CHILL RADAR NEWS

from: Colorado State University

Knowledge to Go Places

Tenth Edition

February 2002

Overview

(Steven Rutledge, Scientific Director)

This is the tenth 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 research, education, and refurbishment activities of the CSU-CHILL facility. In September, 2001 Colorado State University was awarded a third five-year Cooperative Agreement from the National Science Foundation (NSF) for operation and maintenance of the CSU-CHILL, an 11 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. In 1998 the 11 cm Pawnee Doppler radar (located near Nunn, CO) was brought to full operational status, which together with CHILL provides a 48 km dual-Doppler network along the Front Range of Colorado.

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 one NSF-reviewed project during 2001: a Research Experience for Undergraduates (REU) project directed by Prof. Chandrasekar in the Department of Electrical and Computer Engineering. In the REU project, a group of undergraduate engineering students from a variety of universities participated in a two-month long program. The REU students learned various aspects of radar, including polarimetric techniques for remotely sensing hail.

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. In projects of this nature, the Cooperative Agreement provides for radar operational costs. These projects encourage use of the radar for highly focused experiments; as such, these projects continue to be very productive. We supported two 20-hour projects over the past year, which are detailed in the next section.

Highlights of CHILL activities for this period include:

Successful completion of the STEPS deployment and return to normal operations at the Greeley, CO homebase site. The facility has disseminated large amounts of radar data to the STEPS community that is presently being analyzed.

Hosting of another Engineering based Research Experience for Undergraduates (REU) during the summer of 2001. Ten REU students spent 10 weeks working at the CHILL site, acquiring first hand experience with radar operations and radar engineering principles.

Supporting two 20 hour projects. One project supported investigators from the University of Northern Colorado who were conducting detailed studies of gust fronts generated by thunderstorms. A second project involved a joint CSU-USGS (U.S. Geological Survey) pilot project to examine changes in the run off characteristics of forest fire ravaged land. CHILL scanned the Bobcat burn area during multiple events to document precipitation amounts that will ultimately be used to initialize run off models used by CSU's Department of Civil Engineering and the USGS.

CSU was awarded a third Cooperative Agreement for operation of the CSU-CHILL National Radar Facility. Again, CSU contributed significant cost share funds to this proposal.

Prof. Rutledge was invited to give the presentation ***"Educational Innovations in Radar Meteorology,"*** during the David Atlas Symposium at the AMS 82nd Annual Meeting in Orlando, FL. A copy of this presentation can be found at the following website:

http://olympic.atmos.colostate.edu/new.html

A live demo of the VCHILL (described later in this Newsletter) was presented at the Atlas Symposium during the AMS annual meeting in Orlando, FL.

During the spring of 2002, Profs. Rutledge and Bringi will team teach ***a new graduate course on Radar Meteorology and Radar Engineering***.

During the summer of 2002, we will launch our new ***student visitor program***. A description of this program, and information about the application process can be found at the following website:

http://www.chill.colostate.edu/VisitingStudent.htm

CHILL personnel are working with staff from the National Severe Storms Laboratory to consider the deployment of CHILL to Oklahoma in summer 2003 to support the proposed JPOLE experiment.

Many M.S. and Ph.D. theses have also been completed in the past year in Atmospheric Science and Electrical Engineering (these are listed below in the Publications Section). In addition, several papers based on CHILL/Pawnee data sets were presented at the recent Radar Conference in Munich, Germany.

Radar Operations Summary
(Pat Kennedy, Facility Manager)

The CSU-CHILL radar equipment returned to Greeley in August 2000 following the deployment to Burlington, Colorado for the STEPS project. Post-deployment inspections revealed significant mechanical wear to portions of the antenna drive gear train. A major overhaul of the antenna mechanical drive system was conducted during the winter of 2000-2001. Upon the completion of this overhaul, the antenna and radome were re-erected at Greeley on 27 April 2001 in preparation for the convective storm season.

During the summer of 2001, the CSU-CHILL facility hosted a Research Experience for Undergraduates (REU) project under the direction of Prof. V. Chandrasekar (CSU Department of Electrical and Computer Engineering). Fourteen students from 7 different educational institutions participated in this REU program. The students first received several lectures that introduced them to the general areas of radar engineering and radar meteorology. Later in the summer, CSU-CHILL Master Technician Bob Bowie guided the students through the startup, calibration, and data collection procedures that are normally used at the Pawnee Doppler radar. Most of the REU students' efforts were directed towards various radar engineering projects (Fig. 1).

Figure 1. Dave Brunkow, Senior Radar Engineer (on left), helps REU students prepare a calibration sphere launch.

Dr. Hyun-Suk Shin led a group of Korean government officials who visited CSU and the CHILL facility during July and August 2001. Dr. Shin was investigating radar-based techniques to improve flood forecasting in South Korea. In the course of his visit, Dr. Shin became familiar with both theoretical and practical aspects of polarimetric radar observations of precipitation. A crucial product of these observations is the generation of radar-derived rainfall maps to diagnose the spatial distribution of rainfall. Under the direction of Dr. Walt Petersen of the CSU Atmospheric Science Department, Dr. Shin was able to generate a rainfall map using the CSU-CHILL polarimetric data collected on July 8, 2001 during a storm that caused flash flooding in the metropolitan Denver area.

CSU-CHILL operations were also conducted for two 20 hour projects. One of these projects was requested by Mr. John Moody of the US Geological Survey (USGS) office in Denver. John's group is studying rainfall runoff and sediment transport in complex terrain where wild fires have recently occurred. Such a wild fire occurred in the Bobcat Gulch area of the Front Range foothills in the summer of 2000. This burned area is located approximately 60 km west of the CHILL site at Greeley, making it feasible for the radar to observe convective echoes as they pass over the Bobcat Gulch region. Approximately 5 rainfall events were sampled by CHILL during the months of July and August, 2001 over this area. The radar data collected during these events will be used to generate high time resolution rainfall maps over the study area.

