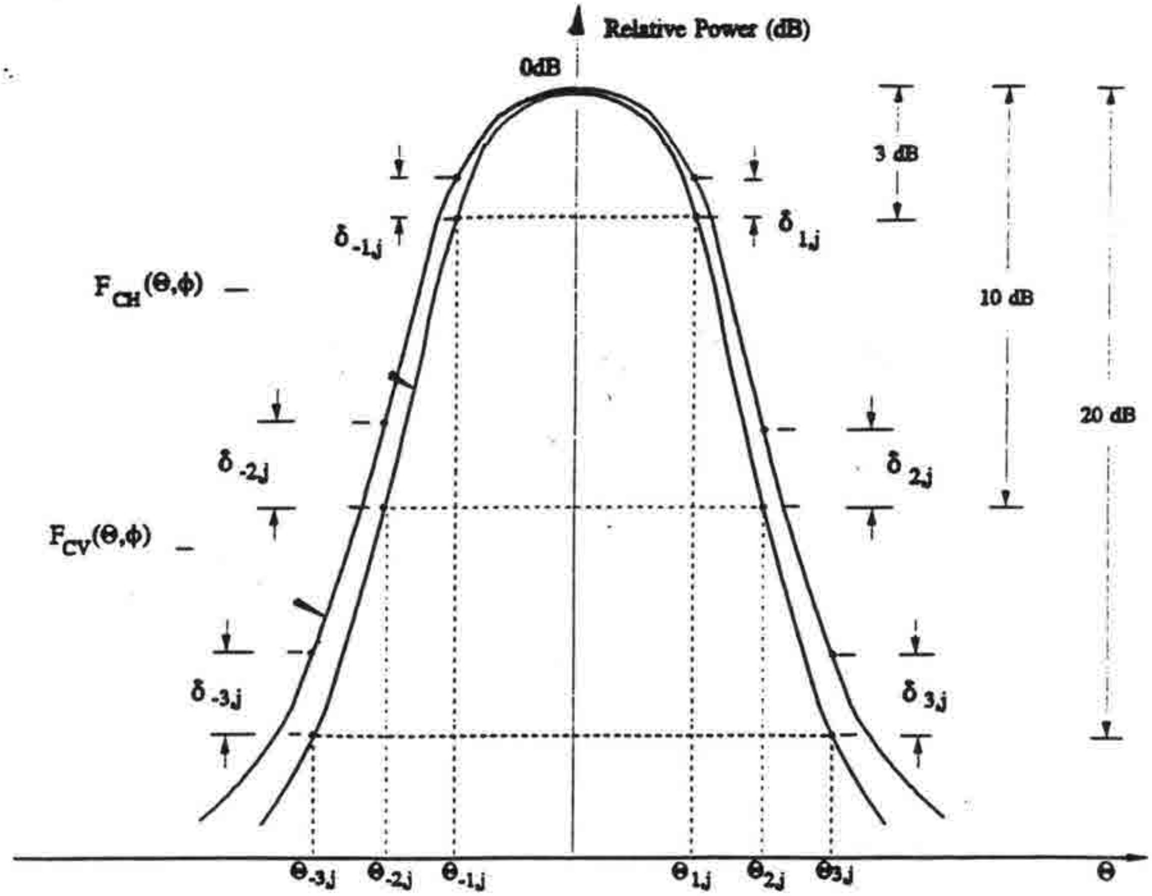


Figure 2. Schematic refers to specification 10

Note: ϕ_j, $j = 1,4$ represents $\phi=0,45,90,135°$ planes respectively.

$F_{CH}(\Theta,\phi)$ is the copolar pattern with H-port excitation.

$F_{CV}(\Theta,\phi)$ is the copolar pattern with V-port excitation.

Spec: $\delta_{1,j}$ and $\delta_{-1,j} \leq 0.5$ dB for $j = 1,4$

$\delta_{2,j}$ and $\delta_{-2,j} \leq 1.0$ dB for $j = 1,4$

$\delta_{3,j}$ and $\delta_{-3,j} \leq 2.5$ dB for $j = 1,4$

THE CSU - CHILL NATIONAL RADAR FACILITY

HISTORY

The CHILL radar was jointly developed by the University of CHicago and the University of ILLinois with National Science Foundation funds in the early 1970's. The initial goal was to develop a high performance, transportable radar system that was capable of collecting a variety of data for meteorological research interests. From 1971 through early 1990 the CHILL participated in numerous research programs ranging from the study of winter snowstorms to studying severe, hail-producing storms. During this period the radar was staffed and operated by the Illinois State Water Survey. As of April, 1990 the National Science Foundation transferred funding for the operation of the radar to Colorado State University. The goals of high quality research data collection and educational support continue at this new location.

DESCRIPTION

The CSU-CHILL is a Doppler weather radar with dual polarization capability. As in coventional incoherent radars, the CHILL can map the three dimensional distribution of precipitation areas within a range of approximately 200 miles. The velocity component towards or away from the radar within these precipitation areas is determined by the radar's Doppler capability. The CHILL can also transmit either horizontally or vertically polarized microwave pulses. Information on the average shape of the precipitation particles can be deduced by examining differences in the returned signal when the transmitter polarization is rapidly switched between horizontal and vertical polarizations. State of the art signal processing and display systems allow all of these precipitation parameters to be calculated and viewed in real time.

CHARACTERISTICS

Wavelength: 11 centimeters
Antenna diameter: 28 feet
Inflatable radome diameter: 73 feet
Maximum transmit power: 1 million watts
Final power amplifier: liquid-cooled Klystron
Normal transmit pulse duration: 1 millionth of a second
Typical maximum range: 230 miles
Typical unambiguous Doppler velocity range: +/- 58 mph

STAFF

The Principal Investigators for this project are Profs. Steven Rutledge and Stephen Cox from the Department of Atmospheric Science and Prof. V.N. Bringi from the Department of Electrical Engineering. Dr. Rutledge is the Scientific Director of the Facility. Permanent staff include Dr. Eugene Mueller, Senior Engineer, Mr. Patrick Kennedy, Facility Manager, Mr. David Brunkow, Software Engineer, and Mr. Kenneth Pattison, Radar Technician.

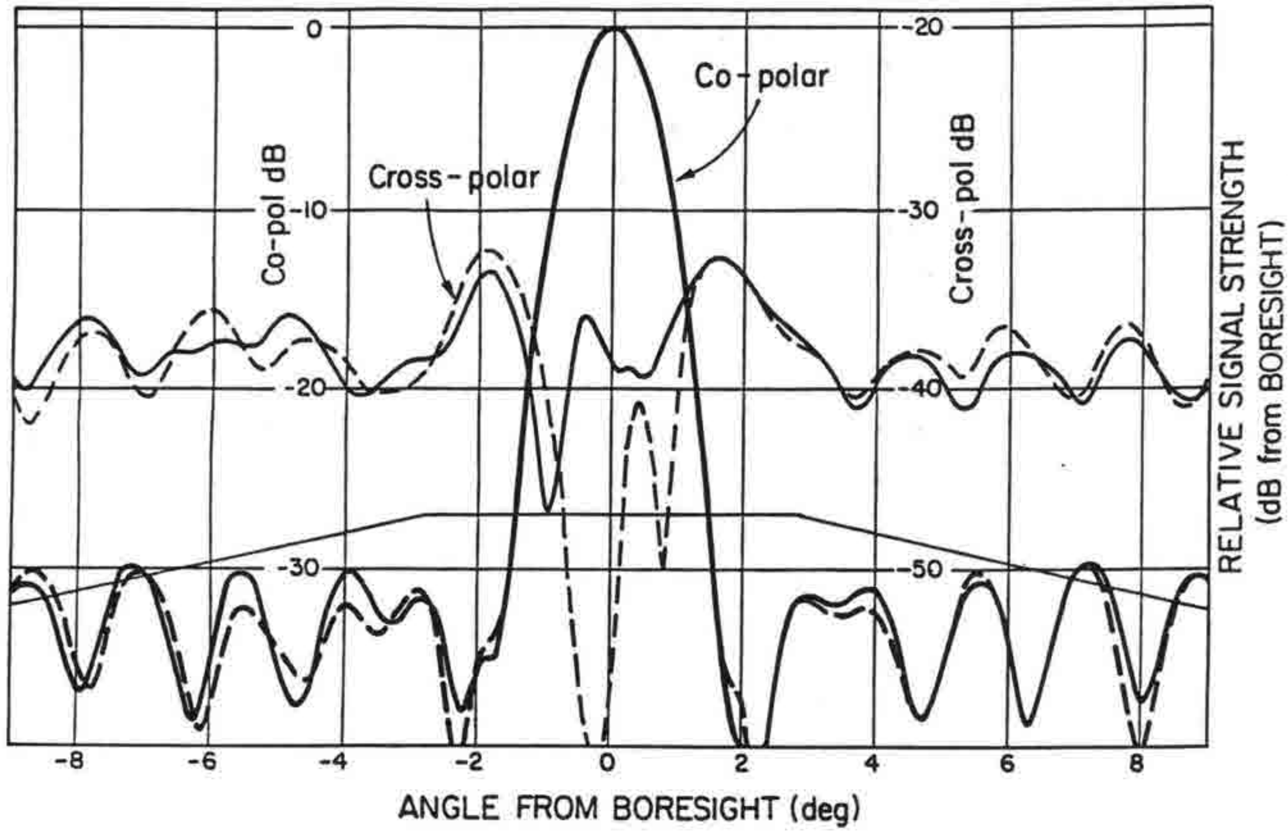


Figure 1. Copolar and crosspolar power plots for horizontal and vertical polarization 135 degree angle.

Appendix B

Letters Associated with Radar Users

11 July 1991

Professor Ramesh Srivastava
The University of Chicago
Department of the Geophysical Sciences
5734 S. Ellis Avenue
Chicago, Illinois 60637

Dear Ramesh:

Enclosed please find two 9 track Universal Format tapes containing the data collected by the CSU-CHILL radar for your 20 hr project. The first tape has the data collected during the 4/8/91 and the 5/16/91 operations; the second covers the activities on 5/22/91 and 6/2/91. A brief summary of the various cases is as follows:

Date	**Remarks**
4/8/91	Mostly virga; profiler in RASS mode; RHI scans; UTC time
5/16/91	Dissipating stratiform rain; PPI scans
5/22/91	Thunderstorm passing Platteville; RHI scans + 1 PPI
6/2/91	Stratiform remnants of a tstm, bright band, RHI scans

The data format follows the UF conventions outlined in the BAMS November, 1980 article, except that the recording density is 6250 BPI instead of 1600 BPI. Also, the Platteville profiler is located approximately on the 196 degree true azimuth from the CSU-CHILL at a range of 31 km.

Please advise me if there is additional information from us that you would find helpful.

Sincerely,

Pat Kennedy

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

29 August 1991

Professor Pierre Julian
Department of Civil Engineering
Colorado State University
Ft. Collins CO 80523

Dear Pierre:

The purpose of this note is to summarize the data collected by the CSU-CHILL radar during the course of your recently completed 20 hr project. Our records indicate that radar data for your project were recorded on the following occasions:

Date	Time (local)	Field Tape #'s	Remarks
5/24/91	1400-1730	115-116	Scattered TSTMS in Fred Ogden's grid
5/31/91	1400-1730	120-121	Small TSTM NW grid corner
6/2/91	1830-2100	123-124	Stratiform TSTM remnants
6/3/91	1200-1530	126-128	TSTM line developing within grid

Gridded data from the primary cases of interest have been provided to Fred Ogden for use in his PhD thesis work. It should be noted that the gridding of the field format radar data was done with the aid of software previously developed by Dave Brunkow of the CSU-CHILL staff.

It is our belief that decisions regarding the analysis of 20 hr project data are best made by the project investigators themselves. However, the CSU-CHILL staff are quite willing to provide technical consultation to users of our data.

Thank you for your interest in using the CSU-CHILL radar facility. We look forward to future opportunities to support your research activities.

Sincerely,

Pat Kennedy

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

29 August 1991

Dr. David Hartley
USDA Agricultural Research Service
Federal Building
P.O. Box E
Ft. Collins CO 80522

Dear David:

The purpose of this note is to summarize the data collected by the CSU-CHILL radar during the course of your recently completed 20 hr project. Our records indicate that radar data for your project were recorded on the following occasions:

Date	Time (local)	Field Tape #'s	Remarks
5/22/91	1430-1500	110	Small TSTM passing Nunn Gages
5/30/91	1630-1703	120	TSTM over gages; radar receiver saturation
6/21/91	1630-1915	138-143	Several TSTM passages over Nunn gages
8/14/91	1635-1715	148	TSTM just missing gages to the NE
8/15/91	1500-1600	150	Developing TSTM passing gages; (no time series data recorded)

You have been provided gridded PPI data from the primary cases of interest. Copies of field format data can be generated to allow Bringi's group to process the time series portion of the data set.

It is our belief that decisions regarding the analysis of 20 hr project data are best made by the project investigators themselves. However, the CSU-CHILL staff are quite willing to provide technical consultation to users of our data.

Thank you for your interest in using the CSU-CHILL radar facility. We look forward to future opportunities to support your research activities.

Sincerely,

Pat Kennedy

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

2 September 1991

Dr. Tom McKee
Department of Atmospheric Science
Colorado State University
Ft. Collins CO 80523

Dear Tom:

The purpose of this note is to summarize the data collected by the CSU-CHILL radar during the course of your recently completed 20 hr project. Our records indicate that radar operations for your project were conducted on the following occasions:

Date	Time (local)	Field Tape #'s	Remarks
6/6/91	1600-1915	134-135	slow moving TSTM near Aurora
7/19/91	1500-1630	none	surveillance; no DEN area storms
8/5/91	1600-1745	145	small TSTM crossing DEN area
8/6/91	1630-1815	146-147	Boulder foothills TSTM; power failure at CHILL
8/15/91	1615-1710	151	small TSTM crossing S DEN area
8/28/91	1500-1600	156	moderate TSTM crossing DEN from SW to NE; meso-anticyclone

Some of the 6/6 case data has been translated into Universal Doppler Exchange Format and delivered to Dave Speltz. We will continue this process as additional times of interest are identified.

It is our belief that decisions regarding the analysis of 20 hr project data are best made by the project investigators themselves. However, the CSU-CHILL staff are quite willing to provide technical consultation to users of our data.

Thank you for your interest in using the CSU-CHILL radar facility. We look forward to future opportunities to support your research activities.

Sincerely,

Pat Kennedy

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

Colorado State University

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

28 July 1992

Professor Ramesh Srivastava
The University of Chicago
Department of the Geophysical Sciences
5734 S. Ellis Avenue
Chicago, Illinois 60637

Dear Ramesh:

Enclosed are the two final 8mm tape cartridges containing CSU-CHILL data from your spring 1992 20 hour project. The contents of these tapes are as follows:
1) The one labeled "Ramesh UF" has the UF data from the 3/4/92 and 4/16/92 operations. The UF from the 4/14/92 operation was sent earlier to verify the tape reading capabilities at U of C.
2) The tape labeled "Time Series Data" contains the vertically pointing time series data from all three of your operational days. These data are in field format; I believe that Dave Brunkow has already supplied John Valdes with the appropriate time series reading software. The 8mm time series data were written in chronological order with an end of file mark separating each of the three operational days.

