CHILL RADAR NEWS

from

Colorado State University

Seventh Edition
October 1997

Overview

(Steven Rutledge, Scientific Director)

This is the seventh 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 research, education, and refurbishment activities of the CSU-CHILL facility. In April 1995 Colorado State University was awarded a second 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.

The use of the CSU-CHILL radar is granted by the National Science Foundation after review by the NSF Facilities Advisory Council and Observing Facilities Advisory Panel. We supported two NSF-reviewed projects during 1997, a Research Experience for Undergraduates project directed by Prof. Chandrasekar in the Department of Electrical Engineering, and PROWS, Polarimetric Radar Observations of Winter Storms, directed by a number of PI's from CSU and NCAR. In the REU project, eleven undergraduate engineering students from a variety of universities participated in a two month long storm chase program, operating instrumented vans to collect hail and rain data to verify polarimetric radar signatures. PROWS consisted of multiparameter observations of winter storms with both the CSU-CHILL and NCAR S-pol radars, along with a variety of ground-based observations, including a 2-D video disdrometer providing hydrometeor images. PROWS addresses the need to improve radar remote sensing of winter precipitation by NEXRAD radars, a research goal of the U.S. Weather Research Program.

For projects requiring less than about 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. These projects encourage use of the radar for highly focused experiments. These projects continue to be very productive. We supported three 20 hour projects in the past year, as detailed in the following sections. The radar also continues to be an integral component of several courses in the Departments of Atmospheric Science and Electrical Engineering.

During the last two to three years, numerous improvements have been carried out at the Facility, including the acquisition of a new high performance antenna, installation of a second FPS-18 transmitter and a second receiver (thus eliminating the need for a polarization switch), temperature stabilization of the front end's of both receivers (to improve estimates of differential reflectivity), and development of automated calibration procedures. These improvements and advances, coupled with regularly scheduled maintenance, have brought the facility to a high level of readiness and reliability.

Another highlight of this past year's activities has been the acquisition of the HOT radar from the Illinois State Water Survey. HOT is a 10 cm, Doppler system. HOT is now being readied for permanent dual-Doppler operations with the CSU-CHILL system. This dual-Doppler system will be available as a community resource. HOT will be located near Nunn, CO, which will provide a 48 km baseline with CHILL. We expect HOT to be operational by the end of summer 98.

The CSU-CHILL facility has been requested to support RACES in the summer of 98, a large experiment that will focus on lightning and severe storms here in Colorado. We also anticipate supporting another REU project during that same summer.

CSU-CHILL was also scheduled to support the WISP 98 project this coming winter in Wisconsin. However, funding for this project was recently declined by the NSF. CHILL staff spent the last two months readying the system for deployment, including identifying an excellent radar site near Green Bay, WI.

Radar Operations Summary

(Pat Kennedy, Facility Manager)

The CSU-CHILL facility supported two NSF-sponsored research programs and three 20 hour projects during the year ending in October 1997. Data were also collected during the historic flash flood event that took place on evening of 28 July 1997 in Ft. Collins.

The first NSF funded project was PROWS97 (Polarimetric Radar Observations of Winter Storms 1997). Both the CSU-CHILL and the NCAR S-POL dual polarization S-band research radar systems participated in the project. The NCAR / S-POL component of the project was directed by NCAR scientist Roy Rassmussen and Jim Wilson. CSU-CHILL operations were supervised by CSU Profs. Steven Rutledge and V. Chandrasekar. The experiment was designed to collect polarimetric radar data sets that could be compared with ground based precipitation observations (i.e., hydrometeor types, sizes, accumulation rates, etc.). These surface observations offered a verification standard against which various radar-derived characterizations of winter precipitation could be tested. Dedicated surface weather observations were made at the state climate network station on the CSU campus, and at NCAR's Marshall field installation near Boulder. The S-POL radar was operated from the Eastlake site (approximately 55 km southwest of CSU-CHILL). Coordinated dual Doppler scans were conducted by the two radars at 30 minute intervals. The overall data set collected in PROWS97 should usefully expand techniques for remotely sensing winter season precipitation with dual polarization radars.

Prof. V. Chandrasekar also was the Principal Investigator on the second NSF project of the year, REU97, which was conducted during the summer semester. This project involved a group of 11 undergraduate engineering students who came to CSU from universities located in four different states. Overview lectures and demonstrations were presented by Gene Mueller (engineering principles of weather radars), and Pat Kennedy (introduction to radar meteorology). Several of the students then participated in convective storm intercept operations that were directed in real time from the user van at the CSU-CHILL radar. The intercept van was equipped to capture falling hailstones as well as to record basic surface weather data (rainfall, wind speed and direction, etc.) The most successful storm intercept took place on the afternoon of 24 June, when hail data were collected at two different locations. The REU students each presented final reports summarizing the results of their summer's research activities.

A smaller scale (20 hour) research project was conducted by Harold Duke, an agricultural engineer in the USDA Agricultural Research Service (ARS). During the 1997 growing season, an ARS project was planned in which crop growth in two irrigated fields near Wiggins, Colorado was to be closely monitored. Dr. Duke desired to use CSU-CHILL data to augment the ARS project by generating radar-based rainfall maps for the region encompassing the test crop fields. These rainfall maps will be used to characterize the spatial variability of the naturally occurring convective season rainfall during selected storm events. Notable storm passages over the test crop sites were monitored by CSU-CHILL on several occasions.

The two final 20 hour radar projects were directed by CSU Atmospheric Science Department personnel. Larry Carey, a Ph. D. candidate, was interested in multiparameter data collected in volume scans of severe thunderstorms. His goal was the continued exploration of correlations between positive polarity cloud to ground (+CG) lightning discharges and thunderstorm severity. Carey collected a useful data set on 2 June 1997, when volume scans were recorded during most of the lifetime of a +CG producing severe storm. The second CSU-based 20 hour project was under the direction of Dr. Walt Petersen, a Research Associate in ATS. Dr. Petersen desired to collect high temporal resolution (under 2 minute cycle time) RHI volume scans of developing convective clouds. These data would be used to characterize the microphysical evolution of convective echoes as they initially become electrified. Preliminary analyses indicate that useful data sets were collected on the 8th and the 24th of July.