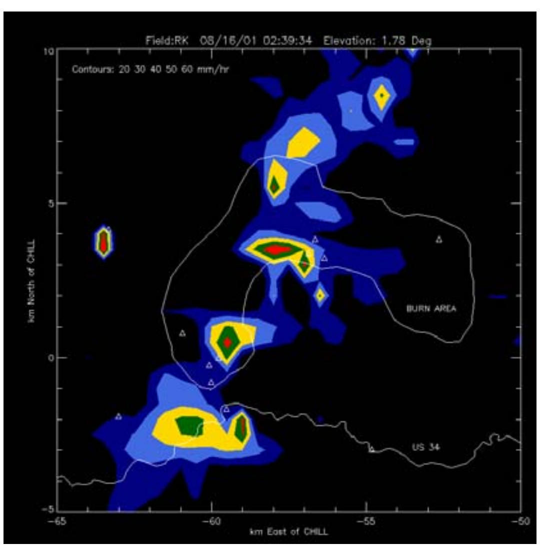


Figure 2. Rainfall rate map from the Bobcat 20-hour project.

(See Fig. 2). The resultant rainfall fields will be used to initialize hydrological runoff models. Analysis of the data collected in this project involves collaborative efforts between the USGS, the CSU Radar Meteorology Group (Prof. Steve Rutledge, Dr. Walt Petersen and Dr. Rob Cifelli), the CSU College of Natural Resources (Profs. Lee Mac Donald and John Stednick) and the Department of Civil Engineering (Profs. Jorge Ramirez and Pierre Julien).

The second 20 hour project was devised by Profs. Bruce Lee and Cathy Finley of the University of Northern Colorado's Earth Sciences Department. They sought high spatial resolution radar data on convergence lines in the boundary layer. Of particular interest were radar observations of the Denver Convergence/Vorticity Zone (DCVZ) and of energetic thunderstorm gust fronts. The DCVZ was unusually inactive during the project, but a severe thunderstorm outflow event that struck the city of Greeley was observed on the evening of July 10, 2001 (See Fig. 3).

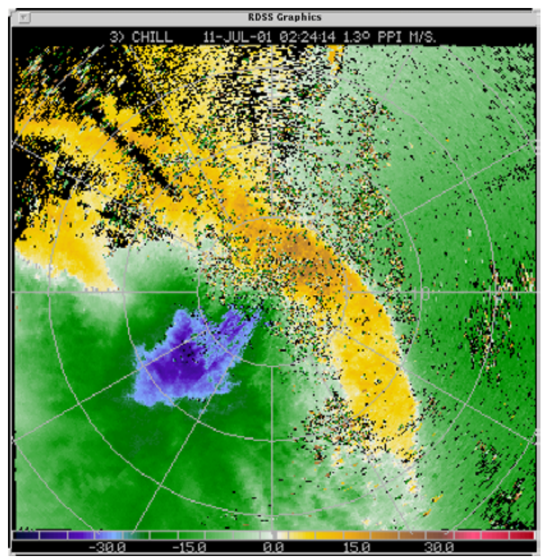


Figure 3. Radar image from UNC's 20-hour project.

Wind speeds in excess of 30 ms^{-1} (65 $mihr^{-1}$) caused extensive tree damage and power outages in Greeley. The UNC investigators plan a detailed analysis of this case.

Finally, some unscheduled CSU-CHILL operations were conducted when potentially interesting echo developments were anticipated. One such operation took place in the early evening hours of 20 June 2001. An intensifying severe thunderstorm was observed to be approaching the Denver International Airport from the north. Data collection was continued as the storm crossed over the airport. The polarimetric radar data contained definite hail indications (reflectivity levels > 65 dBZ; slightly negative Zdr's, and remarkably high (> -15 dB) LDR values (see Fig. 4 below). Large hail caused extensive damage at the airport as well as at many other locations along the storm's path. The CSU-CHILL data from this "target of opportunity" operation will see future use for both research and educational purposes.

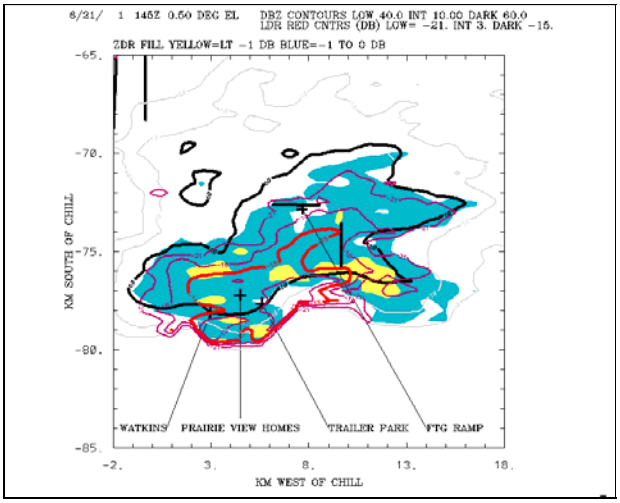


Figure 4. Overlaid CSU-CHILL radar data fields from DIA hailstorm on 20 June 2001.

Additional unscheduled radar operations were also carried out when reasonably intense convective echoes were threatening areas containing volunteer precipitation observers in the Community Collaborative Rain and Hail Study (CoCoRaHS). The general goal of these operations was to collect polarimetric radar data sets that could be compared with direct observations of rainfall amounts, hail characteristics, etc. made by the volunteer observers. This season's CoCoRaHS activities saw the first participation of a mobile observer.

On a large number of days when storm formation prospects looked promising, Mr. Richard Conn patrolled the greater CSU-CHILL radar coverage area and attempted to deploy hailpads in the path of intense thunderstorms (see Fig. 5). Mr. Conn successfully collected hailstone impact data on several occasions. For additional information on the CoCoRaHS project, see the following website:

http://ccc.atmos.colostate.edu/~hail/

Figure 5. Mr. Richard Conn served as the first CoCoRaHS mobile observer during severe storm season.