The delivery of these data constitutes the end of your recent 20 hour project with our facility. I hope that your examination of the data proceeds smoothly from this point. If additional information regarding the data would be useful, please contact me.

Sincerely,

Pat Kennedy

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

Colorado State University

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

11 September 1992

Prof. William Cotton
Department of Atmospheric Sciences
Colorado State University
Ft. Collins CO 80523

Dear Bill:

The purpose of this note is to mark the completion point of your CSU-CHILL Radar 20 hour project. A summary of the radar operations conducted in support of this project is as follows:

Date	Times (MDT)	Remarks
7/20/92	1400 - 1700	Developing tstm line along the foothills
7/21/92	1400 - 1620	Distant activity in WY and NE panhandle
8/3/92	1400 - 1730	Isolated storm crossing CHL-MHR baseline
8/4/92	1400 - 1900	Scattered storms along the foothills.
8/5/92	1200 - 1630	Isolated storms, limited useful data
8/10/92	1400 - 2000	Storms in SE WY and E of DEN, no mergers.
8/11/92	1500 - 2230	Merging storms in E CHL-MHR Doppler lobe

By far the best case occurred during the final operation (8/11/92). The CHILL data for this date have been converted to universal format (UF) and given to Ray McAnelly. If interest develops in any of the other days, the field format data can readily be converted to UF. Should technical questions arise during the data analysis, the staff of the CSU-CHILL Facility are available for consultation.

We look forward to working with you again in the future.

Sincerely,

Pat Kennedy

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

Colorado State University

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

11 September 1992

Prof. Lynn Johnson
Department of Civil Engineering
University of Colorado at Denver
Campus Box 113
P.O. Box 173364
Denver, CO 80217-3364

Dear Prof. Johnson:

The purpose of this note is to mark the completion point of your CSU-CHILL Radar 20 hour project. A summary of the radar operations conducted in support of this project is as follows:

Date	Times (MDT)	Remarks
5/21/92	1300 - 1800	Scattered storms, one passed near radar site.
6/3/92	1300 - 1645	Few small showers, minimal useful data.
6/5/92	1300 - 1530	Numerous small, fast moving storms.
6/7/92	1400 - 1800	Gust front, developing tstm line.
6/8/92	1350 - 1906	Flooding rains N of DEN along I-25.
6/18/92	1100 - 1245	Ground clutter during clear weather.
6/25/92	1340 - ~1500	Front range storms, transition to Bringi ops.
6/26/92	~1330 - 1700	Scattered storms, transition to T28 ops.

Two 8mm tape cartridges containing the above data were given to Mike Dixon. I believe that Mike's processing of the data may already have started. Should technical questions arise during the data analysis, the staff of the CSU-CHILL Facility are available for consultation.

My feeling is that this was a successful project, and I trust that this will be confirmed by Mike's dissertation results. Thank you for your use of our facility.

Sincerely,

Pat Kennedy

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

Colorado State University

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

16 November 1992

Dr. Bob Rauber
University of Illinois
Department of Atmospheric Sciences
105 S. Gregory
Urbana, IL 61801

Dear Bob:

Enclosed please find an 8mm Exabyte tape cartridge containing the Universal Format version of the CSU-CHILL data collected during your recently completed 20 hour project. A scan inventory is also enclosed. A brief summary of the radar operations conducted in support of this project is provided below:

Date	Remarks
10/9/92	Fairly thick cirrus and scattered rain showers.
10/13/92	Primarily mountain wave clouds.
10/16/92	Another wave cloud day. (Antenna azimuth scanning occasionally interrupted by brief drive failures.)
10/19/92	Steadily thinning cirrus coverage.

The data from one additional operation are not included on this tape. On Saturday, 10/10/92, the Sabreliner flew in virtually clear conditions. In view of the lack of weather, the radar was operated to collect verification data for the Research Aircraft Tracking (RATS) system. This was done by scanning the radar so as to obtain a number of direct illumination "skin paints" from the Sabreliner. If you are interested in these data too, an additional UF tape can be provided.

Please advise me if there is any additional information I can supply that will aid in your use of these data.

Sincerely,

Pat Kennedy

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

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

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

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

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

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

22 July 1994

Prof. Tom Holtzer
Head, Department of Entomology
C134 Plant Science
Colorado State University
Ft. Collins, CO 80523

Dear Tom:

The purpose of this letter is to close out our files regarding the 20 hour project that you recently completed using the CSU-CHILL facility. According to our records, radar operations in support of the Russian Wheat Aphid project were conducted on the following dates:

May 1994:
25, 26, 27, 28, 29, 30 ,31
June 1994:
1, 2, 3, 7

As you know, members of your research group took 35 mm slide photographs of the radar display as the data were being collected. Also, the digital radar data recorded on magnetic tape during these operations have been archived and are available for re-display or additional post analysis.

Thank you for utilizing the CSU-CHILL facility in your research activities. Feel free to contact me with any questions that may arise regarding the radar data.

Sincerely,

Patrick Kennedy

Patrick C. Kennedy
CSU-CHILL Facility manager
(303) 491-6248

22 July 1994

Prof. John Hallett
Desert Research Institute
University of Nevada-Reno
5625 Fox Avenue
Reno, NV 89506

Dear John:

The purpose of this letter is to close out our files regarding the 20 hour project that you recently completed using the CSU-CHILL facility. According to our records, radar operations in support of the Thunderstorm Anvil Outflow project were conducted as follows:

Date	Remarks:
5/19/94	Small storm just N of CHL moving off to the N. Small anvil present at start of recording. Interesting boundary layer echo "stairsteps" on S flank of the storm. At least one photograph taken of this storm from the radar site.
5/23/94	Approximately 1 hr of data on storm near Sterling CO (~100 km range from CHL).
6/3/94	Fairly good RHI coverage over ~1 hr period of rapidly developing severe storm NE of CHL. Several cloud photographs taken of the storm from the radar site.

I propose that we place the data from these 3 operations onto a single 8mm tape written in UF. Please advise if this approach will suit your needs; if so we will prepare the tape and mail it to you.

Once you have the opportunity to examine the data, feel free to contact me if any questions arise. Also, we are always interested in our user's evaluation of the CSU-CHILL facility's ability to meet their data needs. We greatly appreciate receiving "feedback" letters from users regarding data quality as well as the general performance of the radar and it's staff.

Sincerely,

Patrick Kennedy

Patrick C. Kennedy
CSU-CHILL Facility manager
(303) 491-6248

4 January 1995

Mr. Peter Clement
Department of Atmospheric Science
Colorado State University
Ft. Collins, Colorado, 80523

Dear Pete:

I'm in the process of closing out our files on the 20 hour projects which were conducted at the CSU-CHILL facility during 1994. According to our joint records, the operations chronology for your project was as follows:

Date	Remarks
2 June	Storms over DEN network, ~1" totals; possible case study day
3 June	Damaging hailstorm in Boulder, under .5" in DEN network
20 June	Heavy rain, flooding, hail in Ft. Collins area; case study day
21 June	Storms stayed in mountains, case study day with -88D data
22 June	No event case
15 July	Storms too far south to be of interest
27 July	Surveillance of Cu line; no storm development
1 August	Storm too far southwest to be of interest
3 August	Isolated storms, all rain totals under .5"
8 August	Very isolated storms under .25" totals
11 August	Storm in W DEN, ~.5" totals; under 1" in Boulder area
12 August	Very isolated storms, under .25" totals
31 August	Some small hail, ~.75" total in parts of DEN area

I believe that UF tapes for the cases of primary interest have been supplied to you since the end of your project. Please let me know if there are additional data sets that should be converted to UF, or if any data questions in general arise. Finally, we are always interested in receiving feedback from the users of the CSU-CHILL facility. A short letter summarizing your perceptions of the performance of the radar system and its staff, as well as any thoughts on the quality of the data recordings, will be most welcome.

Sincerely,

Patrick Kennedy

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

4 January 1995

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

Dear Dr. Bringi:

I'm in the process of closing out our files on the 20 hour projects which were conducted at the CSU-CHILL facility during 1994. According to my records, the primary radar operations conducted in support of your Summer 1994 project were as follows:

Date	Remarks
3 June	Damaging hailstorm in northeastern Boulder
24 July	Damaging hailstorm at Raymer, Colorado
25 July	~Golfball sized hail fall confirmed by the mobile raingage crew near Brush Colorado

Field format copies of the radar data recorded during these three hail events have been supplied to your research group (Scott Bolen). I look forward to our collaborative analyses of these data sets.

Sincerely,

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

4 January 1995

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

Dear Ray:

I'm in the process of closing out our files on the 20 hour projects which were conducted at the CSU-CHILL facility during 1994. According to our joint records, the operations chronology for your project was as follows:

Date	Remarks
25 July	Small cluster of severe storms near Ft. Morgan
1 August	Generally disorganized storms associated with a cold front
8 August	Developing squall line
12 August	Widely scattered storms over eastern Colorado

I know we have already supplied you with a UF version of the data from the case of primary interest (8 August). Please let me know if there are additional data sets that should be converted to UF, or if any data questions in general arise. Finally, we are always interested in receiving feedback from the users of the CSU-CHILL facility. A short letter summarizing your perceptions of the performance of the radar system and its staff, as well as any thoughts on the quality of the data recordings, will be most welcome.

Sincerely,

Patrick Kennedy

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

Colorado State University

Department of
Atmospheric Science
Fort Collins, Colorado 80523-1371
(970) 491-8360
FAX: (970) 491-8449

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

Colorado State University

Department of
Atmospheric Science
Fort Collins, Colorado 80523-1371
(970) 491-8360
FAX: (970) 491-8449

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

Colorado State University

Department of
Atmospheric Science
Fort Collins, Colorado 80523-1371
(970) 491-8360
FAX: (970) 491-8449

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
(970) 491-6248

Colorado State University

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Atmospheric Science
Fort Collins, Colorado 80523-1371
(970) 491-8360
FAX: (970) 491-8449

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
(970) 491-6248

Colorado State University

Department of Atmospheric Science
Fort Collins, Colorado 80523-1371
(970) 491-8360
FAX: (970) 491-8449

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
(970) 491-6248

Colorado State University

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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
(970) 491-6248

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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 etc)
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

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
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18 December 1991

Dr. Steven A. Rutledge
Scientific Director, CSU-CHILL Radar Facility
Dept. of Atmospheric Sciences
Colorado State University
Fort Collins, CO 80523

Dear Steve,

On behalf of the WISP participants, we would like to thank you and your CHILL crew for the outstanding job you did supporting WISP91. The radar collected useful data on nearly all WISP cases, and the operators were always available when needed. The data examined during the project was of high quality, and will be a valuable part of the WISP dataset. We are particulary impressed with this performance considering that this was first major research project after CHILL was moved from Illinois, and that there were considerable upgrades performed on the system just prior to the project.

There were only two problems areas worth mentioning:

1) Reliability of the ZDR switch. The ZDR switch did not provide reliable data during the field season, especially during the beginning. While this in no way compromised field operations, some ZDR data on winter storms was lost.

2) Funding. We understand that the level of funding for CHILL's WISP support may not have been sufficient. It's always hard to estimate ahead of time the resources needed to run a field project. Add to that the uncertainty of winter weather, the long (12 weeks!) field season and the complication that WISP studied every type of storm from beginning to end, and it is no surprise that CHILL exhausted its funding. Again, the field project was not compromised, but it seems that some agreement needs to be made with NSF to ensure that sufficient funds are available to cover CHILL operating costs throughout the field season, even if the original estimate is overrun. CSU should not be forced to foot the bill for this.

It was a pleasure working with your crew during WISP. It was no doubt a valuable learning experience for the students serving as radar operators; there is little enough opportunity for direct participation for students in field programs. We look forward to working with you in the future.

Sincerely,

Roy Rasmussen

Roy Rasmussen
WISP Scientific Steering Committee Chairman

Marcia K Politovich

Marcia Politovich
WISP Field Operations Coordinator

University of Colorado at Denver

Department of Civil Engineering

Campus Box 113
P.O. Box 173364
Denver, Colorado 80217-3364
Location: 1200 Larimer Street, Room 3027
(303) 556-2871 Fax: (303) 556-2368

26 September 1992

Patrick Kennedy
CSU-CHILL Facility Manager
Department of Atmospheric Science
Fort Collins, CO 80523

Dear Dr. Kennedy,

This letter is in reference to your letter of 11 September noting the summary of radar operations conducted in support of Mike Dixon's research project. I understand that Mike is making good progress on the analysis of the data and would expect some good results to be obtained.

Let me thank you and your group there at the CHILL radar site for providing a means for collection of the radar data, for working cooperatively with Mike, and for conducting all of these activities in a very efficient manner. Availability of the radar to operate in specialized modes for such purposes is a valuable resource to the research community and provides a basis for new insights into the science of rainfall estimation.

I look forward to future opportunities for our students to conduct research with your radar facility.

Sincerely,

Lynn E. Johnson
Associate Professor

cc/ Mike Dixon, NCAR,RAP

PENNSTATE

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

1855

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

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

Mark Carter
Research Associate
Entomology
491 - 7820s

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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

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

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6 May 1994

Dr. Stephen Rutledge
Department of Atmospheric Sciences
Colorado State University
Fort Collins, CO 80523

Dear Dr. ~~Rutledge~~ Steve:

WISP94 ended up being very successful with all the scientific objectives being achieved, with over 15 wave clouds and 20 winter storms being studied during the two month field effort. A large part of our success can be attributed to the excellent support provided by the CSU CHILL radar facility. Pat Kennedy and the rest of your support staff worked hard to make the project successful. CHILL was was ready for operations on the requested date, and collected data on nearly every storm studied during the project.

Thanks for your excellent support and I look forward to working with your staff in future field programs.

Best regards,

Roy M. Rasmussen

Roy M. Rasmussen
Chairman, WISP Scientific Steering Committee

Colorado State University

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

July 06, 1994.

Pat Kennedy
CHILL Radar Site
Colorado State Univ.

Dear Pat

I'd like to thank the crew at CHILL for your asssistance with this year's Russian Wheat Aphid helicopter sampling. We've started to evaluate the insect material, and this year has turned out to be a sucess. We recovered RWA from a variety of altitudes and many of the atmospheric layers identified by the CHILL site. We have yet to complete the lipid anaylsis on all of the sampled individuals, but so far the results are quite promising with regard to publication.

We were impressed by the preformance of both the radar and the crew. We also greatly appreciate the CHILL crew coming in over the wekends, especially the Memorial Day Weekend. As you know, we were limited in the time we had for sampling, and the availability of the CHILL crew and equipment was very much appreciated.

The data from the radar runs was interesting for a number of reasons, and I'll be out this fall to further review some of it. I believe we may find some strong correlations between insect captures and certain atmospheric conditions we observed with the CHILL, especially the strong thermals we saw in the afternoons. I plan to present some of the data on the relationship of the observed atmospheric layers and aerial insect distribution at the National meeting of the Entomological Society of America this December. There will be at least two other presentations by CSU and University of Illinois researchers at the same meeting utilizing some aspects of the CHILL radar data.

Thanks again for all you assistance this year.

