ACTIVITIES & FINDINGS
CSU-CHILL RADAR FACILITY

RESEARCH AND EDUCATION:

YEAR 1: 11/15/2011 – 10/31/2012

Research project support:

NSF-funded projects:

1.) **Deep Convective Clouds and Chemistry Experiment** (DC3; M. Barth, W. Brune, C. Cantrell and S. Rutledge; 14 May – 30 June, 2012).

The DC3 project was a major field project designed to examine the various ways in which deep, midlatitude convective cloud systems impact the composition and chemistry of the upper troposphere / lower stratosphere levels. The in-situ chemistry measurements were made by three research aircraft: The NSF GV operated by NCAR, the NASA DC-8, and the DLR Falcon. To support research flights across a large fraction of the continental US, all of these project aircraft were based at Salina, KS.

The aircraft observations were coordinated with ground-based instrumentation centered in three different geographic regions: Northern Alabama, central / Western Oklahoma, and Northeastern Colorado. Each of these ground sites provided mobile sounding equipment, multiple Doppler weather radar networks to support the synthesis of three dimensional airflow fields within the storms, and Lightning Mapping Array (LMA) networks to provide detailed measurements of the locations of lightning discharges in space and time. (The high temperatures in the lightning channels are critical to the evolution of various oxides of atmospheric nitrogen.)

Figure 1 shows the ground-based instrumentation configuration of the Northeastern Colorado DC3 site. Dual Doppler data collection was primarily done by the CSU-CHILL and Pawnee S-band radars. (The multiple Doppler coverage region was expanded using measurements provided by the neighboring WSR-88D radars.) A network of LMA stations distributed to optimize measurements in the CHILL – Pawnee dual Doppler area was installed by personnel from New Mexico Institute of Mining and Technology during the fall of 2011. (This LMA installation was left in place after DC3 and will become a permanently element in the northeastern Colorado region.)

The DC3 project data collection efforts were generally quite successful. The observations made in the Northeastern Colorado region will support several research initiatives into storm electrification and dynamics as well as upper air chemistry. (See Findings section for example DC3 data).

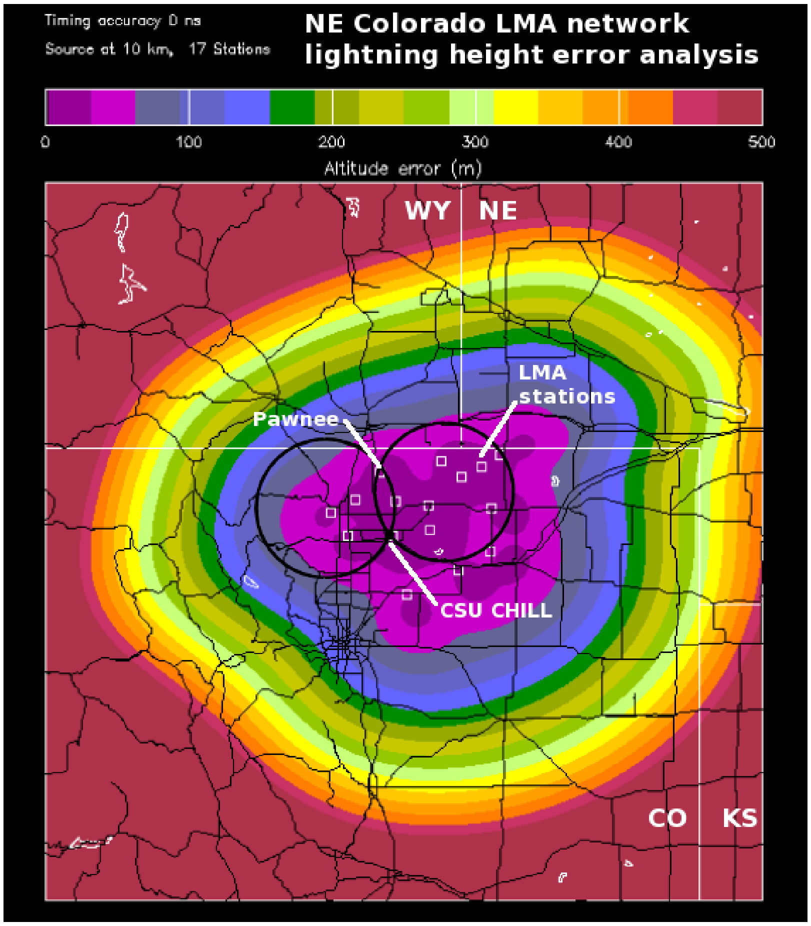

Figure 1: Northeastern Colorado fixed ground-based instrumentation for the DC3 project. Interlocking circles are the 30^{o} beam intersection angle lobes for the CSU-CHILL and Pawnee radar dual Doppler network. LMA stations are shown as open white boxes. Color fill is expected error (m) of the LMA measurements of lightning discharge heights.