Electrical Engineering

V. N. Bringi, Professor:

In collaboration with Dr. E. Gorgucci of CNR/Italy, Drs. Bringi and Chandrasekar have developed alogrithms for retrieving the parameters of a gamma raindrop size distribution model using radar measurements of Z_h, Z_{dr} and K_{dp}. The breakthrough has been in accounting for changes in the slope of a linear axis ratio versus diameter relation that can change due to drop oscillations or canting induced by turbulence and/or multimode oscillations. The slope is estimated from the radar measurements themselves, and leads to nearly unbiased retrievals of the gamma parameters, especially the “normalized” intercept (N_w) and the mass-weighted mean diameter (D_m). The radar-based retrievals using CSU-CHILL, SPOL and NASA/Kwajalein radars have been compared with disdrometer data from different climatic regimes in a statistical manner, i.e., by comparing log N_w versus D_m in stratiform and convective rain. Note that N_w is similar to N_o of the exponential Marshall-Palmer distribution.

Fig. 6 for stratiform rain shows that there is an inverse relationship between log N_w and D_m; in fact, it is quite remarkable that a straight-line fit (shown as a dashed line) results from the composite disdrometer/radar retrievals that encompass a number of climatic regimes from near equatorial (Papua New Guinea) to the High Plains (Colorado). From a microphysical perspective, stratiform rain results via the melting of snowflakes and/or tiny graupel or rimed particles. If the bright-band is "strong", then it likely reflects melting of larger, low density and dry snowflakes into rain, whereas if the bright-band is "weak" then it may reflect the melting of tiny, compact graupel or rimed snow particles. In fact, the transition from large, dry snowflakes to tiny, compact graupel or rimed particles during a stratiform rain event leads to the so-called "N_o-jump" effect. In essence, the large, low-density snowflakes lead to *dsd*s that have smaller N_w and larger D_m relative to the tiny, compact graupel or rimed snow particles. The straight-line in Fig. 6 may reflect such microphysical differences in stratiform rain *dsd*s from different climatic regimes.

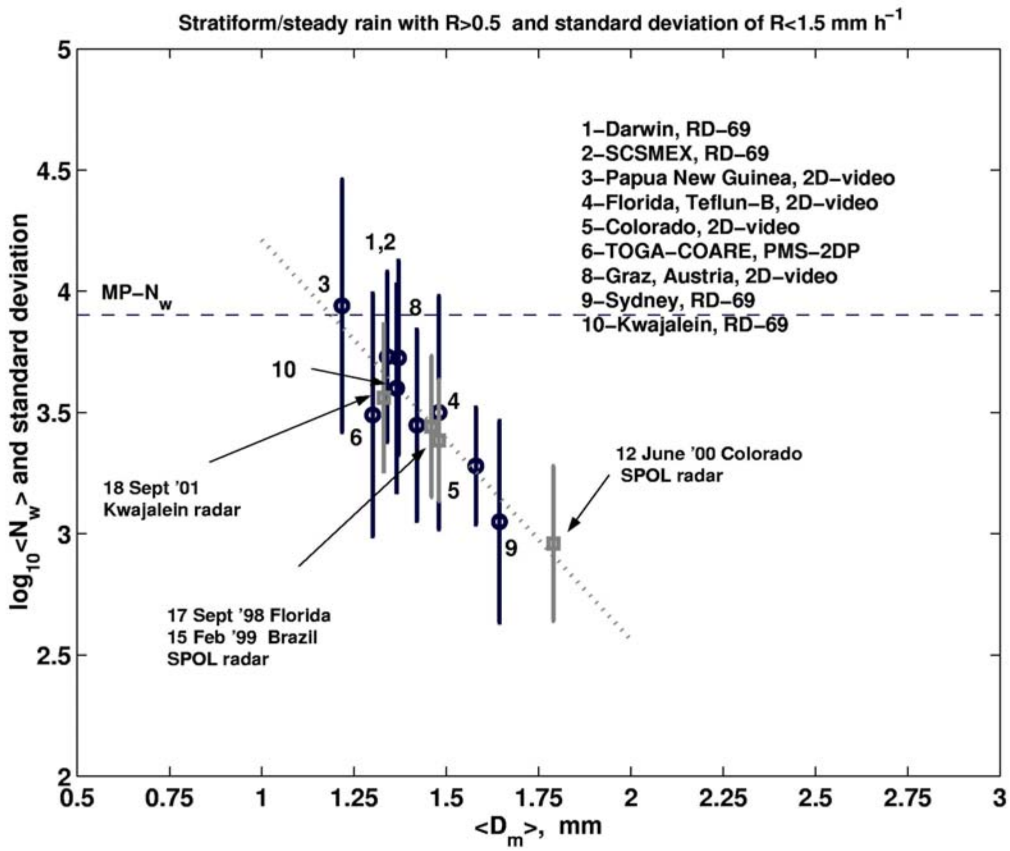


Figure 6. The average value of $\log_{10} N_w$ (with $\pm\sigma$ standard deviation bars) versus average Dm from disdrometer data and radar retrievals as indicated for stratiform rain. Dotted straight line is the least squares fit.

Fig. 7 shows similar results for convective rain with R> 5 mm/h. There appears to be a cluster of data points with $\langle D_m \rangle$= 1.5-1.75 mm and $\log_{10}\langle N_w \rangle$= 4-4.5, the regime varying from near equatorial (Papua New Guinea) to sub-tropics (Florida, Brazil) to oceanic (TOGA-COARE, Kwajalein, SCSMEX). This cluster may be referred to as a "maritime"-like cluster where rain *dsd*s are characterized by a higher concentration of smaller–sized drops. The Fort Collins flash-flood event is unusual for Colorado as the data fall in the "maritime"-like cluster. The second "continental"-like cluster is characterized by $<D_m>$= 2-2.75 mm and $\log_{10}<N_w>$= 3-3.5, the regime varying from the U.S. High Plains (Colorado) to continental (Graz, Austria) to sub-tropics (Sydney, Australia) to tropics (Arecibo, Puerto Rico). The "continental"-like cluster reflects rain *dsd*s characterized by a lower concentration of larger-sized drops as compared with the previously-defined "maritime"-like cluster.

