

**University:** Colorado State University

**Name of University Researcher Preparing Report:** Robert Cifelli

**NWS Office:** WFO Boulder

**Name of NWS/DOT Researcher Preparing Report:** Chad Gimmestad

**Partners or Cooperative Project:** Improving quantitative precipitation estimation through combined use of dual polarimetric radar and a high density volunteer precipitation network

**UCAR Award No.:** S02-38660

**Date:** 1 July 2004

## **SECTION 1: PROJECT OBJECTIVES AND ACCOMPLISHMENTS**

1.1 The overall objectives of the project included:

**Scientific:** Apply rain and hail data from a very dense volunteer network over both plains and mountainous areas in combination with dual polarimetric radar measurements to help the local NWS Forecast Office improve quantitative precipitation estimates, forecasts, warning verifications, and the use and interpretation of radar products for selected case studies.

**Operational:** (1) Present NWS personnel with a quantitative assessment of conventional NWS radar-derived precipitation estimation (*Z-R*) vs. polarimetric rainfall algorithms using the NSF-funded CSU-CHILL radar (<http://chill.colostate.edu/>) and the volunteer network for selected case studies. (2) Use the CSU-CHILL polarimetric radar in conjunction with the volunteer network hail reports to evaluate the efficacy of the NWS hail detection algorithm in selected storms along the Colorado Front Range.

**Educational:** (1) Instruct WFO personnel on the climatological characteristics of rainfall and hail and potential for improved hail detection and rainfall estimation using polarimetric radar. (2) Provide results of this study to forecasters, research meteorologists, and COMET to improve understanding of the magnitude of variability of precipitation and hail over small areas along the Colorado Front Range.

The scope of research included development and refinement of software to estimate radar rainfall and hail damage potential from the CSU-CHILL polarimetric radar. The rainfall estimation methodology included both state of the art polarimetric (i.e., blended) techniques combined with a hydrometeor identification (HID) routine as well as traditional NWS NEXRAD *Z-R* methodology. Validation of the radar rainfall accumulation and intensity was performed using data from a volunteer precipitation network (CoCoRaHS [www.cocorahs.org](http://www.cocorahs.org)) and from the Denver Urban Drainage and Flood Control District ALERT network (<http://alert.udfcd.org/>). Validation of hail

damage estimation was performed through ground surveys and interviews in areas where hail was reported. These surveys were conducted by experienced CSU personnel.

A key scientific finding of our COMET work was that the performance of the polarimetric algorithm over the NEXRAD Z-R increased with the fraction of precipitation ice (graupel and hail) in the radar volume (Fig.1). These results lead to the development of software to display polarimetric vs. NEXRAD rainfall products (Fig. 2). These products are now available on the CSU-CHILL web site ([www.chill.colostate.edu](http://www.chill.colostate.edu)) in near real time. The event shown in Fig. 2 nicely illustrates the problem forecasters face when using the traditional NEXRAD Z-R for rainfall estimation in the presence of hail: because the NEXRAD Z-R uses backscattered power to estimate rainfall, this technique is especially prone to overestimating rainfall when hail is present. This is a situation where the polarimetric technique, based on specific differential phase is clearly superior. Specific differential phase is largely immune to precipitation ice and senses only oblate raindrops. An example of the difference in rainfall intensity calculated using the blended vs. NEXRAD Z-R methodology is shown in Fig. 3.