Atmospheric Science: The Ft. Collins Flood of 28 July 1997: Polarimetric Radar Observations

(Walter Petersen, Lawrence Carey, and Steven Rutledge, Atmospheric Science)

On the night of 28 July 1997, the city of Fort Collins, Colorado experienced a devastating flash flood that caused five fatalities and extensive property damage across the western side of the city. The CSU-CHILL radar was operating on that particular evening, providing an unprecedented documentation of the convection and rainfall associated with a flash flood from the view of an S-band dual-polarized radar.

Hydrologically, saturation of the soil in the surrounding area occurred in association with heavy rain showers that developed on July 27 and lasted through the morning of July 28. These rains were later followed by a series of training convective systems that propagated through the region during the afternoon and evening of July 28. Between 1700 and 2000 MDT on the 28th, two convective systems moved over the city from the south producing brief heavy rain, moving rapidly toward the north. However, between 2000 and 2300 MDT, a third group of convective cells moved over the headwaters of Spring Creek, situated in southwestern Fort Collins, and remained nearly stationary from 2045 MDT to 2215 MDT. Though stationary, the convection pulsed several times during this hour, sending embedded cores of very heavy rain eastward along the creek drainage and over the western portions of the city. This resulted in total rainfall amounts (gauge measured) over a five hour period that exceeded 10 inches on the southwestern side of Fort Collins (Fig. 1).

In some respects, the convection associated with this event seemed to be tropical "monsoon-like," exhibiting heavy convective rainfall with relatively little lightning. Indeed, when reflectivity-based estimates of rainfall (Z-R) were compared to amounts estimated using polarimetric variables (e.g., Kdp, Zdr), some interesting differences were observed, and it seems likely that some of the contrast is due to cloud microphysical characteristics associated with the "atypical" convective rainfall regime.

During the flood, the CSU-CHILL radar, located about 42 km to the east-southeast of Fort Collins, obtained low-level surveillance scans every 6-15 minutes. We utilized three observed polarimetric variables to estimate rain rates: the horizontal reflectivity, Zh; the differential reflectivity, Zdr; and the differential phase. The data were carefully edited to remove ground clutter contamination and other spurious data. The specific differential phase, Kdp, which is nearly linearly proportional to the rain rate, was estimated using a finite impulse response (FIR) filtering technique on the differential phase data. The following equations were utilized to create grids of instantaneous rain rate:

$$Zh = 300\ R^{1.4} \qquad (1)$$

(WSR-88D algorithm with standard 53 dBZ truncation)

$$R(Kdp) = 39.72\ Kdp^{0.866} \qquad (2)$$

(Doviak and Zrnic, 1993)

$$R(Kdp, Zdr) = 52\ Kdp^{0.96}\ Zdr^{-0.447} \qquad (3)$$

(Ryzhkov and Zrnic, 1995)

The grids of instantaneous rain rate from 1700 to 2215 MDT were converted to cumulative rainfall maps by assuming a 1-minute, step-wise linear interpolation between radar scan times.

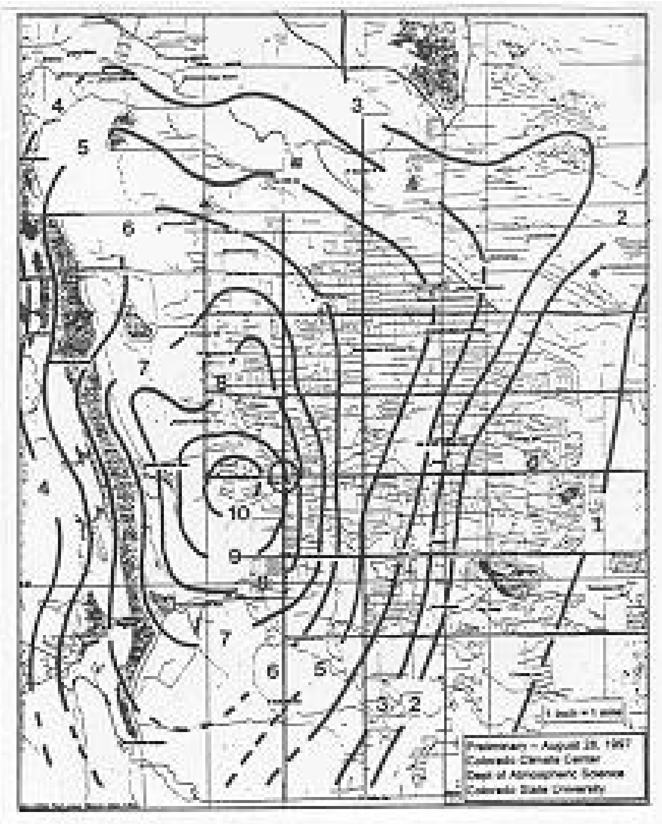

Figure 1. A cumulative rainfall map contoured in inches for the time period 17:30 to 2300 MDT on 28 July 1997. The "O" marks the origin of accompanying radar rainfall estimates shown in Figs. 2-3. East-west and north-south lines in figure denote major roads in the city. This road grid is identical to that shown in Figs. 2-3. Figure provided by Dr. Thomas McKee of the Colorado Climate Center and Department of Atmospheric Science.