The origin of various Z-R relations can easily be traced to differences in the parameter <Nw> in different regimes. For a gamma dsd model, the multiplicative coefficent in the Z-R relation is proportional to the inverse of (Nw)^0.5 while the exponent is fixed at 1.5. This implies that the coefficient for the maritime regime will be lower than for the continental regime. In other words, the multiplicative coefficient in the $Z = aR^{1.5}$ power law relation will be a factor 2.5 higher in Colorado as compared to Florida, in general agreement with numerous disdrometer-based studies comparing Z-R relations from the tropics to the High Plains. Since now the coefficient "a" can be determined from polarimetric radar measurements, it is possible to derive "polarimetrically"-tuned Z-R relations that can "track" the dsd within a storm event as well as from event to event. It will not be necessary to classify rain types (e.g. stratiform versus convective). We believe that this development will be very important for the anticipated polarimetric upgrades to the WSR-88D system.

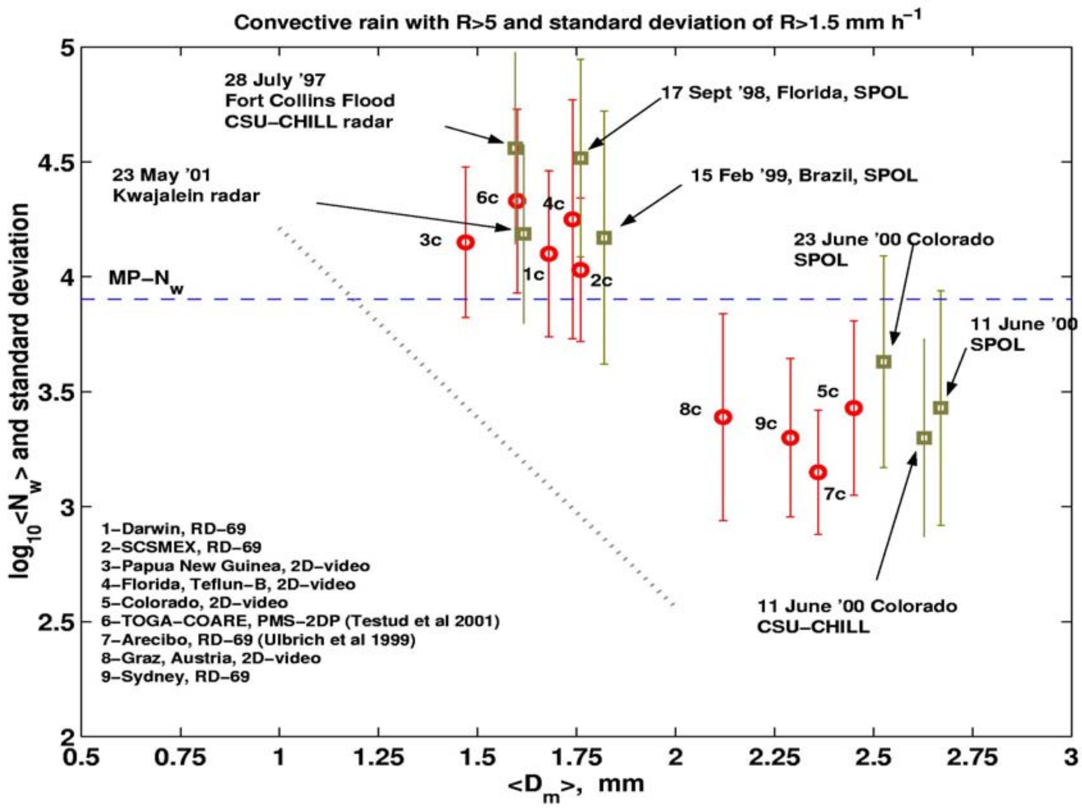


Figure 7. As in Fig. 6 except for convective rain with R>5 mm/h. Dashed red line is for stratiform rain from Fig. 6 reference.

V. Chandrasekar, Professor:

VCHILL Initiative

CSU has embarked on a major initiative entitled VCHILL, with the objective of bringing the research and educational mission of CSU-CHILL closer to the research and educational institutions in the U.S, in a virtual sense. The VCHILL initiative will enable real-time operation of the radar to be distributed over the Internet. This method of access to a research radar represents a paradigm shift from the conventional mode of operation in which radar users assemble at the radar facility. Fig 8 depicts the VCHILL concept, where students from distant universities will participate in conducting radar experiments as part of their educational experience. Full control of the radar (i.e., adjustment of antenna scanning parameters) is possible from these remote classrooms.

The access that is being developed is far beyond what is presently available. Remote users are provided with a real time, ray-by-ray data display. Also, high bandwidth communication techniques are under development that will permit the transmission of the digitized complex radar signal samples (i.e., the time series data stream) to a remote site. Fig. 9 shows the overall client – server based system architecture. The VCHILL system is also being adapted to various network protocols as part of our research.

Figure 8. VCHILL Concept.

A two-way video conferencing capability is also being developed to augment distance-learning activities. The video conferencing system permits remote demonstrations of various aspects of radar hardware and operational procedures (solar calibrations, etc.). Fig. 10 shows the model of CHILL being used through the video conferencing system for use in classrooms.

Figure 9. Architecture of VCHILL.

