CHILL RADAR NEWS

January 2005 **Thirteenth Edition**

Overview *(by Prof. Steven A. Rutledge, Scientific Director)*

The CHILL radar arrived at Colorado State University in June of 1990 from the Illinois State Water Survey. At that time, it was then designated as the CSU-CHILL National Radar Facility and has since been operated by CSU as an NSF national facility with continuous funding from the NSF and CSU. In past editions of this Newsletter we have described major technical improvements to the Facility, including a new high performance antenna in 1993-94, the transformation of the radar to a dual-transmitter, dual-receiver configuration, eliminating the need for a ferrite polarization switch, and making possible a variety of polarization bases for microphysical studies. We also acquired and designed a spacious operations van that can easily seat 6-7 scientists for field operations. In the 98-99 timeframe, we transitioned to the Lassen DRX signal processor and digital (dual) receiver system. Courtesy of the Illinois State Water Survey, we received the

The CSU-CHILL Radar Facility after a summer rain storm.

HOT radar in 1997, and by summer 1998, had it fully operational 40 km north of CHILL. Under the leadership of Brenda Dolan, a master's student in CSU's Radar Meteorology group, CHILL now has a unique real-time software capability to display dual-Doppler fields (at present using CHILL and the Denver WSR-88D dual-Doppler pair) along with polarimetric-based rain maps and hydrometeor identification in horizontal and vertical cross section format. This software has proven to be a great advantage for real-time decision-making in field projects.

Our immediate future upgrades are two-fold. First, under the leadership of Prof. V. N. Bringi (CHILL Co-PI), CSU was awarded a Major Research Instrumentation grant from the NSF to purchase a new antenna. This antenna is presently being developed by Vertex/RSI and is scheduled for delivery June 1st 2005. The critical design review for the new antenna was completed in September 2004. This new antenna is an offset Gregorian antenna, and will be the first of this type to be mated with a high power, S-band weather radar. The new antenna will provide markedly reduced sidelobes compared to the current antenna (8 db reduction, two-way). The second major improvement is focused on shifting the dual-transmitters, receivers and signal processor to the "old" NCAR CP-2 transmitter trailer. This trailer has "air ride" suspension that better protects the radar equipment during transport. It is also configured for both heating and air conditioning, which will provide a cleaner environment for hardware operation, and a more comfortable environment for users. This new trailer is expected to be fully configured by fall 2005.

A major contribution of the facility has been the development of the V-(Virtual) CHILL software package led by Prof. V. Chandra (CHILL Co-PI) and D. Brunkow (CHILL Chief Engineer). V-CHILL allows remote users, in particular, any classroom that has Internet connectivity, to fully access CHILL data in real-time, and to control the scanning of the antenna. V-CHILL also features an audio/video conferencing capability, allowing lectures to be delivered from CHILL and questions fielded from the remote classroom. V-CHILL has been a major outreach success for our Facility. Recently, Jochen Deyke (the newest member of our CSU-CHILL staff) has moved the V-CHILL software to the JAVA environment to provide broader access. In addition to this general change, he has added a real-time

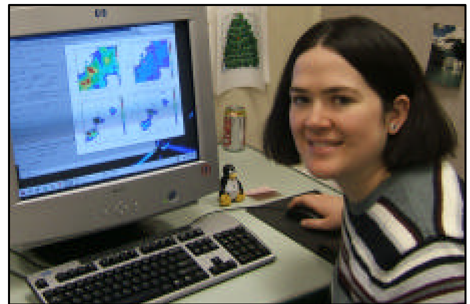
(Continued on page 2)

Inside this issue:

Overview *(continued)*

movie looping capability as well as software to process and display the K_{dp} field and a rain map from K_{dp}. Velocity unfolding has also been added. The CHILL web page provides a set of instructions for downloading the JAVA version of V-CHILL.

As detailed in the following sections, data collection highlights in 2004 included support of another REU (Research Experience for Undergraduates) project, and the Global Precipitation Measurement Front Range Pilot Project (FRPP). The FRPP featured a unique collection of instruments including the CSU-CHILL radar, the NOAA/ETL X-band polarimetric radar, profilers from NOAA, as well as disdrometers and raingauges aimed at developing ground validation experimental design and observational strategies for the proposed GPM satellite mission. Of course, the CSU-CHILL radar continued to collect data outside of formal projects whenever interesting weather was nearby. These data collection activities have proven to be invaluable for assembling case studies for radar meteorology classes at CSU and elsewhere.



ATS graduate student Brenda Dolan developed interactive software that derives and displays a multitude of radar-based products in a common display grid. This product was tested in real-time during last summer's Front Range Pilot Project (FRPP).

2004 Operations Summary *(by Pat Kennedy, Facility Manager)*

The CSU-CHILL radar collected research data during most of the active precipitation months of 2004 in Northeastern Colorado. During late January and most of February, radar operations were conducted in support of the radar tests that NCAR was performing to shake down the second frequency (Ka-Band) system that had been recently added to their SPOL radar. The most useful data set was collected during the afternoon and early evening hours of 19 February when several areas of rain and snow showers traversed the area between the two polarimetric radars. Direct, ground-based hydrometeor observations were also collected by NCAR during this event. Comparative analyses of the CSU-CHILL and SPOL radars and ground level in-situ hydrometeor data are currently underway.

During the warm season convective storm months, radar operations were primarily centered around two field programs. The first, an NSF-funded Research Experience for Undergraduates (REU) project, was led by Prof. V. Chandrasekar of the CSU Electrical Engineering and Computer Science Department. A group of 8 students from 7 different universities participated in the 2004 REU program. The majority of the projects undertaken by this year's REU students involved the analysis of time series data sets collected by the CSU-CHILL system. One such project examined techniques for spectral domain noise removal; a procedure that is being investigated for future use in the CSU-CHILL signal processing system.

The second major warm season field program was the Global Precipitation Mission (GPM) Front Range Pilot Project. This was a cooperative data collection effort conducted on behalf of NASA. Scanning radar operations in the pilot project were centered on making coordinated polarimetric observations of precipitation areas using both the 11 cm wavelength CSU-CHILL system and the 3.2 cm wavelength NOAA-D radar (located near Erie, CO). Additional vertically-pointing profiler radar data were collected at two locations (NOAA's BAO tower and Platteville field sites). To collect ground truth data, surface-based precipitation sensors, including a two-dimensional video disdrometer, were also installed at these two profiler sites. Various rainfall estimators are currently being evaluated using both the 11 and 3.2 cm wavelength radar data. These analyses will be used to guide the design of the ground validation sites that are to be constructed to calibrate the GPM satellite-borne radar system. Additional links to GPM Pilot Project web sites may be found at:

http://radarmet.atmos.colostate.edu/gpm/pilot.html

Target of opportunity CSU-CHILL data sets were collected when such activities did not conflict with the more formal project operations described above. In these situations, the CHILL scanning was often adjusted to include wider angular coverage that better matched the operational scans used by the Denver Front Range (KFTG) WSR-88D radar. The resultant two-radar data sets were then used to test various aspects of the real-time multiple Doppler/polarimetric hydrometeor identification software package that Brenda Dolan (Atmospheric Sciences Spring 2005 MS graduate) was developing. Her software automatically monitors the real-time availability of CSU-CHILL and WSR-88D level II data files on a high performance PC located in the operations van. The detection of new volume scan data files triggers the execution of a sequence of data processing and image generation programs. Three-dimensional multiple Doppler wind field syntheses are done whenever adequate volume scan start time synchronization exists among the input radars. Users can readily adjust the various analysis program parameters (i.e., interpolation grid size and location, data field display presentations, etc.).

The following figures (1-5) present example plots from Brenda's software package based on data collected during the early evening hours of 29 June 2004 (30 June on UTC). At this time, numerous thunderstorms were present over the greater Denver area. The CSU-CHILL radar was conducting a series of low elevation angle 360° PPI surveillance scans.

(Continued on page 3)

2004 Operations Summary *(continued)*

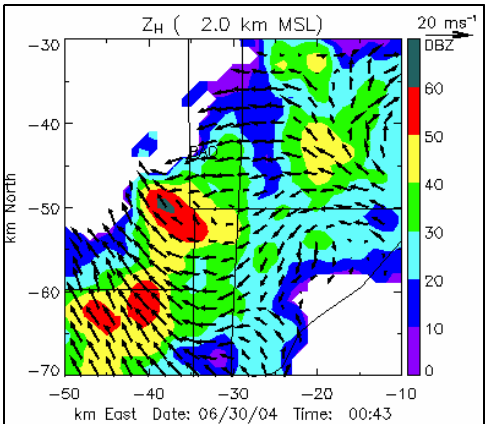


Fig. 1. CSU-CHILL reflectivity levels and earth-relative horizontal wind field vectors at the 2 km MSL CAPPI height at 0043 UTC on 30 June 2004. Wind field is synthesized from the radial velocities observed by the CSU-CHILL and NWS KFTG radars. Axis labels are in km from an origin at the CSU-CHILL radar site near Greeley. Background map lines are county boundaries and interstate highways.

