# CHILL RADAR NEWS

from:

NATIONAL SCIENCE FOUNDATION

Colorado State University
Knowledge to Go Places

Eleventh Edition
January 2003

## Overview

*Steven Rutledge,*
*Scientific Director*

This is the eleventh edition of the Colorado State University (CSU)-CHILL newsletter that we distribute on an annual basis. The newsletter is intended to provide information to the community regarding on-going research, education, and technical improvement activities of the CSU-CHILL facility.

The use of the CSU-CHILL radar is granted by the National Science Foundation after review by the NSF Facilities Advisory Council (FAC) and Observing Facilities Advisory Panel (OFAP). We supported two NSF-reviewed projects during 2002: a project conducted by South Dakota School of Mines and Technology (SDSMT) using the T-28 aircraft to collect in situ measurements; and, a Research Experience for Undergraduates (REU) project directed by Prof. Chandrasekar in the Department of Electrical and Computer Engineering.

For projects requiring less than 20 hours of radar operational time, the Scientific Director of the CSU-CHILL facility may award the use of the radar without OFAP/FAC review. The Cooperative Agreement provides radar operational costs for projects of this nature. These projects encourage use of the radar for highly focused experiments; as such, these projects continue to be very productive. We supported three 20-hour projects over the past year, which are detailed in the next section.

Highlights of CHILL activities for 2002 include:

***Acquiring a new antenna.*** A $1.4 million National Science Foundation MRI grant will enable the CSU-CHILL facility to design and install a 9-meter dual-offset Gregorian antenna. Technical design studies for the new antenna are complete.

***Collecting in situ measurements.*** Researchers from South Dakota School of Mines & Technology spent the month of June flying their T-28 research aircraft through cumulonimbus clouds to make various situ measurements.

***Hosting another Engineering based Research Experience for Undergraduates (REU) during the summer of 2002.*** Five REU students spent 10 weeks working at the CHILL site, acquiring first hand experience with radar operations and radar engineering principles, including polarimetric techniques for remotely sensing hail.

***Supporting three 20-hour projects.*** The first 20-hour project supported a joint effort between NCAR and CSU-CHILL to gather cold season precipitation data. A second project involved a collaborative effort by CSU's Department of Atmospheric Science and the Colorado Climate Center, along with the National Weather Service for a pilot precipitation measurement study. The third project supported investigators from the University of Northern Colorado who were continuing detailed studies of gust fronts generated by thunderstorms.

***Expanding use of the VCHILL system.*** During April, Facility Manager Pat Kennedy presented VCHILL seminars at the University of Illinois (Champaign-Urbana) and the University of Oklahoma. Additional collaboration on accessing VCHILL for classroom applications continues with researchers from the University of Washington and Texas A & M University.

During the Colorado State University's spring semester, Profs. Rutledge and Bringi team-taught ***a new graduate course combining the principles of both Radar Meteorology and Radar Engineering***. This course will be taught again during the spring of 2004.

***Conducting educational outreach activities***. For the first time, CHILL staff participated in the Colorado Farm Show held during January in Greeley, CO. Staff shared an educational booth with CoCoRaHS observers and the National Weather Service. The booth won first place for the show's Best Educational Display by highlighting Colorado's hydrological cycle, precipitation variation, remote sensing, severe storms, and research collaboration among these groups. In March 13 undergraduate students from Iowa State University visited the facility for a tour and presentation. During April, the radar facility hosted high school students from the Colorado Science & Engineering Fair. Staff members conducted tours of the CHILL facility, discussed on-going research projects and potential careers in radar meteorology and radar engineering with students. Over the course of the year, several undergraduate and graduate students from CSU also toured the radar facility.

Several M.S. theses have been completed in the past year in Atmospheric Science and Electrical Engineering (these are listed below in the Publications Section). In addition, M.S. theses and Ph.D. dissertations are being written using CSU-CHILL data collected in STEPS 2000.

## Radar Operations Summary

*Pat Kennedy, Facility Manager*

During 2002, the CSU-CHILL Radar supported five research projects; two of these were sponsored by NSF funding and three were of the 20 hour "small project" variety. Persistent drought conditions limited the data collection possibilities for all of these projects, but all investigators obtained at least some useful data.

The first NSF project was conducted at the request of Profs. Detwiler, Smith and Helsdon (all from the South Dakota School of Mines and Technology, SDSMT) and Profs. Bringi and Chandrasekar from CSU. The general goal of this project was the collection of various types of in situ measurements (hydrometeor size spectra, Nitrogen oxide concentrations, and 3D electric field mappings) inside cumulonimbus clouds using the SDSMT "armored" T-28 research aircraft. The CSU-CHILL and Pawnee radars both collected data from the storms selected for T-28 penetrations. Research flights for the T-28 project were curtailed after 16 June 2002 (approximately ten days early) when a serious oil leak developed in the aircraft's engine.

Example data from this project are shown in Fig. 1. The horizontal wind fields at the T-28's altitude are synthesized from the coordinated CHILL and Pawnee volume scans. The overlaid color-coded line depicts the T-28 flight track, with the red portion of the track identifying locations that were recorded during the minute starting at 2256 UTC. Figure 1 shows that the T-28's pass was generally along an axis of convergent horizontal flow that extended along the length of the small echo system. Around 2256, the aircraft penetrated a small 40 dBZ reflectivity maximum. Figure 2 shows some of the in situ data collected by the T-28 during this pass. The vertical electric field component approached 40 $kVm^{-1}$ shortly before 2256; the rapid field decrease thereafter is probably due to a lightning discharge. Just after 2256, a localized spike occurred in the NO concentration trace (Fig. 3). This localized NO pocket was generated by a lightning discharge.

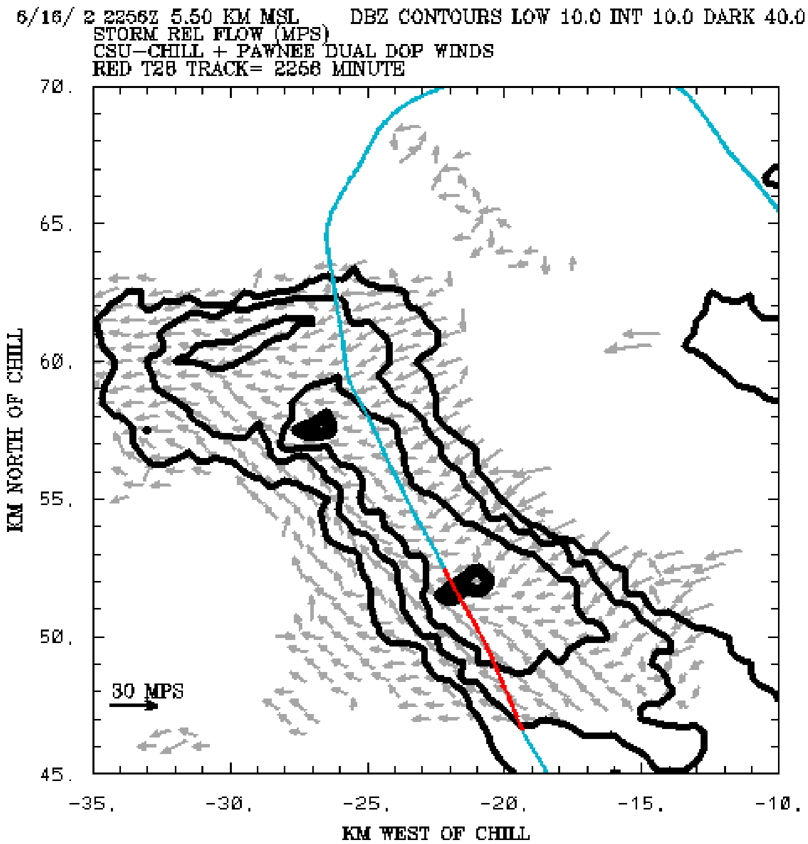


**Fig. 1. Dual-Doppler horizontal wind field synthesis using CHILL and Pawnee radars. Colored line depicts T-28 flight track.**