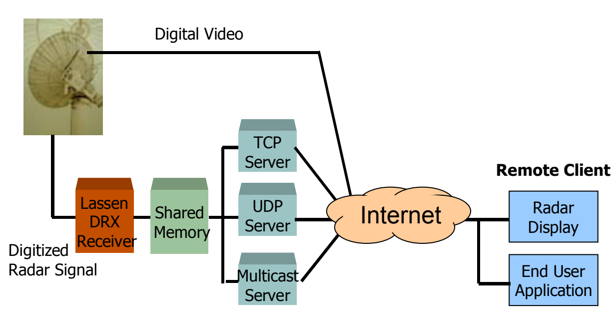
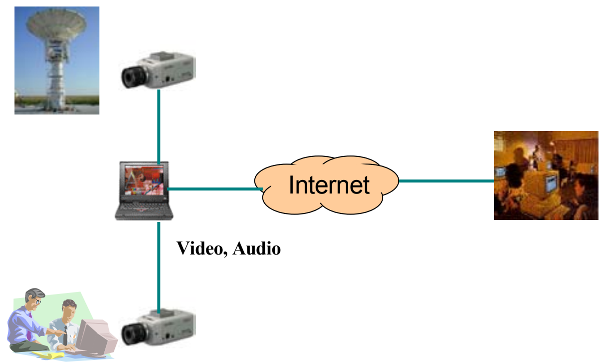


Figure 10. Video Conferencing for classroom demonstration.



We have developed a complete set of Internet tools to facilitate the analysis of archived radar data, such as radar data browsers, hydrometeor classification systems and detailed analyzing systems on the Internet. We are also implementing a Virtual Private Network (VPN), such that students from multiple institutions can participate in a field experiment, without physically having to leave their home institution. More details will shortly be announced as to how universities and laboratories can access the V-CHILL.

John L. Hubbert, Research Associate:

Mean Hydrometeor Canting Angle and Antenna Polarization Errors

The mean canting angle of raindrops is typically assumed to be zero. Techniques to investigate this hypothesis have thus far involved mathematical approximation and have only been able to measure the magnitude of the angle, not the sign. Eigenpolarization analysis of the 3X3 radar covariance matrix gives the sign and magnitude without approximations. First well-calibrated covariance matrices need to be constructed as outlined in Hubbert and Bringi, 2001 and Hubbert al., 2001. To estimate polarization errors it is assumed the mean canting angle of the propagation medium will be zero on average. The individual backscatter resolution volumes may, however, have non-zero mean canting angles. It is known that if precipitation particles have a mean canting angle of zero and if they are symmetrically distributed around zero degrees, then theoretically $R_x^A = R_x^B = 0$ (the two co-to-cross channel covariances) when operating in the H/V polarization basis. In practice these numbers are relatively small so that $\rho_{hh,vh}$ (co-to-cross correlation coefficient) and $\rho_{vv,hv}$ (the other co-to-cross correlation coefficient) are typically on the order of 0.1 to 0.2 for a rain medium. Since the polarization errors can be non-orthogonal, finding the tilt angle in the eigenpolarization basis will not reveal the true error terms. Thus, the errors are determined by finding values of the error terms, τ_h, ε_h, τ_v, ε_v,, that minimize $\rho_{hh,vh}$ and this is done via a simple search method. The errors are defined as: τ_h, ε_h, the horizontal polarization tilt and ellipticity angle errors and τ_v, and ε_v, the vertical polarization tilt and ellipticity angle errors.

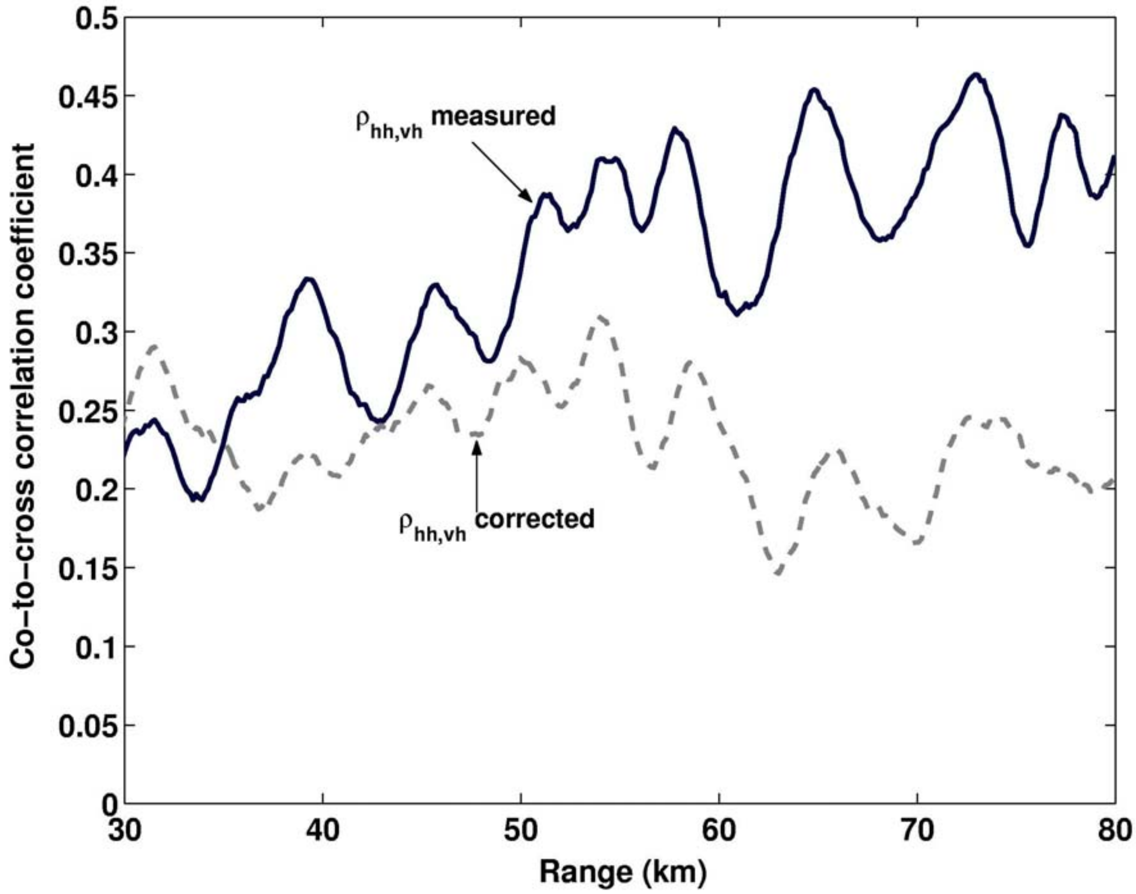


Figure 11. Range profile of filtered $\rho_{hh,vh}$ and polarization error corrected $\rho_{hh,vh}$.