At 0043 UTC adequate synchronization was detected between the volume scan starting times of the CSU-CHILL and KFTG radars. The resultant dual-Doppler synthesis of the earth-relative horizontal wind field at 2 km MSL is shown in Fig. 1. A diverging wind field is present in association with a dissipating cell centered near X=-17 km, Y=-42 km. Wind speeds are somewhat higher near the more intense reflectivity cores in the southwestern portion of the analysis grid. A generally consistent pattern is seen in the 3 km MSL vertical air velocity field (Fig. 2). The strongest downdrafts are present in the eastern portion of the echo complex (generally east of X= -25 km); larger scale updraft centers exist west of the X=-30 km line. The hydrometeor identifications at the 2 km MSL level based on a fuzzy logic weighting procedure (Lim (2001), K. Wiens, personal communication, 2004) applied to the polarimetric radar data are shown in Fig. 3. Rain is widespread; several pockets of hail are also identified near the leading portion of the western end of the convective line. Instantaneous rain rates based on the CSU-CHILL polarimetric data and on the KFTG reflectivity data are shown in Figs. 4 and 5 respectively. The particular rain rate estimator used at each grid point in the CSU-CHILL plot is objectively selected based the local polarimetric data field values (Chandrasekar *et al.* (1993), Cifelli *et al.* (2003), Petersen *et al.* (1999). For example, if joint consideration of the reflectivity (Z_h) and differential reflectivity (Z_{dr}) values suggests that the ice particle component of the precipitation is large enough to contaminate the reflectivity measurement, a rain rate estimator based on specific propagation differential phase (K_{dp}) will be used. The KFTG rain rates are based exclusively on a conventional, reflectivity-based, Z(R) relationship. Inspection of Figs. 4 and 5 confirms that the KFTG rain rates generally exceed the polarimetric rates in the cells where the presence of hail enhances the reflectivity levels. While hail is not the predominant hydrometeor type in the dissipating cell at X=-20 km, Y=-42 km, the polarimetric

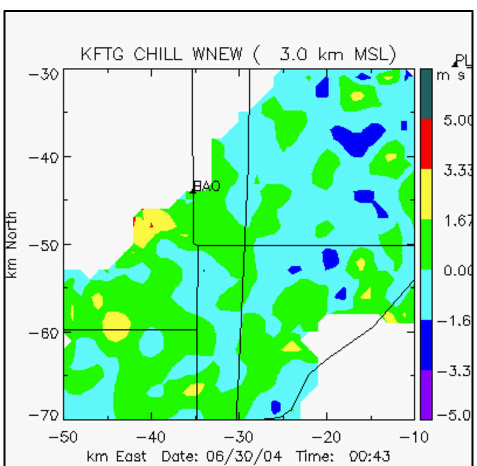


Fig. 2. Vertical air velocities at the 3 km MSL CAPPI height based on upward integration of the divergence fields contained in the CSU-CHILL / KFTG dual-Doppler synthesis at 0043 UTC on 30 June 2004.

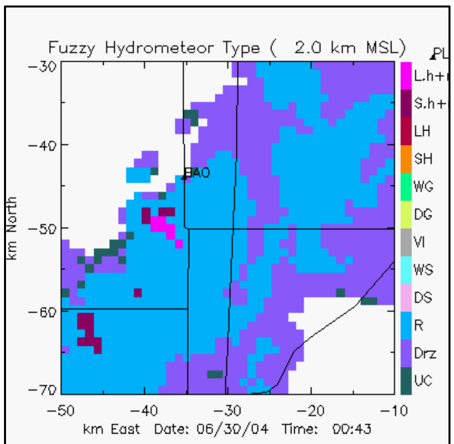


Fig. 3. As in Fig. 1 except data field is hydrometeor classifications based on a fuzzy logic scheme applied to the CSU-CHILL polarimetric data. Color bar hydrometeor classification codes are: L.h+r=large hail and rain, S.h+r=small hail and rain, LH=large hail, SH=small hail, WG=wet graupel, DG=dry graupel, VI=vertically oriented ice particles, WS=wet snow, DS=dry snow, R=rain, Drz=drizzle, UC=unclassified.

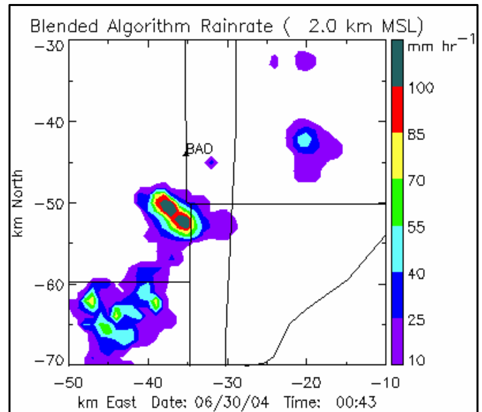


Fig. 4. As in Fig. 1 except data field is instantaneous rainfall rate based CSU-CHILL polarimetric radar data. A CSU-developed decision tree is used to select the optimal precipitation rate estimator (i.e., R(Z), R(Z,Z_{dr}), R(K_{dp}), etc.) for use at each analysis grid point.

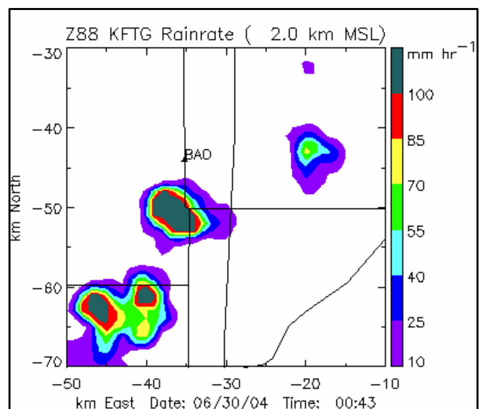


Fig. 5. As in Fig. 4 except data field is the instantaneous rainfall rate based on the KFTG reflectivity data. The operational NEXRAD R(Z) coefficients and upper reflectivity limit (53 dBZ) are used.

(Continued on page 4)

2004 Operations Summary *(continued)*

diagnosis does indicate that the ice fraction in the precipitation is ~17%. The resultant reflectivity enhancement may be positively biasing the KFTG rain rate values in this cell.

The initial testing of the automated multiple radar data processing software that was conducted during 2004 has provided promising results. The capability to calculate and display multiple Doppler wind fields, three dimensional hydrometeor classification patterns, etc. during real time operations can be quite useful in adapting radar scan coverage to developing convection, directing research aircraft and ground vehicles, etc. The software can also readily process archived data sets to produce a wide variety of "first look" analyses.

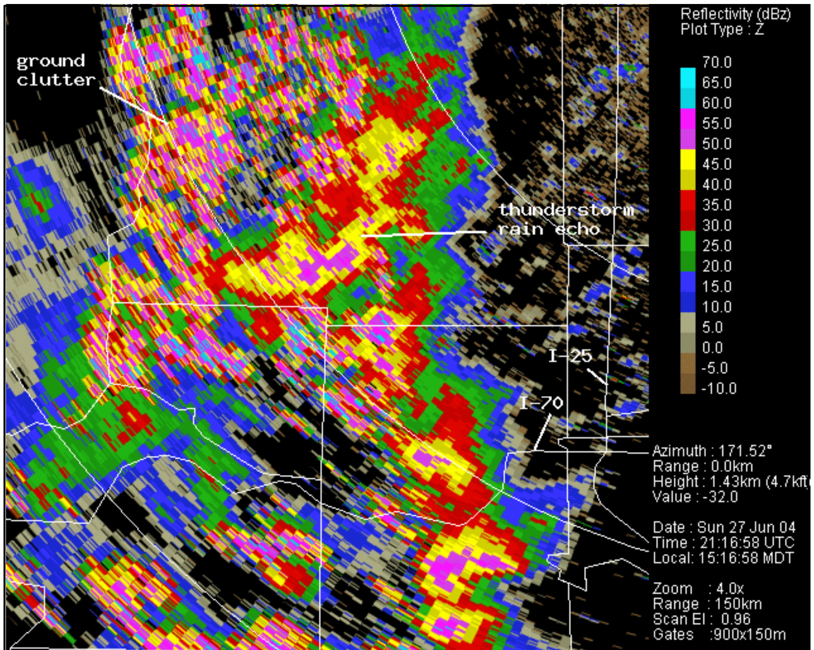


Fig 6. CSU-CHILL reflectivity field at 2116 UTC on 27 June 2004 at an antenna elevation angle of 0.5°. (At the time of the image capture the antenna had started moving up in preparation for the next sweep, thus the 0.96° notation in the lower right corner.) Gates where the Normalized Coherent Power (NCP) is 0.25 or less are not displayed.