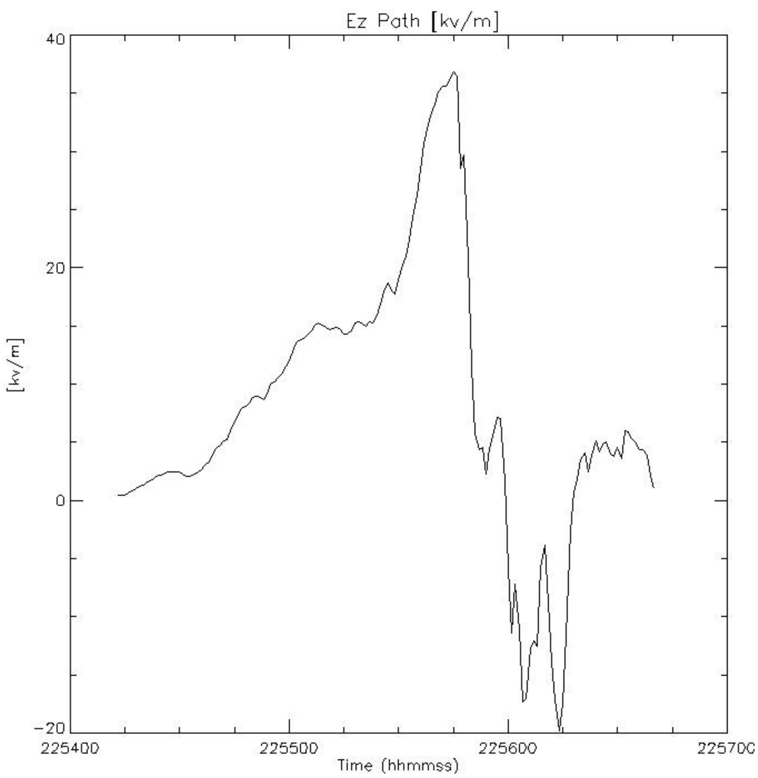


**Fig. 2. The vertical component of the electrical field as measured by the T-28.**

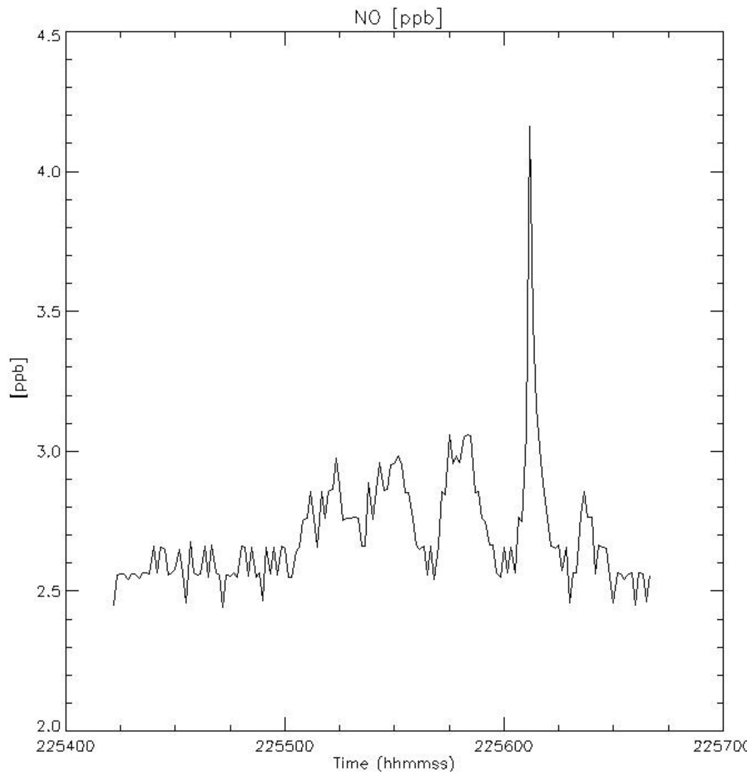


**Fig. 3. NO concentration time trace as measured by the T-28.**

The second NSF funded project that was supported in 2002 was a Research Experience for Undergraduates (REU) program headed by Prof. V. Chandrasekar. By design, the size of this year's REU class was restricted to 5 students. These students were given an introductory lecture on radar meteorology as well as a tour of the CSU-CHILL facility. The student's primary research projects also involved data sets collected by the radar facility.

The first 20-hour project of the year was a joint effort between Dr. E. A. Brandes (NCAR) and Pat Kennedy of the CSU-CHILL staff. This project sought to gather polarimetric data under a variety of cold season precipitation situations. Local atmospheric monitoring for this project was enhanced when NCAR installed an automated surface mesonet station at the Easton–Valley View Airport (approximately 13 km south-southeast of the CHILL radar site). During selected events, direct manual observations of the precipitation particle sizes and characteristics were made at the Easton airport site as well as below an open roof hatch in a cloud physics cold room at NCAR's Foothills Laboratory in Boulder. This project experienced several of the challenges that typically confront winter season field experiments: uncertain precipitation onset times, relatively shallow echo systems with ill-defined polarimetric signatures at S-Band, cold temperature-induced mechanical equipment problems, and difficulties in properly capturing precipitation particles under windy conditions. Despite these hurdles, useful data were collected during several precipitation events. The highest analysis priority is being given to the locally heavy snowbands that crossed the Boulder and Greeley areas on 8 March 2002.

The second 20-hour project of the year was a pilot precipitation measurement study under the direction of Dr. Rob Cifelli (CSU Atmospheric Science Department), Mr. Pat Kennedy (CSU-CHILL Radar Facility) and Mr. Nolan Doesken (Colorado Climate Center). Collaboration with the National Weather Service Forecast Office at Boulder, through the participation of forecasters David Barjenbruch and Chadd Gimmestad, was arranged under a small grant from the COMET program office. This project was designed to integrate warm season observations collected by a volunteer network (CoCoRaHS) with quantitative measurements from CSU-CHILL and the NWS KFTG radar in Denver. The goal of the project is to provide validation for CSU-CHILL hail detection and rainfall accumulation algorithms and, ultimately to improve similar algorithms currently used by the National Weather Servcie. A series of 4 low-level PPI scans were used to collect data in selected storms. To the degree possible, CHILL scanning was performed so that comparisons could be made with the KFTG NEXRAD radar.

Radar-derived rainfall estimates were developed by Department of Atmospheric Science personnel. This method automatically applies several quality control tests to the input radar data, and then interpolates the accepted range gate data to a plane of constant height Cartesian gridpoints. At each such grid point, the program uses a set of rules to select the optimal method for developing an instantaneous rain rate estimate. The available rain rate estimation methods are: (1) A basic Z–R relation. (2) An estimator using a combination of Z and differential reflectivity ($Z_{dr}$). (3) A specific propagation differential phase ($K_{dp}$) estimator. In general, method 1 is favored in low reflectivity areas and method 3 is used when the presence of hail is inferred. The instantaneous rain rates are integrated over time to develop storm total rainfall maps. The technical aspects of the map generation and display techniques are presented in the Facility Engineering section of this Newsletter.

The hail feature of the 2002 COMET project centered on the collection of post-storm ground truth data by Pat Kennedy and Atmospheric Science M.S. candidate Ms. Tracy Depue, to evaluate the polarimetrically-based Hail Quadrature Parameter (HQP; Kennedy et al. 2001). HQP is the magnitude of the vector sum of the Hail Differential Reflectivity (HDR; Aydin et. al, 1986) and the Linear Depolarization Ratio (LDR). Both of these components are only considered over a range of values typical of hail (HDR range of 5 to 50 dB, and LDR range of –25 to –10 db). In the calculation of HQP, the input HDR and LDR measurements are normalized with respect to these value ranges so that HQP can take on magnitudes between zero and the square root of two (Fig. 4).

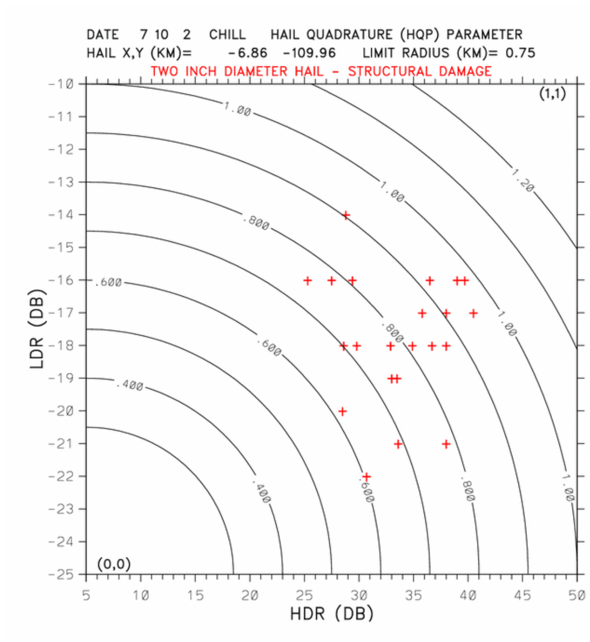


**Fig. 4. Red crosses are individual range gate HQP values. These gates were located within 750 m of the x,y point listed at the top of the figure. Two-inch diameter hail was documented at this same location.**

Previous studies of hail characteristics have found that as hailstone diameter increases, there is some tendency for the shape to become increasingly aspherical (Knight, 1986). Assuming that the typical gyrating motions are taking place as the hailstone falls, the long axis of the stone will at times be canted significantly relative to the polarization plane of the illuminating radar pulse; a situation which increases the degree of depolarization in the signal that is backscattered to the radar. The basic shape/ orientation effects on the depolarization level will be strongly influenced by the stone's density and degree of surface wetting. Furthermore, the depolarization level may be increased if the hailstone's size and surface roughness qualities cause the backscattered signal to be appreciably affected by Mie resonances. Thus, it might be expected that enhanced (less negative) LDR values would

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be associated with the presence of relatively large, high-density hailstones.