As noted above, an important objective of the COMET project was also to test whether the inclusion of Linear Depolarization Ratio (LDR) information from the CSU-CHILL radar could improve the ability of the Hail Differential Reflectivity (HDR) parameter (Aydin et al. 1986) to characterize the general severity (in terms of maximum hailstone sizes and / or structural damage probability) of radar-identified hail areas. LDR is defined by:

$$\text{LDR (dB)} = 10 \log_{10} (Z_{VH} / Z_{HH}) \quad (1).$$

LDR is the ratio of the cross-polar return signal component (V received signal from an H transmission) to the co-polar return signal (H receive after H transmit). For meteorological scatterers, the cross-polar signal level is typically only a few percent of the co-polar signal level, resulting in LDR values in the -20 to -30 dB range. Spherical targets produce an infinitesimally small cross-polar return signal. The cross-polar signal is enhanced when the radar pulse illuminates non-spherical particles whose major axes are oriented appreciably out of the polarization plane. It should be noted that the cross-polar signal strength, as well as that of all of the other backscatter signals ( $Z_{HH}$ ,  $Z_{DR}$ , etc.), is directly weighted by the particle's bulk density as expressed by the index of refraction (Herzogh and Jameson, 1992). Thus, presence of irregularly-shaped, gyrating, high-density hailstones would increase the LDR values.

The Hail Quadrature Parameter (HQP, Kennedy et. al. 2001) is a method of combining HDR and LDR. In this formulation, HDR and LDR are scaled into ranges that are appropriate for hail ( $5 < \text{HDR} < 50$  dB;  $-25 < \text{LDR} < -10$  dB); the scaled values are then treated as orthogonal vector components. HQP is the magnitude of the resultant vector sum. Once  $Z_{DR}$  becomes 0 dB (as expected in hail), HDR becomes a simple offset from  $Z_{HH}$ . In contrast, the HQP parameter continually remains sensitive to LDR. It was hypothesized that the additional hail

characterization information provided by the LDR data might improve the performance of the traditional HDR parameter.

To evaluate the relative performance of the HDR and HQP hail parameters, post storm driving surveys of the HQP hail swaths were conducted within a few days of the radar-observed events. Efforts were made to interview individuals who had directly experienced the storm passage. The storm witnesses were asked a standard series of questions regarding the hailstone sizes, hardness, resultant damage to structures, vehicles, vegetation, etc. Hailstone diameters were estimated by presenting the interviewees with a series of calibration spheres from which they selected the most representative size(s). A hand held GPS unit was used to identify the geographic locations associated with the hail observations.

Figure 4 provides an example of a combination of an HQP hail map and a collection of post storm survey observations. The slow moving storm resulted in a compact area within which appreciably large ( $>\sim .6$ ) HQP values occurred. The post storm surveys found that large hail as defined by the NWS (diameter of 19 mm / .75 inch or larger) were frequently observed in and near the higher magnitude HQP contours. Some of the most comprehensive observations were collected by a CoCoRaHS observer located at the indicated point in Fig. 5. His hail pad was partially destroyed by hailstones of nearly 3-in in diameter (Fig. 5). He also collected some example hailstones in his freezer and took a number of associated photographs. The information collected by such dedicated volunteer observers is of great utility to both operational warning forecasters as well as to researchers. Detailed comparisons of the CSU-CHILL polarimetric radar hail characterizations with the verification observations obtained from ground observers will be presented in a forthcoming journal article.

## **SECTION 2: SUMMARY OF UNIVERSITY/ NWS/DOT EXCHANGES**

2.1 A number of meetings between CSU and NWS project personnel were held at the CSU-CHILL radar facility to discuss project goals, analysis techniques, and relevant issues related to forecasting. CSU and DEN-BOU WFO personnel also attended the 2003 and 2004 Mountains-Plains Weather workshop sponsored by the Cheyenne NWS. At these workshops, CSU and the DEN-BOU WFO presented material relating to the COMET project and also discussed ways to collaborate with the CYS WFO. CSU and the NWS WFO in DEN-BOU collaborated on a number of publications that are described below.

## **SECTION 3: PRESENTATIONS AND PUBLICATIONS**

### **3.1**

Cifelli, R., Doesken, N. J., Kennedy, P. C., Carey, L. D., Rutledge, S. A., Depue, T. and Gimmestad, C., 2004: The Community Collaborative Rain and Hail Study: An Informal Education Project Involving Scientists and Local Citizens. *Bulletin of the American Meteorological Society*, in review.