Additional unscheduled radar operations were conducted when locally heavy rainfall situations were forecast. One such event took place during the afternoon hours of Sunday, 27 June 2004 when localized flash flooding occurred at some places in the foothills west of Denver. The storms responsible for this flooding were located over complex, elevated terrain where ground clutter often contaminates the basic radar data. Ground clutter from the foothills terrain during the 27 June flooding event is apparent in the reflectivity field shown in Fig. 6. The differential reflectivity (Z_{dr}) data from this same PPI scan are presented in Fig. 7. The spatial variability of the Z_{dr} pattern is visibly greater in the clutter returns as compared to the thunderstorm rain echoes. Giuli et al. (1991) have found that the magnitude of the standard deviation of Z_{dr} over nine gate regions (3 gates in range by 3 beams in azimuth) can be used to differentiate between ground clutter and rain echoes. During 2004, CSU-CHILL computer scientist Jochen Deyke added the Z_{dr} standard deviation calculation to the radar display and data recording systems. Figure 8 shows the reflectivity field after an upper limit threshold on the Z_{dr} standard deviation has been applied. The imposition of this threshold (in addition to the standard Normalized Coherent Power (NCP) threshold) has removed much of the ground clutter contamination. The impact of this method of ground clutter removal on the CSU-CHILL rainfall estimates during the 27 June 2004 heavy rain event is being investigated.

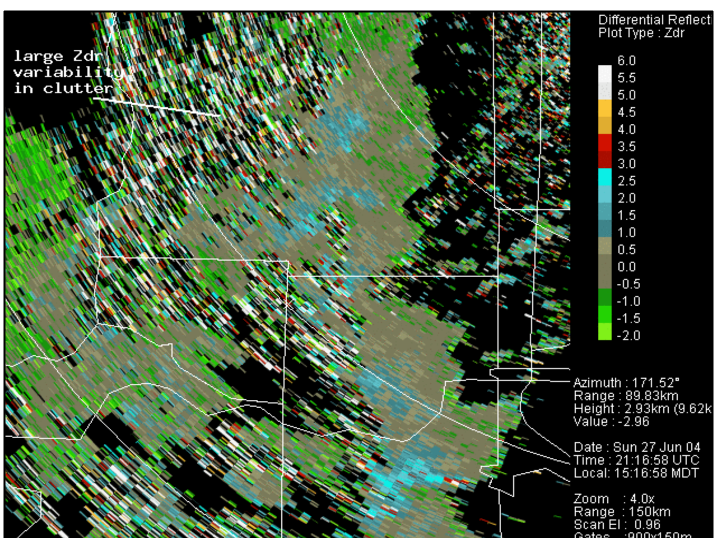


Fig 7. As in 6 except the displayed field differential reflectivity (Zdr).

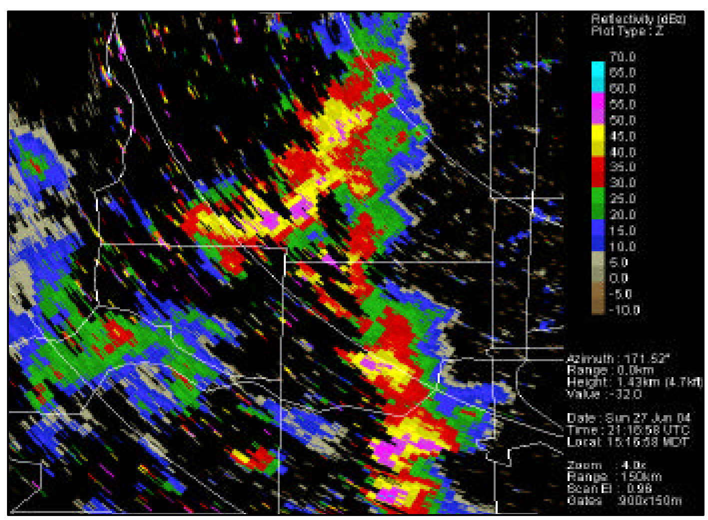


Fig 8. As in 6 except an additional threshold based on the spatial standard deviation of the Z_{dr} field has been imposed to reduce ground clutter contamination.

Chill Facility Developments *(by David Brunkow, Senior Engineer)*

New Antenna

Preparations for the new antenna system were well underway during 2004. All of the components for the servo drive upgrade are on hand and are being assembled and tested. These include more powerful motors, robust servo drive amplifiers, and a dedicated motion control computer. These components will soon be mounted on the pedestal. This minimizes the number of slip rings required for the system. Every component of the new system is of decade(s) newer design than those being replaced, which should provide improved reliability on the antenna drive system. The plan is to test the new system for several months before the new antenna is delivered in summer of 2005.

Parallel Receiver

The parallel receiver is a second receive channel that has been added to the CHILL radar. The 10 MHz IF signals from the two receiver channels were split to feed both the Lassen DRX signal processors, and an off-the-shelf digital receiver board (the ICS-554). New printed circuit cards were developed to produce stable clock, trigger, and status signals for the new receiver. These interfaces included several CPLD (complex programmable logic devices) to allow for easier modifications to the system as new needs arise. One of these is decoding the serial AZ/EL angles to be ingested by the Linux computer system which houses the ICS-554 digitizer. The new digitizer uses a 14 bit A/D converter. Although there is just one converter per receiver, its 14 bits will provide over 80 dB useful dynamic range. We plan to move the ICS-554 to the Pawnee Radar next summer, where it will become the primary signal processor for that radar. To be more precise, the ICS-554 will produce the I/Q time series which are passed along to Linux compute servers that perform the rest of the signal processing. The Nunn Telephone Company is testing a new DSL service which should provide economical internet access to the Pawnee radar site. This will be used to provide moment data from the Pawnee radar to campus for applications such as the near-real-time multiple Doppler analyses.

Jim George is a new graduate student in CSU's Electrical & Computer Engineering program whose work is focused on signal processing. He is currently working on developing and improving the parallel receiver system.

Development of the New CSU-CHILL Radar Antenna *(by Prof. V. N. Bringi & Yanting Wang)*

Major progress has been achieved in the development of the new dual-offset Gregorian antenna for the CSU-CHILL radar. On September 20-21, the project team from CSU and the manufacturer VertexRSI joined to hold the critical design review. The feed/OMT component (see Fig. 1) has been completed in production. The port-to-port isolation of OMT is better than 60 dB. The RF performance of the feed was tested in anechoic chamber that will satisfy the specification (see the 11th CSU-CHILL newsletter) for the on-axis level (<-50 dB on average). The off-axis cross-pol level is under question due to the limitation of the testing facility in VertexRSI. In order to improve the prediction of the antenna patterns, the feed/OMT will be delivered to Ball Aerospace for further testing.

(Continued on page 6)

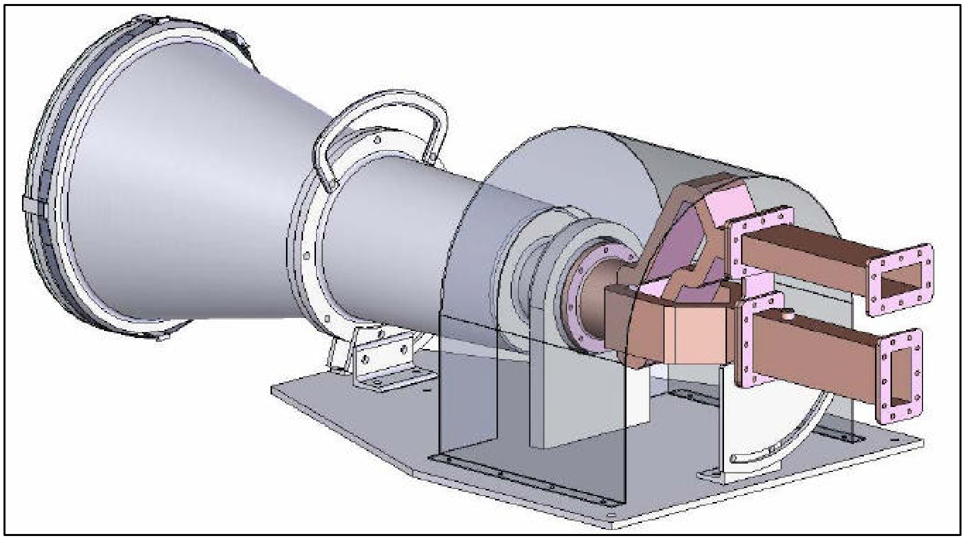


Fig. 1. The perspective view of the feed/OMT system.