The polarization error estimation method is as follows. A range profile(s) of data is selected where there is significant increase in ψ_{dp} (copular differential phase) which will accentuate the errors. For example, if significant tilt error is present (a few tenths of a degree is sufficient) then in general $\rho_{hh,vh}$ will increase significantly with increasing ψ_{dp}. Calibrated covariance matrices are constructed at each sample point (0.15 km in the following case). For all the covariance matrices, error terms τ_h, ε_h, τ_v, ε_v, are varied and the minimum of the sum

$$\Omega = \sum_{i=1}^{n} \rho_{hh,vh}(\tau_h, \tau_v, \varepsilon_h, \varepsilon_v) \qquad (1)$$

is found where n is the number of covariance matrices. The resulting tilt and ellipticity angles are considered polarization errors.

The following data was collected during STEPS (Severe Thunderstorm Electrification and Precipitation Study) on 21 July 2000 through a heavy rain cell with reflectivities of 40 dBZ to 60 dBZ. 333 covariance matrices are used in the minimization procedure. The resulting polarization errors are τ_h=0.5°, ε_h= 0.1°, τ_v=90.5°, ε_v=-0.4°. Using these error terms a 3X3 transformation matrix can be constructed and the polarization errors can be removed from the data by pre and post multiplying the measured covariance matrices by this matrix (Huang et al., 2001). Range profiles of the corrected data can then be made. Fig. 11 shows filtered $\rho_{hh,vh}$ and corrected $\rho_{hh,vh}$ and as expected, corrected $\rho_{hh,vh}$ is significantly reduced to an average level that is consistent with rain.

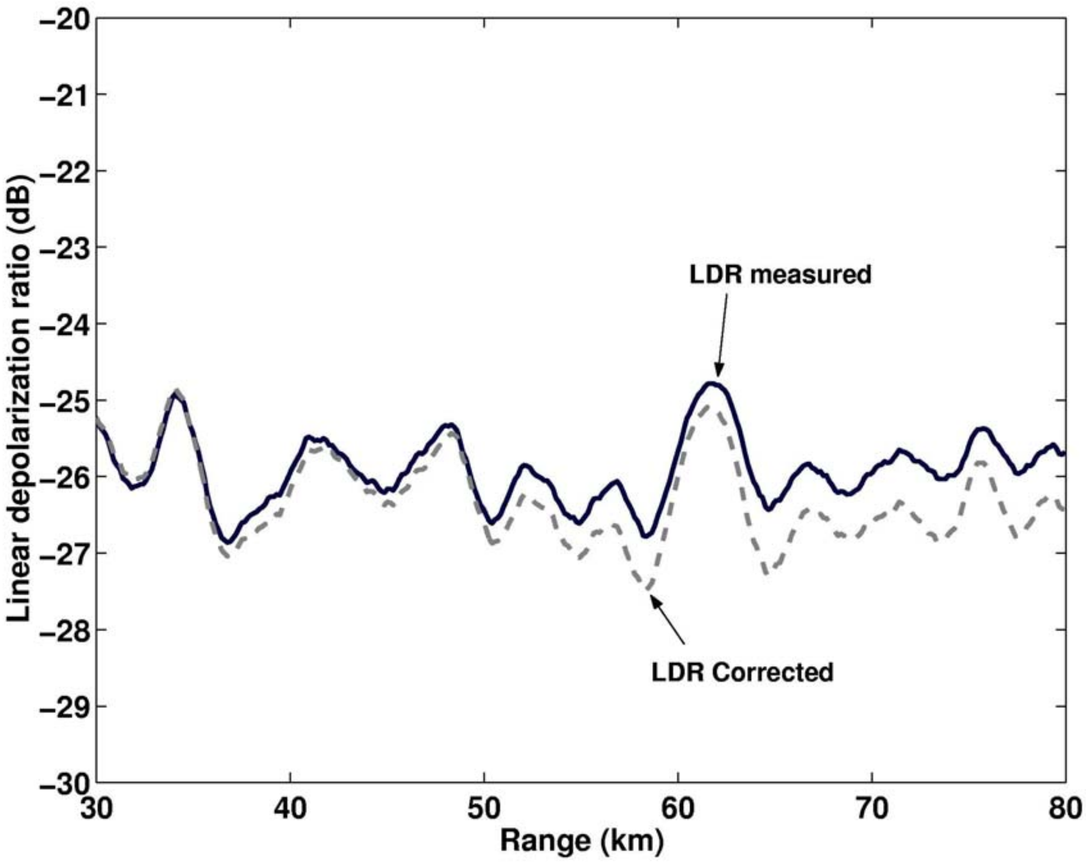


Figure 12. Range profile of filtered LDR and polarization error corrected LDR.

Similarly, Fig. 12 shows filtered LDR and corrected LDR. Again the corrected LDR is reduced, as it should be with the polarization errors removed. The eigenvalue problem can also be solved for each covariance matrix and this will yield a mean canting angle ($\bar{\beta}$) of the "optimal" polarization basis. Once $\bar{\beta}$ is known, the covariance matrix can be transformed to a linear polarization-basis whose tilt angle is 45° away from $\bar{\beta}$. The difference in LDRs in these two bases (i.e., the optimal basis and the one 45° away) is known to be a function of the variance in canting angle only, independent of any "shape" effects and thus, this difference in LDRs is a good estimator of the standard deviation of canting angles σ_β. This is now illustrated with data gathered during STEPS on 11 June. Fig. 13 shows a histogram of $\bar{\beta}$ from PPI scans through the core of the storm cell at low elevation angles (well below the melting level and in the rain layer). The mode is close to 0.5° with extremes of the histogram less than 8° in magnitude. We believe that the mode of $\bar{\beta}$ at 0.5° is most probably related to a system offset, i.e., the transmitted H/V basis is rotated by 0.5°.