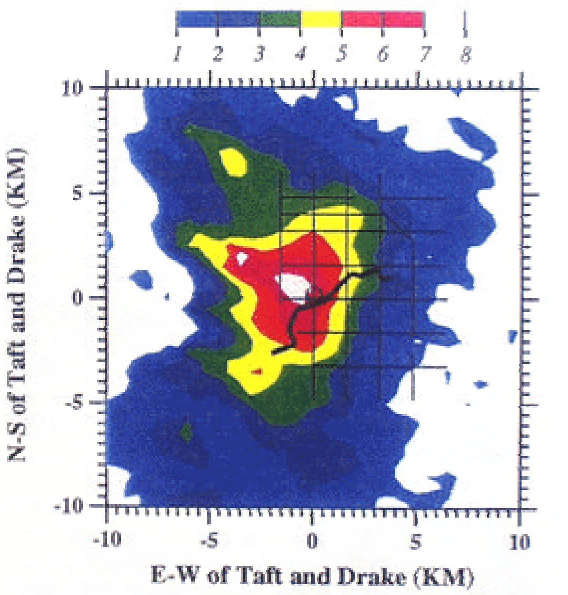

Figure 2. Cumulative rainfall totals (inches) computed from the R(Kdp,Zdr) technique, 28 July 1997, 1800-2215 MDT. An approximate city street map is overlayed with the origin at the intersection of Taft Hill and Drake streets in Fort Collins. A portion of Spring Creek is indicated by the bold, curved line.

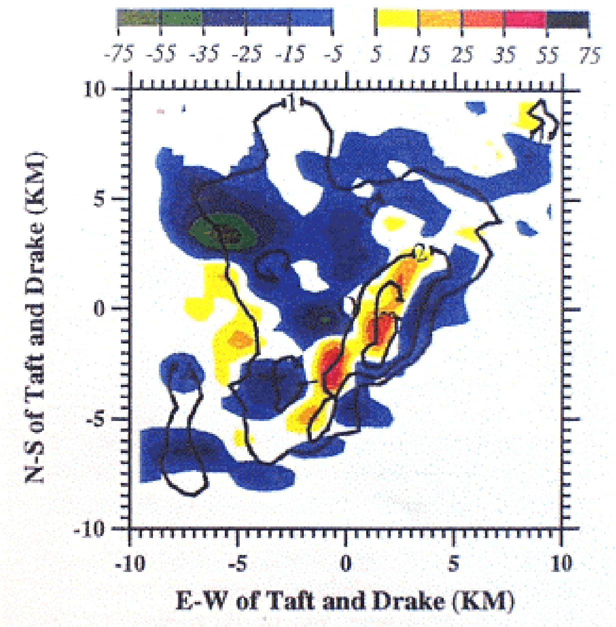

Figure 3. Instantaneous difference (mm/hour) in rainfall rate between the R(Kdp,Zdr) and Z-R methods [R(Zh) - R(Kdp,Zdr)] at 2145 MDT. Overlayed are contours of Zdr at 1dB intervals beginning with a value of 1dB. Origin at the intersection of Taft Hill and Drake.

Figure 4: Photo of 2D-video distrometer installed in van.

For comparison with Fig. 1, the cumulative rainfall as estimated by CSU-CHILL measurements of Kdp and Zdr (Eqn. 3) is shown in Fig. 2. Note the similarity in the overall structure of the radar estimated and gauge measured rain maps. The north-south orientation of the flood event along the foothills of the Front Range (located at x = -4 km in Fig. 2) is well represented by the R(Kdp,Zdr) rain map. More importantly, both the gauge and radar rainfall totals are characterized by a strong east-to-west gradient located over central Ft. Collins (x = 2.5 km). As can be seen from both Figs. 1 and 2, rainfall accompanying the Ft. Collins flood was extremely localized, occurring primarily over western portions of the city. The cumulative rainfall as estimated by R(Kdp,Zdr) over Ft. Collins is within 70% to 75% of the gauge measured totals. The overall cumulative rainfall maximum estimated from Eqn. 3 is 7.4 inches (compared to 10.2 inches from the rain gauges). The location of the R(Kdp,Zdr) estimated maximum rain accumulation (x = -1 km, y = 0.5 km) compares very favorably to the corresponding gauge position. The southern portion of the extreme rainfall amounts (> 5 inches in Fig. 2) are located directly over the drainage basin for Spring Creek (dark line in Fig. 2), consistent with the property damage and fatalities which occurred in the vicinity of this creek.

Using rain gauge totals as ground truth, it is clear that the R(Kdp,Zdr) algorithm outperformed rainfall estimates from both R(Kdp) and R(Zh). Peak rainfall totals as estimated from R(Kdp) and R(Zh) were 6.15 and 5.75 inches respectively. This factor of two underestimation by the WSR-88D R(Zh) algorithm may be due in part to the unique, monsoon-like, microphysical nature (i.e., the drop size distribution) of the convection responsible for the flood.

To explore this hypothesis, we calculated R(Zh)-R(Kdp,Zdr) at 2145 MDT which was the approximate time of the most intense rainfall (Fig. 3). Throughout most of the echo, this difference is negative (cool colors) with some deficits in R(Zh) as high as 55 mm/h or more. In most of the regions in which R(Zh) < R(Kdp,Zdr), the differential reflectivity is characterized by small to moderate values (0.5 < Zdr < 1.5 dB). These values of Zdr correspond to reflectivity weighted drop diameters of 1.2 to 2.7 mm. Based on many eyewitness accounts, the presence of "sheets of small drops" was a common characteristic of the heavy rain in the Ft. Collins flood. This is consistent with the pattern of Zdr in Fig. 3 and suggests that the standard WSR-88D rain algorithm (Eqn. 1) may cause a significant underestimation of rain rates in monsoon-like convection characterized by small drops. On the other hand, R(Zh) > R(Kdp,Zdr) in a 2 km wide southwest-to-northeast oriented band at the leading edge of the storm (warm colors in Fig. 3) by 35 mm/h and more. This region is closely correlated with enhanced values of the differential reflectivity (2 < Zdr < 4 dB), and hence with the presence of large drops (3.3 < D < 5.7 mm). This potential over-estimation of the rain rate in regions characterized by a few large drops is consistent with the fact that reflectivity is proportional to the sixth moment of the drop diameter, and is therefore overly sensitive to the presence of large drops.