- Depue, T. K., P. C. Kennedy and S. A. Rutledge, 2004: Ground Truth and Modeling Verification of the Hail Quadrature Parameter. In preparation for submission to J. Applied. Met.
- Doesken, N. J., 2004: CoCoRaHS: Community Collaborative Rain and Hail Study. Abstract, 84<sup>th</sup> Annual Meeting of the American Meteorological Society, 13<sup>th</sup> Symposium on Education, Seattle, WA, 11-15 January 2004.
- Doesken, N., R. Cifelli, and C. Gimmestad, 2003: CoCoRaHS Grows – The Community Collaborative Rain and Hail Study Heads to the Central Great Plains, 2003 Mountain Weather Workshop, Boulder, CO, 26 March, 2003.
- Kennedy, P.C., and T. Depue, 2003: Overview of the CSU-CHILL Radar and Hail Quadrature Parameter (HQP), 2003 Mountain Weather Workshop, Boulder, CO, 26 March, 2003.
- Cifelli, R., P.C. Kennedy, N. Doesken, S. Rutledge, C. Gimmestad, D. Barjenbruch, and T. Huse, 2003: Polarimetric vs. NEXRAD Rainfall Accumulations, 2003 Mountain Weather Workshop, Boulder, CO, 26 March, 2003.
- Cifelli, R., D. Barjenbruch, D. Brunkow, C. Davey, N. Doesken, C. Gimmestad, T. Huse, P. Kennedy, and S. A. Rutledge, 2003: Evaluation of an Operational Polarimetric Rainfall Algorithm. Abstract, AMS 31<sup>st</sup> International Conference on Radar Meteorology, Seattle, WA, 6–12 August 2003.
- Depue, T. K., 2003: Ground Truth and Modeling Verification of the Hail Quadrature Parameter. M.S. Thesis, Department of Atmospheric Science, Colorado State University (Advisor: Prof. Steven A. Rutledge).
- Kennedy, P. C., T. K. Depue, R. Cifelli, D. Barjenbruch, C. Gimmestad, D. A. Brunkow, and S. A. Rutledge, 2003: Ground Truth Verification of the Hail Quadrature Parameter (HQP). Abstract, AMS 31<sup>st</sup> International Conference on Radar Meteorology, Seattle, WA, 6-12 August 2003.

## **SECTION 4: SUMMARY OF BENEFITS AND PROBLEMS ENCOUNTERED**

### **4.1**

By working with the NWS, CSU researchers have gained more insight into the challenges faced by WFO forecasters with regard to nowcasting and forecasting flash floods and severe thunderstorms in the area of northeast Colorado. Discussion with forecasters were a strong impetus in the development of the rainfall and hydrometeor identification display plots shown in Fig. 2.

The only major problem from the academic side was figuring out a way to display both KFTG and CHILL data side by side in near real time. This was finally accomplished by a graduate student (Brenda Dolan) who took advantage of the LDM data link (UNIDATA) available to universities across the country and constructed the plots in Fig. 2.

If we had it to do over, one aspect of the project that could have been improved was the amount of face to face contact between CSU and NWS personnel. This would have been especially helpful in regard to going over data collected for a specific event (both from the NWS side and from the CSU-CHILL side) and figuring out exactly when, where, and how the CSU polarimetric data would have been most effective for forecasters.

## 4.2

Immediate benefits include the data made available from the expanding CoCoRaHS observation network and forecaster exposure to the CSU CHILL polarized radar data. During the convective season in 2002, these reports constituted nine percent of our significant weather reports, and five percent of our reports that were a factor in warning decisions. There were six occasions on which the CoCoRaHS report was the only ground truth data available for a warning decision. This included one event when a storm produced three inch diameter hail in a small area for an hour and another instance where the WFO lost access to all radar data while three severe thunderstorm warnings and a flash flood warning were in effect. Continued network expansion and emphasizing real time reporting in 2003 and 2004 have resulted in further increase in the value of this network, with a steady stream of hail reports from the high density portion of the network during severe thunderstorms.