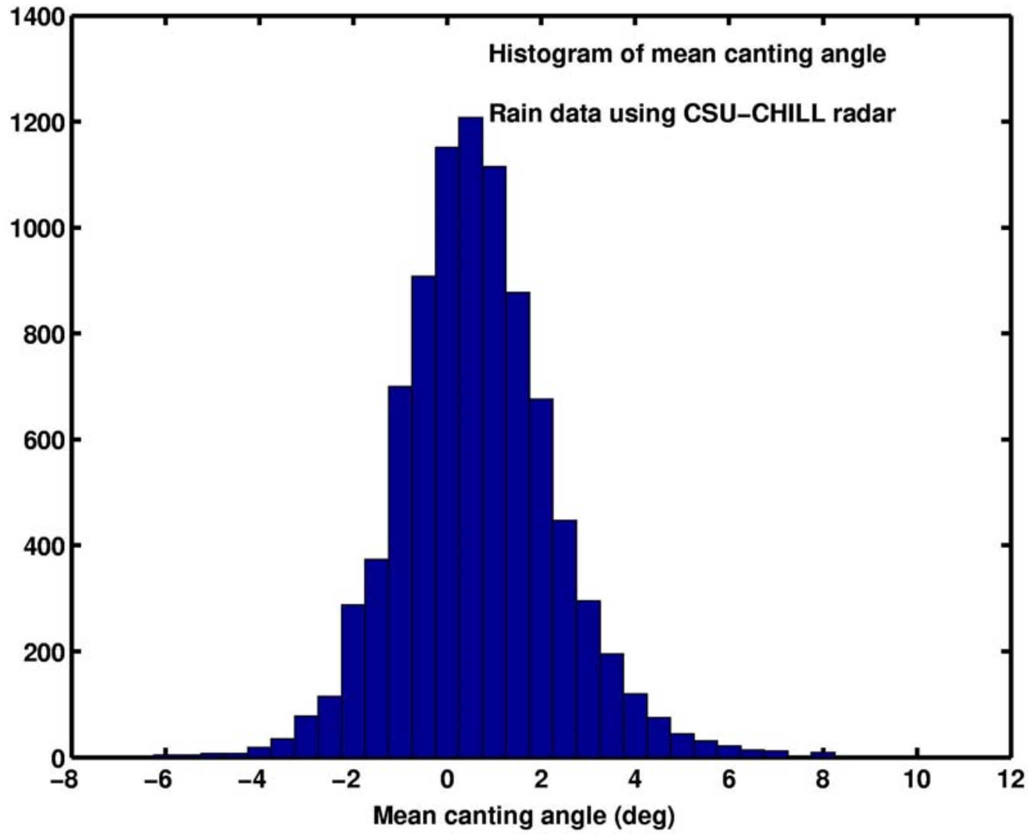


Figure 13. Histogram of $\overline{\beta}$.

This agrees very well with the polarization error estimates given above. The histogram of σ_β is shown in Fig. 14 with mode near 10°, generally validating the assumption used in several rain models for deriving polarimetric rain rate algorithms. Finally, Fig. 15 shows σ_β versus Z_{dr} as a scatterplot (each data point is from one range resolution volume). The decrease of σ_β with Z_{dr} can be related to the increased stability of large raindrops versus small ones; large raindrops are formed by the melting of large ice particles and the presence of a melting ice core tends to stabilize the orientation of the particle. We believe these are the first data to show the decrease of σ_β with increasing Z_{dr} in convective rain, and such a behavior may need to be included in rain models used for deriving polarimetric-based rain rate algorithms.

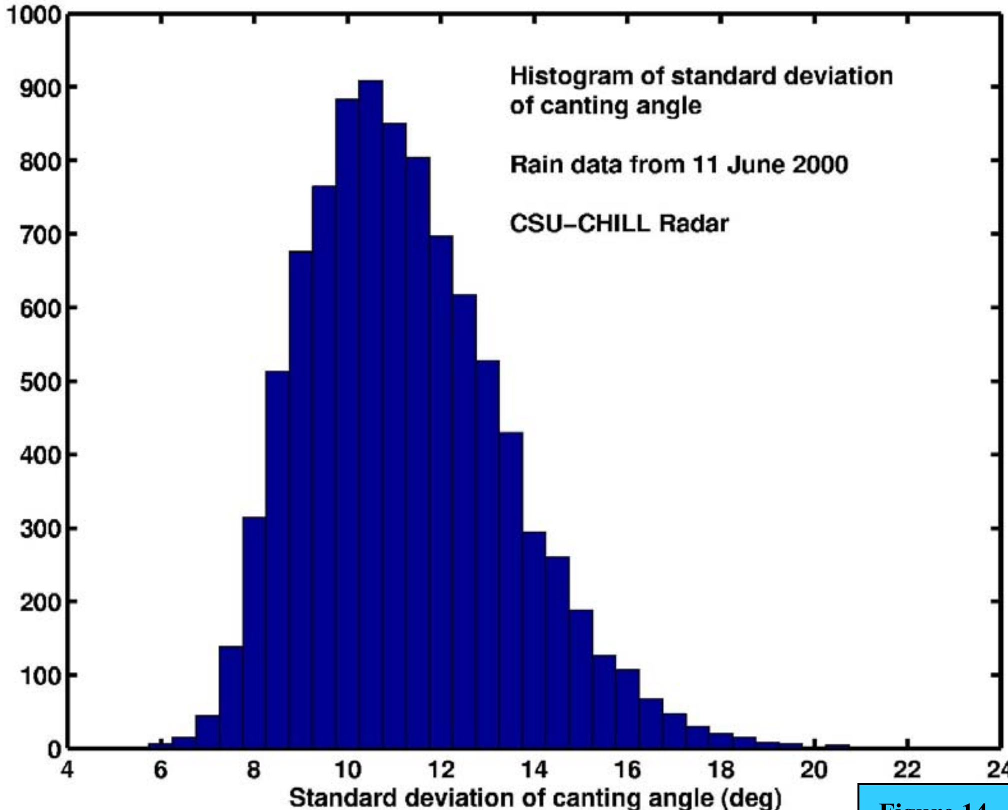


Figure 14. Histogram of σ_β.