The above results suggest that dual-polarimetric radar data (along with rain gauge data) can be used to "tune" WSR-88D rainfall algorithms for particular storm types (tropical monsoon-like in this instance). Future work at Colorado State University will explore this potential. In addition, we plan to investigate the vertical kinematic and microphysical structure of the convection using CSU-CHILL and both Cheyenne and Denver WSR-88D radar data. A detailed cumulative rainfall comparison between rain gauges, CSU-CHILL polarimetric radar, and the two WSR-88D Doppler radars is currently underway. Lastly, we are investigating the utility of cloud-to-ground (CG) lightning data in the nowcasting of flash floods, particularly those of a tropical monsoon nature. Collision-coalesence (or warm rain) appears to be the dominant microphysical process responsible for heavy rains in these storms. Since the production of CG lightning is linked to the presence of a vigorous in-cloud mixed-phase process, preliminary results suggest that CG lightning may be of only limited use as a nowcasting tool for "monsoon-like" flash flood events.

Electrical Engineering

A. REU 96 Project

(V. N. Bringi, Co-Principal Investigator)

Classification of hydrometeor types in winter precipitation using polarimetric radar techniques is an area of effort within EE and ATS as part of PROWS97. To assist in this research, the 2D-video disdrometer was leased from Joanneum Research in Graz, Austria and installed in a van as shown in Fig. 4. The van was located (during the 1997 winter) for one period at the CSU campus weather station, and for another period at the NCAR Marshall field site near Boulder.

Fig. 5 presents a schematic of the measurement principle. The two line scan cameras are directed towards the openings of the illumination devices.

The optical system is designed in such a way that (as seen through the camera lens) the slit of the illumination device appears as an evenly illuminated background of extreme brightness. To the cameras, any particle passing through the beam of light will appear as a dark silhouette against this bright background. A small height separation (» 6 mm) between the two optical planes allows the fallspeed to be estimated. Once the fallspeed is known, the height/width ratio of the particle can be calculated from the cameras' data as well as the volume-equivalent spherical diameter, D_{eq}. The size of the virtual measuring area is around 10 cm x 10 cm and only fully visible particles are counted. Horizontal particle velocity introduces image distortion; however, a correction can be applied by estimating the horizontal velocity. This is accurate when the particle has a symmetry axis, e.g., raindrops. Determination of D_{eq}, fallspeed and height/width ratio is independent of horizontal velocity. The horizontal resolution is better than 0.22 mm, while the vertical resolution is better than 0.3 mm (for fallspeed < 10 ms-1). The fallspeed accuracy is better than 5%. Fig. 6a shows the front and side views of a raindrop with D_{eq} = 7.4 mm from the 22 June, 1995 event. Fig 6b shows similar views of a large snowflake during a winter event on 6 February, 1997.

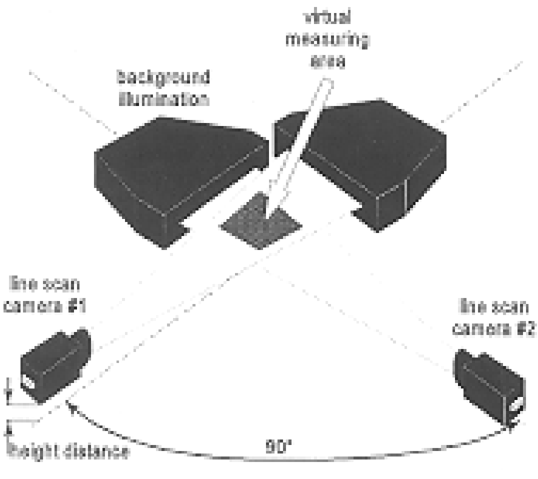

Figure 5: Schematic of measurement principle for the 2D-video distrometer.

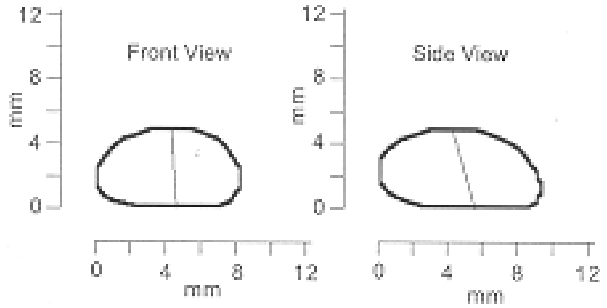

Figure 6a: Sample of front/side views of large raindrop.

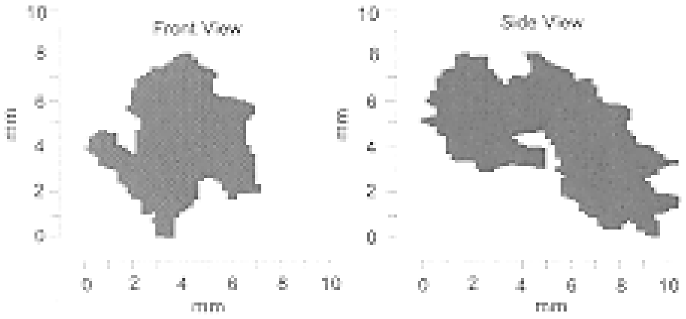

Figure 6b: Sample of front/side views of a large aggregate.

Fig. 7 shows drop size distributions during two periods of the 22 June, 1995 event analyzed by Hubbert et al. (Preprints 28th AMS Conf. Radar Meteor.). Fig. 8 shows an example of snow size distribution averaged over a 15 min. period from the 6 February, 1997 event. Aggregates up to 10 mm in size can be noted. One of our goals is to classify precipitation types using the polarimetric parameters such as Zdr, LDR and ρhv by directly comparing the signatures with hydrometeor image data.