Another benefit has been forecaster exposure to real time CSU-CHILL polarized radar data. While this data has not yet been well integrated into warning operations, several opportunities to use the polarized radar products have demonstrated their value, most notably in confirming the absence of large hail in high reflectivity thunderstorm cores. The comparisons made between the two radars have produced a greater sensitivity to the limitations of the current radar algorithms.

Longer term benefits include increased understanding of the small scale variabilities of precipitation, both for individual events and in the climatology.

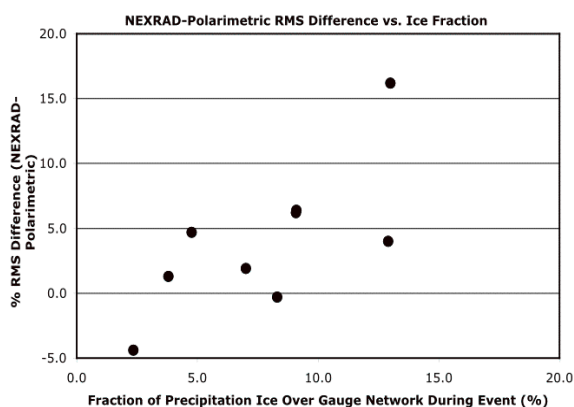


Figure 1. Scatter plot of percentage ice over rain gauge network during event vs. the RMS difference between the NEXRAD Z-R and polarimetric rainfall methods (NEXRAD RMS minus polarimetric RMS). Large positive values on the ordinate indicate large RMS errors in the NEXRAD method compared to the polarimetric method.