Development of the New CSU-CHILL Radar Antenna *(continued)*

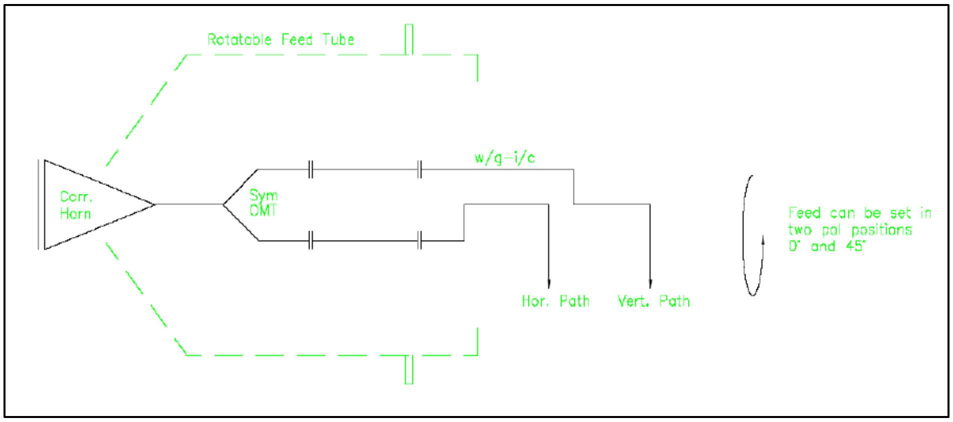


Fig. 3. The 2-port linear polarization feed system.

The design of the main reflector, which is composed of a number of panels (as shown in Fig. 2), has been finalized with a surface tolerance (RMS) of 0.020 inch expected. Applying the measured primary patterns for the feed, the antenna patterns of the whole dual-offset system are simulated and compared to the specification. The feed can be rotated to the 45/135 degree planes such that the new radar system can work in slant 45/135 degree linear polarization basis (see the diagram shown in Fig. 3). Structural analysis has also been performed under the worst-case operating and non-operating conditions based on a computerized finite element model.

The structural view of the new antenna is illustrated in Fig. 4. Deflections of the antenna, maximum member stresses, and margins of safety for materials were calculated and compared against the required limits. It is found that the antenna will survive the maximum design wind speed plus gravity loads and the acceleration forces plus gravity without permanent damage. A detailed test plan has been drafted and checked to be consistent with the specifications. The new antenna is scheduled to be delivered in spring 2005.

It had been shown before by the Radar and Communication Group at CSU that with the availability of full polarimetric covariance matrix, the radar measurement in linear polarization basis is equivalent to that obtained in circular polarization for representing the particle orientation information. Based on the model of precipitation medium that is composed of mutually independent size, shape and orientation distributions, simple manipulation has demonstrated that the orientation parameters can be retrieved from the linear polarimetric covariance matrix. With investigation of the polarimetric observation from the CSU-CHILL radar for different precipitation events, relations between the polarimetric radar observables and the underlying physical properties are explored for improving hydrometeor type classification. The radar reflectivity Z_H is found to act as an important dimension in classification because the change in Z_H due to the orientation distribution is fairly small compared to the dynamic range of intrinsic Z_H. Another important dimension is attributed to the co-polar correlation coefficient r_{co}, which can be biased by less than 20% only if the intrinsic correlation

(Continued on page 7)

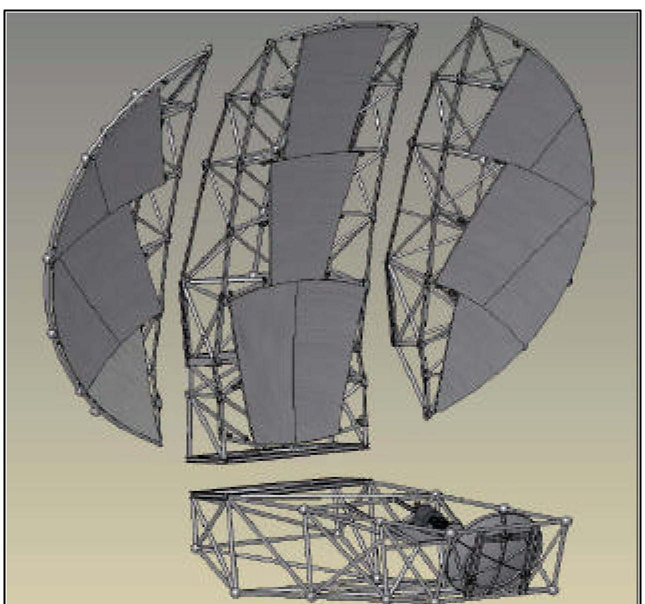


Fig. 2. The assembly diagram of the main reflector.

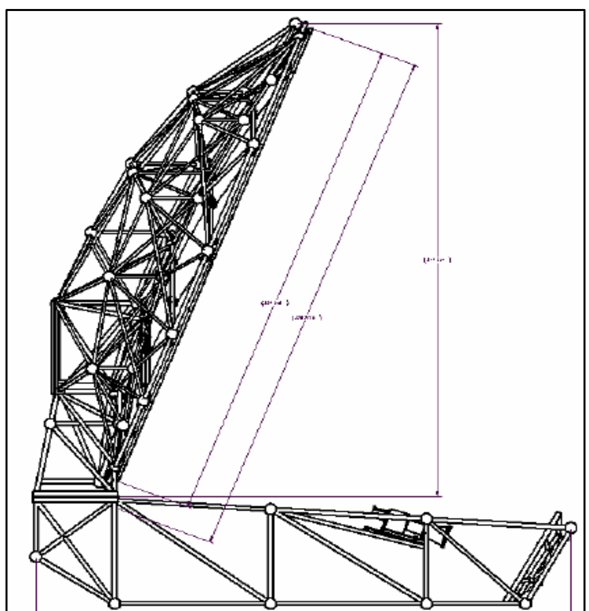


Fig. 4. The structural diagram of the new antenna system.

Development of the New CSU-CHILL Radar Antenna *(continued)*

is very low and the dispersion of orientation is very wide (the latter features with low r_4). However, if the orientation factors are significant, the incurred bias on the differential reflectivity Z_{DR} could be as large as several dB, e.g., when the mean canting angle $ß_0$ is far off from zero or the orientation is nearly isotropic. More importantly, *LDR* reflects the most of ambiguity suffered by linear polarimetric radar measurement as it is strongly related to both the orientation distribution and shape distribution. For example, *LDR* can increase dramatically with high degree of oblateness, low correlation, non-zero canting angle and/or random orientation. *CDR* is found to generally have a correspondence with Z_{DR} but has significant dependency on the correlation even though it is independent of the orientation distribution. Statistics of the estimated mean canting angle over some typical storms show that the mean canting angle is close to zero in general (see Fig. 5). As a result, the Z_{DR} bias would be less than a few tenths of a dB, and the pair of Z_H and Z_{DR} can still act as a good indicator of the precipitation types (see Fig. 6 for an example). The estimated orientation dispersion r_4 can resolve much of the ambiguity in the use of *LDR* to represent orientation information. Figure 7 shows that better alignment of orientation is always expected for raindrops with higher degree of oblateness. Besides, the ice particles aloft are found to have lower r_4 compared to the melted drops or wet particles at lower altitudes. *CDR* can provide more insight on the precipitation properties when it is considered along with other polarimetric observables such as Z_{DR} and r_{co}. Note the large values of *CDR* for both large size raindrops and wet hailstones in Fig. 8. In addition to the improvement on the qualitative studies of the precipitation medium, it is also shown that the rainfall estimation, using a $R\text{-}Z_H/Z_{DR}$ relation, can be fine-tuned to account for a nearly 5% bias due to orientation distribution with respect to r_4 of 0.9.