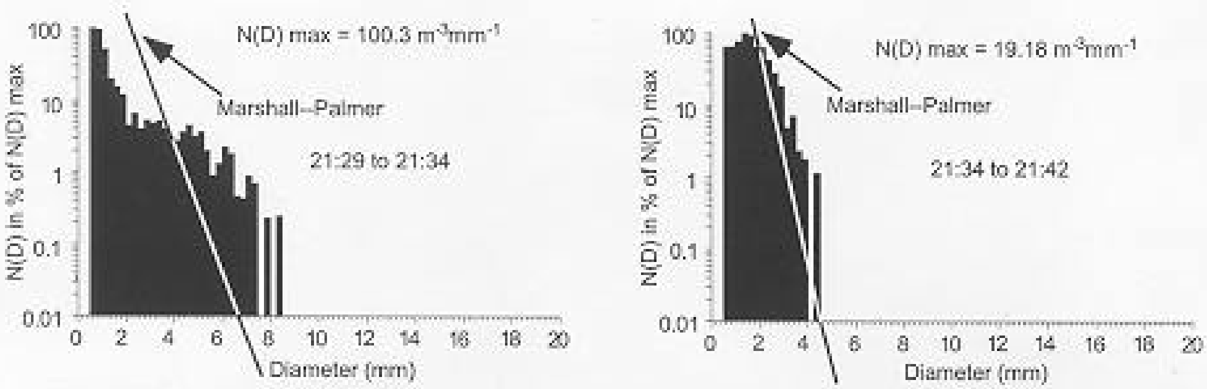

Figure 7: Drop size distributions in a convective rainshaft from the 2D-video distrometer on 22 June, 1995: a) (left) the high rainrate period and b) (right) the low rainrate period.

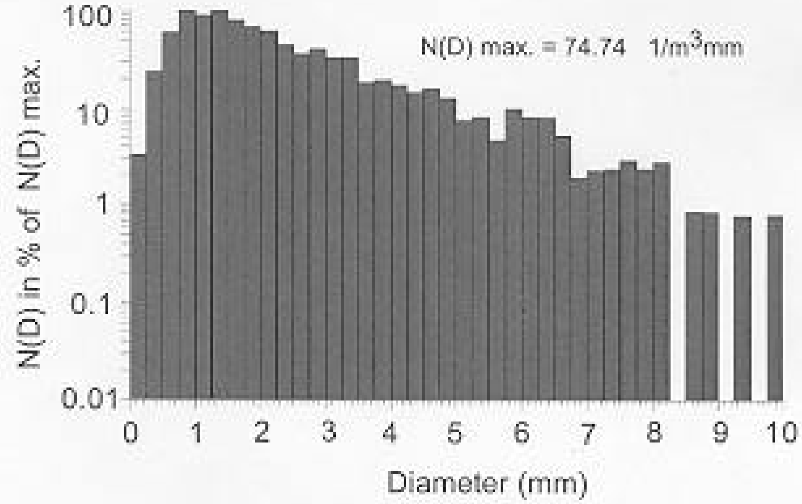

Figure 8: Snow size distribution from the 2D-vidio distrometer on 6 February, 1997 at the CSU campus site. The averaging period is 15 minutes.

A related effort within EE is the use of the Graves power matrix (or, polarization power matrix) to calculate the so-called asymmetry ratio (A) which is the ratio of equivalues of the power matrix (Kwiatkowski et al. J. Atmos. Ocean. Tech., 1995). The asymmetry ratio is similar to conventional Zdr except that it is independent of the canting angle. Fig. 9a shows A-Zdr versus conventional LDR for convective rain. For LDR < -26 dB, the data points fall within the scattering model curves (solid and dashed lines)

which are based on a Gaussian canting angle distribution (`q = 0, s = 5, 10, 12.5°) with equilibrium shapes and Marshall-Palmer distribution. Data points with LDR > -26 dB are likely rain mixed with hail. Previous observations of positive Zdr (typically a few dB) in winter storms have been ascribed to oriented planar crystals. Fig. 9b shows a scatter plot of

A-Zdr versus conventional LDR from a winter storm where data points correspond to resolution volumes characterized by planar crystals (most likely dendrites). Also shown are scattering model results (solid and dashed lines) for oblate spheroids of ice with axis ratio varying between 0.1 to 0.5. For a fixed axis ratio, the mean canting angle in the model is increased from 0 to 45°. Note that the data points fall within the modeled curves quite well. Thus, it appears that the axis ratio (or, mean shape for oblates) and mean canting angle effects may be separable by using the asymmetry ratio in combination with conventional Zdr and LDR measurements. We believe that the asymmetry ratio may be a useful "proxy" for circular depolarization ratio (or, CDR) which is sensitive to particle oblateness but is independent of canting angle.