Sincerely,

Ian MacRae
Research Associate
Dept. of Entomology

Colorado State University

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Fort Collins, Colorado 80523
(303) 491-8360
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(303) 491 8341

January 9, 1995

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 4 January 1995 concerning your closing of files on our 20-h CSU-CHILL project for 1994 and your request for "feedback" letters. As you indicated, we collected data for four days in 1994: 25 July, and 1, 8, and 12 August. The 8 August 1994 case ended up being the only one of high interest to us. We have performed a case overview using the CSU-CHILL UF dataset you provided for this case, and we found no problems with the data (please let us know if a velocity correction should be applied as in the previous seasons). This case features the growth of a multi-cellular convective ensemble into a broken, curved squall line. During this evolution, the ensemble undergoes an apparent meso-β-scale convective cycle prior to its primary development into the mature MCS stage. Since documenting this type of evolution was the primary field objective, we are quite satisfied with the operations. We will proceed with in-depth dual-Doppler analysis of this case in conjunction with WSR-88D data from Denver, which we have also obtained. We see little chance of needing data for the other three days.

Our 1994 season completes the third and final season of these 20-h projects. In total, we have five good cases of MCS development, one from 1992, three from 1993, and the case described above from 1994. Although we hoped for at least one good case of full upscale development into a mesoscale convective complex (MCC) within dual-Doppler range, such development never occured quite within range. Nevertheless, the datasets collectively cover developing MCSs of less-than-MCC scale, with a wide variety of convective substructures, and they all display early meso-β-scale convective cycles. Our primary research objective is in documenting the dynamic link between the burst of latent heating associated with the β-scale convective maximum and the subsequent upscale development to mature MCS stage. We are currently writing a manuscript for *Monthly Weather Review* which focusses on the 1992 case and includes preliminary results from one of the 1993 cases. The other three cases are under ongoing investigation by myself and Jason Nachamkin. Jason also will investigate the dynamics of upsacale development in these cases with the RAMS numerical model.

In summary, we are very pleased with the opportunity to participate in the 20-h CSU-CHILL projects over the last three years. The datasets are of high quality, meet most of our primary field objectives, and are undergoing continued dual-Doppler analysis in conjunction with Mile High and WSR-57 radar datasets from Denver. As was the case in 1992 and 1993, we found the CSU-CHILL staff to be most cooperative in all phases of our 1994 project.

Sincerely,

Ray L. McAnelly

Ray L. McAnelly
Research Associate

Colorado State University

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(303) 491-8545

January 13, 1995

Dr. Steve Rutledge
Director, CHILL Radar
Atmospheric Science Department
Colorado State University
Fort Collins, CO 80523

Dear Dr. Rutledge:

This letter is in reference to our use of the CSU-CHILL facility for a 20-hour project from June to August 1994. I would like to provide feedback on the quality and performance of the facility's operations for our project, the performance of the radar, and special acknowledgment to the facility's staff.

Operations for our project. The facility's staff had to juggle a number of different projects, with each customer pursuing areas of study, resulting in different scan strategies and modes of operation. However, the staff continually sought and provided the ever elusive win-win arrangement, which could appease all customers' concerned. This necessary flexibility did not interfere with our particular project, but I would recommend caution in accepting larger number of diverse projects. Most of our periods of data collection extended beyond the normal operating hours. To alleviate the long summer hours, you may want to consider summer shifts to cover the most likely times of convection 1400-1900L.

Performance of the radar. The radar met or exceeded all of our expectations. The radar's unique multiparameter capabilities, specifically Zdr and Kdp, enabled the use of additional techniques to determine rain rates and indicate presence of frozen hydrometeors. The recent improvement in the radar antenna has increased the quality and confidence in the data provided. As an aside, one interesting case, we observed this summer, was the locating of an ongoing forest fire using the Zdr field – an interesting case for the forest service.

The facility's staff. We thoroughly enjoyed working with the CSU-CHILL's staff. Their knowledge of the radar operations, multiparameter variables used, radar data format, and programs used to process the data, was absolutely essential for us to collect, process, and interpret the data necessary for our research. I would like to acknowledge both Pat Kennedy and Dave Brunkow for their assistance and patience throughout our 20-hour project.

Sincerely,

Thomas B. McKee
Professor

opb
cc: Peter Clement, Capt.

Colorado State University

Department of Atmospheric Science
Fort Collins, Colorado 80523
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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
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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

Joint Centre for Mesoscale Meteorology

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READING, RG6 6FN, UK
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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
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).

Appendix C

CSU-CHILL Newsletters

CHILL RADAR NEWS

from

Colorado State University

1991

Overview
(Steven Rutledge, Scientific Director)

This is the first edition of the Colorado State University (CSU)-CHILL newsletter which we plan to 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.

Several improvements to the radar have been carried out since its relocation to Colorado including the installation of a new inflatable radome and airlock entryway system, the purchase of a new ferrite fast polarization switch, and a new diesel generator for back up power. In addition, the radar control and data display system of the radar are presently being replaced with a new SUNrise system developed by Lassen Research. Presently, five SUN workstations are available to users on this system for data display and analysis. A permanent, 2500 sq. ft. staff building has been constructed at the radar site. This building provides offices for the radar staff and visiting scientists in addition to conference, shop and laboratory space. Details of several improvements to the radar are provided in the following sections.

Besides the refurbishment activities, it has been a busy period for both research and education projects. The radar played an integral role in the 1991 Winter Icing and Storms Project (WISP), operating in support of this experiment from 15 January to 31 March. The CSU-CHILL was used in combination with the NCAR CP-2 , CP-3, and Mile High radars, as well as the University of North Dakota portable Doppler radar. The CSU-CHILL also collected dual-polarization data during the project. Several students in the Departments of Atmospheric Science and Electrical Engineering are developing theses around this data.

Normally 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 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 recently supported five such projects including a multi-parameter study by Prof. R. Srivastava of the University of Chicago, time series studies of polarimetric data by Prof. A. Kostinski of Michigan Technological University, a radar-based hydrology study by Prof. P. Julien of the Civil Engineering department at Colorado State University, an urban stream flood program by Prof. T. McKee of the Department of Atmospheric Science at Colorado State in association with the U.S. Geological Survey, and a radar-raingage intercomparison study by Dr. David Hartley of the U.S. Department of Agriculture. More details of these 20 hour projects will be given in the following section. These small projects allow investigators to conduct highly focussed research with the CSU-CHILL radar.

Educational projects involving the CSU-CHILL radar are also ongoing. In May of 1991 Profs. J. Hallett and M. Wetzel of the University of Nevada-Reno and a group of 12 graduate students came to the CSU-CHILL facility for a two week period for a short course in radar meteorology. The format of the course consisted of lectures by Profs. Rutledge and Bringi, as well as real time operations. A number of excellent data collection sessions were conducted where the students studied a wide range of meteorological events including multi-cell hailstorms, a mesocyclone, and a squall line. Each student was given time on the SUN workstations at the radar and were trained in various data analysis techniques.

Undergraduate education is also being addressed. Prof. V. Chandresekar of the Colorado State electrical engineering department was recently awarded a grant to support several undergraduate research projects through the NSF Research Experience for Undergraduates (REU) program. This grant will provide summer employment during 1992 for approximately 10 engineering students who have completed their junior year. These summer activities will be the basis for subsequent senior year projects.

Operational Highlights
(Pat Kennedy, Facility Manager)

During 1991 the CSU-CHILL radar has collected data in support of a wide variety of interests. The context in which these data were collected has varied from comprehensive, multi-sensor observational programs to locally directed "target of opportunity" operations. The following is a brief overview of some of the highlights of these data collection efforts.

The CSU-CHILL was one of five Doppler radars that participated in the 1991 version of the Winter Icing and Storms Project (WISP91). A major goal of this project was the study of the production and depletion of the regions of concentrated supercooled water that are conducive to the formation of aircraft icing. Real time operations of both the radars and research aircraft were coordinated from NCAR's Research Applications Program (RAP) field control center. In general, the combined data from the WISP91 radar network will be used to determine the three dimensional wind field within echoing regions. In addition, on several occasions the CSU-CHILL collected dual polarization data in close proximity to the research aircraft flight paths. These aircraft data will provide useful in-situ measurements for comparison with the remotely sensed radar data.

On a smaller organizational scale, the series of 20 hour projects supported by the CSU-CHILL were designed to allow their investigators to identify specific days of interest for data collection. As always, the actual scientific yield from days that initially showed interesting prospects varied, but data of some value were obtained in each of the projects:

Professor Ramesh Srivastava of the University of Chicago was interested in collecting dual polarization data with the CSU-CHILL at various heights above the NOAA profiler located near Platteville, Colorado. An evening during which stratiform remnants from a dissipating thunderstorm passed over the profiler provided the bright band echo structure that Prof. Srivastava desired. The echo requirements in Dr. Kostinski's 20 hour project were less stringent; he was interested in some of the statistical properties of time series data from precipitation targets in general. He returned to Michigan Technological University with data recorded in rain and snow shower activity that occurred during his late April visit to the radar. In a project designed to collect radar data for the initialization of a hydrological runoff model, Prof. Pierre Julien of the Colorado State civil engineering department was interested in observing a variety of precipitation regimes. Convective echo systems with several degrees of spatial organization were observed during this project. Some of these data are currently being used for model initializations in the Ph.D. thesis of Fred Ogden, a student under the supervision of Prof. Julien. Another project centered around rainfall runoff implications was conducted under the guidance of Prof. Tom McKee of the Colorado State atmospheric science department. His focus was on convective precipitation events which generated rainfalls in excess of one inch in the foothills region lying immediately west of the Denver - Boulder metropolitan areas. Several drainages in this area have been instrumented to provide both streamflow and rainfall data in realtime. Many of the Denver area storms observed by the CSU-CHILL reached their most intense stages after they had moved east of the instrumented drainages. Nevertheless, Dave Speltz, an Atmospheric Science department Masters Degree candidate, has started a preliminary analysis of the radar and surface data. The final 20 hour project supported by the CSU-CHILL radar during this period was a radar - raingage comparative study organized by Dr. David Hartley of the USDA Agricultural Research Service (ARS). The ARS operates a network of raingages clustered near Nunn, Colorado, located approximately 40 km north of the CSU-CHILL site. Polarimetric data in both conventional and time series modes were recorded when precipitation echoes were observed over the raingage network. The heaviest storm that crossed the network contained hail as well as rain. Initial results show improvements in the radar-raingage comparisons when differential reflectivity data are used to identify the presence of hail.

In addition to the 20 hour projects summarized above, the CSU-CHILL radar was also operated for several "target of opportunity" cases. The goal here was to collect data that could be used as classroom case studies at Colorado State and could also be made available for similar applications at other institutions. The Colorado convective season of 1991 succeeded in providing several such opportunities. Several series of volume scans of thunderstorms bearing mesocyclone circulations were recorded. Explosive thunderstorm development following fine line interactions was observed over a two hour period early in the evening of 8/19/91. We hope to record additional "target of opportunity" cases during the upcoming winter season.

The final category of CSU-CHILL data collection has been to support in-house research investigations. Time series data, some of which were collected with 30 m range resolution, have been recorded briefly on several occasions for examination by Prof. Bringi's group in the Colorado State electrical engineering department. Also, a significant portion in the lifetime of a hailstorm that occurred on the plains east of Denver was observed. The evolution of the reflectivity core structure in this storm appeared to involve the cyclic growth and decay of series of bow echoes. Dual-Doppler analyses of this storm using data from the CSU-CHILL and Mile High radars are now in progress.

Engineering Highlights

(Eugene Mueller, Senior Engineer)

A number of engineering improvements in the system were accomplished during the past year:

1. In order to improve the match between the antenna sidelobe patterns at both horizontal and vertical polarizations, the feedhorn/waveguide support struts were rotated 45 degrees when the antenna was assembled at Greeley. After the implementation of this rotation, it was deemed necessary to check the focusing of the antenna and to map the beam patterns. It was found that better patterns resulted when the horn position was moved toward the dish by one inch. Patterns were obtained for both copolar and cross polar antenna operations. An experiment to determine the improvement of the patterns by enclosing the struts with radio wave absorbent material was conducted. This resulted in unmeasurable differences in the copolar patterns both on the main lobe pattern and on the strengths of the side lobes. However, there was some effect on the cross polar patterns that will be verified by a repetition of pattern measurements.

2. Sphere calibrations were also conducted to check the overall calibrations of the radar. These tests confirmed the calibration accuracy of the system. In addition there were simultaneous measurements of weather echoes from the CSU-CHILL and the Mile High Radars. These two radars showed agreement within 2 db on the average with a reasonable scatter of points around this mean.

3. There were a number of additions to the system during the year that enhance either the operational capability or provide additional reliability of operation and equipment integrity. The more important of these were:

a) A new radome monitor which monitors conditions at the site and provides control of standby devices to increase the chances of survivability during severe weather or power loss. This device will also alert maintenance personnel by phone when unusual conditions are in existence.

b) A third blower was added to the radome inflation system. This blower is powered by a gasoline engine and thus does not require either commercial or backup diesel power. Control of this blower is redundant and it will start either from control of the radome monitor or from its own radome-pressure switch.

c) A new Diesel power plant was purchased for the radar system. This plant is sufficiently large that it can run the radar and data system in the event of commercial power failure, thus permitting uninterrupted data collection.

d) The fast polarization switch was updated with a new electronics printed circuit board and a more accurate temperature control system. In addition, a completely new polarization switch has been purchased. This switch will be used as a spare and/or eventually in a three switch configuration to improve the isolation.

Many of the engineering improvements have been installed by Mr. Kenneth Pattison, who serves as a full-time technician for the CSU-CHILL radar.

Computer Systems

(David Brunkow, Software Engineer)

Part of the upgrade of the CSU-CHILL system was the replacement of the video digitizer. The new digitizer was purchased from Lassen Research. It consists of one signal processor (SP20) card which contains all of the circuitry for digitizing the I, Q and Log Power video channels. In addition, this card controls the switchable attenuators used in the Instaneous Automatic Gain Control (IAGC) and combines the linear and log channels to develop the floating point I and Q values used in the SP20 signal processor. The card is controlled through a micro-coded control program which allows flexible selection of sampling rates and averaging options. This same card generates the four triggers which drive the radar and polarization switch. The new card has centralized many of the radar control functions, and provides an improved solution to the problem of removing DC offsets and balancing the gains of the I-Q channels. Both the offset and gain of each channel are now controlled by the host computer. This card was installed in the fall of 1990, and it has made visible improvements in the area of DC offset removal, and spectral width estimates which previously exhibited artifacts which were attributed to imbalances in the I and Q channels.

The switchable attenuators became operational during the summer of 1991. As a part of this installation, it was discovered that the existing attenuator arrangement was limited to about 36 db of attenuation. This was traced to leakage inside the attenuator box, and was corrected with additional shielding. The attenuator can now be switched from 0 to 60 db in 12 db steps. The static performance of the IAGC is good, but work is continuing on improving the switching characteristics. Part of this work has included the installation of a new low distortion quadrature detector, which will produce significantly higher video voltages than were previously available.