During the COMET project, HQP maps were prepared from low elevation angle CSU-CHILL scans made through thunderstorm precipitation areas. A distance dependent Cressman weighting scheme was used to develop HQP values at regular Cartesian grid points based on the nearby individual range gate data values. A new set of HQP values were generated by the low elevation angle PPI sweep in each volume scan. An overall storm hail swath map was generated by recording the highest HQP value reached at each grid point during the storm passage.

Hail verification data were obtained by making post storm driving surveys of areas where the HQP maps indicated that hail had occurred. The primary effort in these surveys was to contact people who had first hand experience with the storm event. A series of questions were asked to obtain information on hailstone sizes, hardness, extent of ground coverage, damage effects, etc. The locations at which these hail observations were taken were determined using a handheld GPS unit.

An example map containing both the HQP and observer verification data is shown in Figure 5. This hailstorm struck The Pinery community (located approximately 5 miles southeast of Parker, Colorado) during the afternoon of July 10, 2002. The storm moved quite slowly during its intense phase; several observers experienced various combinations of hail and heavy rains continuously for approximately 30 – 45 minutes. Roof damage due to hail was also frequently reported. The color shading in Fig. 5 depicts the .3, .7, and .9 HQP levels. The majority of the larger, damaging hail was observed at locations where the HQP was greater than .7 (yellow and red shading).

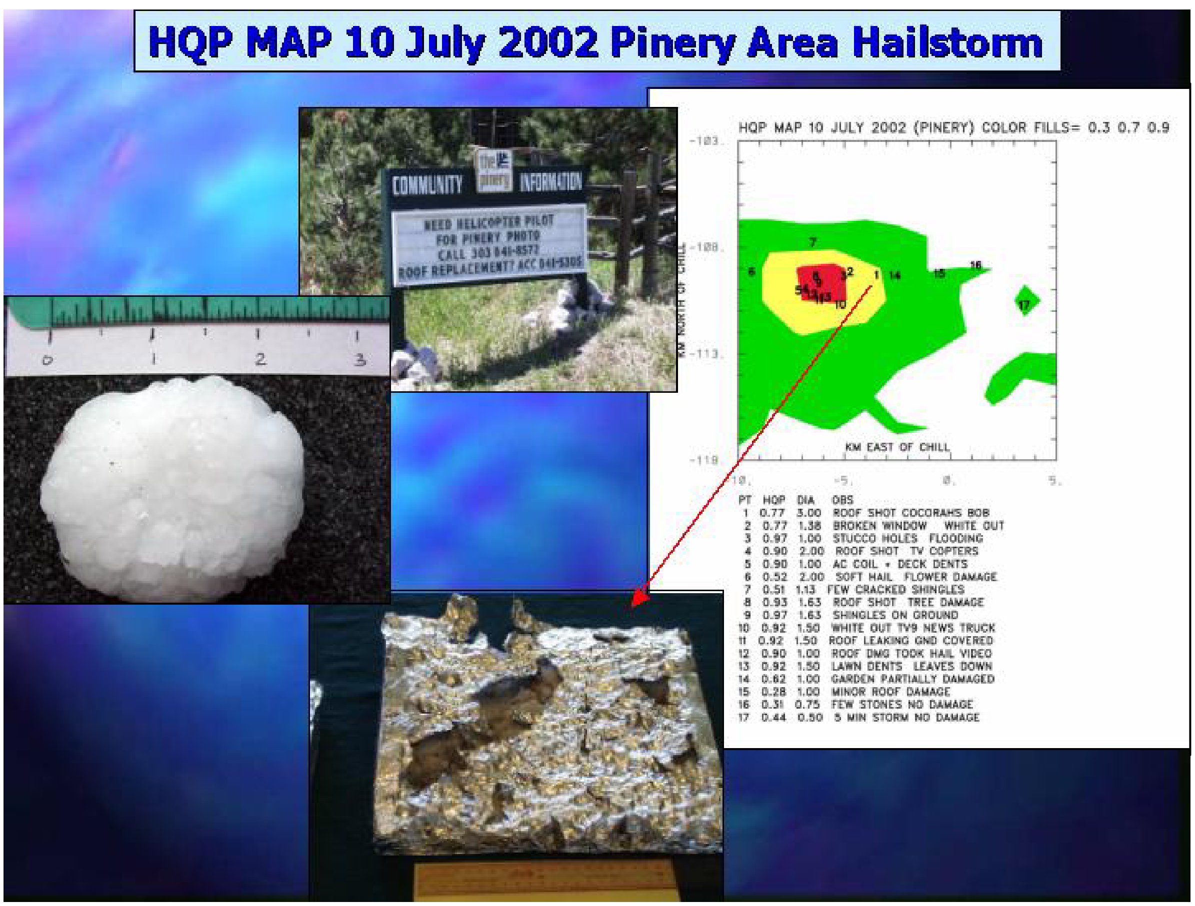


**Fig. 5. Summary of observations from 10 July 2002 Pinery area hailstorm. Photographs of the hailstone and hail pad were obtained by Mr. Bob Burkhart, who was located at Point 1 on the HQP map. It is suspected that strong winds caused the hailstones to follow sloping trajectories as they fell to the ground from the height where they were observed by the CSU-CHILL radar (approximately 1.2 km above the ground. Thus, Mr. Burkhart's location is not centered in the overall HQP contour pattern.**

Of particular interest are the comprehensive observations taken at point number one by Mr. Bob Burkhart. Mr. Burkhart is a volunteer observer with the Community Collaborative Rain and Hail Study (CoCoRaHS). (For more information on the CoCoRaHS project, see the following web site: http://www.cocorahs.com.) These observers are equipped with foil-covered Styrofoam "hail pads". The impressions left in these hail pads provide useful information on the hailstone size distributions. Mr. Burkhart's hail pad was partially destroyed by the impact of wind-driven hailstones of 2.5 to 3 inches in diameter. He also recorded a detailed chronology of the storm's precipitation characteristics, and measured a rainfall total of 2.56 inches. The collection of these high quality hail and rainfall observations is of fundamental importance in evaluating the polarimetric radar algorithms that are being tested in the COMET project.

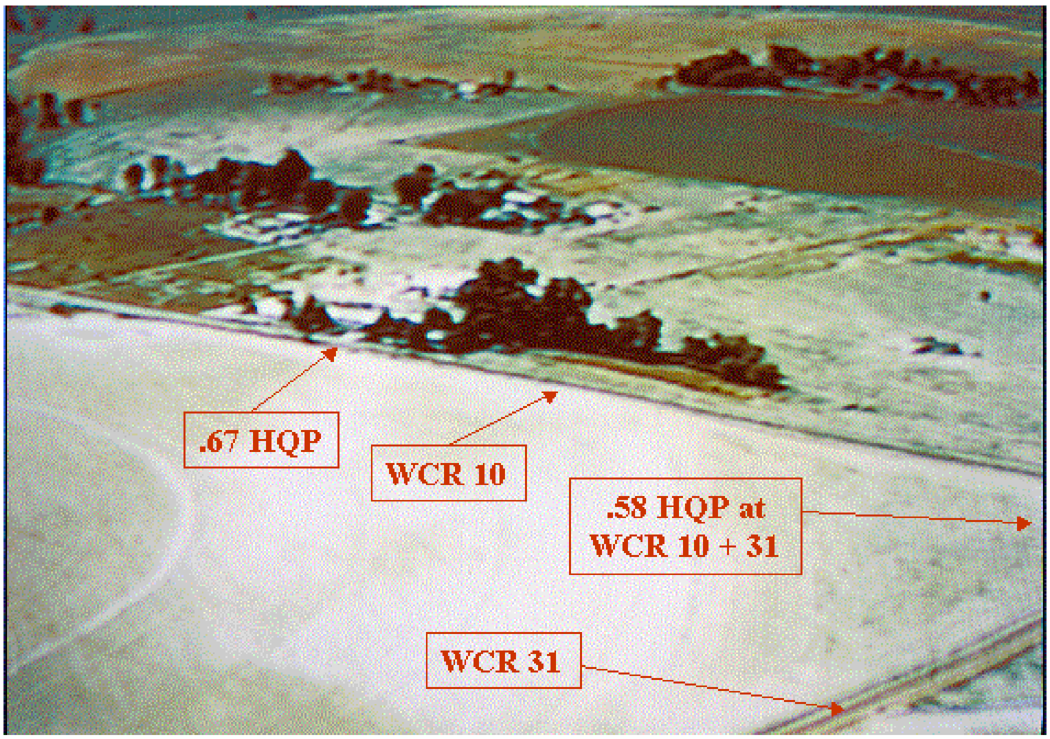


**Fig. 6. Spatial ground coverage of hail as documented by Mr. Mike Silva, helicopter pilot for Denver station KCNC Channel 4.**