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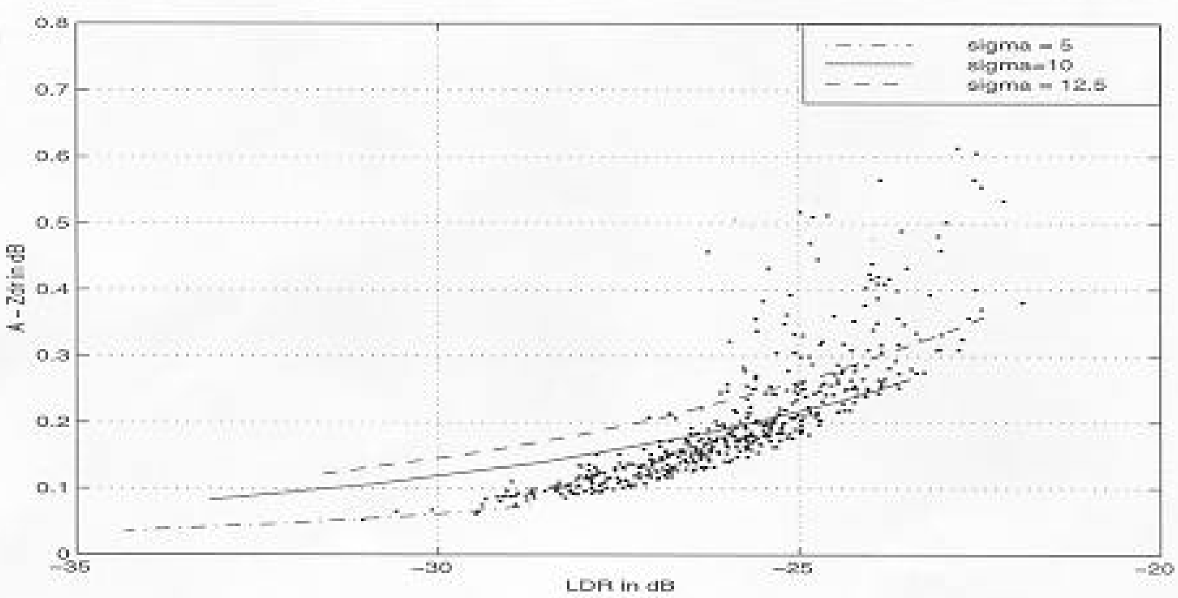

Figure 9: (a) The $A - Z_{dr}$ vs LDR Scatter Plot for Rain.

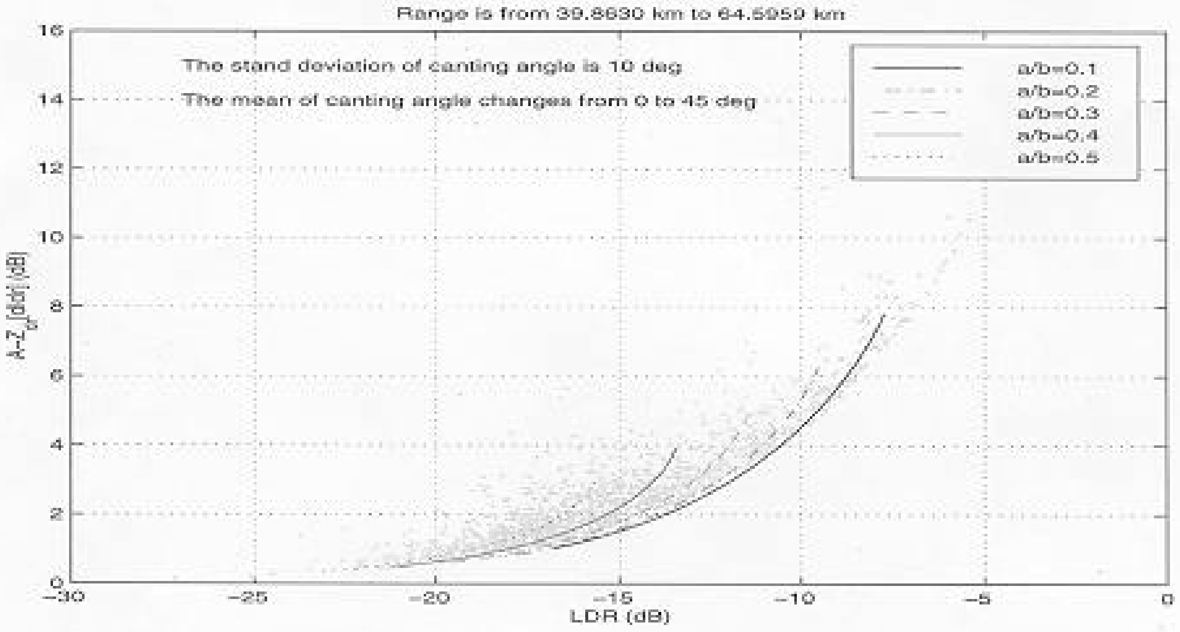

Figure 9: (b) The $A - Z_{dr}$ vs LDR Scatter Plot for winter event.

Another effort within EE is the evaluation of measuring conventional Zdr, ϕdp, and ρhv using slant 45° transmission with simultaneous reception of the horizontal and vertical polarized signals in a dual-channel receiver. Such a scheme is under consideration for the prototype WSR-88D radar system as a potential polarization upgrade. As an initial step in this evaluation, we have analyzed data acquired in the so-called STAR mode (simultaneous transmit, alternate receive, see Brunkow et al., Preprints 28th Radar Meteor. Conf.), i.e., simultaneous transmit means that both transmitters are "fired" simultaneously resulting in approximate slant 45° polarization, while the horizontal and vertical polarized received signals are alternately received via a single receiver (to avoid gain/phase mismatch when two receivers are used). The 4-panel Fig. 10 shows range profiles of reflectivity, Zdr, ϕdp and ρhv in a convective storm comparing STAR and conventional VH modes.