Another activity which was pursued was the verification of the SP20 signal processing software used in the alternating VH polarization mode. To perform this test, a time series simulating an alternating VH polarization radar was produced at the Colorado State electrical engineering department. This time series was placed in a program and downloaded to a spare SP20 card. This program disabled the normal SP20 input card, and caused the simulated data to be placed on one of the SP20 busses in place of the normal input data. The remaining SP20 cards processed the data as usual. The results were recorded on tape for later comparisons. The correct values for the reflectivity, velocity, and VH and HV correlations and HH lag 2 correlations were calculated independently on one of the CSU-CHILL workstations, and then compared with the SP20 results. All fields produced by the SP20 agreed with the expected values. This experiment will be repeated with other known time series and other SP20 processing modes.

The SUNrise radar data/display system is an ongoing development by Lassen Research. When installation is complete, it will allow users to view CSU-CHILL product files and control scans from the laboratories on the Colorado State University campus. The product files will include conventional PPI scans as well as constant altitude PPI's (CAPPI), VAD's, and arbitrarily oriented vertical cross sections. These images are transmitted back to Fort Collins via a T1 data line, which extends the campus network to the CSU-CHILL site. Lassen Research plans to complete the SUNrise installation during the Fall of 1991. Part of the SUNrise system is operational now. It produces a remote real-time PPI display of reflectivity or velocity. In this mode CSU-CHILL data via SUNrise has been used in class demonstrations by the Atmospheric Science department.

Contact information: Potential users of the radar or anyone else desiring more information about this facility should contact Pat Kennedy at 303-491-6248 (E-mail; pat@lab.chill.colostate.edu). Other CSU-CHILL contacts are:

Prof. Steven Rutledge
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Omnet: S.Rutledge
E-mail: rutledge@olympic.atmos.colostate.edu

Dr. Eugene Mueller
Phone: 303-491-6248
E-mail: gene@lab.chill.colostate.edu

Mr. David Brunkow
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Prof. V. N. Bringi
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CHILL RADAR NEWS

from

Colorado State University

1992

Overview
(Steven Rutledge, Scientific Director)

This is the second 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 (see the following section for details). 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 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 four 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.

One of the highlights of the past year saw the CSU-CHILL radar as the focal point for an undergraduate education program. Prof. V. Chandrasekar of the Colorado State electrical engineering department was recently awarded a grant to support several undergraduate research projects through the NSF Research Experience for Undergraduates (REU) program. This grant provided summer employment during 1992 for 10 engineering students. These summer activities will be the basis for subsequent senior year projects by these students. An overview of this REU program is given in the following section.

Operations Summary
(Pat Kennedy, Facility Manager)

During the past year the CSU-CHILL Radar has supported six research projects. Two of the projects received NSF support from the Facilities Advisory Council after review by the Observing Facilities Advisory Panel (OFAP) and NSF Facilities Advisory Council. The remaining four programs were CSU-CHILL allocated "20 hour" projects.

The first NSF-supported project was an NSF Research Experience for Undergraduates (REU) grant. The Principal Investigator was Prof. V. Chandrasekar of the CSU Electrical Engineering Department. This project introduced junior and senior year electrical engineering students to meteorological radar systems. A total of ten students participated in the program from the following institutions: Colorado State University, New Mexico Institute of Mining and Technology, South Dakota School of Mines and Technology and University of California-San Diego. The students visited the CSU-CHILL Facility between 3 June and 14 August 1992.

During the first two weeks of this period, a series of lectures was presented at the CSU-CHILL facility to introduce the students to the general design theory and operational applications of microwave meteorological sensors. The lecturers and their topics were as follows:

Pat Kennedy (CSU-CHILL)	Introduction to radar meteorology.
Dr. Gene Mueller (CSU-CHILL)	Introduction to meteorological radars.
Dr. Jeff Keeler (NCAR/RSF)	Radar signal processing techniques.

Cynthia Mueller (NCAR/RSF/RAP)	Doppler radar nowcasting applications.
Dr. Joe Turk (CSU EE Dept.)	Passive microwave remote sensing techniques.
Frank Pratte (NCAR/RSF)	Radar calibration techniques using solar flux measurements.

In addition to the lecture series, the students participated in a variety of "hands on" activities involving both the radar system hardware and real time meteorological data collection. During the 92-93 academic year at least five senior engineering student projects will be based on efforts begun during this REU project.

The second NSF-funded project supported by the CSU-CHILL radar involved flight tests conducted by the South Dakota School of Mines and Technology (SDSMT) T-28 research aircraft. SDSMT personnel have recently upgraded the T-28's data system and were interested in conducting a field test of the system. The T-28 was directed from both the CSU-CHILL and NCAR Research Applications Program (RAP) facilities during the test period (June 15 - 26). Despite this short operational period, missions were flown on a total of seven days. On five of these days, the CSU-CHILL radar collected multi-parameter data near the T-28's track. It is anticipated that useful comparisons between the radar and aircraft data sets can be made under these conditions. The REU students also benefited from seeing the T-28 flight facility.

During the past year, the CSU-CHILL facility supported four "20 hour" programs. In March and April multi-parameter data were collected during three stratiform precipitation events for Prof. Ramesh Srivastava of the University of Chicago. Echoes occurring over the NOAA Platteville CO profiler site were of greatest interest since Prof. Srivastava is attempting to characterize the raindrop size distributions by combining the CSU-CHILL and profiler data. University of Colorado Ph.D. student Mike Dixon sought radar data to process with a technique that he has developed for automated storm tracking and precipitation estimation. Suitable data were collected during a number of thunderstorms in the May - June period. Clusters of thunderstorms were the target of interest in a 20 hr project supervised by Prof. Bill Cotton of the CSU Atmospheric Science Department. He and his associate, Ray McAnelly, were interested in situations in which individual thunderstorms become organized into larger convective systems. On 11 August 1992, an example of such a merger was observed while the CSU-CHILL was scanning in synchronization with the NCAR Mile High Radar (MHR). The final 20 project was an exploratory effort devised by Prof. Jim Connell of the CSU Civil Engineering Department. He was hoping to collect both radar and time lapse photographic data on isolated, orogenic thunderstorms occurring along the Laramie Range in southeastern Wyoming. Unfortunately, intervening clouds spoiled most of the photographic portion of the study, but Prof. Connell may be able to make use of the radar observations that were recorded on several days in August.

To date, the CSU-CHILL Facility has supported a total of four projects receiving NSF deployment pool funds after OFAP/FAC review, and ten 20 hour projects. Appendix A summarizes these projects and their outcomes.

System Improvements
(Gene Mueller, Senior Engineer)

For a number of years, solar calibrations of radar receivers have been in vogue for meteorological radars. The CSU-CHILL radar has not chosen to perform this procedure in the past for two reasons: our system did not have a calibrated noise source until very recently; and the measurement is not necessarily made at the transmitter frequency. However, during the last year a calibrated high power noise source was obtained for another purpose (see discussion on polarization switch monitoring below) and since it was available, a solar receiver calibration was performed by Frank Pratt of NCAR working together with CSU-CHILL staff. This solar calibration was demonstrated to the students in the REU program. The results of this calibration and a second calibration one month later confirmed the receiver coefficients and the antenna gain well within experimental accuracy. The noise figure of the radar from the solar calibrations was determined to be 4.3 dB against the previous value of 4.4 dB. The antenna gain differed from the previous values by less than 0.2 dB. These comparisons indicate that both methods lead to the same result and provide confidence in both.

The polarization switch has been very reliable during the past year. However, as there are more and more analyses of the CSU-CHILL data that are dependent upon the absolute stability of the switch, (i.e. there are new variables being investigated such as differential propagation phase, correlation between horizontal polarization and vertical polarization co-polar signals, full Nyquist velocity measurements when transmitting alternate horizontal and vertical polarizations, etc.) it was felt that a procedure in which the switch could be continually monitored in both transmit and receive direction and for both isolation and insertion values would be extremely valuable. To accomplish receive isolation and insertion values a source of signal on the antenna is necessary. It is somewhat difficult to bring the transmitter frequency to the rotating part of the antenna and the likelihood of leakage into the receiver (and thus poorer sensitivity) is high. To place a sufficiently stable oscillator onto the antenna is quite expensive. Thus the decision was made to obtain a noise source which is wide band and thus does not have to "stay in tune". This source also permits the solar calibration as mentioned above. (The disadvantage of not being tuned for receiver calibration suddenly becomes an advantage when used for switch monitoring.)

The monitor (which is nearly operational) will be controlled by a micro-processor on the antenna. The radar control processor will communicate with this microprocessor and at any time the noise source can be turned on and a signal injected into either the horizontal or the vertical directional coupler. The signal level on both channels will then be measured by averaging a number of signal gates from the receiver. The noise source will then be switched to the other port and measurements made. From these measurements the insertion loss and the isolation of the switch in the receive direction can be found. A power meter will be on the pedestal and the transmitter power measured in each port while on both horizontal only and vertical only operation. From these measurements the insertion loss and isolation in the transmit direction can be deduced. These values will be included on the data tape for later corrections to the appropriate parameters. The installation of the polarization monitor has been performed by Ken Pattison, the CSU-CHILL Technician.

Computer/Data Systems
(Dave Brunkow, Software Engineer)

The CSU-CHILL radar uses an Instantaneous Automatic Gain Control (IAGC) system to implement a wide dynamic range linear receiver. The IAGC uses the signal level from a log receiver to set the state of a switchable attenuator which prevents the linear receiver channel from saturating. Tests during the summer of 1991 showed that while the static performance of the attenuators was good, significant degradation of the differential reflectivity (ZDR) field occurred when the IAGC was operated in weather echoes. The problem was traced to a timing error relating to the combination of the exponent from the log channel, and the mantissa from the linear channel which together form the floating point number used in the signal processor. This modification allowed wide dynamic range (~85 dB) measurements to be made during the 1992 operational season. Studies of the statistics of the observed fields in weather echoes have agreed favorably with the theoretical expectations.

For the 1992 operational season, the CSU-CHILL software was upgraded to support the calculation and display of differential propagation phase (ϕ_{DP}) and zero lag cross correlation ($\rho_{HV}(0)$) estimators in real-time. Much of the motivation for these improvements came from Profs. V. N. Bringi (CSU-CHILL Co-PI) and V. Chandrasekar of the CSU Department of Electrical Engineering. In particular, these two new parameters are useful in the analysis of mixed phase precipitation regions, such as the snow melting level (bright band), and hail mixed with rain.

The most efficient scheme for collecting this multi-parameter data is to use a sequence of alternating horizontal and vertical transmit pulse polarizations (i.e., HVHVHV...). Traditionally, to avoid the effects of propagation phase differences between the two polarizations, radial velocity estimates were based only on returns from the H pulses. This method effectively doubled the inter-pulse time, and thereby cut the maximum unambiguous (Nyquist) radial velocity in half; significantly increasing the amount of "folding" in the velocity data. This drawback has been overcome in the current CSU-CHILL system by the implementation of the velocity correction scheme developed by Sachidananda and Zrnic (CIMMS Report #71, 1986). In this procedure, the ϕ_{DP} data are used to remove the differential propagation effects from radial velocity estimates based on pairs of pulses with alternate polarizations. Thus, the "folding" velocity remains unchanged during multiparameter data collection.

The utility of these capabilities can be seen in RHI data collected in a hail-producing thunderstorm that occurred near the Colorado - Wyoming border on 24 June 1992. Several severe thunderstorm echo characteristics are present in the reflectivity field (Fig. 1). The deep, intense (> 60 dBZ) reflectivity core located near the 60 km range ring, and the overshooting echo top are evident. The multi-parameter data allow some precipitation characteristics of this storm to be inferred: The presence of hail was inferred from the 0 to -1.5 dB differential reflectivity (ZDR, not shown) values seen in much of echo core. Near the forward edge of the core (range = 58.6 km), at above freezing temperatures (i.e. heights below 2 km AGL), a relative minimum occurs in the $\rho_{HV}(0)$ field (Fig. 2). Balakrishnan and Zrnic (reference in footnote) have found that when substantial negative ZDR values occur in conjunction with low $\rho_{HV}(0)$

magnitudes, hail larger than 2 cm in diameter is likely. Hailstones with diameters up to 4.4 cm were reported along the path of the 22 June 1992 storm.

ϕ_{DP} is generally more strongly influenced by rain than by hail. This is due to the sensitivity of ϕ_{DP} to the integrated effects of oblate water drops present along the radar beam propagation path. In the 22 June 1992 storm, the largest ϕ_{DP} range gradients, and thus the highest rain rates, are found at ranges beyond 62 km (Fig. 3). Thus, the combination of multi-parameter data fields suggests that hail, some of which was large, was occurring in the forward portion of the echo core, while rain predominated in the trailing part of the storm.

Despite the differential propagation phase effects of this storm, the general pattern of radial velocities calculated from the alternating VH polarization sequence is quite plausible (Fig. 4). Since the full Nyquist range is now retained under the new VH mode signal processing scheme, velocity folding is restricted to the inbound portion of the storm top divergence couplet (near a range of 56 km).

Figure Captions

Fig. 1.) Range Height Indicator (RHI) display of CSU-CHILL reflectivity data on an azimuth of 341° at 1723:45 MDT on 22 June 1992. The color bar on the right indicates reflectivity levels in dBZ. Height lines (km AGL) are plotted with a 2 km increment. The green cursor at the base of the image and the curved, dashed white line mark the 60 km range from the radar.

Fig. 2.) As in Fig. 1, except data field is zero lag cross correlation ($\rho_{HV}(0)$). Correlation values are depicted by the color bar on the right. (Note: the display magnification is larger in Fig. 2 than in Fig. 1.)

Fig. 3.) As in Fig. 2, except data field is differential propagation phase (ϕ_{DP}). Color bar units are degrees.

Fig. 4.) As in Fig. 1, except data field is radial velocity. These data were taken with a transmit polarization sequence of HVHV... Color bar units are ms^{-1}, with negative velocities representing motion towards the radar. (Note: the display magnification in Fig. 4 is the same as was used in Fig. 1.)

Contact information: Potential users of the radar or anyone else desiring more information about this facility should contact Pat Kennedy at 303-491-6248 (E-mail; pat@lab.chill.colostate.edu). Other CSU-CHILL contacts are:

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APPENDIX A: CSU-CHILL Project Summary: Greeley Site Activities Through 9/15/92:

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.

CHILL RADAR NEWS

from

Colorado State University

1993

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.