The utility of hail verification data obtained from an airborne platform is illustrated in Figure 6. This image was extracted from a videotape sequence taken by Mr. Michael Silva, helicopter pilot for station KCNC (Channel 4 in Denver, Colorado). Mr. Silva took the video footage shortly after the passage of a hailstorm a few miles northeast of Brighton, Colorado during the afternoon of June 3, 2002. During a subsequent driving survey, the GPS locations of several landmarks visible in the helicopter video were determined. HQP values were then calculated for these landmarks. As shown in Fig. 7, HQP values were slightly higher in the visually dense hail coverage near the center of the image. The helicopter image also suggests a possible hole in the hail coverage in the upper (northwest) portion of the images. A similar hole is also present in the HQP map (Fig. 7). Clearly, the visible hail hole might be a false impression due to obscuration of the hail by taller foliage, etc. In general, however, the hail patterns documented in the videotape images are providing useful data for comparison with the HQP map results.

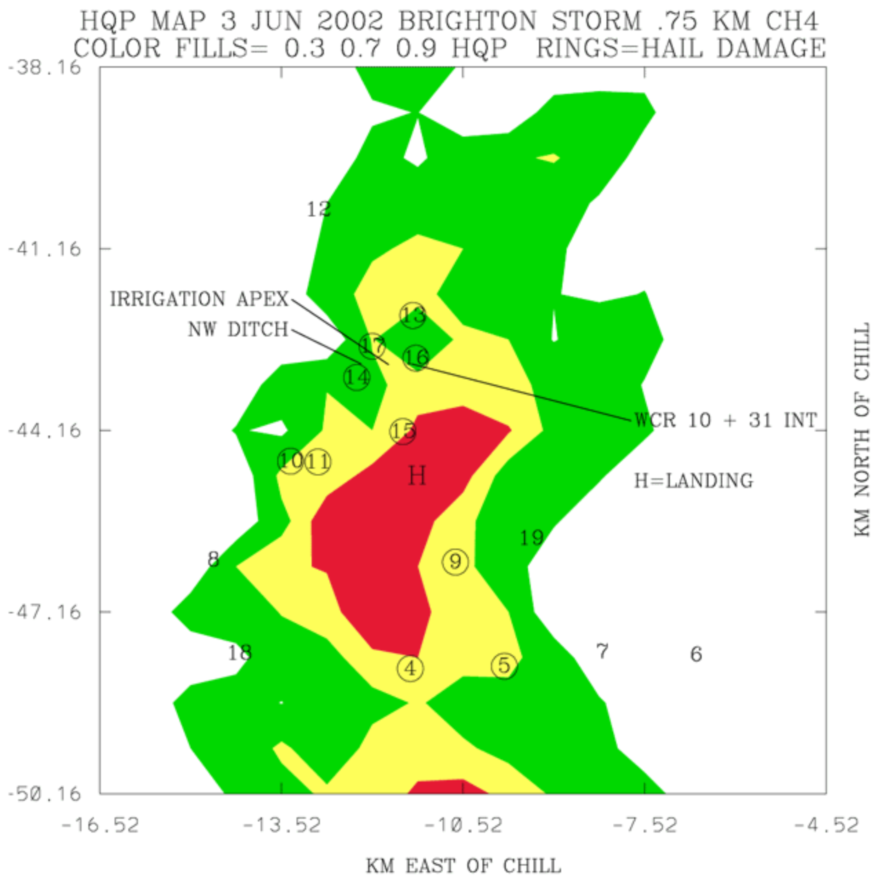


**Fig. 7. HQP map from the 3 June 2002 Brighton hailstorm. The point labeled "irrigation apex" corresponds to the location marked by the .67 HQP box in Figure 6. Numbered points are locations where post-storm damage surveys were conducted; hail damage was confirmed at the circled points.**

The third 20-hour project supported during 2002 was directed by Profs. Bruce Lee and Cathy Finley from the University of Northern Colorado. This project was a continuation of their efforts to use CSU-CHILL observations to document the detailed velocity and radial velocity structures present along two types of convergence zones in the boundary layer. The topographically-induced Denver Convergence and Vorticity Zone (DCVZ) was of interest due to its apparent ability to influence the ultimate organization of thunderstorms that subsequently form along it. Thunderstorm gust fronts were the second type of convergence lines studied in this project. In this case, the objective was the documentation of the fine scale "lobe and cleft" structure that typically occurs along the leading edge of intense thunderstorm outflows (Lee and Finley, 2002). Unfortunately, the desired convergence zone types occurred very infrequently during the dry summer of 2002. The radar data from the most promising cases are being reviewed for possible analysis.

In addition to these formal research projects, the CSU-CHILL Radar Facility was able to provide "target of opportunity" support to the NCAR Instrument Development and Education in Airborne Science 2 (IDEAS2) project. IDEAS2 was designed to make the NCAR C-130 aircraft available to test a variety of new instruments. The participation of atmospheric science graduate students in these tests was of particular interest. One of the students participating in a C-130 flight was Kyle Wiens, a Ph.D. candidate at CSU. Kyle suggested the possibility of operating the CHILL when IDEAS2 flights were being conducted in the radar's coverage area. This resulted in the collection of radar data during four IDEAS2 flights in October, 2002. Two of these flights sampled smoke plumes generated by wildfires in the Rocky Mountain foothills. Two other flights were made through snow echoes in the Cheyenne, Wyoming area. The smoke plume observations are of particular interest for future analysis.

Due to the continuing drought, smoke plumes drifted into the CHILL coverage area on several occasions in 2002. An example of the resultant radar observations, 19 August, is shown in Figure 8. The broad, hollow ring-shaped reflectivity pattern occurred as the radar beam intercepted the smoke layer in the 9,000 to 15,000 ft MSL altitude band (Fig. 8a (dBZ image)). Within the smoke layer, the radial velocity pattern showed that the wind direction veered with height from approximately 220 to 300 degrees (Fig. 8b (radial velocity image)). The associated differential reflectivity (ZDR) pattern is particularly striking (Fig. 8c (ZDR image)). Remarkably large positive ZDR values (~+9 dB) are evident near the zero radial velocity regions, while ZDR minima are present when the radar is pointed along the westerly mean wind direction. This implies that the large (presumably ash) particles in the smoke plume had oblate shapes and were generally aligned with the wind. Thus, the smoke particles presented their most oblate (broad side) appearance when the radar viewed them in the cross wind direction, and their least oblate (end on) shape when the radar illuminated them in the along-wind direction. The azimuthal variation in the basic $Z_H$ reflectivity pattern also shows how the smoke particle's horizontal dimension was maximized in the crosswind viewing direction. CSU Atmospheric Science Research Scientist Dr. Tim Lang and Steve Rutledge are making a detailed study of the smoke plume data.