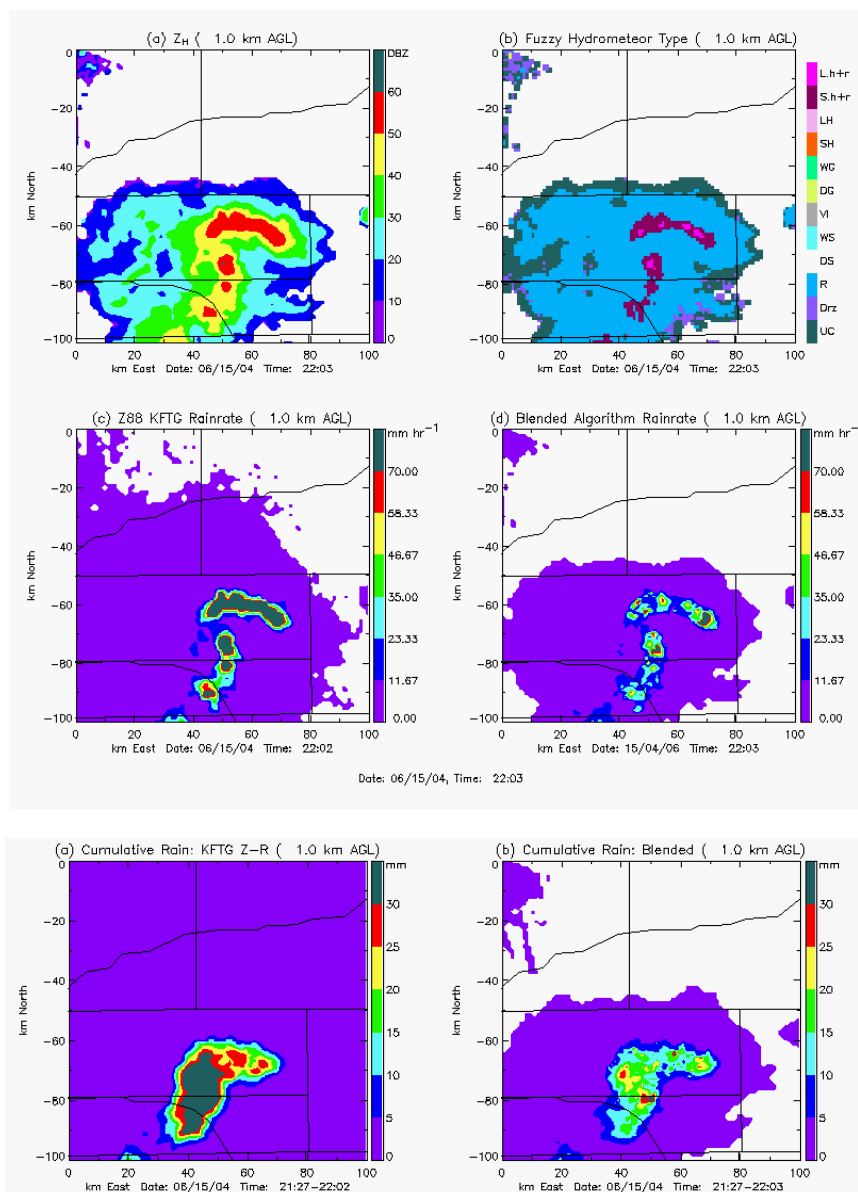


Figure 2. Display of CSU-CHILL reflectivity (upper left), hydrometeor identification (upper right), KFTG rain rate using the standard NEXRAD Z-R (middle left), and CSU-CHILL blended rain rate (middle right), KFTG cumulative rainfall (lower left), and CSU-CHILL blended cumulative rainfall (lower right).