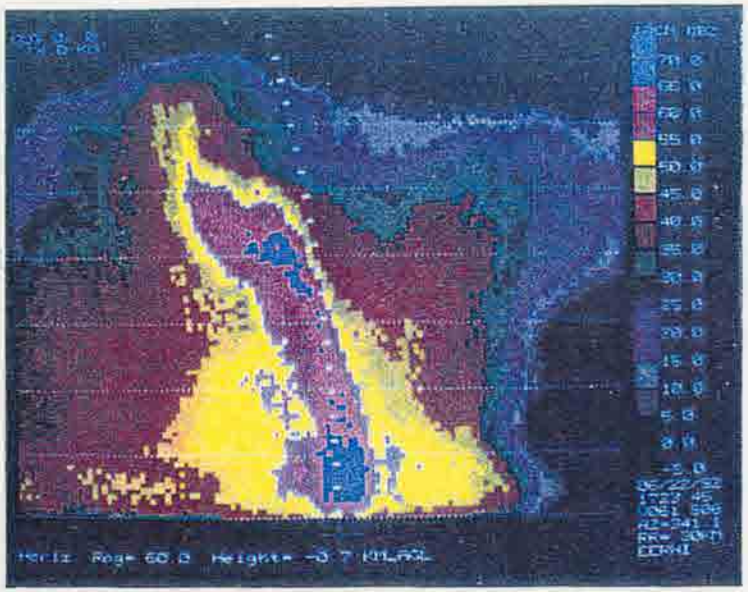
In late November 1993, the present CSU-CHILL antenna will be replaced with a new antenna (reflector and feedhorn) built by Radiation Systems, Inc. of Sterling, VA. The acceptance tests presently being conducted indicate the new antenna will be superior to the existing antenna, especially in sidelobe 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)

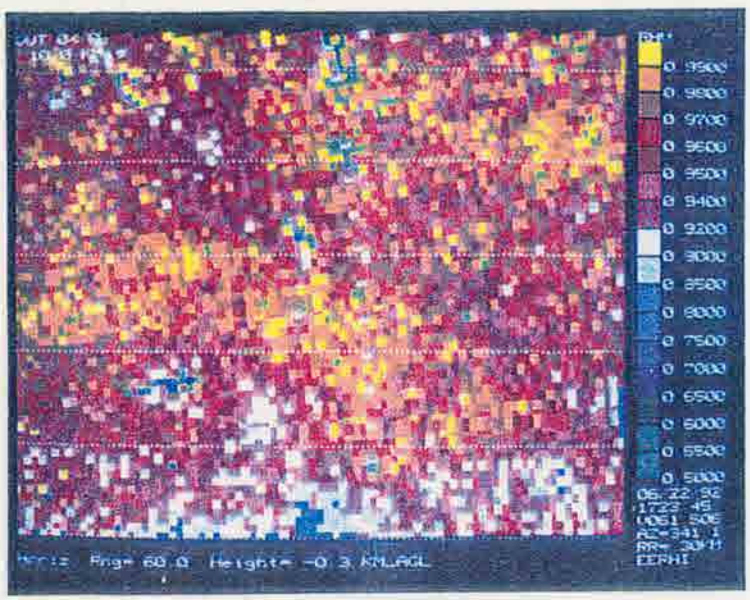
Nine 20 hour projects were supported at the CSU-CHILL facility during the past 12 months. The target data sets sought in these projects covered a broad spectrum of meteorological conditions.

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.



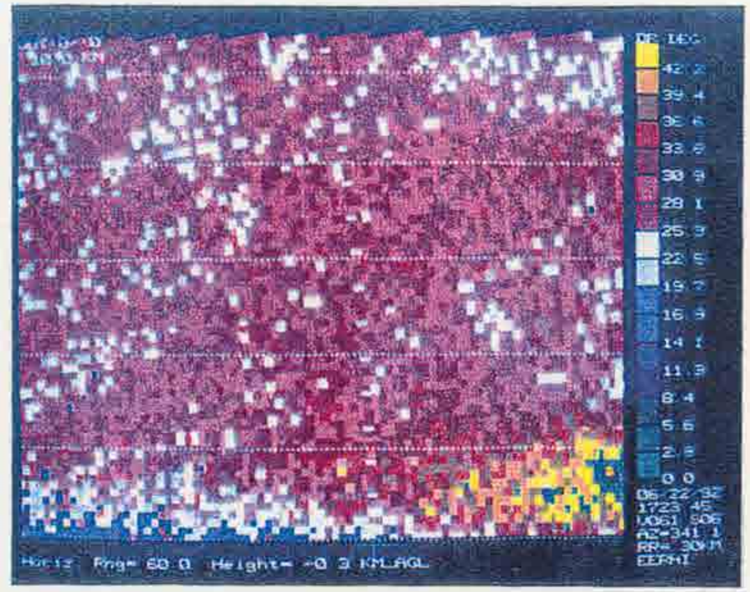
52 + 56 + 60 + 64 + 68 KM

FIG 1



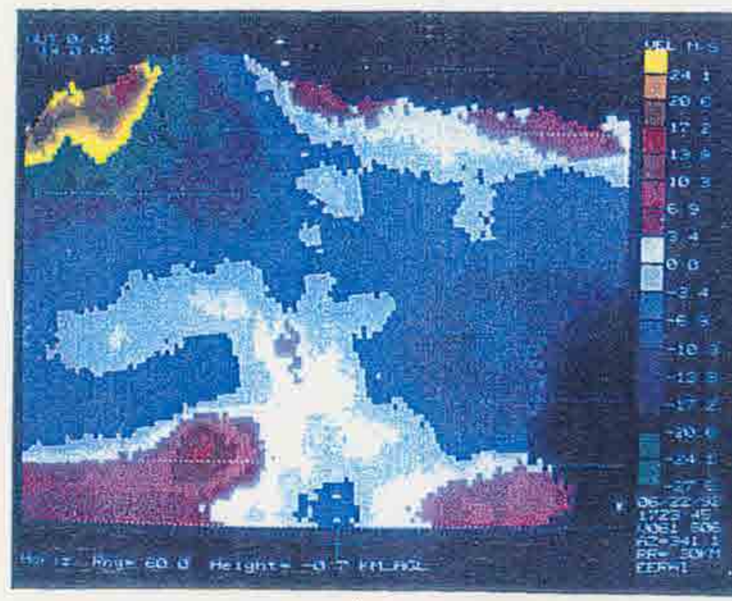
+ 56 + 60 + 64 KM

FIG 2



+ 56 + 60 + 64 KM

FIG 3



52 + 56 + 60 + 64 + 68 KM

FIG 4

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}, ° 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} ≈ 0 dB).

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.

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.

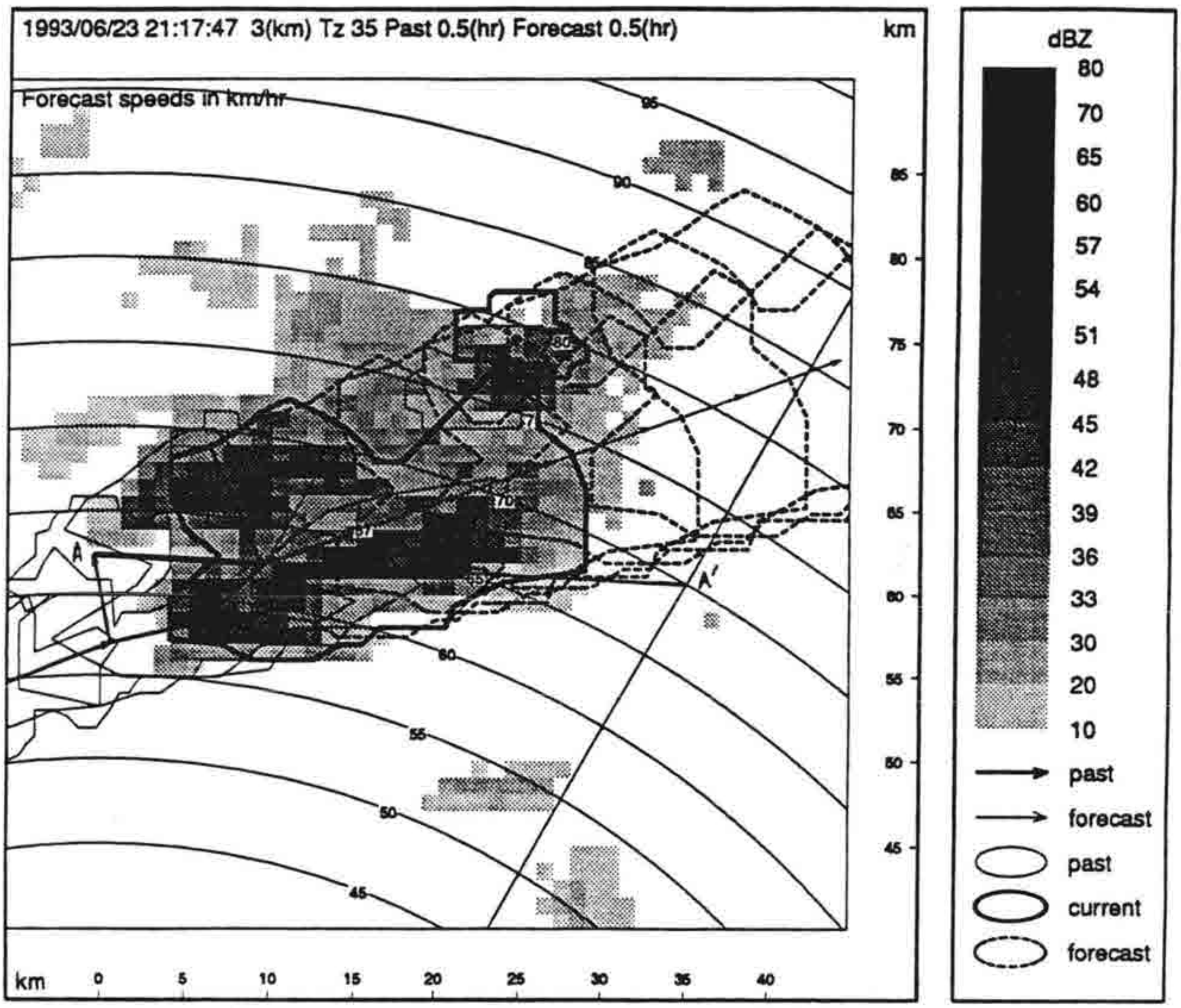


Figure 5: CAPPI - CHILL Reflectivity

CHILL RADAR NEWS

from

Colorado State University

Fourth Edition
September 1994

Overview
(Steven Rutledge, Scientific Director)

This is the fourth 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. Recently, we have submitted a proposal to the NSF for a second five year Cooperative Agreement, to begin in April 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 two formal NSF projects during the past year 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 small projects allow investigators to conduct highly focused research with the CSU-CHILL radar.

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-polar isolation. The latter quantity is critical to the measurement of LDR (linear depolarization ratio), which is now being recorded by the CSU-CHILL radar. Presently, the system limit on LDR is about -20 dB, being limited by the cross polar isolation of the fast ferrite polarization switch. To take full advantage of the isolation offered by the new antenna, which is about -35 dB, a second transmitter/receiver chain is presently being installed. By summer 1995, we expect to be operational with the dual channel system. Not only will this development increase the dynamic range of LDR, but will for the first time yield information on the full covariance matrix at a non-attenuating wavelength. We then expect to embark on a series of exploratory studies to investigate the additional insights into cloud microphysics afforded by the off-diagonal elements in this matrix.

Radar Operations Summary
(Pat Kennedy, Facility Manager)

The first program in which radar operations were funded by NSF was the Winter Icing and Storms 94 (WISP94). This year's efforts focused on the formation of ice particles in winter cloud systems. *In situ* data were recorded by the University of Wyoming King Air and NCAR Electra aircraft. Multiparameter observations of these cloud systems were made by the CSU-CHILL and NOAA K radars. CSU-CHILL also coordinated with NCAR's CP4 radar in the collection of dual Doppler data. A variety of winter precipitation situations developed during the 25 January - 25 March field season and the project ended with a useful data set.

The second NSF project was a Research Experience for Undergraduates (REU) program directed by Prof. V. Chandrasekar of the CSU Electrical Engineering Department (CSU EE). Twelve engineering students from 5 different states participated in this summer project. A series of introductory lectures and demonstrations for the students were held at the CSU-CHILL site. The lecture sequence was as follows:

1) Intro. to Radar Meteorology
   P. Kennedy (CSU-CHILL)
2) Intro. to CSU-CHILL Radar
   E. Mueller (CSU-CHILL)
3) Weather Radar Equation / Radar Design
   C. Frush (NCAR)
4) Intro. to Digital Signal Processing
   J. Keeler (NCAR)
5) Calibrations of Weather Radar Systems
   F. Pratte (NCAR)
6) Passive Microwave Remote Sensing
   J. Turk (CSU EE)
7) Instrumentation on the NCAR Sailplane
   D. Breed (NCAR)
8) Nowcasting with Doppler Radar
   C. Mueller (NCAR)
9) Doppler Radar and Air Safety
   M. Politovich (NCAR)
10) Design of Digital IF Receivers
   M. Randall (NCAR)

Along with the lectures, the students participated in real time radar operations at CSU-CHILL. During the later portion of the summer, the students returned to the main CSU campus to pursue individual projects under the supervision of Electrical Engineering Department faculty members.

The past year's 20 hour project activities covered a wide range of research interests. RHI data were taken through evolving thunderstorm anvils for Prof. John Hallett (University of Nevada Desert Research Institute). Prof. Hallett's study centered on the characterization of the flux of precipitation particles from the main storm updraft into the anvil outflow region. At least 2 of the 3 events observed in this project appear to hold analysis possibilities. For the second year, Prof. Tom Holtzer of the CSU Department of Entomology directed a project in which the insect-laden boundary layer was monitored by the CSU-CHILL radar. The target of interest was the annual spring migration of the Russian Wheat Aphid into Colorado. As before, a specially equipped helicopter from the University of Illinois captured airborne samples of the insect population. Successful catches of Russian Wheat Aphids were made on several occasions. Peter Clement, an Air Force MS student in the CSU Atmospheric Science department under the supervision of Prof. Tom McKee, designed a project to collect radar data during several heavy rain events in the greater Denver area. Pete's thesis work involves comparing several radar techniques for rainfall estimation, including multiparameter methods, to actual rain accumulations collected by a gage network operated by the Denver Flood Control District. Ray McAnelly, a Research Associate working with Prof. W. Cotton in the CSU Atmospheric Science Department, continued to direct an investigation into the early evolutionary stages of Mesoscale Convective Systems (MCS). Unfortunately, this year's late July - early August period provided relatively few days of organized convective activity at suitably close ranges to CSU-CHILL, so Ray ended up with only a single candidate case study day. Finally, John Beaver is studying the impacts of various atmospheric attenuation effects upon earth to satellite microwave communication paths as his Ph.D. thesis topic at CSU EE. He used CSU-CHILL data to characterize various forms of precipitation that passed through an experimental microwave link maintained between a geostationary satellite and a ground receiver located at the CSU-CHILL site.

Dual Channel Upgrade
(Gene Mueller, Senior Engineer)

The major advances in radar meteorology in the last decade and a half have been in the emergence of polarization variables. Such variables as differential reflectivity, differential propagation phase, and the correlation of horizontal and vertical polarization returns are called copolar variables. These variables use only the values of power return having the same polarization as the transmitted wave. Compared to copolar work, there has been some limited work in using depolarization, or cross polar information, like LDR. In theory, the scattering matrix and related matrices involving copolar and cross-polar variables provide all of the information in the radar return. It is believed that further advancement in meteorological radar will be found in these matrices and variables related to individual terms of these matrices. Thus it becomes important for a National Radar Facility like the CSU-CHILL, to have high quality capabilities in the area of polarization diversity.