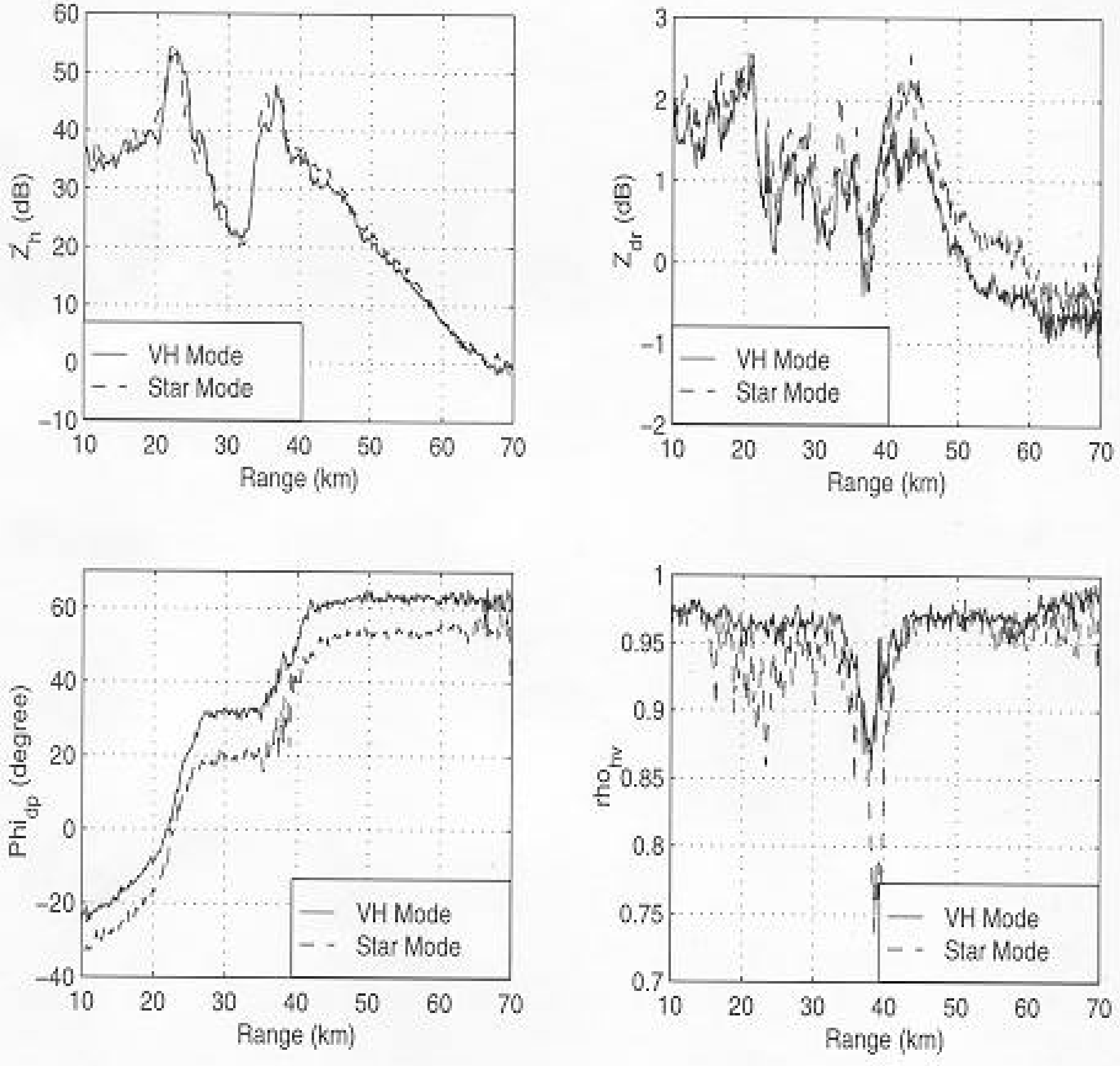

Figure 10: Four-panels comparing VH with Star-mode.

These two modes were separated in time by a few minutes. While the reflectivity, Zdr and ϕdp agreement is good, there is a tendency for the STAR-mode ρhv to be biased low which we believe may be due to cross-pol coupling. We are using our generalized Stokes vector based propagation-cum-scattering model to study biases in radar measurands under the STAR-mode.

A related effort in EE together with the CSU-CHILL staff is the use of the two transmitter/two receiver system to measure the covariance matrix in the slant 45° /135° and circular RHC/LHC bases, in addition to our conventional linear H/V basis. Because we have two transmitters we can adjust the phase difference between channels to 0, 180° , or ± 90° quite easily while maintaining nearly equal power. We propose to receive the horizontal and vertical polarized signals simultaneously in our two receivers and essentially "re-construct" via software the copolar and cross-polar received components (i.e. the received components that are copolar and cross-polar to the transmit polarization state). This scheme avoids any high power microwave network "switch" which tends to compromise system isolation between channels.

The EE group is continuing its range/velocity ambiguity resolution studies using phase/polarization coding and waveform design (for example, see Zhao et al., 28th Conf. Radar Meteor.). The CSU-CHILL radar is capable of transmitting random or systematically phase coded pulses with flexible PRTs. Further time series data will be collected and analyzed to evaluate the suppression of multiple trip overlaid echoes and unfolding of both first and multiple trip velocity signatures. A phase coding technique studied by Sachidananda and Zrnic (28th Conf. Radar Meteor.) will be evaluated. Simulations of this technique show that it is superior to random phase coding. Plans are underway to upgrade the CSU-CHILL radar with new dual-channel digital receivers and signal processor. The new receivers will sample the transmit pulse phase, and will provide phase corrections on a pulse-by-pulse basis to provide 0.1 deg rms error (with a target of 0.05 deg rms) over an integration interval of 50 ms. Such high accuracy is needed to fully realize the potential of the systematic phase coding technique proposed and simulated by Sachidananda and Zrnic (28th Conf. Radar Meteor.)

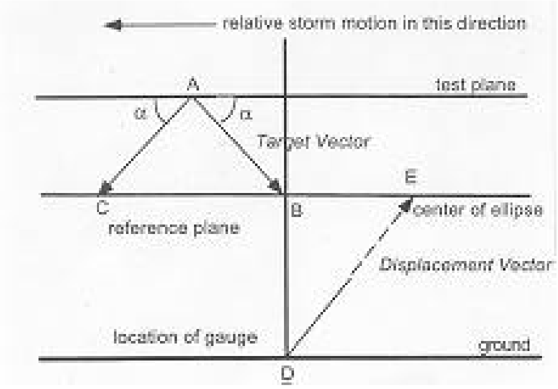

Figure 11: Schematic of the optimal area method.