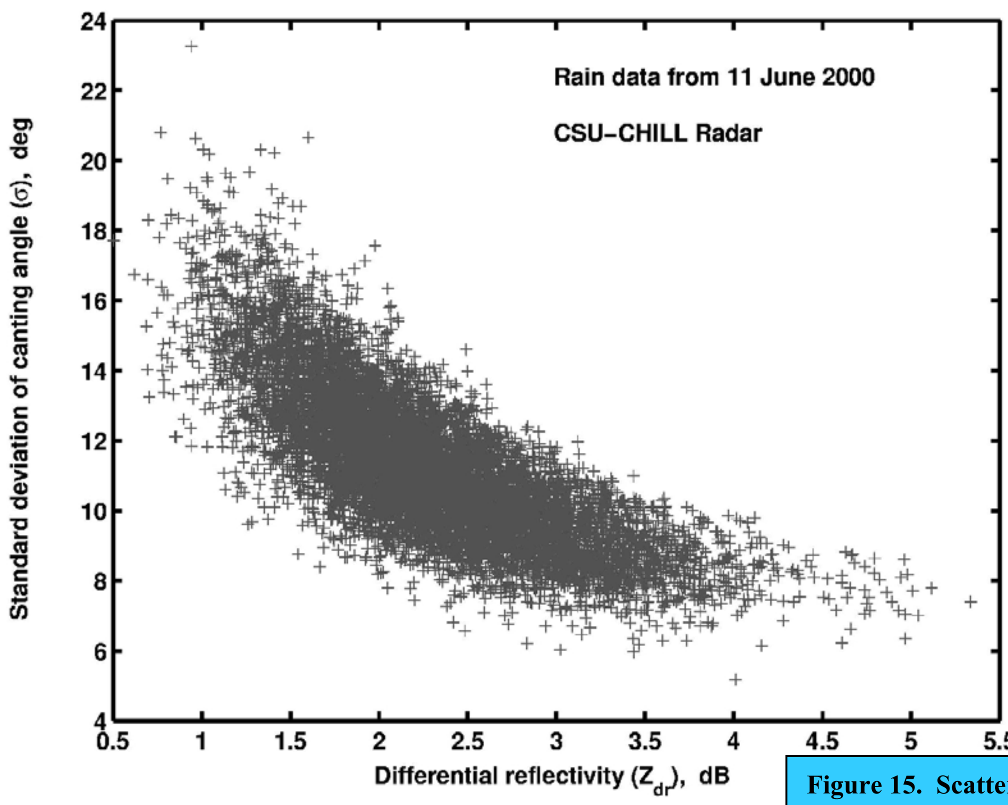


Figure 15. Scatterplot of σ_β vs. Z_{dr}.

Radar Engineering

(Dave Brunkow, Senior Engineer)

Technical Improvements

After the completion of the STEPS project, the radar was disassembled and returned to the Greeley field site. We took this opportunity to rebuild all eight gearboxes in the pedestal. The large low-speed gearboxes were sent to the NCAR machine shop for refurbishing. One of these had some internal damage caused by a snap ring falling through the gears. Both azimuth low-speed boxes showed some wear on the final drive gear which engages the pedestal bull-gear. In response to these two issues, two azimuth low-speed gearboxes were borrowed from the currently retired CP2 pedestal at NCAR. These were refurbished and installed on the CHILL pedestal.

The antenna drive motors and control system have been an area of concern for several years. The velocity feedback loop was originally implemented on the analog motor control boards residing on the antenna pedestal. There was one amplifier/drive board for each motor, and two motors for each axis. The amplifier boards were configured in a master/slave arrangement where the current drive from the master board was fed into the input of the slave board. There were two issues with this arrangement. The velocity loop was not optimally tuned to the load resulting in poor dynamics when seek a desired azimuth position. There was also a problem with 60 Hz interference in the input signal to the slave board. Both of these problems lead to poor antenna motion dynamics and premature failures of the azimuth slave motors. We have considered replacing the motor and amplifier systems, but during the summer of 2001 we tried another option. It was found that by disabling the velocity loop on the amplifier cards and running them as torque amplifiers, the master/slave configuration was much smoother. The antenna control program, currently running on a Micro-VAX computer, was modified to implement the velocity loop. It was then possible to improve the antenna dynamics while reducing the wear and tear on the motors. At the same time, other improvements were added to assure that the antenna is in the proper starting position before commencing the scan.

Traditionally, we have distributed the archived data via 8mm tape. This has occasionally led to problems where a user's tape drive would have difficulty recovering the files. For the STEPS data, we prepared UF files for about 15 of the most interesting operational periods. We also created web pages for each operation which presented scan file information about each volume scan as well as a link which would allow the user to immediately download the UF file for that volume scan. Other links were provided to find archived images from the scan and to present time-lapse loops for the day in question. As of October 2001, about 900 UF files have been downloaded to users via this web interface.

A new program was developed to facilitate the playback and review of archived CSU-CHILL data. This consists of a graphical user interface client program called "replay" which runs on the user's machine, and a server program that resides with the archived data. The replay program can run anywhere on the internet as long as sockets are not blocked by firewalls. The replay displays a list of all the data available on the server. After the user chooses an operational day to look at, a list of all volume scans available is presented. The user can then just click on the volume scan and the desired sweep to select it for viewing. The replay program launches the PPI manager program, which is the same software used for viewing data during real-time operations. Currently the display software require a Sun Solaris workstation, although we are currently porting the display to LINUX. In Fall 2001 we successfully demonstrated the use of this same display system in a real-time mode with Professor Roger Wakimoto, from the Department of Atmospheric Sciences at UCLA.

Acknowledgements:
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Publications

(October 1999 to January 2002)

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