The staff of the CSU-CHILL system, believing that the best possible implementation of a polarization radar is necessary, have embarked on radar upgrade which replaces the switchable ferrite circulator, which had an isolation limit of about 20 dB, with a dual transmitter/receiver system, which has an isolation exclusive of the antenna of 50 dB, for improved polarization capability, system characterization, and reliability. These dual channel plans have been extensively reviewed by the CSU-CHILL Radar Advisory Committee (RAC) and a positive recommendation has been made by the RAC to move ahead on this system.

The new antenna has an isolation between horizontal and vertical channels of 35 dB, and the measurement of cross-polar parameters becomes practical if the remainder of the system isolation can be made comparably large. The CSU-CHILL Facility is presently proceeding with the transition to the dual-channel configuration. A second FPS-18 transmitter, high-voltage power supply, and cooling system have been obtained from the National Severe Storms Laboratory. This transmitter is currently being updated with a solid state Intermediate Power Amplifier (IPA), and solid state rectifiers. A new transmit/receive circulator will be installed in place of the original FPS-18 TR/ATR system. The existing solid state frequency chain will be shared by both transmitters with minor additions to modulate the second channel. The two transmitters will be triggered independently by the signal processor.

A number of additional advantages will also be obtained by using this dual transmitter/receiver configuration. For example, it becomes possible to simultaneously transmit both horizontally and vertically polarized signals and to simultaneously receive the returns from both polarizations. This in turn allows better estimates of the copolar variables, such as differential reflectivity (Z_{dr}), zero lag correlation ($\rho HV(0)$), and differential propagation phase (ϕ_{dp}) to be made. In particular, a more direct estimate of the correlation between the signal returns in the two channels will be possible. It is probable that the $\rho HV(0)$ magnitudes calculated with the simultaneous H and V transmission scheme will increase from the estimates currently being made by the lag correlation algorithm.

Multiparameter Developments
(V. N. Bringi, CSU-CHILL Co-PI, and Pat Kennedy, Facility Manager)

New Antenna

The new antenna manufactured by Radiation Systems, Inc. was installed in December 1993. The reflector is identical to the 7.6m reflector manufactured by RSI for the TDWR program with additional 0.9m extension panels. The surface accuracy was specified to be better than 0.5 mm (rms) which was validated by RSI. The dual-polarized horn is a scalar horn with excellent rotationally symmetric primary patterns and very low cross-polar levels. The far-field copolar and cross-polar patterns were measured at RSI's test range in four ϕ-planes (0^o, 45^o, 90^o and 135^o) and at three frequencies (2.725, 2.8 and 2.875 GHz). The $\phi = 45^o$ and 135^o planes contain the four feed-support spars and the two waveguide runs. Fig. 1 shows the copolar and cross-polar patterns in the $\phi = 45^o$ plane. Note the excellent main lobe pattern match for excitation at the two ports, as well as the low sidelobe and cross-polar levels.

The integrated two-way cross-polar ratio (ICPR2) in the worst-case $\phi = 45^o$ or 135^o planes, defined as,

$$\mathrm{ICPR}_2 = \frac{\int_{45^\circ \text{ plane}} F_{hh} F_{vh} \sin\theta d\theta}{\int_{45^\circ \text{ plane}} F_{hh} \sin\theta d\theta}$$

was computed to be ≤-35dB. Note that F_{hh} is the normalized copolar pattern while F_{vh} is the cross-polar pattern. In the principal ϕ planes (0^o, 90^o), the $ICPR_2$ was much less, as expected, by an additional 5 to 10 dB. We expect the new antenna to yield excellent linear depolarization ratio data for cloud physics applications.

The copolar correlation coefficient (ρ hv) measurement has improved significantly due to improved phase matching between the H and V polarizations across the main lobe. This was measured by the CSU-CHILL radar using a test horn transmitting a slant 45^o linear polarized signal, with the radar alternately measuring H and V-returns. Fig. 2 shows the phase difference

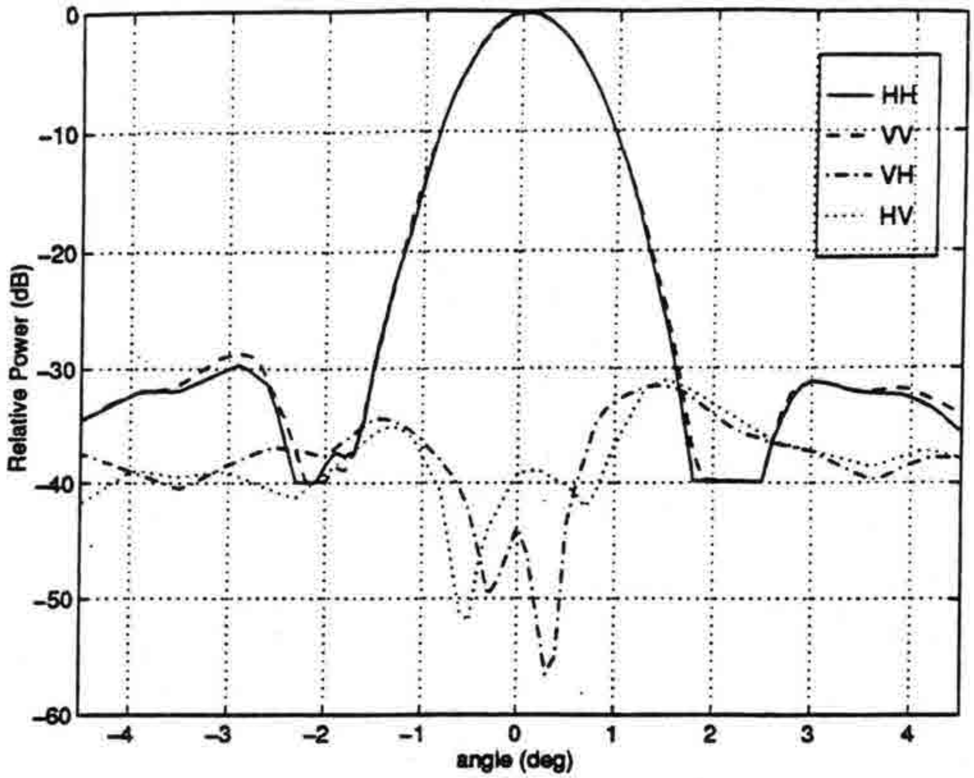


Figure 1: Co-polar and Cross-polar patterns in the $\phi = 45^o$ plane.

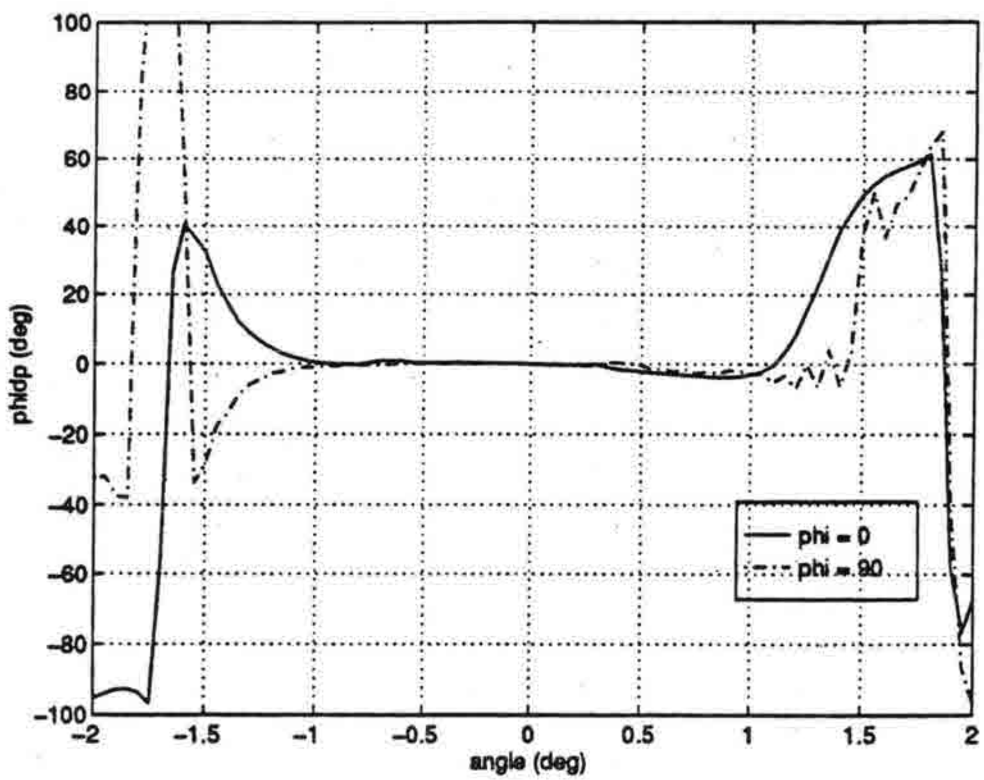


Figure 2: Phase difference pattern of the new antenna in the $\phi = 0$ and 90^o planes.

pattern in the $\phi = 0^o$ and 90^o planes. Note the nearly constant phase difference within the main lobe (|angle|<1.3°), a notable improvement over the old antenna. The ρ hv data is useful for identifying clutter, anomalous propagation, partial beam blocking, three-body "hail" flares, and side-lobe generated artifacts in very strong gradient regions, all of which cause ρ hv to be generally <0.8. In most precipitation ρ hv is generally >0.9, and is particularly useful in identifying, for example, the base of the melting layer, and regions of rain mixed with hail.

For highly accurate Z_{dr} measurements, the copolar difference pattern within the main lobe should equal zero (dB) in all the ϕ-planes. The patterns measured at RSI indeed show that the pattern matching is excellent (|difference| < 0.1 dB) within the main lobe in all the 4 ϕ-planes (angular extent defined by |angle| $\leq 1.3^o$, power level down by 20 dB). In spite of excellent mainlobe matching, close-in sidelobe mismatches (near |angle| ≈ 1.75,° power level down by ~27 dB) occasionally produce artificial Z_{dr} signatures in high gradient regions (spatial gradients ≥ 30 dB km^{-1}, near hail cells for example) which are easily identified by ρ hv which rapidly falls to below 0.5 in such side-lobe contaminated regions.

Time Series Analysis

For every transmitted pulse, the complex video sample (I+jQ) can be recorded in the time series mode of data acquisition. This mode is useful to evaluate signal fluctuations, and at times can be used to identify radar system problems which often bias the statistical estimators or cause unduly high fluctuations compared to theory. Here, we compare the standard deviation of the ρ hv estimator based on analysis of time series data and based on simulations, versus the number of complex video sample pairs (each pair consists of one H and one V-polarized sample). Time series records were collected in stratiform rain with the antenna stationary. Data were selected from light rain and in bright-band. Since the ρ hv fluctuations depend on Doppler spectral width (σ_v) as well as the true ρ hv, these were estimated from the data itself using very long time averaging. Fig. 3 shows the results of the standard deviation in ρ hv (termed "stdv Rohv") versus number of sample pairs. The time series simulations are based on classical Gaussian statistics (see, Liu et al. J. Tech., 11, 1994). In Fig. 3a, the light rain case is shown where the "true" ρ hv was estimated to be 0.9928 and $\sigma_v = 1.385$ ms^{-1}. The simulations were done assuming two values for "true" ρ hv as shown, and are compared with data. Fig. 3b shows the bright-band case where the "true" ρ hv = 0.945 and $\sigma_v = 1.08$. Simulations were again performed for two values of "true" ρ hv as shown. The excellent agreement between simulations and data analysis gives confidence in both the theoretical assumptions as well as radar system performance.

Hailstorm Observations

One of the first opportunities to observe a significant hailstorm with the new CSU-CHILL antenna occurred during the evening hours of 3 June 1994. During this event, a small cluster of thunderstorm cells developed along the eastern slopes of the Rocky Mountains and moved northeastward over portions of Boulder, CO. Hail damage occurred as the strongest of these cells crossed the extreme northeastern districts of Boulder.

Figure 4 presents data collected in a 0.4° elevation angle PPI sweep at 1826 MDT. The contours are based on individual range gate data values; the data have not been interactively edited or gridded. Considerable damage to roofs and automobiles took place within some 3 km of point B (x = -46.2, y = -42.8 km). At 1826, the region near point B was experiencing the passage of a >60 dBZ echo core (Fig. 4a). Due to the presence of quasi-spherical, tumbling hailstones, the differential reflectivity (Z_{dr}) in much of this core was near 0 dB (Fig. 4b). Further insights into the horizontal distribution of the hail are presented in Figure 4c. Relatively low copolar correlation (ρ hv(0)) was found in an elongated area immediately north of the reflectivity core. Balakrishnan and Zrnic (J. Atmos. Sci., 47, 1525 - 1540) have associated such ρ hv(0) reductions with the combined presence of rain drops and hailstones within the radar pulse volume. Additionally, specific differential propagation phase (K_{dp}, not shown), was used to estimate the reflectivity component due to rain (Balakrishnan and Zrnic, J. Atmos. Sci., 47, 565 - 583). The hail fraction was then obtained from the difference between the rain and total (observed) reflectivities. As shown in Fig. 4c, the primary area with a high hail component was in the southwest portion of the reflectivity core

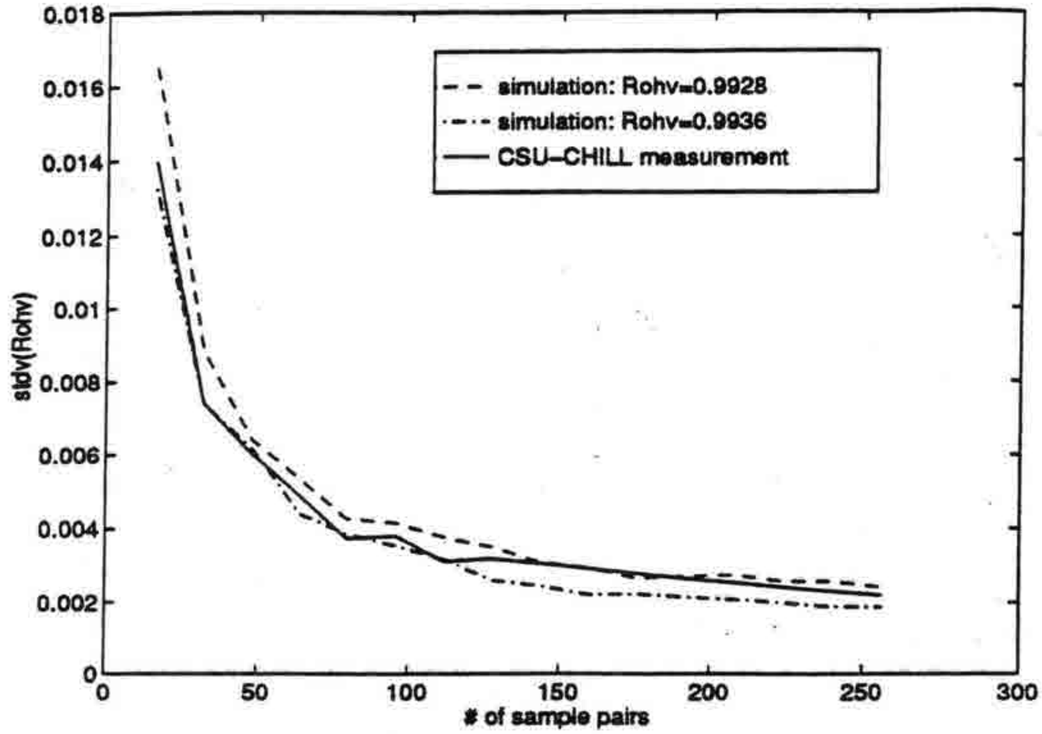


Fig. 3a Standard deviation of ρ_{hv} versus number of (H,V) sample pairs. Solid line shows the CSU-CHILL data from light rain below the bright-band. The mean ρ_{hv} (Rohv) and Doppler spectral width σ_v are obtained from long-time averaging of the data, and are used as input to the simulations. Two simulations are shown with mean ρ_{hv}=0.9928 and 0.9936, respectively, and $sigma_v$=1.385, Guassian shape spectrum.