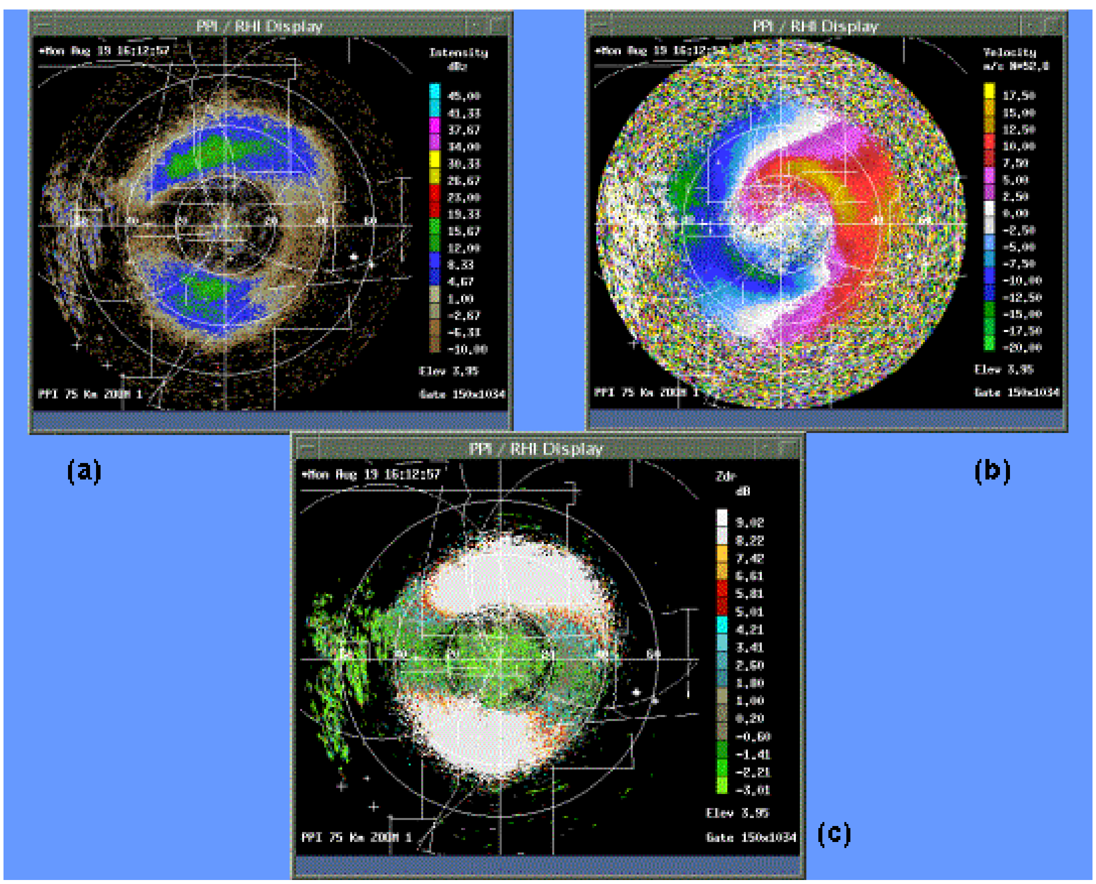


**Fig. 8. CSU-CHILL PPI data collected in a wildfire smoke plume at 1612 UTC on 19 August 2002. The PPI elevation angle is 3.95 degrees. The individual data fields are: (a) Horizontal polarization co-polar reflectivity factor ($Z_H$, dBZ); (b) Radial velocity (m $s^{-1}$); (c) Differential reflectivity (10 $Log_{10}$ ($Z_H/Z_V$), dB).**

References:

Aydin, K. A., T. A. Seliga, and V. Balaji, 1986: Remote sensing of hail with a dual linear polarization radar. J. Climate Appl. Meteor., 25, 1475-1484.

Kennedy, P. C., V. N. Bringi, D. A. Brunkow, S. A. Rutledge, and N. J. Doesken, 2001: Hail characterization via the joint utilization of reflectivity, differential reflectivity and linear depolarization ratio data, Preprints, 30th Conference on Radar Meteorology, Munich, Germany, Amer. Meteor. Soc., 433-435.

Lee, B. D., and C. A. Finley, 2002: Fine-scale outflow structure of the 10 July 2001 Greeley CO, convective wind event. Preprints, 21st Conference on Severe Local Storms, San Antonio, TX, 12-16 August, 2002.

## Electrical Engineering

***V. N. Bringi, Professor and Yanting Wang***

### Upgrade of CSU-CHILL with 9-meter Dual-Offset Gregorian Antenna

With a $1.4 million Major Research Instrumentation grant from NSF, the CSU-CHILL Radar facility will undergo another major upgrade by replacing the current parabolic reflector antenna with a 9-meter dual-offset Gregorian antenna in the next two years. The development of this high-performance antenna is expected to greatly improve the accuracy of radar measurements and allow radar meteorologists to conduct new levels of weather-related research. The antenna is being developed and built in collaboration with world-leading antenna designer VertexRSI of Kilgore, Texas. It is the largest antenna of its type ever constructed by the company and, to the best of our knowledge, will be the only 9-meter, dual-offset antenna available for meteorological radars in the world. Once assembled and tested, it will place the CSU-CHILL Radar facility at the forefront of weather radar research for the next decade.

Over the last two decades the CSU-CHILL Radar Facility has been undergoing continuous improvement to attain the most accurate radar measurements. Among these continuous upgrades, a major advancement was the conversion to dual-transmitter/dual-receiver configuration, together with the more recent implementation of digital IF receiver technology. Because of these upgrades, the CSU-CHILL radar system is able to measure the full polarimetric covariance matrix in the horizontal/vertical polarization basis in real-time, including the estimates along the matrix diagonal such as $Z_h$, *LDR*, $Z_{dr}$ as well as the complex correlation terms.

The observables $Z_{dr}$, *LDR*, $\rho_{co}$ and $\Phi_{dp}$ have been thoroughly investigated in the last two decades. However, it is only recently that the full covariance matrix has been utilized. The co-to-cross correlation terms $\rho_{xh}$ and $\rho_{xv}$ are just beginning to be investigated; from these terms the mean and standard deviation of the canting angle distribution may be retrieved. These data have provided important new information on “effective” canting angles due to multimode oscillations of raindrops. It is also expected that the theory of optimal polarizations will provide a more physical-based method of hydrometeor classification that is expected to reduce the ambiguities in the current fuzzy-logic methodology based on the five parameters set, $Z_h$, $K_{dp}$, $Z_{dr}$, *LDR*, and $\rho_{co}$. Therefore, the cutting-edge research in polarimetric radar meteorology lies in exploiting the information contained in the full covariance matrix and in the application of optimal polarization concepts for improved understanding of the microphysics of precipitation formation and evolution.

To fully realize this goal it is imperative that the antenna be capable of high performance so that the relatively “weak” cross-polar signal can be extracted with minimal interference from antenna-induced polarization errors. The leakage from the strong co-polar signal needs to be suppressed to a very low level relative to the “weak” cross-polar signal, so the cross-polar performance of the antenna is vital for accurate measurement of *LDR* and the co-to-cross correlation coefficients.

It is also critical that the antenna have low sidelobes so that precipitation-gradient induced artifacts can be minimized as much as possible. The major issue related to antenna sidelobe levels is the distributed nature of precipitation and the fact that the reflectivity of precipitation can vary by many orders of magnitude over very short distances, especially in severe storms (40 dB/km or higher). In addition to errors induced in the conventional Doppler data, mismatched sidelobe-induced artifacts have been studied and modeled for at least several decades in the content of dual-wavelength radars and $Z_{dr}$ measurements. While the mainlobe in well-designed systems can be accurately matched for H and V-polarizations, there can be significant mismatches in the sidelobes that generally cannot be controlled. Furthermore, it is less appreciated that strong spatial gradients of reflectivity can also cause *LDR* errors. Therefore, in addition to excellent cross-polar level performance, the lowering of the sidelobe levels in all planes is necessary for a high performance dual-polarized antenna.

In 1994, the current prime-focus reflector antenna was purchased from RSI and installed on the CSU-CHILL Radar. This led to greatly improved sidelobe and cross-polar performance levels compared to the original CHILL antenna built in the early 1970s by RSI. The performance of the current CHILL antenna has been well documented, both in terms of antenna patterns in four $\Phi$-planes made by the manufacturer and through extensive field measurements. While good performance was achieved in the principal E/H planes of a prime-focus parabolic reflector antenna, the performance in $\pm 45^{o}$ planes, which contain the feed support struts, deteriorates as shown in Fig. 9. In these planes, the sidelobe levels of CHILL antenna peak at approximately –28 dB and decrease very slowly away from boresight. It follows that mismatches in the H and V-polarized sidelobes in these planes can cause significant $Z_{dr}$, $\rho_{co}$ and $\Phi_{dp}$ artifacts when there is large spatial gradient of precipitation echo across the beam. Vertical gradients of reflectivity often cause $Z_{dr}$ errors, even just above the ‘bright-band’ in horizontally homogeneous stratiform events. While it is possible to model these errors or determine the spatial regions that may be affected by such errors using the measured reflectivity gradients, there is no way to “correct” for these errors. General practice is to visually examine the $Z_{dr}$, $\rho_{co}$ or $\Phi_{dp}$ data for signs of sidelobe-induced artifacts and subjectively edit these data. Another time-consuming option is to objectively determine the affected regions by convolving the measured reflectivity data with the antenna pattern over spherical surfaces (from the radar location) and “flag” the error prone regions for $Z_{dr}$, $\rho_{co}$ and $\Phi_{dp}$. In addition, it is also near gradients, e.g., near the updraft/downdraft interface in severe storms, that are often of most interest microphysically and kinematically. For example, positive $Z_{dr}$ columns in severe storms are often microphysically interesting since they indicate supercooled raindrops rising above the $0^{o}$ level where they freeze and rapidly grow into hailstones. The new data on positive $K_{dp}$ columns in severe hailstorms indicate small supercooled drops shed by wet hailstones, which can form embryos for large hail.