2.) **Research Experience for Undergraduates 2012** (REU V. Chandrasekar May through July 2012).

Prof. V. Chandrasekar of the CSU Department of Electrical and Computer Engineering (ECE) conducted an eight week summer program that centered on the use of the CSU-CHILL radar facility to provide visiting students with direct experience in the conduct of research in the areas of both radar meteorology and electrical engineering. Six students, all from home institutions outside of CSU participated in the program; their majors included Electrical Engineering, Computer Science, and Meteorology. CHILL Facility staff provided the entire group with a tour of the radar and several introductory lectures on meteorological radar technology and data applications. Each student completed a research project under the guidance of mentors from the CHILL Facility and CSU Electrical and Computer Engineering (ECE) Department staff.

Figure 2: Members of the REU 2012 group (right) during the launch of an NCAR mobile radiosonde (MGAUS) from the CSU-CHILL radar site on 16 July 2012.

<u>20 hour projects:</u>

1.) **University of Iowa X-band radar tests** (W. Krajewski; 1 August – 14 August 2012).

The Civil and Environmental Engineering Department at the University of Iowa has recently acquired four transportable dual-polarization X-band weather radar systems which they plan to use for the remote sensing of rainfall. To verify the basic measurement capabilities of these radars, one of the units was installed adjacent to the CSU-CHILL radar in early August, 2012. Basic engineering characterizations of the Iowa radar's performance were done. Coordinated scans of precipitation echoes by the Iowa and CSU-CHILL radars were also done. Comparisons of the data collected by the Iowa system and the X-Band channel of the CSU-CHILL radar are currently in progress at both of the radar's host institutions.

Figure 3: University of Iowa portable X-Band radar installed just southeast of the CSU-CHILL radome at the start of a 20 hr project on 1 August 2012.

In-house Activities / Target of Opportunity Operations

During this reporting period, the dual frequency (simultaneous S and X-Band) capability became operational on the CSU-CHILL radar. Target of opportunity operations were conducted primarily to collect dual frequency data in a variety of meteorological conditions. A widespread snow event was observed in early February, 2012, and data from a number of heavy rain-producing thunderstorm events was collected starting in July, 2012. Data from the February event was analyzed as part of Elizabeth Thompson's M.S. thesis in ATS.

Key results from all of the above projects are in the Findings section.

Educational Activities:

- Prof. V. Chandrasekar used archived CSU-CHILL data and Facility tours in the teaching of ECE 742 (Topics in electromagnetics; Spring 2012) and in ECE 512 (Digital Signal Processing; Fall 2011).

- Three graduate students from ATS participated in data collection activities during DC3 providing them valuable hands-on radar experience.

- CSU-CHILL example data will be used in Prof. S.A. Rutledge's Fall, 2012 Cloud Physics course (ATS 620).

- Prof. W. Flynn is planning to bring here radar meteorology class at the University of Northern Colorado (Greeley) to visit the CSU-CHILL Facility in October, 2012.

- Virtual tours of the radar presented to remotely-located educational sites were conducted as follows:

1.) 17 February 2012: Prof. R. Rauber's radar meteorology class at the University of Illinois at Urbana-Champaign.

2.) 24 March 2012: Student AMS chapter meeting at Iowa State University.

3.) 12 April 2012: Prof. S. Yuter's remote sensing class at North Carolina State University.

4.) 23 June 2012: Prof. D. Moisseev and V. Chandrasekar's short course on polarimetric weather radar presented at the ERAD Conference, Toulouse, France (Fig. 4)

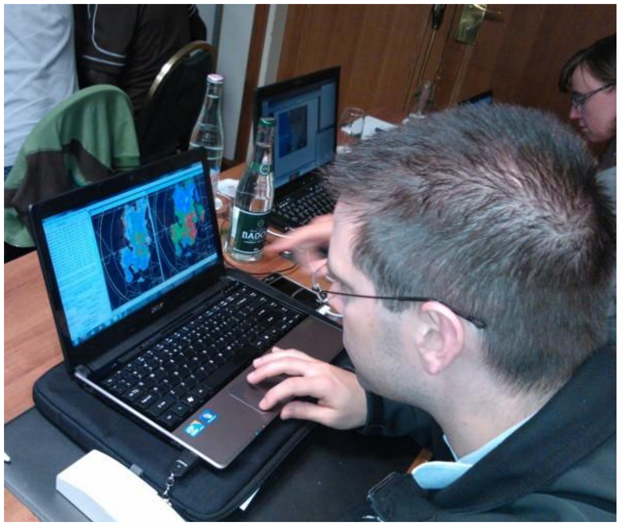

Figure 4: Students in the polarimetric radar short course taught at the ERAD conference in Toulouse, France using VCHILL to interact with educational examples from the CSU-CHILL Facility on-line data archives.