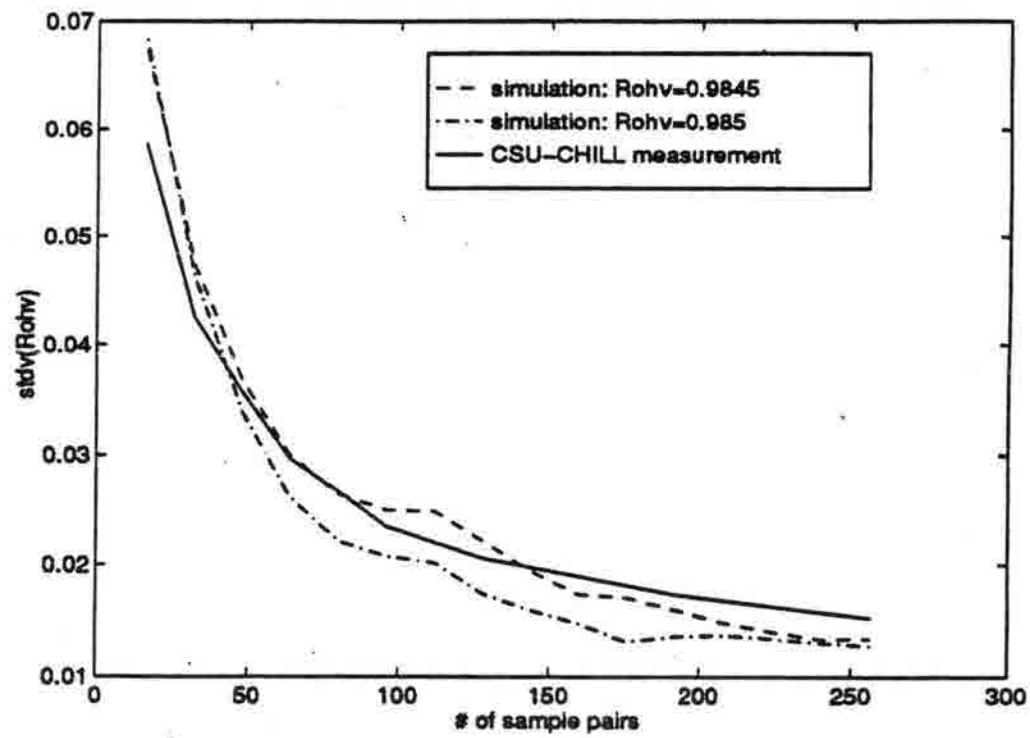


Fig. 3b As in Fig. 3a except data collected in the bright-band. The mean ρ_{hv} are 0.95 and 0.945, respectively, and σ_v=1.08 ms^{-1}.

(x = -47, y = -43.7 km). The precipitation sequence reported by observers near point B followed that suggested by Fig. 4c: As the storm moved northeastward over the area, rain became mixed with hail, followed by a brief episode of concentrated, damaging (golfball sized) hail.

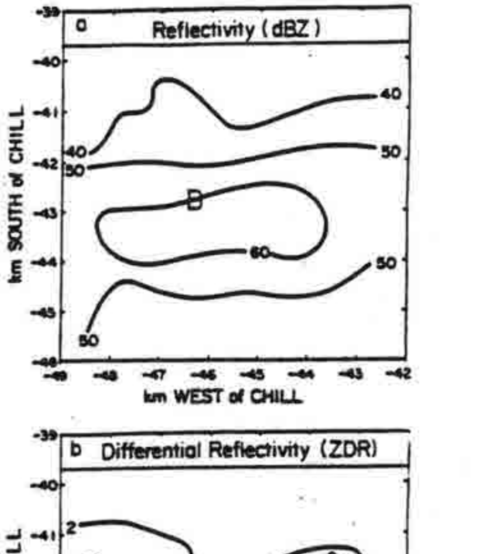


Figure 4: Data at 1826 MDT, 6/3/94. Beam height is ~600 m AGL. Hail damage occurred in the area of point "B". a) Reflectivity (dBZ). b) Differential reflectivity (Zdr, dB). c) Regions of relatively low copolar correlation and relatively high hail fraction (shaded). See text for details.

Software Engineering
(Dave Brunkow, Software Engineer)

LDR Calculation

One of the primary benefits of the new CSU-CHILL antenna is improved cross-polar isolation. Linear Depolarization Ratio (LDR=10log(Svh/Shh)) is the simplest of the crosspolar parameters. A new LDR data collection mode was added to the signal processor program. A four pulse polarization sequence (VHXH) is utilized, where V and H are copolarized Vertical and Horizontal samples, and the X is a transmit H, receive V sample. All of the previously available fields (Z, Z_{dr}, Velocity, Φ_{dp}, and $\rho_{hv}(0)$) are calculated during the HVH sequence, while the cross-polar power calculation is performed during the X sequence slot. The lowest observable LDR was limited by the polarization switch to about -20 db. Still, this did allow a first look at LDR fields during the Spring/Summer of 1994. After the dual transmitter/receiver installation is complete, this lower limit should be reduced to approximately -35 db. The second receiver will also eliminate the need for the X polarization slot, and LDR can be calculated using the normal VH alternating polarization sequence.

An example of the initial LDR data obtained during the last year is shown in the height profiles presented in Fig 5. These data were taken when light, stratiform rain was falling at the radar. Melting of the precipitation particles begins as they fall through the 0^{o} C level near a height of ~2.3 km AGL. As the particles transition from ice to water, a reflectivity bright band results centered just below 2 km (Fig. 5a). The melting also results in a Z_{dr} enhancement as the particles become increasingly wet and dense, yet maintain oblate shapes (Herzegh and Jameson, Bull. Amer. Soc., 73, 1365-1374). In the lower portion of the melting layer, only the largest particles remain in a partially frozen, oblate state. Since the differential reflectivity is particularly sensitive to the shapes of the larger sized particles, positive Z_{dr} values extend down to ~1.5 km (Fig. 5a). Below ~ 1.5 km where the particles have fully melted, both the Z_h and Z_{dr} profiles stabilize atvalues typical of light rain. Within the melting layer the larger ice particles are still in a water-soaked transition state, while some smaller particles have completely melted into drops. The coexistence of these particle shapes leads to a

ρ hv(0) reduction to ~.87 at the 1.8 km height level (Fig. 5b). Also, the presence of relatively large, wet melting particles in this mixed layer raises the LDR return to -14 dB (Fig. 5b). Thus, with the current CSU-CHILL configuration, plausible LDR observations have been made under conditions in which the cross-polar return is sufficiently strong. When the upgrade to the dual channel configuration is completed, cross-polar measurements, such as LDR, will be possible in a much wider variety of meteorological echoes.

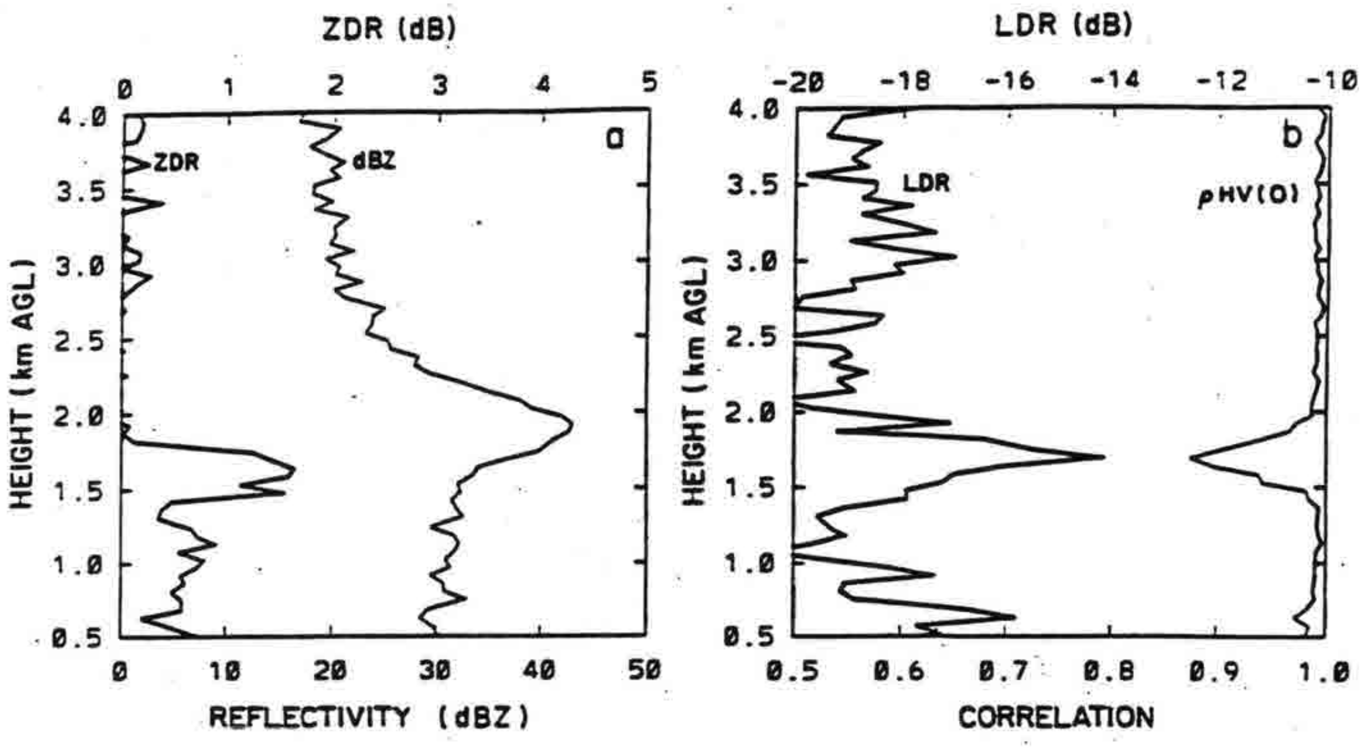


Figure 5: Bright band data recorded at 1554 MDT on 5/13/94. The RHI azimuth is 168°. Data from a range of 11.8 km were used to construct the vertical profiles. (a) Reflectivity (dBZ, thin line), and differential reflectivity (Z_{dr}, thick line). (b) Copolar correlation coefficient (ρ hv(0), thin line), and linear depolarization ratio (LDR, thick line).

Recent CSU-CHILL Publications (Reprints available on request)

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. Accepted for publication in *J. Appl. Meteor.*

Bringi, V. N., L. Liu, P. C. Kennedy, V. Chandrasekar and S. A. Rutledge, 1994: Dual multiparameter radar observations of intense convective storms: The 24 June 1992 case study. *J. Meteor. Atmos. Physics*, in press.

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.

Carey, L. D., and S. A. Rutledge, 1994: A multiparameter radar case study of the microphysical and kinematic evolution of a lightning producing storm. *J. Meteor. Atmos. Phys.*, in press.

Kennedy, P. C., and S. A. Rutledge, 1994: Dual-Doppler and Multiparameter Radar Observations of a Bow Echo Hailstorm. *Mon. Wea. Rev.*, in press.

Kennedy, P. C., N. E. Westcott, and R. W. Scott, 1994: Reply to the comments of C. A. Doswell III on "Single-Doppler radar Observations of a Mini-Supercell Tornadic Thunderstorm", *Mon. Wea.. Rev.* in press.

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. *J. Ocean. Atmos. Tech.*, in press.

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

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

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.

Rauber, R. M., M. K. Ramamurthy, and A. Tokay, 1994: Synoptic and Mesoscale Structure of a Severe Freezing Rain Event: The St. Valentine's Day Ice Storm. *Wea. and Forecasting*, 9, 183-208.

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

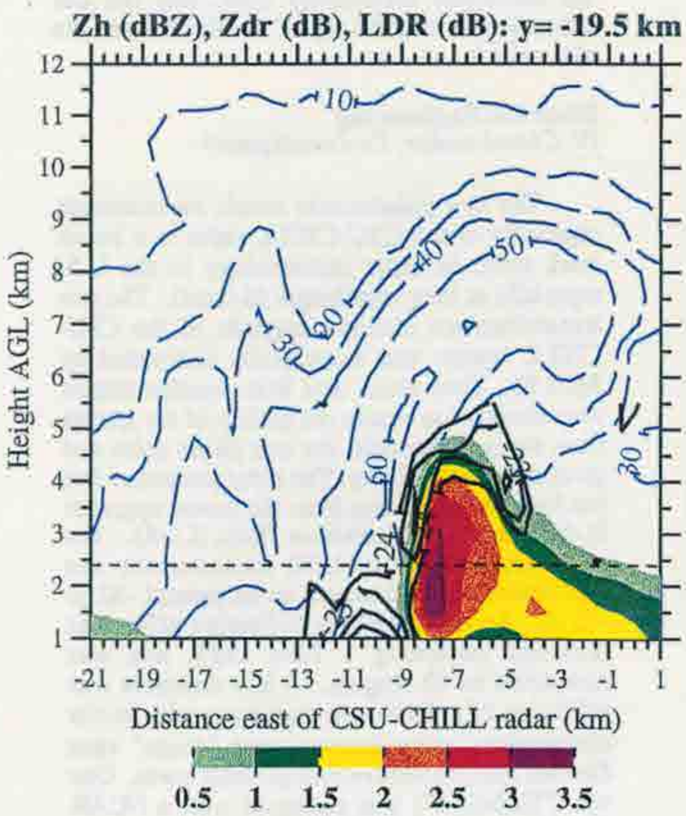


Figure 1 (See text for details)

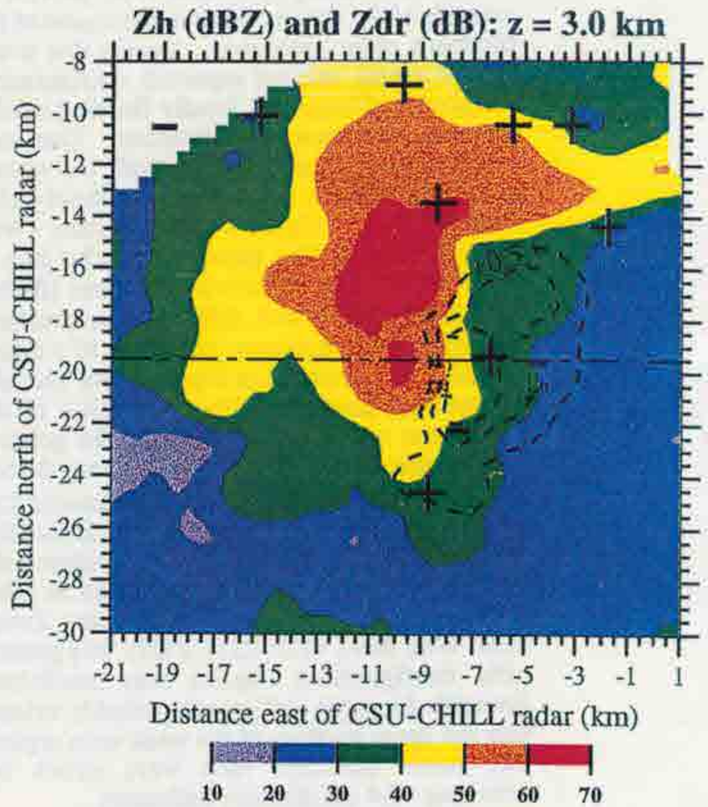


Figure 2 (See text for details)