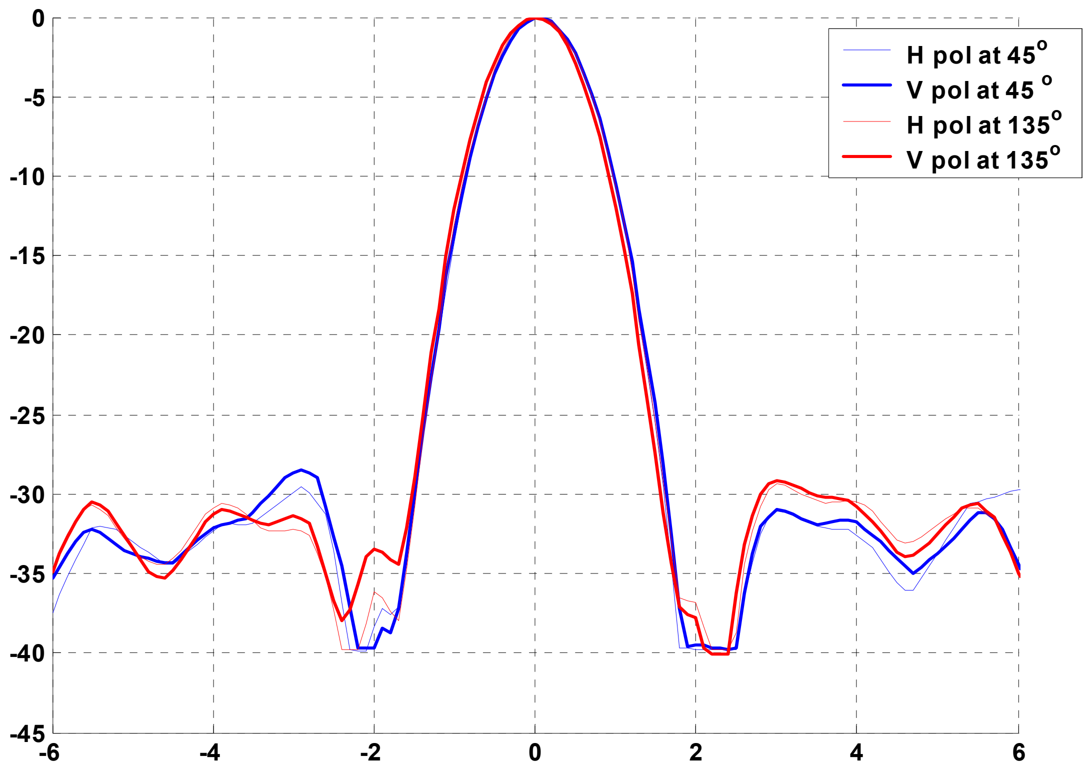


**Fig. 9. Measured co-polar patterns of current CHILL antenna in the ±45° planes.**

The current analysis of CSU-CHILL data collected from severe storms shows that regions with spatial gradients of measured reflectivity exceeding 20-25 dB/km at 50 km range should be viewed with caution. The tolerable gradient levels decrease with increasing range. With the new antenna, the tolerable gradient levels will double (in dB/km scale) relative to that for the current antenna (e.g., 40-50 dB/km relative to 20-25 dB/km at 50 km range). This will lead to significantly improved data quality in the polarimetric measurands compared with that achieved at present, and likely presents a limit on what can be achieved with state-of-the-art antenna technology. More importantly, much more confidence will be gained in the data quality in microphysically interesting regions where spatial gradients are likely to be high. As a byproduct, the clutter power leaking via the sidelobes will also be greatly reduced (by around 12 dB). It will also greatly improve the quality of conventional Doppler data especially in the context of data assimilation by numerical models.

The dual-offset antenna being developed for the CSU-CHILL system is expected to greatly improve data quality for basic research. The specifications drawn for this antenna are quite stringent and push the antenna design and manufacturing technology to the cutting-edge of applied R&D. The specification will focus on attainment of low sidelobe levels. A substantial reduction in sidelobe levels over the current CSU-CHILL antenna is expected (worst-case of –33 dB in any $\Phi$-plane, and, in particular, in the 45/135 degree planes). As well, the cross-polarization levels are expected to be less than -37 dB in any plane. A sample simulated antenna pattern for one design under evaluation is shown in Fig. 10. Currently, several designs are under study at VertexRSI. We have essentially completed negotiating the list of specifications and scope of work with VertexRSI. We have an advisory team consisting of Gene Mueller (retired Chief Engineer of the CHILL facility), P. Ramanujam (Senior Technical Fellow at Boeing), Marco Terada (Professor at NMSU), Brooks Martner of NOAA and Jack Fox of NCAR. Once the finalized contract is given to VertexRSI, we will have a preliminary design review (around mid-February of 2003) followed by a critical design review 6 months later. Range testing will be done at VertexRSI and the antenna is scheduled to be shipped to the CHILL facility in early spring of 2004.

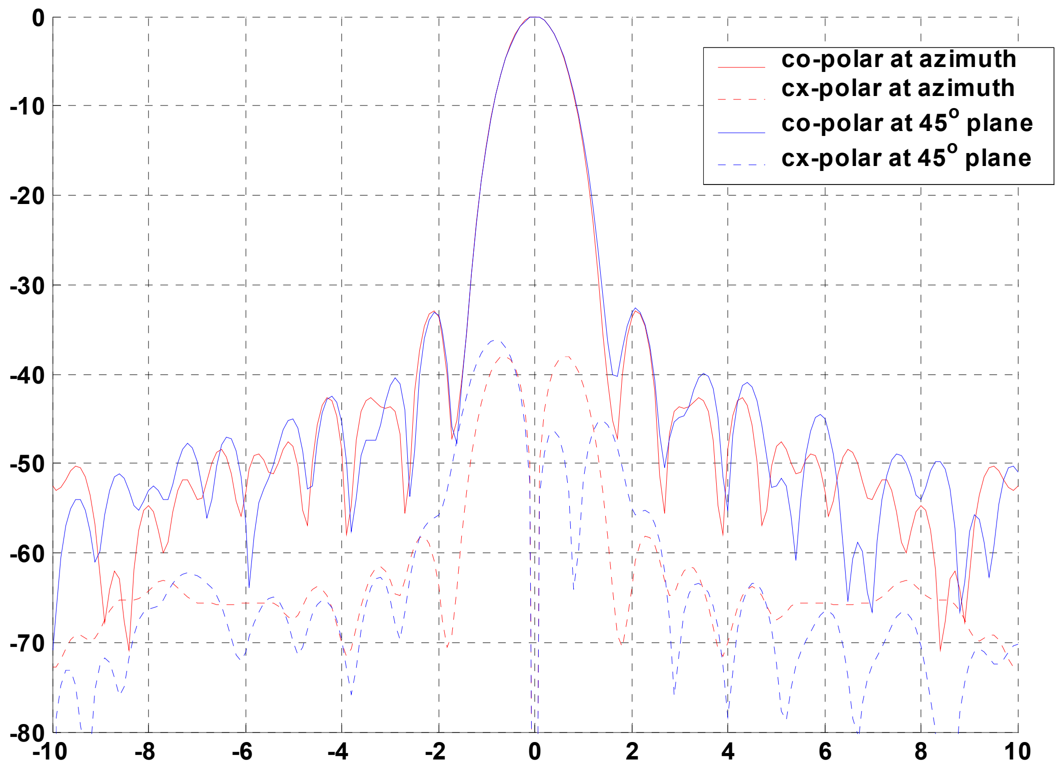


**Fig. 10. Simulated antenna patterns under study for the new dual-offset antenna.**

***V. Chandrasekar, Professor***

## Update on the Virtual CHILL (VCHILL) Initiative

CSU has pursued the VCHILL initiative to enable the operation and control of the CSU-CHILL radar over the Internet with the goal of bringing the radar into the classroom and providing easy access to researchers. The first phase of the project involved developing the appropriate interface in terms of software and hardware, and demonstrating the proof of concept via specific test sites. The first demo in a classroom environment was done at South Dakota School of Mines and Technology in Rapid City, South Dakota, and the first demo of radar control was done at UCLA at the radar analysis lab of Prof. Roger Wakimoto. Subsequently, VCHILL has served the class needs at other locations. More recently, Prof. Chandrasekar conducted a virtual radar tour for the Instrumentation class taught by Prof. Sandra Yuter at University of Washington, where a live two-way data/audio/video interface was implemented and utilized for a remote field trip. As part of the VCHILL we have also developed an extensive set of *courseware material* for educational purposes that can be accessed via the following website: www.chill.colostate.edu. In addition the same location provides software that can be downloaded to install the VCHILL Graphical User Interface that can be used to access, control, and display radar data.