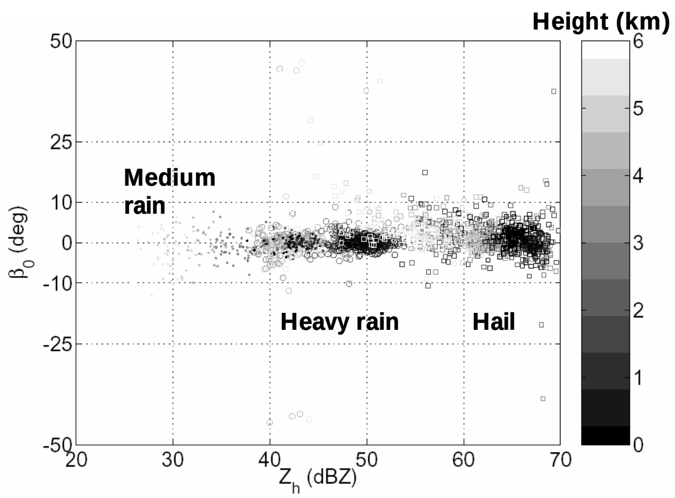


Fig. 5. The scattergram of estimated mean canting angle for different precipitation types.

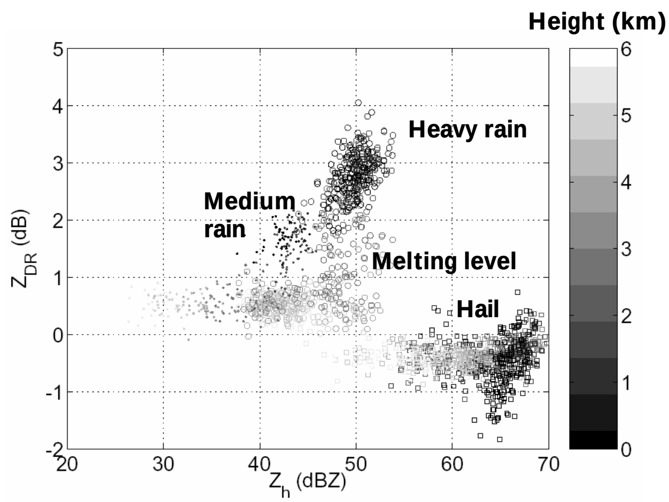


Fig. 6. The scattergram of Z_{DR} versus Z_H for different precipitation types.

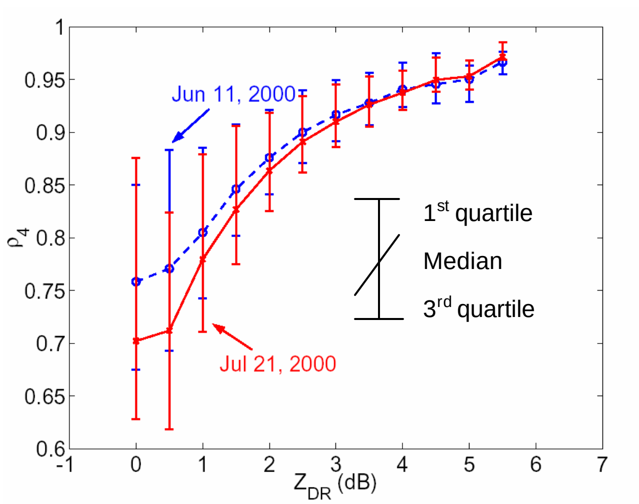


Fig. 7. The statistics r_4 of versus Z_{DR} for raindrops.

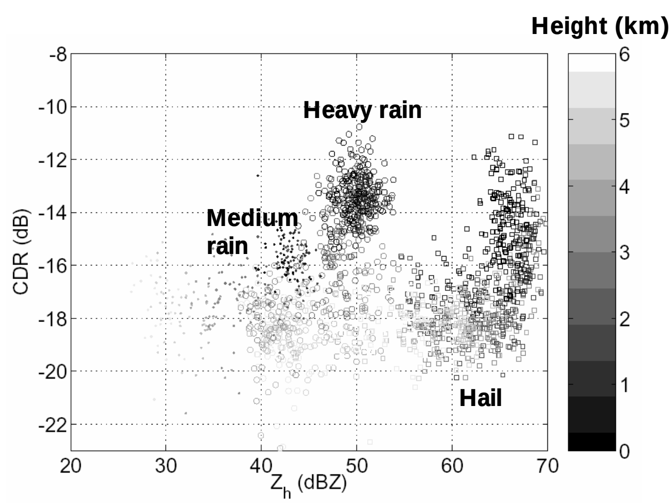


Fig. 8. The scattergram of *CDR* versus Z_H for different precipitation types.

Research Experience for Undergraduates Program, 2004

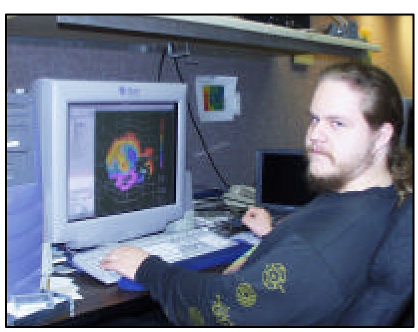
(by Prof. V. Chandrasekar and Erich Heffner)

REU Class of 2004 (from left to right:): James Golden, Miguel Galvez, Michael Albertus, Rebecca Adams, Yaritza Mejias-Rolon, Danny Bynum, Michael Yeung, and Alexander Deyke.

The 2004 REU students were chosen for this program through a highly competitive process in which only 6 out of 100 applicants were accepted. Two other students were admitted through the CASA Engineering Research Center applicant pool. The students came from all over the U.S., representing states from California to Pennsylvania and Michigan to Texas. The REU students arrived on campus in late May and stayed for 10 weeks to complete their research experience at CSU. While they were here, the students were exposed to the basics of radar engineering and radar meteorology, and then they focused in on their own individual areas of interest for their research topic. The students gave presentations on their weekly progress. They were given the opportunity to improve both their presentation skills and their technical writing skills; each student had to develop and present an interim and final report that provided an in-depth description of his or her focused research. Some of them attended Graduate Education Workshops. The REU students were also exposed to some local industry through a guided tour of the Ponnequin Wind Facility, one of the plants providing power for Xcel Energy.

The REU students were involved in a variety of radar engineering projects during the summer months. Rebecca Adams worked on an analysis of correcting reflectivity for attenuation with data collected by the TRMM Precipitation Radar. Michael Albertus examined X-band signal attenuation. Danny Bynum's project involved working with the new parallel digital receiver that was installed at the CSU-CHILL Radar Facility, and benchmarking it against the existing DRX receiver. Alexander Deyke implemented a proxy server with the VCHILL server, which increased the abilities of the VCHILL server to supply other types of data. James Golden compared the performance of filters for clutter filtering. Michael Yeung dealt with the accurate recovery of various spectral moments in the presence of range ambiguities. Yaritza Mejias-Rolon and Miguel Galvez were involved with the 2-D Video Disdrometer. Miguel implemented a portable point-to-point wireless communication network bridge for the remote collection and analysis of data obtained with the 2-D VD.

Most of the 2004 REU students have expressed intentions of pursuing graduate education or applied work in radar research or related areas. Alexander Deyke has joined the CSU-CHILL Radar Facility as a Research Associate working with the VCHILL project. Miguel Galvez is also working at CHILL as an hourly student helping to prepare the facility for the new antenna upgrade. Some of the students have applied to top graduate schools such as Harvard, MIT, and UC Berkley (based on the references requested). The students reported that the experiences they gained during the REU program have been a valuable asset to both their academic and career goals.



Miguel Galvez (left) and Jochen Deyke (right) are both employed at the CSU-CHILL Radar Facility.

For information on the REU 2004 summer program contact access the following website:

http://www.engr.colostate.edu/ece/www_research/reu_chill.shtml

The NASA Front Range Pilot Project: Research and Development for the Global Precipitation Mission's Ground Validation *(by Drs. Steve Nesbitt and Rob Cifelli)*

NASA's Global Precipitation Mission (GPM) satellite is set to launch near the end of the decade, however work is underway here along the Front Range to develop ground validation (GV) instrumentation and methodology for the project's continental GV sites. The Front Range Pilot Project (FRPP) was conducted by scientists from the Atmospheric Science and Electrical and Computer Engineering departments at Colorado State University, NOAA's Environmental Technology Laboratories (ETL) and Aeronomy Laboratory (AL) and the University of Colorado at Boulder (CU) during May-July 2004. Table 1 shows a full list of project participants.