Outreach Activities:

1.) 18 June 2012: Demonstration of real time remote data display and radar control at the NSF Lower Atmosphere Observing Facilities user workshop at NCAR.

2.) 14 July 2012: Demonstration of real time remote data display and radar control at the CSU Department of Atmospheric Science as a part of the Department's 50th anniversary open house.

The production of monthly featured articles and featured images for dissemination on the Facility web page. These items provide educational examples of a variety of meteorological phenomena that have been identified in the data archives.

Year 1 Publications and Presentations 11/15/2011 – 10/31/2012:

Observations of Heavy Rainfall in a Post-wildfire Area using X-Band Polarimetric Radar, 2011: R. Cifelli, S. Matrosov, D. Gochis, P. Kennedy and J. Moody; 2011 Fall AGU Meeting, San Francisco, CA; 5-9 December, 2011.

FRONT: The Front Range Observational Network Testbed, 2012: J. Hubbert, P. C. Kennedy, V. Chandrasekar, S. Rutledge, W. C. Lee, V. Bringi, T. M. Weckwerth, J. Wilson, D. A. Brunkow, M. Dixon, J. George, E. Loew, J. Van Andel, A. Phinney, R. A. Rilling, and S. Ellis; 92nd Annual Meeting of the American Meteorological Society, New Orleans, LA, 22-26 January, 2012.

X-Band Addition to the CSU-CHILL Radar Facility, 2012: V. Chandrasekar, V.N. Bringi, D. Brunkow, F. Junyent, P. Kennedy, J. George, R. Bowie, and M. Galvez. The seventh European Conference on Radar and Meteorology in Meteorology and Hydrology (ERAD), Toulouse, France, 25-29 June, 2012.

FINDINGS:

YEAR 1: 11/15/2011-10/31/2012

NSF-funded projects:

DC3:

The CSU-CHILL user van served as the field operations center for the northeastern Colorado DC3 region. The radar scientist position was filled by personnel from the Prof. Rutledge's group in the CSU Atmospheric Science Department. A major activity of these radar scientists was the coordination of CSU-CHILL and Pawnee volume scans to support dual Doppler air motion syntheses of the targeted storms. Figure 5 shows an example dual Doppler horizontal airflow analysis obtained at the anvil level from an isolated storm located in the western CHILL – Pawnee dual Doppler load. The vector pattern contains divergence at the southwestern end of the storm where air rising in the updraft decelerates due to the increased static stability at the tropopause. The color fill indicates the magnitude of the horizontal air flow. Accelerated wind speeds are apparent as the southwesterly ambient flow deviates around the lower momentum air delivered by the updraft. Detailed airflow analyses of this type will be of use in understanding the evolution of the chemical species that were sampled in the anvil region on many DC3 flights.

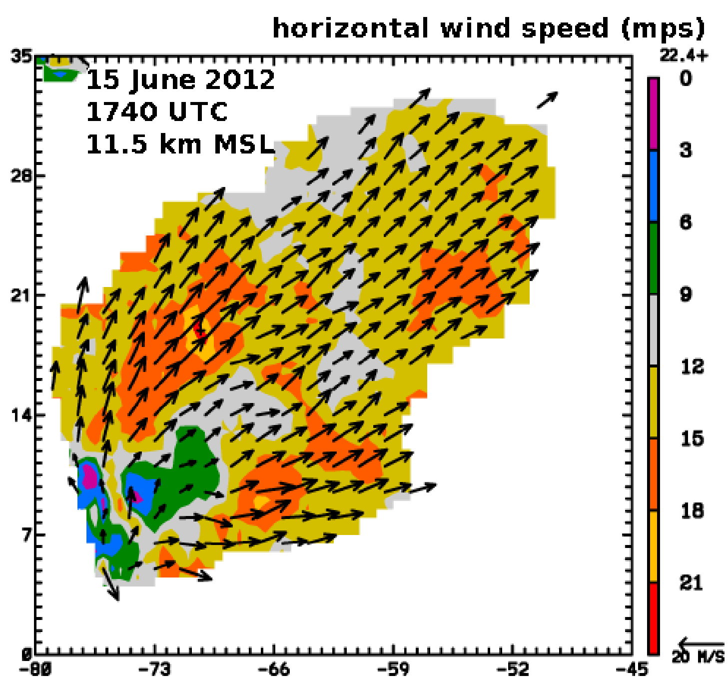

Figure 5: Earth-relative horizontal wind vectors at 11.5 km MSL synthesized from synchronized volume scan data collected by the CSU-CHILL and Pawnee radars during DC3. Color fill is the horizontal wind speed magnitude (ms^{-1}).