While the basic access, display and control of the radar have been achieved, the VCHILL initiative has moved to its second phase which has two goals: a) multiple radar networking with the neighborhood WSR-88D radars as well as the Pawnee radar; and b) network access to high bandwidth radar data using a parallel receiver channel (see Fig. 11). The first initiative is to develop a Front Range radar network environment so that groups of radars can participate in dual-Doppler radar data collection. The second initiative is to provide a platform where graduate students and researchers can develop and display advanced products based on raw signal samples from the CSU-CHILL receivers.

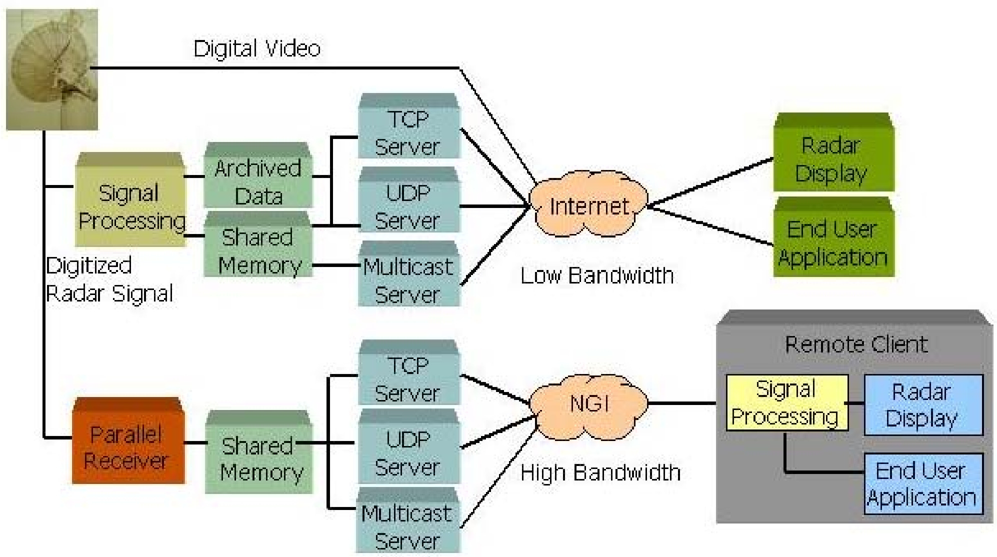


**Fig. 11. VCHILL communication architecture.**

In order to facilitate flexibility in new parameter computation as well as display, VCHILL has developed an end-to-end architecture for transmitting the real-time digital data at the pulse sample level, while simultaneously developing computation and display tools. The architecture has been successfully implemented on both Sun/Solaris and Linux platforms. Performance evaluation results conducted with network emulation tests shows that the end system computing capability critically determines the end-to-end throughput when TCP-based transport protocol is deployed. In addition, we have developed a source-based transfer rate control algorithm with feedback to provide TCP friendliness with UDP-based transport protocol. The purpose of this effort is to enable the end users of CSU-CHILL to be able to develop their own products and display them, as opposed to the earlier paradigm of the researchers having access to the products computed at the radar site. Examples of such projects include graduate students testing different types of phase coding schemes for second trip suppression.

## Hydrometeor Classification based on Polarimetric Radar Measurements

Classification of hydrometeor types is one of the important applications of polarimetric radar measurements. Fuzzy logic techniques have been used to classify hydrometeor type from polarimetric radar observations. Currently there are two independently developed fuzzy logic models for hydrometeor classification: the CSU model, and the NCAR/NSSL model. Though the basic principles of these models are similar, they have been developed based upon different underlying philosophies. The CSU model handles the data quality and hydrometeor classification as two separate processes, puts out fewer classes and has adopted the philosophy of obtaining hydrometeor classes strictly based on radar observations (without any auxiliary input such as temperature). Furthermore, the CSU model has sub-models to account for lack of reliable cross–polar observations.

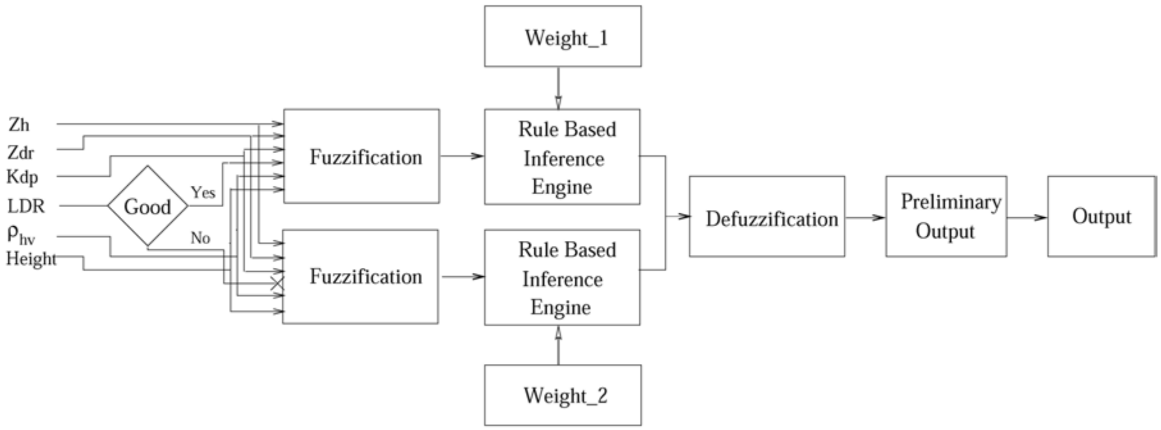


**Fig. 12. The block-diagram of fuzzy hydrometeor classification.**

The CSU model uses five polarimetric radar measurements: horizontal reflectivity ($Z_h$), differential reflectivity ($Z_{dr}$), differential propagation phase shift ($K_{dp}$), correlation coefficient ($\rho_{hv}$), and linear depolarization ratio (*LDR*), and the altitude of observation. The output of the fuzzy hydrometeor classification system is categorized as drizzle, rain, wet snow, dry snow, graupel/small hail, large hail, and mixture of rain and hail. The fuzzy logic classification system has three principal components: 1) fuzzification, 2) fuzzy inference, and 3) defuzzification. The inputs are fuzzified, where $Z_h$, *LDR*, $\rho_{hv}$, and altitude are fuzzified by one-dimensional membership functions, while $Z_{dr}$ and $K_{dp}$ are fuzzified by two-dimensional membership functions. After fuzzification, the inference process is derived using the hybrid method, which is a combination of both addition and product of proposition strengths. Often the signal-to-noise ratio of the cross-polar channel is very low, resulting in noisy LDR measurements. The hydrometeor classification scheme is developed such that the quality of LDR is taken into account in the decision process. Fig. 12 shows the block diagram implementing the classification scheme.

The performance of the hydrometeor classifier using polarimetric radar measurements was evaluated by comparing the results with in-situ observation collected by T-28 aircraft using 2DC, HVPS and hail spectrometer during the STEPS experiment. On June 29 2000, there was a supercell storm in the STEPS' eastern Doppler lobe for over two hours. The T28 aircraft flew through the storm at altitude of about 4.75 km above ground. Fig. 13 shows radar CAPPI of reflectivity (with the T28 tracks superimposed) observed during this storm, hydrometeor class as derived by the CSU-CHILL radar along the T28 aircraft track, and hail diameter and concentration observed by the T-28 along the track. The CSU model described here provides significant advances over the previous fuzzy hydrometeor classification algorithm developed by Liu and Chandrasekar, described in earlier newsletters. The comparison of the CSU model and the T28 aircraft data shows fairly good agreement.