Table 1: FRPP Participants

Organization	Participants
CSU – Atmospheric Science	Steven Rutledge Robert Cifelli Stephen Nesbitt Timothy Lang
CSU – Electrical and Computer Engineering	V. Bringi V. Chandrasekar
CSU – CHILL National Radar Facility	Patrick Kennedy David Brunkow Robert Bowie
NOAA – AL	Kenneth Gage Christopher Williams*
NOAA – ETL	Brooks Martner* Sergey Matrosov*

*Also affiliated with CIRES – University of Colorado at Boulder

Figure 1 shows a map of the instrument locations during the FRPP. CSU-CHILL (with its dual-polarization S-Band capability) was operated on a "target of opportunity" basis along with ETL's X-Band dual-polarization radar. The X-Band radar was located near Erie, Colorado, and CHILL and X-Band were operated on days where precipitation was possible within X-Band's 38 km range. Two primary ground sites were maintained within X-Band's range: one at the NOAA Boulder Atmospheric Observatory (BAO) southwest of Erie and NOAA/CU Platteville Atmospheric Observatory (PLT). Both of these sites were equipped with S-Band, 915, and 449 MHz precipitation/wind profilers, Joss-Waldvogel (J-W) raindrop disdrometers, tipping bucket rain gauges from AL and ETL. In addition, V. Bringi and colleagues at CSU operated their 2-D video disdrometer (2DVD) during the experiment.

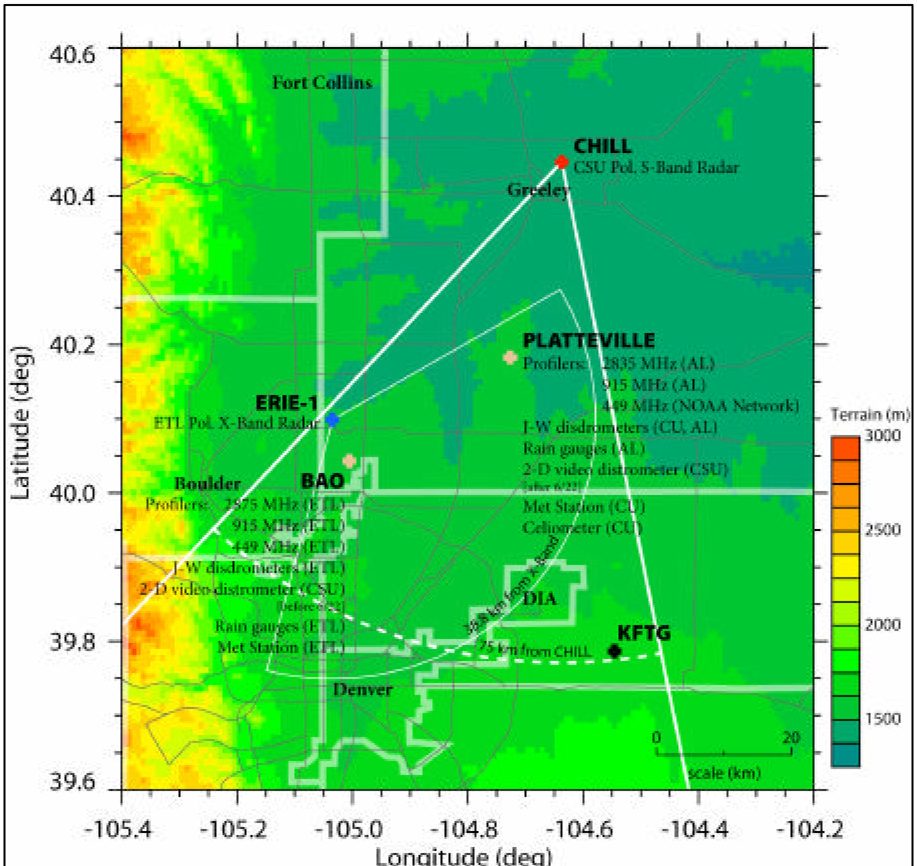


Fig. 1. Map of the study areas showing the locations of experiment sites (bold plus signs) with instrument list, radar scan coverage areas (white lines), terrain (shaded), principal highways (grey lines), and county boundaries (thick opaque lines) also shown. KFTG is the Denver NEXRAD radar site.

In all, 21 cases were collected in precipitation regimes ranging from light stratiform drizzle to supercell thunderstorms, providing an excellent database of precipitation observations to examine. The FRPP was a demonstration of three facets of GPM GV:

1. **Dual-wavelength radar DSD and rain rate estimate intercomparison, validation, and error characterization.** Demonstration of dual-wavelength polarimetric radar network for creating rain estimates and documenting associated errors. The X-Band radar's improved phase sensitivity in light rain was evaluated against the S-Band radar's performance in such conditions. The S-Band's known insensitivity to attenuation in heavy rain and mixtures of rain and precipitation ice was used to evaluate the X-Band radar's ability to correct for attenuation using its specific differential phase measurements, and thus diagnose rainfall in these situations.

2. **Profiler demonstration in the supersite concept.** Selection of UHF profiler frequencies that will best complement S-Band profiler measurements at a midlatitude site

(Continued on page 10)

The NASA Front Range Pilot Project: Research and Development for the Global Precipitation Mission's Ground Validation *(continued)*

and allow for the most accurate retrieval of drop size distribution characteristics as a further goal of the FRPP. A ancillary goal was to perform quantitative comparisons of drop size distribution (DSD) characteristics between the profilers and scanning radars in order to evaluate assumptions in the scanning radar retrieval technique (e.g., equilibrium drop shape relationship) as well as spatial variability of the DSD.

3. **Rain rate and drop size distribution characterization in the context of supersite observations, rainfall regimes.** The Pilot Project sought to demonstrate the complementary role played by rain gauges and surface disdrometers (both 2DVD and JWD types) in determining the error characteristics of multi-frequency profiler DSD estimates and dual-frequency radar DSD and rain estimates.

Based upon preliminary analysis of the FRPP data set, we are able to make several initial recommendations for GPM-GV planning. It was shown that under high rain rate conditions (rates of several tens of mm hr^{-1}) X-Band signals are subject to severe attenuation losses that are likely not correctable using differential phase techniques. Figure 2a shows a photograph from a supercell storm near PLT as seen from the X-Band radar at Erie. A comparison of Figs. 2b and c shows X-Band attenuation-corrected reflectivity (using differential phase to correct for attenuation) does not adequately correct for attenuation losses in such heavy rain and hail situations. X-Band polarimetric radar is capable of estimating rain rates as low as ~2 mm hr^{-1} (see Fig. 3 for an example of X-Band K_{dp} reliably estimating light precipitation in (a), while panel (b) shows a comparison of rain accumulation from all instrumentation at BAO). For this case, reliable polarimetric-based rain estimates at S-band begin at 5-7 mm hr^{-1}; at rain rates less than this, S-band polarimetric measurements are noisy and rainfall must be determined from the conventional Z-R estimator, which can be subject to significant error due to variability in the drop size distribution and calibration uncertainties. Therefore, S-Band and X-Band form a complimentary combination that can apply the more accurate polarimetric rain estimators to a wider range of rainfall rates than either could handle alone.

We also offer the recommendation that two vertically pointing profilers operating at different frequencies be collocated at the GPM GV sites. The profilers, operating at 449 MHz (UHF) and 2835 MHz (S-band), would be used to provide independent measurements of the drop size distribution (DSD) from near the surface to just below the freezing level. The UHF profiler operating at 449 MHz is sensitive to Bragg scattering and would be used to estimate the vertical air motion. This information is then used to deconvolve the clear air and hydrometeor components of the S-band profiler Doppler spectra. Algorithms to combine the UHF and S-band measurements and retrieve DSD characteristics have been developed by Chris Williams at the NOAA AL. 2-D Video and Joss-Waldvogel momentum disdrometers proved to be invaluable in characterizing calibration and algorithm uncertainty in all radar, profiler measurements made in the Pilot Project. See Fig. 4 for an example of mass-weighted mean diameter D_m retrievals from the scanning and profiling

(Continued on page 11)