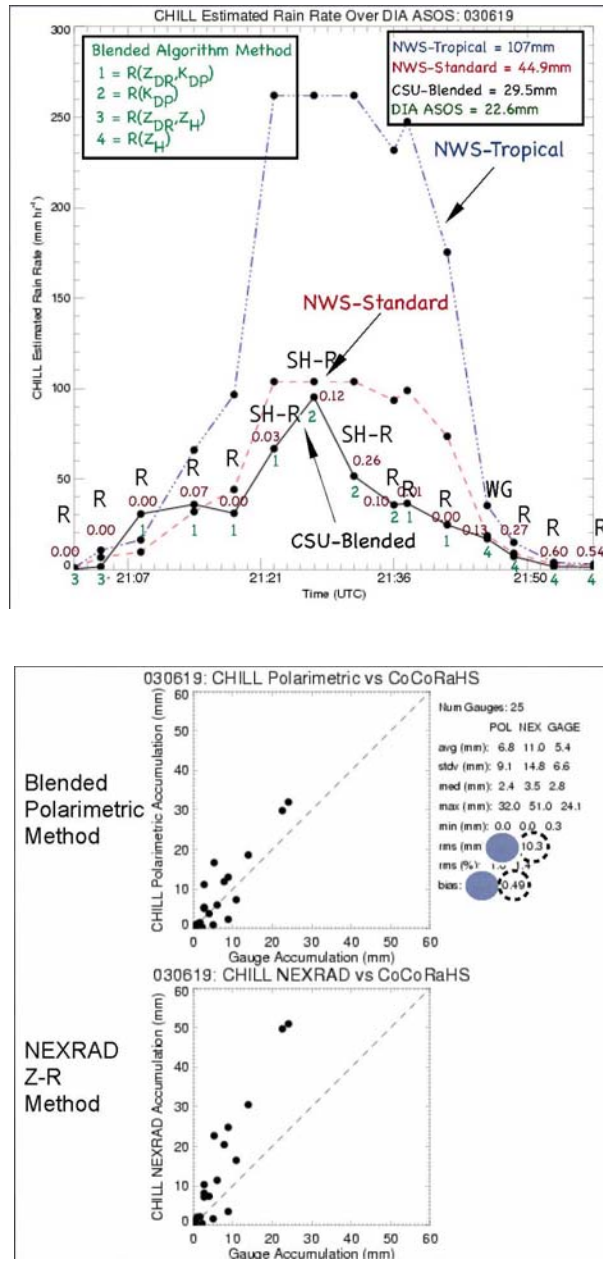


Figure 3. (Top) CSU-CHILL rain rate time series over the Denver ASOS on 19 June 2003. Solid line is the blended algorithm trace, dashed red is the standard NEXRAD Z-R and blue dashed is the NEXRAD tropical Z-R. Green numbers at each time indicate polarimetric technique used to estimate the blended rainfall (reference the methods in upper left corner). Red numbers indicate ice fraction over the ASOS location. "R" indicates rain, "SH-R" indicates small hail and rain, and "WG" is wet graupel as determined by the HID algorithm. Rainfall totals by each method are indicated in the upper right portion of the figure. (Bottom) Scatter plot of ALERT gauge vs. CSU-CHILL radar precipitation.



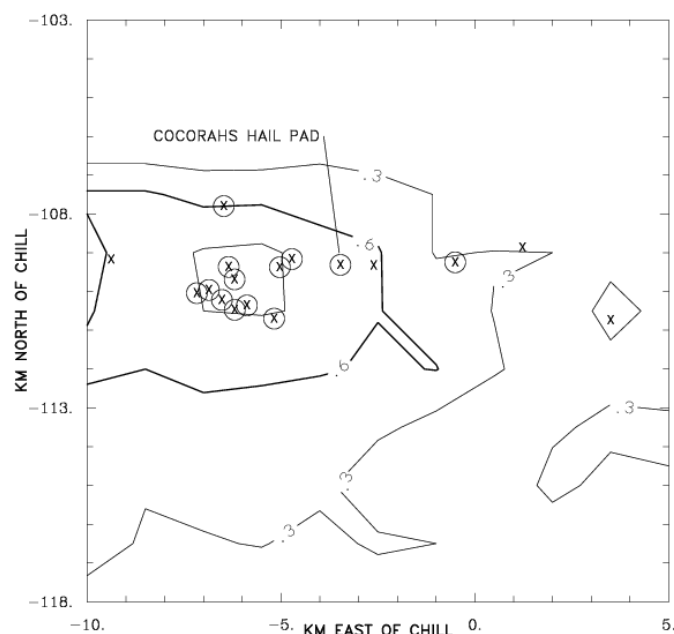


Figure 4. HQP hail map and a collection of post storm survey observations for a severe thunderstorm south of Denver, CO sampled by the CHILL radar on 10 July 2002. HQP values of 0.3, 0.6, and 0.9 are contoured; the 0.6 contour is darkened. The circled X's indicate locations where structural damage due to hail was confirmed.

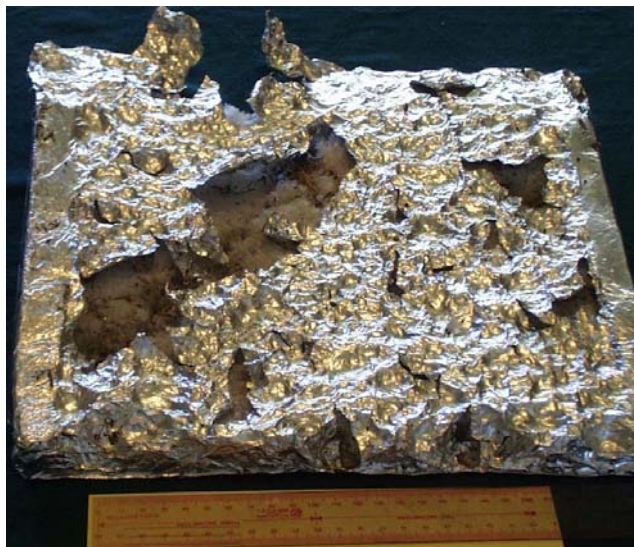


Figure 5. CoCoRaHS hail pad after sampling 3-in diameter hail.