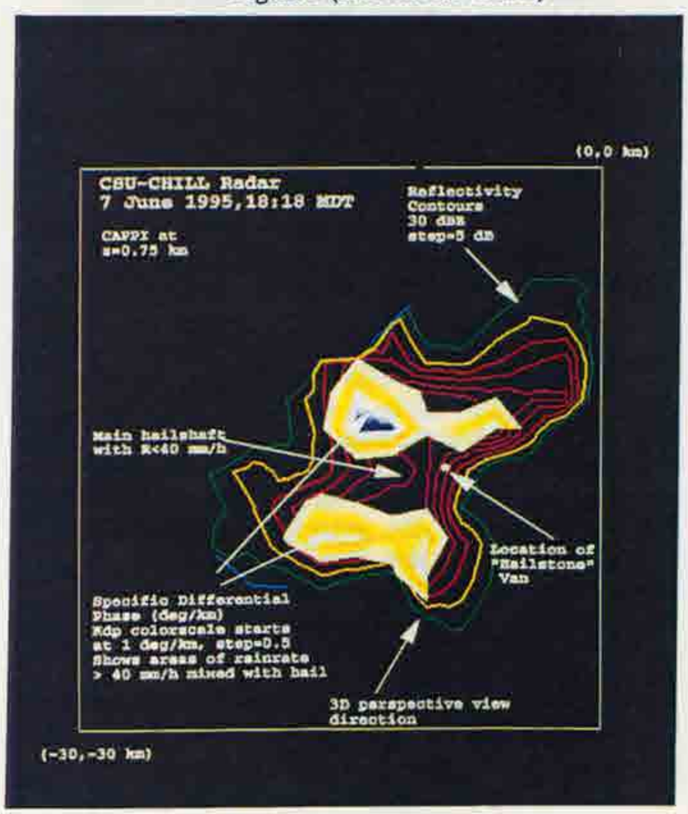


Figure 3 (See text for details)

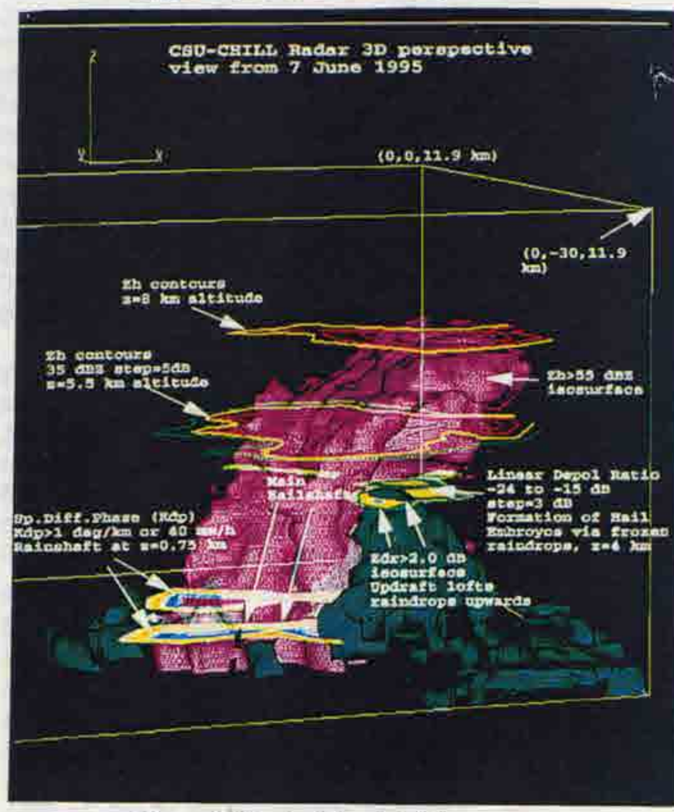


Figure 4 (See text for details)

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, ρHV(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.

Publications Between October 1994 and October 1995

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

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

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, 1994: Multiparameter radar study of a highly electrified squall line. AGU Fall Meeting, San Francisco, CA, December.

Carey, L. D. and S. A. Rutledge, 1995: Positive cloud-to-ground lightning in severe hailstorms: A Multiparameter Radar Study. AMS 27th Conference on Radar Meteorology, Vail, CO, 9-13 October.

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.

Dobaie, A. M., 1995: Application of Tomographic Technique for the analysis of differential Propagation Phase measurement, AMS 27th Conference on Radar Meteorology, Vail, CO, 9-13 October.

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

Kennedy, P. C., N. E. Westcott, and R. W. Scott, 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.

Kennedy, P. C., V. N. Bringi, S. Bolen, and S. A. Rutledge, 1995: An examination of dual polarization signatures associated with confirmed occurrences of large hail. AMS 27th Conference on Radar Meteorology Vail, CO, 9-13 October.

Liu, L., V. N. Bringi, V. Chandrasekar, E. A. Mueller and A. Mudukutore, 1994: Analysis of the copolar correlation coefficient between horizontal and vertical polarizations, *J. Atmos. Ocean. Tech.*, **11**, 950-963.

Liu, L., V. N. Bringi, and A. Mudukutore, 1995: Statistical fluctuations in multiparameter radar: Comparing radar time series measurements with simulations. AMS 27th Conference on Radar Meteorology, Vail, CO, 9-13 October.

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

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

Mueller, E. A., S. A. Rutledge, V. N. Bringi, D. Brunkow, P. C. Kennedy, K. Pattison, R. Bowie, and V. Chandrasekar, 1995: CSU-CHILL Radar upgrades. AMS 27th Conference on Radar Meteorology, Vail, CO, 9-13 October.

Rutledge, S. A., V. N. Bringi, V. Chandrasekar and P. Kennedy, 1995: Interdisciplinary educational uses of the CSU-CHILL Radar at Colorado State University. AMS 27th Conference on Radar Meteorology, Vail, CO, 9-13 October.

Appendix D

Letters From Members of the CSU-CHILL Radar Advisory Committee

ENVIRONMENTAL RESEARCH LABORATORIES

National Severe Storms Laboratory
1313 Halley Circle
Norman, OK 73069

June 4, 1993 R/E/NS

Dr. Cliff Jacobs
National Science Foundation
Atmospheric Sciences Division
1800 G. Street
Washington, DC 20550

Dear Dr. Jacobs,

This is in reference to a recent advisory panel meeting concerning the CSU-CHILL radar facility. The meeting highlighted recent progress at the facility which I have also followed through informal contacts with Dr. Rutledge, Bringi, Chandrasekar and Mueller as well as through my visit with Mr. Kennedy and Brunkow. Furthermore I had ample exposure to the many papers at the 26 Radar Meteorology Conference which were produced by the PIs, their students, and post doctoral fellows.

The new home at CSU has instilled a breadth of fresh air in the personnel and I believe has truly lived up to the NSF expectations. First I support the present research and development direction. In the near future the radar will have a new antenna with which we should be able to asses the scientific and practical utility of depolarization measurements. The radar is currently providing valuable data that will allow us to map and gauge hydrometeor evolution within precipitating systems.

I am also impressed with the educational component. To my knowledge CSU is the only university where atmospheric science has blended well with electrical engineering. Thus both disciplines can benefit from each other. Also I am enthusiastic about the 20 hour projects for small field experiments. This is an extremely cost effective way to train students to do research as well as to obtain valuable data for scientific inquiries.

Overall the program has been a great success and I believe will continue to prosper in both research and in offering training opportunities to future radar meteorologists.

Sincerely yours,

Dusan S. Zrnic, Chief,
Doppler Radar & Remote Sensing
Research Group

cc: S. Rutledge
V.N. Bringi
G. Mueller
P. Kennedy
D. Bronkow

Atmospheric Technology Division – Remote Sensing Facility
Memorandum

14 July 1993

Memo to: Steve Rutledge, CHILL Scientific Director
From : Jeff Keeler, NCAR/ATD/Remote Sensing Facility
Subject: **CHILL Radar Advisory Committee comments**

Jeff

This memo addresses several points we discussed at the recent Radar Advisory Committee meeting in Norman, OK on 25 May 93.

I was pleased to hear of your recent activities regarding the new antenna acquisition, the planned pulse compression test, and the "ftp" CHILL radar data archive. All these activities play an important role in your educational mission as well as developing new research capabilities for CHILL. I was especially impressed with your success of several very interesting 20 hour projects. Roger Wakimoto suggested that you document and publicize these research accomplishments as you would a full blown field project and I support his suggestion.

You stated that your first 5 year contract with NSF is nearing completion and that NSF will be considering extending CSU's contract to operate the CHILL radar as an educational and national facility. I would urge NSF to exercise its option for a 6th year of operation under the current contract and definitely support an additional 5 year contract. The performance of the entire CHILL staff has shown its enthusiasm and professionalism in developing the radar and applying it to the education of the next generation of radar meteorologists and engineers.

You also described that you were integrating the Thunderstorm Initiation Tracking and Analysis Network (TITAN) display, courtesy of Mike Dixon at NCAR/RAP. Although this is a fine display, my impression is that it was developed as a specific research tool, not as a general purpose radar data display which seems to be your intent. I would recommend that you investigate NCAR/ATD's "zeb" display for a Cartesian-space data integration display. I'm not at all up on "zeb"'s capabilities, but it can combine various data sets from the radar and other sensors (including aircraft tracks). Cindy Mueller or Jon Corbet can give you all the details you'd like. "zeb" has been ported to many other universities and some CHILL visitors would already be familiar with "zeb" and perform extended analyses once they return to their own facilities.

My only other comment is that I think the entire CHILL RAC should be convened on a regular basis (say once or twice a year) to allow a better and more frequent exchange of information and advice.

Overall, I'm very impressed with the contribution you all have made and encourage you and NSF to continue this fine work.

cc: Wakimoto, Zrnic, Hildebrand

UNIVERSITY OF CALIFORNIA, LOS ANGELES UCLA

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April 9, 1994

Professor Steve Rutledge
Dept. of Atmospheric Sciences
Colorado State University
Fort Collins, CO 80523

Dear Steve,

This is my own follow-up letter concerning our recent RAC meeting at the CHILL site on 8 April 1994. It was a pleasure to hear and evaluate your accomplishments during the past year and over the entire duration of the Cooperative Agreement with NSF. CSU's record in maintaining and upgrading the radar as well as overseeing its implementation in research and education is a modern day success story. I have been especially impressed with the mileage you have attained with the 20-hr research projects. As a member of a competing university, I have to admit to be envious of your success. In fact, compared with NCAR, your facility has better served the university community as an educational tool. Moreover, you will soon have the state-of-the-art multiparameter radar that will be in exceedingly high demand as a research tool.

The following comments merely serve as minor suggestions that you should consider over the next few months:

1. In assessing CHILL's impact on education, I believe some attempts should be made to quantify its effectiveness There are various ways to do this -

   i. Soliciting written comments by the students during course evaluations specifically addressing the impact of the radar.

   ii. Tracking your graduate students to see if exposure to the CHILL radar made an impact in future job opportunities. This may be too early to implement now since your students have only recently used the radar.

   iii Comparing your graduate applications over the past few years to see if the quality (GRE and GPA scores) and quantity of entering students wishing to work in the area of radar meteorology has increased.

2. In the future, you should consider inviting high school teachers

to a workshop. This may be fairly simple if you coordinate with various UCAR programs. I believe Project LEARN invites teachers to Boulder, accordingly, you would only need to bus them up to Greeley for an all-day session.

I would also suggest that you advertise your 20-hr research projects at the upcoming UCAR Members' Reps/Heads & Chairs meeting in the Fall. You may also want to submit a short article to the UCAR Newsletter.

3. I agree with the rest of the RAC that an effective case has been made for a renewal of the 5-year Cooperative Agreement with NSF. I strongly endorse continued funding by NSF at approximately the same levels for the next 5-year agreement. NSF must be pleased with the commitment by CSU for significant cost-sharing (cash support estimated to be $100,000/year).

   For this next proposal, I recommend that the CHILL radar continue to collect high quality research and educational case studies in Colorado. However, to truly be a national facility and also to indoctrinate the radar as part of the fleet of high-quality research radars, future deployments in other geographic locations should be considered. In particular, I think there will be a growing demand by the microphysical community wishing to see the radar deployed in a semi-tropical climate to study warm-rain processes. Although the radar is more difficult to deploy, its unique capabilities should be tested at other sites.

I, again, wish to compliment you and your staff for the excellent job as caretakers of the CHILL radar. The joint efforts of the Departments of Electrical Engineering and Atmospheric Science are truly exemplary. You have convinced the community (and responded to any critics) that a national facility can be successfully maintained as a research and education tool at a major university. Good luck in your future endeavors.

Sincerely,

Roger

Roger M. Wakimoto
Professor of Meteorology

Colorado State University

Engineering Research Center
Foothills Campus
Fort Collins, Colorado 80523

April 11, 1994

Dr. Dusan Zrnic, Chairman
CSU-CHILL Radar Advisory Committee

Dear Dr. Zrnic:

Upon your request, it is my pleasure to report on the CSU-CHILL activities in the past four years, as we discussed last Friday in Greeley. I am very impressed with the on-going and past activities of the CSU-CHILL radar since it is located near Greeley.

The radar is operated by competent personnel. At least three faculty, Profs. Rutledge, Bringi and Chandrasekar, are working in close collaboration for the development and use of the facilities. Several post-docs and research associates complement the research programs. Hardware and software problems are also tackled by competent scientists such as Dr. Muller and Kennedy.

Most projects lead to refereed journal publications, which reflects on the top quality of the research. Several Ph.D. dissertations also centered on radar use and developments. The 20 hour projects are helpful for testing new initiatives and attract outside scientists.

The new antenna and upcoming dual channel capabilities should lead to significant technological improvements. The radar is a unique platform for testing Dr. Bringi's ϕ_{DP} precipitation algorithm. At Greeley, the radar is also uniquely located for the analysis of winter storms, severe thunderstorms in complex terrain, melting layer, and possibly tornadoes.

The budget is well-distributed among personnel, hardware and software. The CSU matching contribution is substantial and expected to be maintained. The resources are carefully used to optimize the scientific output of each component purchased.

In summary, I am impressed with the on-going and planned activities at the CSU-CHILL radar facility. There are true feelings of competence and friendly collaboration among research scientists that can only foster significant contributions to radar technology and atmospheric sciences.

Sincerely,

Pierre Y. Julien, Ph.D.
Assoc. Prof. of Civil Engineering