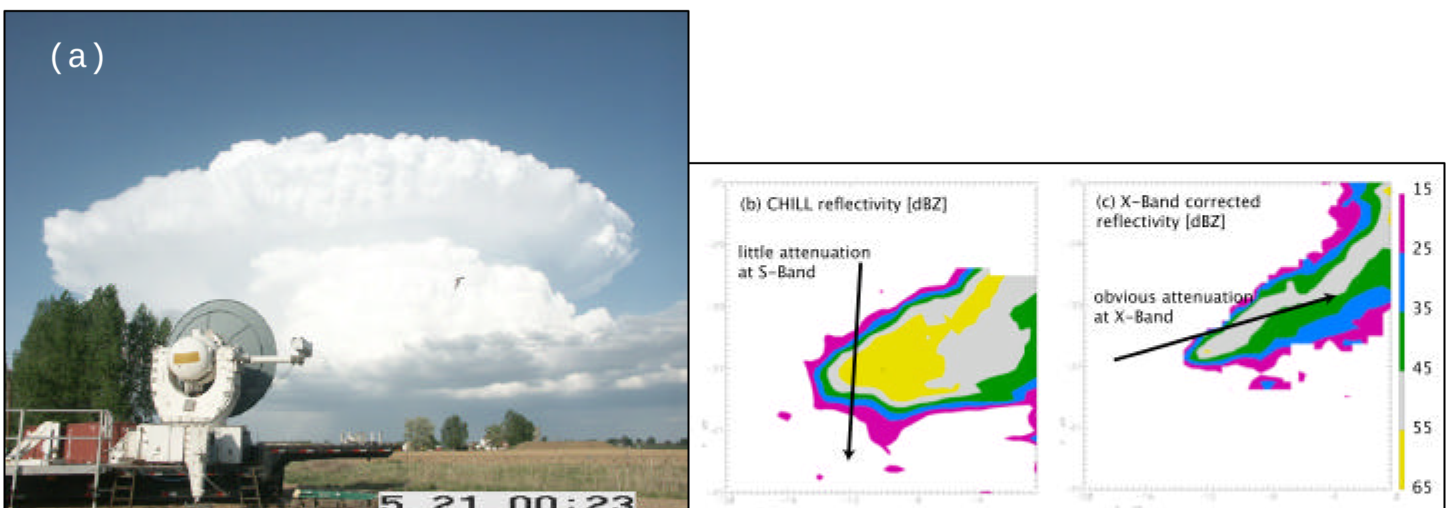


Fig. 2. (a) Photograph of X-Band radar scanning a supercell to the northeast near PLT at 00:23 UTC 21 May 2004. (Photo courtesy of Brooks Martner, NOAA-ETL). At 0023 UTC: (b) CHILL (S-Band) relatively unattenuated reflectivity (dBZ) and (c) X-Band attenuation-corrected reflectivity (dBZ). The arrows indicate approximate beam propagation paths.

The NASA Front Range Pilot Project: Research and Development for the Global Precipitation Mission's Ground Validation *(continued)*

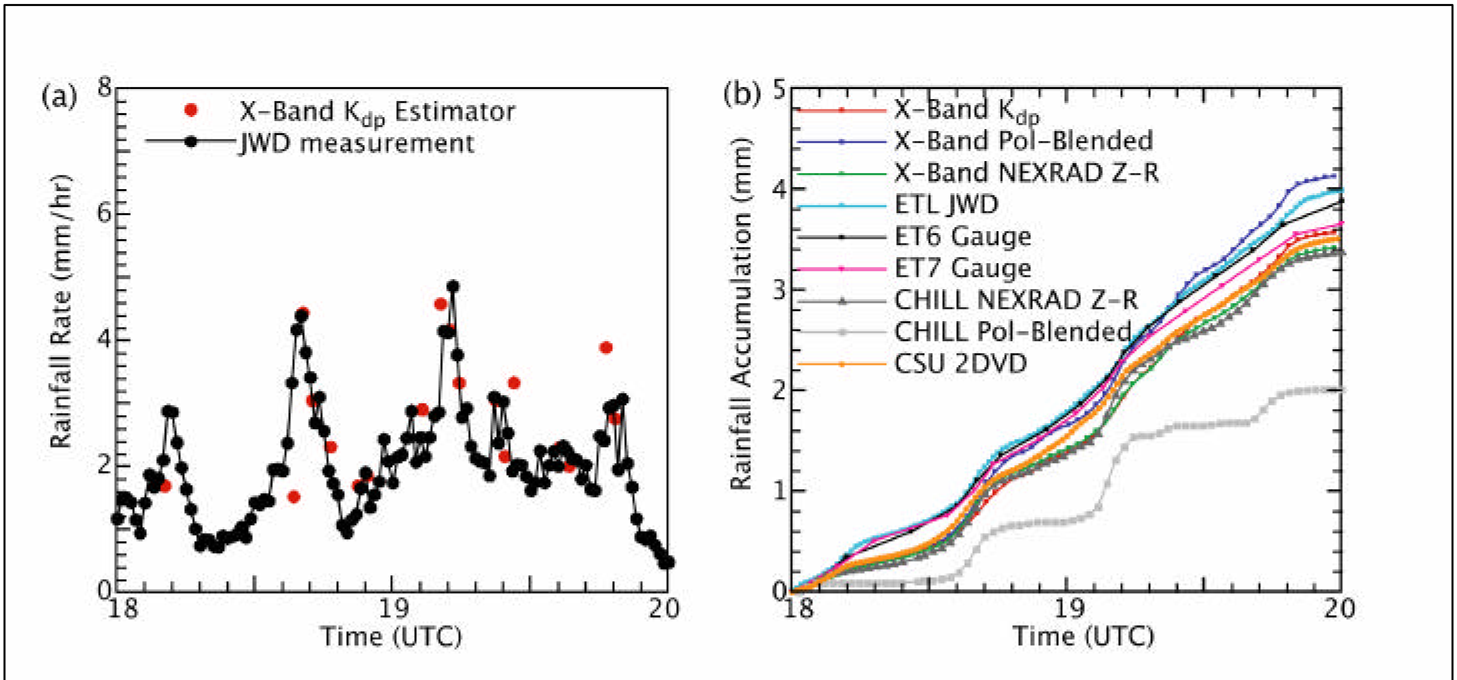


Fig. 3. For 21 June 2004: (a) rainfall rates from JWD and X-band K_{dp}-based estimators, (b) rainfall accumulations from different radar estimators and ground-based instruments.

radars as well as the 2DVD and JW disdrometers on 15-16 July at PLT.

Future research to be carried out in FY05 will further examine the data collected during the FRPP and to solidify our planning and recommendations for the continental Supersite deployment. Specific areas of research include: developing error statistics for rainfall rate and microphysical retrievals from the FRPP in the context of precipitation "regimes", which can be identified by the GPM satellites and ancillary observations (such as NWP model analyses and other satellite retrievals of the atmospheric state) as well as further design and planning of the Supersite scientific and infrastructural capabilities.

***Acknowledgments**: Thanks to the TRMM/GPM Office, Dr. Richard J. Lawrence and Dr. Ramesh Kakar, at NASA Headquarters for providing base funding for the FRPP, as well as CSU's Paul Hein and Margi Cech for computer and administrative support, respectively.*

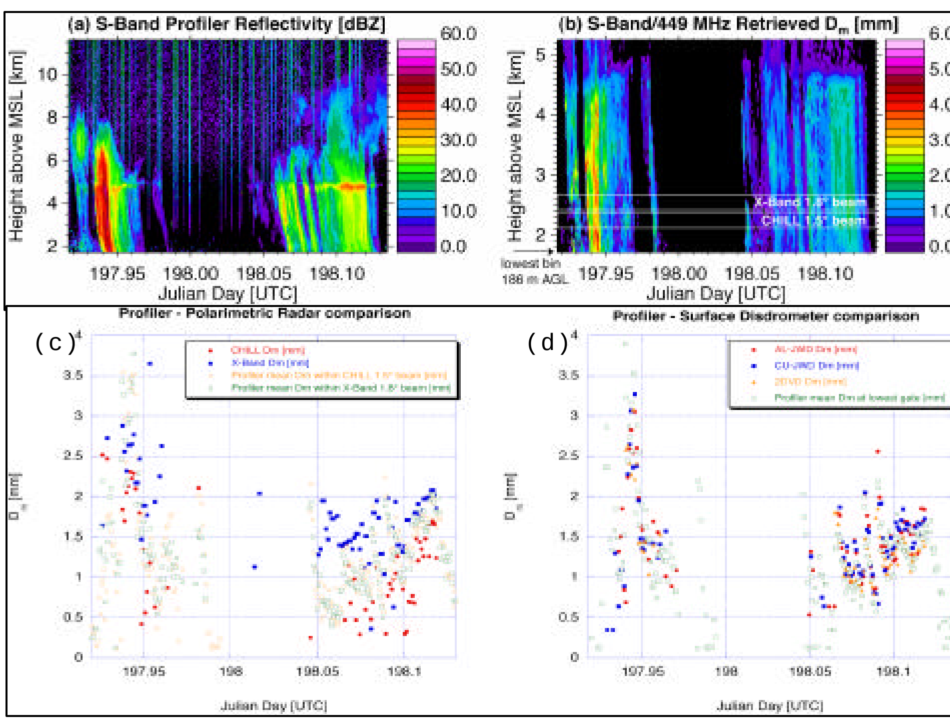


Fig. 4. For 15-16 July 2004: (a) Time series of the vertical profile of measured equivalent reflectivity [dBZ_e] from the NOAA-AL S-Band profiler. (b) Time-series of the vertical profile of S-Band/449 MHz retrieved mass-weighted mean diameter D_m. The sample volume of the scanning radars is denoted by the white rectangles. (c) Time series of D_m estimates from the polarimetric scanning radars and average profiler-retrieved values within the scanning radars' sample volume. (d) Time series of D_m estimates from the surface disdrometers and profiler-retrieved values at 186 m AGL.