Mr. Scott Bolen of the Rome Laboratory has developed, as part of his Ph.D. thesis, several optimal area methods for comparing polarimetric radar rain rate estimates made aloft to surface rain gauge measurements (Bolen et al. 28th Conf. Radar Meteor.). Radar PPI scan data of Kdp at two elevation angles are used to map an arbitrary point on the surface to a corresponding optimal area on the PPI scan plane, including an estimate of the optimal delay. A schematic is shown in Fig. 11 which shows the two PPI scan planes (test plane and reference plane), as well as the target and displacement vectors. The displacement vector, in essence, maps the gauge location to the center of an optimal ellipse on the reference plane. Rain rate from Kdp is averaged spatially over this optimal ellipse. An optimal delay is also calculated which is used when comparing R(Kdp) with rain rate from the gauge.

Fig. 12 shows an example comparison of using this method from the 6 July, 1996 event. Data from a mobile storm intercept van equipped with a Young capacitance rain gauge was used for comparison against CSU-CHILL radar rain rate estimates using a Kdp-based algorithm.

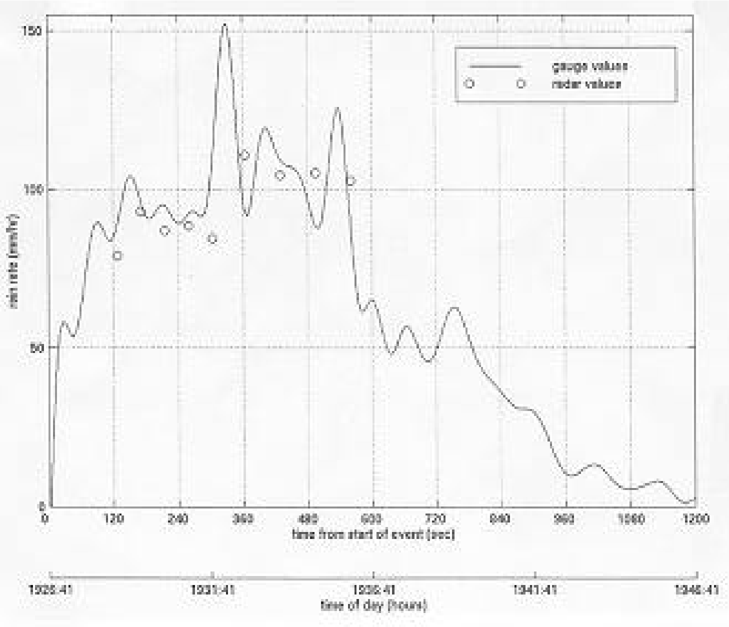

Figure 12: Rainrate from K_{dp} (open circles) versus gauge (solid line) for 6 July event.

Radar Engineering

(Dave Brunkow, Senior Engineer)

Technical Improvements

Real-Time Web Page

An automated system was developed which can grab images from the Adage display system, convert them to GIF format, and a create world wide web index to provide access to the images. The transfer of images from the VAX Adage host to a Sun workstation takes several minutes, but is fast enough to transfer 4 images every 15 minutes. Access to the images is via a standard web browser program. This has proved to be a very handy way of for researchers to keep track of the data acquisition phase of their projects without actually traveling to the radar. To see these images, look for the "Near-Real-Time Image" option on the CSU-CHILL Web page (http://olympic.atmos.colostate.edu/CHILL).

Simultaneous Transmit Tests

First tests of the simultaneous transmit operating mode were conducted. During these tests, only a single receiver was used. The receiver was alternately switch between the horizontal and vertical channels. This produced the same sequence of data at the copolar receiver that is produced in the alternating VH transmit mode, which simplified the signal processing requirements. This Simultaneous Transmit with Alternating Receivers (STAR mode) does have some practical application in the upgrading of existing radars to multi-polarization operation. Also of interest is the mode where both receivers are processed simultaneously. This requires somewhat greater signal processing capability, but has the advantage of isolating the differential phase (ϕdp) measurements from the velocity measurements. It also doubles the unambiguous range of the ϕdp measurements. This mode will be implemented on CSU-CHILL within the next year. Some images from alternating and simultaneous transmit modes are available on the web pages under "Misc. Research in Progress". The results looks promising, although there are some artifacts apparently due to crosstalk from depolarization on cases where there is significant hail present.

Remote Deployment Issues

The CSU-CHILL system was requested for participation in a winter project in the Great Lakes region. Although the project was canceled for reasons not related to the radar, progress was made on a variety of issues which will facilitate future deployments of the system. The first of these was the re-design of the concrete pad which supports the antenna pedestal. The size of the octagon was reduced from 28 to 18 feet, and the thickness was reduced to 42 inches. Design features were incorporated to facilitate the removal of the pad after a project is complete. This reduced the cost of site restoration to about $6000 in the Green Bay area. This issue proved to be of critical interest since all of the sites considered for this project would have required the removal of the pad. The new design still will support the antenna with a failed radome draped over it in a 100 mile per hour wind.

The second issue relates to the viability of the transmitters in new locations. It was found that available frequencies in the 2700-2900 MHZ band were very difficult to obtain in much of the proposed project area (Michigan). A frequency was available in Green Bay, but it was above 2800 MHZ, so it required a change of Klystrons in the transmitters. There are not as many tubes available in the higher frequency range, so there was some uncertainty there, but we found that we did have Klystrons which operated well in this part of the band. We now know that an operation above 2800 MHZ would be feasible.

Another issue related to the transmitters was the requirement to meet the NTIA RSEC criteria. These are a set of standards which have been established to allow as many radars as possible to operate in a region without interfering with one another. We found that the CSU-CHILL transmitters were very close to meeting these criteria without modification. Further, it was found that by reducing the rise time of the pulse we could easily meet the required bandwidth limitation and emission vs. frequency envelope required. These findings have reduced the uncertainty over licensing the radar in other locations, however, the crowded nature of this frequency band has made deployment to certain regions very difficult. This issue should be considered early-on in any future remote deployments.

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