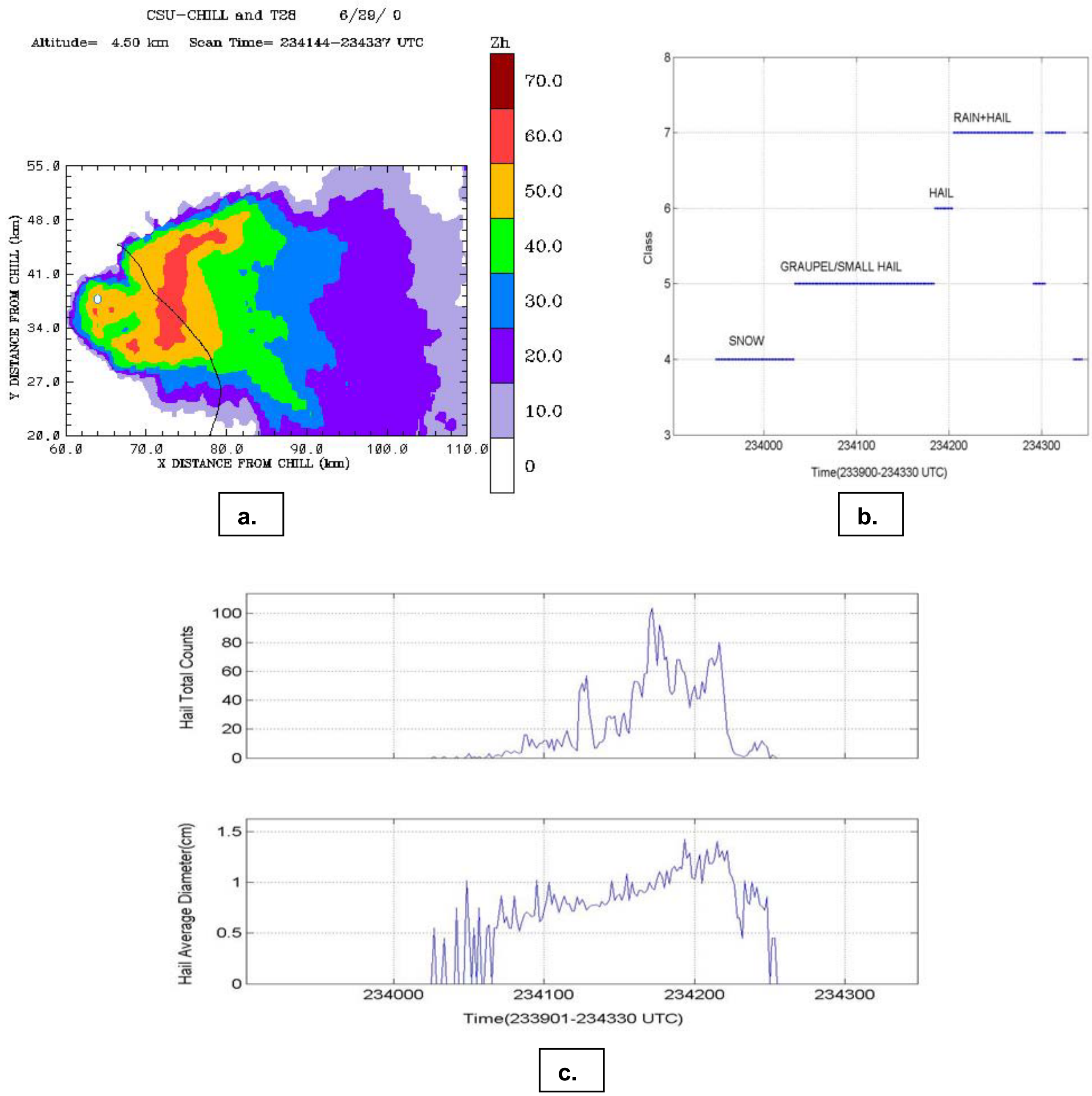


**Fig. 13. (a) Radar CAPPI of reflectivity (with the T-28 tracks superimposed on that) observed on June 29 during STEPS program; (b) Hydrometeor class as derived by the CSU-CHILL radar; (c) Hail diameter and concentration observed by T-28 along the track.**

## Radar Engineering

*Dave Brunkow, Senior Engineer*

Technical Improvements

Several upgrades were made to both hardware and software aspects of the CSU-CHILL radar data system in 2002. Benefits resulted to both local and remote radar users.

A new 2.0 Tera-Byte raid array was added to the facility early in 2002. This expands our online storage capacity by more than a factor of 10, which allows us to keep data online starting with the STEPS project in 2000 though the next several years of operation.

New this year is a process scheduler program that automatically runs selected radar product generation routines as soon as the required input data are available. The process can be run either after a specified PPI sweep number has completed, or after the entire volume scan has completed. This allows an early start for products that do not require the complete volume.

The hailmap product is based on the Hail Quadrature Parameter (HQP), as described in the radar operations summary section of this Newsletter. For real-time product generation purposes, the original FORTRAN implementation of the HQP calculation code has been converted to a more efficient C language version. The HQP field is currently based on input data from a single PPI sweep or a few low angles sweeps, so product generation can start before the entire volume scan is completed. The individual hailmaps (one per volume scan) are posted on the CSU-CHILL web page as soon as they become available. Also, information from the individual hailmaps is combined over time to generate a hailswath image that is also posted on the radar facility web page.

The rainfall accumulation product uses a program suite that was developed over the last 5 years in the Radar Meteorology Group at CSU's Atmospheric Science Department through the work of Drs. Larry Carey, Walt Petersen, Steve Rutledge, and most recently, Rob Cifelli. Once an input PPI volume scan file is available on disk, the process scheduler initiates the following sequence of events:

1) The basic CHILL archive format data are converted to Universal Doppler Exchange (UF) format.

2) Suspect quality data are automatically removed, and a cleaned up UF output file is generated that includes the specific propagation differential phase ($K_{dp}$) field.

3) The cleaned-up UF data are interpolated to a single height level (typically 1 km AGL) Cartesian grid by the NCAR Reorder program.

4) The gridded radar data are input to the optimized rainrate estimation program. On a gridpoint basis, the internal logic in this program selects a rain rate estimation technique. (Both polarimetric and conventional reflectivity-based estimators are available, see Fig. 14.)

5) The rain rates are integrated in time to calculate the incremental rainfall contribution during the current volume scan. The volume scan rainfall is added to the running total rainfall accumulation grid.

6) Two IDL processes are run to produce contour maps of the rain-rate for the current volume scan, and of the updated the total rain accumulation grid.

7) These two, color-filled contour maps are then immediately posted on the facility web page.

As part of the COMET 20 hour project, personnel at the National Weather Service Forecast office in Boulder accessed the CSU-CHILL hail and rain map products in near real-time via the Internet. Their initial reactions to these radar products have been quite favorable.

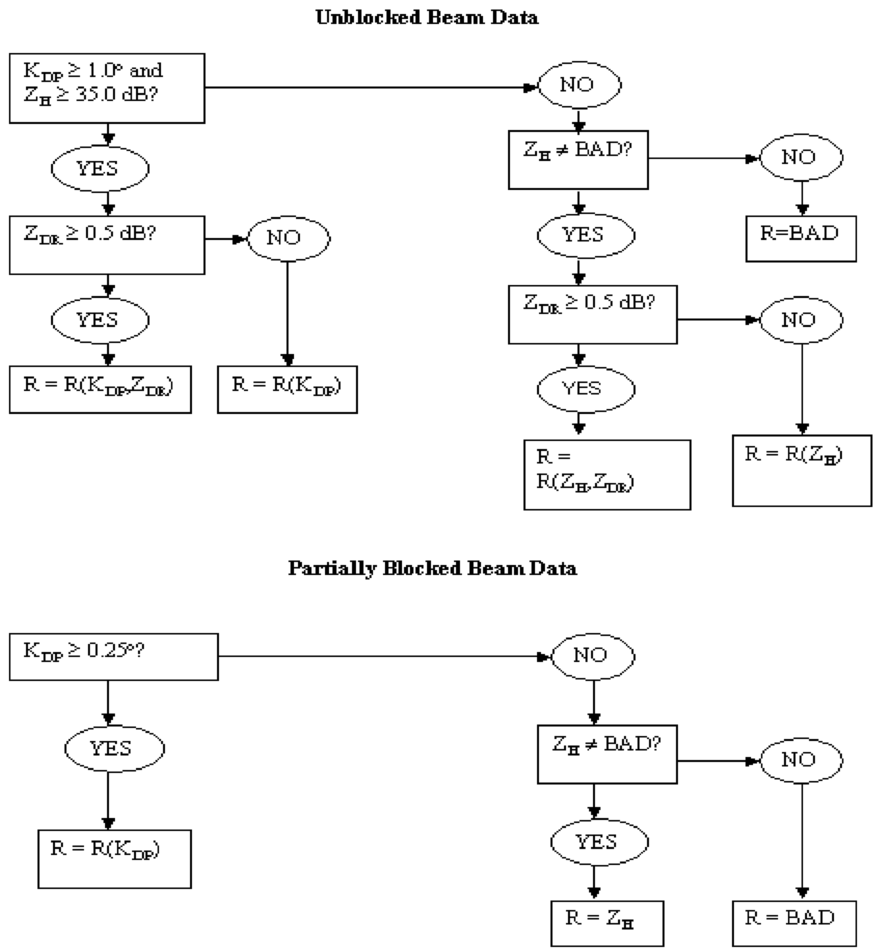


**Fig. 14. Polarimetric optimization flowchart used in the CSU-CHILL rainfall accumulation product algorithm.**

Finally, the Virtual CHILL (VCHILL) remote display software concept was integrated into routine radar operations during 2002. This included the development of a client-server suite to allow remote users to be able to control the radar operations and scans from a distant location. A web-based site (accessible via the radar's normal home page) was developed to allow users to register with the facility. This establishes a user ID and password. Registered users are able to download the client software they need to access and view either real-time or archived CSU-CHILL data. This system was demonstrated in several public venues this year as discussed elsewhere in the newsletter.

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