CSU-CHILL Outreach Activities *(by Margi Cech)*

In addition to the many research activities pursued throughout the year, the CSU-CHILL Radar Facility also performs educational and scientific outreach activities as part of its mission. Some of these events, such as support for the REU program, have been described elsewhere in this newsletter. Other outreach activities conducted throughout the year include:

VCHILL Activities

In May we conducted a live VCHILL tour for 15 students in Prof. Sandra Yuter's instrumentation class at the University of Washington. In October, Prof. Chandrasekar conducted live, remote data display demonstrations of the VCHILL system from Estes Park, CO, and from the Engineering building on CSU's main campus, for CASA workshop attendees. Then in November, a live VCHILL tour was conducted for 8 graduate students in Prof. Larry Carey's mesoscale meteorology class at Texas A & M.

University Classes

In February, 16 CSU students enrolled in Prof. Chandrasekar's radar design class toured the CHILL facility. Also in February, CSU's Prof. Steven Rutledge hosted 17 graduate students from his AT741 Radar Meteorology class. Thirty undergraduate students from the University of Northern Colorado's Earth Science program visited the facility in April. During June, Dr. Gene Mueller, retired Radar Engineer, presented 2 lectures on radar engineering at the facility for CSU's new REU students.

Other Collaborations

- January - Cathy Rubin from University of Massachusetts, CASA project
- February - ATS Ph.D. student Sarah Tessendorf hosted a tour of the CHILL facility for her mentoring student and her student's father. At the time, this student attended the 6th grade at Johnson Elementary School in Ft. Collins
- April - UF data files from the STEPS2000 experiment were sent to a University of Alabama-Huntsville graduate student, who will also be working on UF files from the STERAO project
- October - the facility hosted an Open House for 12 CASA Workshop attendees
- November - data and figures depicting CHILL research and operations were included in a CoCoRaHS and GLOBE-sponsored NE BOCES (Northeast Colorado Board of Cooperative Educational Services) Workshop, "Using Radar and Satellite Information to Improve Weather Forecasts," for 25 K-12 teachers and students in Haxtun, CO
- December - University of Massachusetts radar engineers visited the CHILL facility to determine how the CASA prototype radar could be temporarily installed at the site for "certification testing" to be conducted in spring of 2005.

Prof. V. Chandrasekar (far right) hosts a tour of the CSU-CHILL Radar Facility for attendees of an October CASA Workshop.

Publications (January 2004 to December 2004)

Baldini, L., E. Gorgucci, and V. Chandrasekar. 2004: Hydrometeor Classification Methodology for C-band Polarimetric Radars, *Proceedings of ERAD (2004), pp. 62 – 66.*

Bharadwaj, N., 2004: Range-velocity Ambiguity Mitigation for Dual Polarized Weather Radars. M.S. Thesis, Electrical and Computer Engineering, Colorado State University (Advisor: V. Chandrasekar).

Bringi, V. N., T. Tang, and V. Chandrasekar, 2004: Evaluation of a New Polarimetrically Based Z-R Relation, *J. Atmos. Ocean. Tech.*, **21**, 612-623.

Chandrasekar, V. , E. Gorgucci, S. Lim, and L. Baldini. 2004: Simulation of X-band Radar Observation of Precipitation from S-band Measurements, *Proceedings of Geoscience and Remote Sensing Symposium, 2004 IEEE International. Volume:* 4, pp. 2752 – 2755.

Chandrasekar, V., 2004: The Role of Dual-Polarization Radars for Monitoring Extreme Precipitation Events, *6th Plinius conference on Mediterranean storms.*

Chandrasekar, V., and V. N. Bringi. 2004: Dual Polarization Radar Estimates of Rainfall: Recent Advances, *6th International Symposium on Hydrological Applications of Weather Radar,* Melbourne, Australia.

Choudhury, S., 2004: Wideband Reception and Processing for Polarimetric Radars. M.S. Thesis, Electrical and Computer Engineering, Colorado State University (Advisor: V. Chandrasekar).

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

Cifelli, R., P. C. Kennedy, S. A. Rutledge, L. D. Carey, C. Gimmestad, and D. Barjenbruch, 2004: Comparison of Accumulated Rainfall in NorthEast Colorado Using a Blended Polarimetric and NEXRAD Z-R Technique. AGU Joint Assembly Meeting, Montreal, Canada, 17-21 May 2004.

Dolan, B., 2004: An Integrated Display and Analysis Tool for Multi-Variable Radar Data. M.S. Thesis, Atmospheric Science, Colorado State University (Advisor: Prof. S. A. Rutledge).

(Continued on page 13)

Publications *(continued)*

Lang, T. J., S. A. Rutledge, and J. L. Stith, 2004: Observations of Quasi-Symmetric Echo Patterns in Clear Air with the CSU-CHILL Polarimetric Radar. *Journal of Atmospheric and Oceanic Technology*, **21**, 1182-1189.

Lang, T. J., S. A. Rutledge, and K. C. Wiens , 2004: Origins of Positive Cloud-to-Ground Lightning Flashes in the Stratiform Region of a Mesoscale Convective System. *Geophysical Research Letters*, **31**, L10105, 10.1029/2004GL019823.

Lang, T. J., J. Miller, M. Weisman, S. A. Rutledge, L. J. Barker, V. N. Bringi, V. Chandrasekar, A. G. Detwiler, N. J. Doesken, J. Helsdon, C. Knight, P. Krehbiel, W. A. Lyons, CCM6, D. MacGorman, E. Rasmussen, W. Rison, W. D. Rust, R. Thomas, 2004: The Severe Thunderstorm Electrification and Precipitation Study (STEPS). *Bulletin of the American Meteorological Society*, **85**, 1107-1125.

Long, D., 2004: Evaluating the Use of Polarimetric Cloud Radars for Studying Winter Storms. M.S. Thesis, Atmospheric Science, Colorado State University (Advisor: Prof. S. A. Rutledge).

Moisseev, D., C. Unal, H. Russchenberg, and V. Chandrasekar, 2004: Radar Observations of Snow Above the Melting Layer, *Proceedings of ERAD (2004), pp. 407 – 411.*

Moisseev, D., C. Unal, H. Russchenberg, and V. Chandrasekar. 2004: Dual Polarization Spectral Retrievals of the Effective Raindrop Shapes, *Proceedings of ERAD (2004), pp. 412 – 415.*

Rutledge, S. A., R. Cifelli, T. J. Lang, and S. W. Nesbitt, 2004: The Front Range Pilot Project for GPM. The 2nd TRMM International Science Conference, Nara, JAPAN, 6-10 September, 2004.

Tessendorf, S. A., L. J. Miller, K. C. Wiens, and S. A. Rutledge, 2004: The 29 June 2000 Supercell Observed During STEPS. Part I: Kinematics and Microphysics. *Journal of the Atmospheric Sciences*, In review.

Tessendorf, S. A., K. C. Wiens, and S. A. Rutledge, 2004: Lightning and Radar Observations of Three Storms Observed During STEPS. AMS 22nd Conference on Severe Local Storms, Hyannis, MA, 4-8 October, 2004

Wang, Y., 2004: Studies of the Polarimetric Covariance Matrix Using the CSU-CHILL Radar. Ph.D. Dissertation, Electrical and Computer Engineering, Colorado State University (Advisor: Prof. V. N. Bringi).

Wiens, K. C., S. A. Rutledge, and S. A. Tessendorf, 2004: The 29 June 2000 Supercell Observed During STEPS. Part II: Lightning and Charge Structure. *Journal of the Atmospheric Sciences*, In review.

Acknowledgements:

The CSU-CHILL Radar Facility is supported by NSF Cooperative Agreement ATM-0118021, and supplemented by cost sharing funds from Colorado State University.