The LMA system detects the VHF impulses that are generated as lightning channels propagate through the atmosphere. Based on the varying arrival times of these impulses across the LMA station network, the three dimensional locations of the discharge source locations can be determined. The color codes in Fig. 6 indicate the density of discharge sources during a ten minute period starting at the time of the dual Doppler analysis in Fig. 5. An overhead plan view of the LMA data is shown in the lower left portion of the plot. The storm in the western lobe was electrically active at the time of the dual Doppler analysis. Projections of the discharge densities onto east-west and north-south vertical cross sections are shown along the upper and right portions of the plot respectively. The LMA's ability to provide high resolution, three dimensional mappings of lightning discharge locations is will provide a unique framework for the study of the atmospheric chemistry impacts of high temperature lightning channels. Relationships between other radar-detected storm characteristics, including dual-polarization data fields and LMA data sets are also an active area research in the DC3 program.

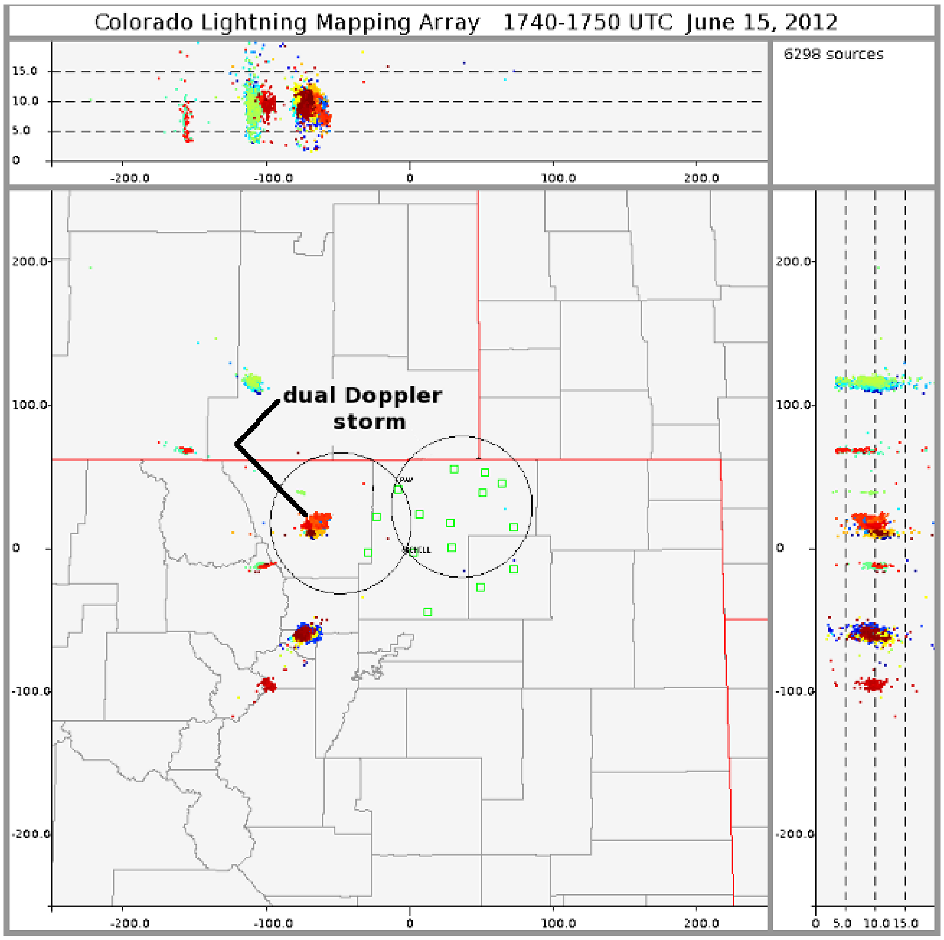

Figure 6: Lightning discharge point density observed by the Northeastern Colorado LMA network between 1740 and 1750 UTC on 15 June 2012 during the DC3 project.

- REU 2010: See Training and Development section

University of Iowa 20 hr project:

In August 2012, a transportable X-Band dual polarization radar that was recently acquired by the University of Iowa was brought to the CSU-CHILL site under the auspices of a 20hr project to characterize the new system's general performance. The radar was one of four identical units that the University of Iowa plans to use primarily in a networked configuration to assemble composited rainfall maps over targeted watersheds. Both engineering tests of the Iowa radar hardware (i.e. receiver bandpass and gain calibrations, antenna pointing accuracy, etc.) and meteorological observations done in coordination with CSU-CHILL were done. An example of basic reflectivity data collected by the Iowa radar in a PPI sweep through showers and thunderstorms is shown in Fig. 7. Staff members from the CSU Electrical and Computer Engineering and Atmospheric Science Departments are continuing more detailed analyses of the various data sets collected during this 20 hr project.

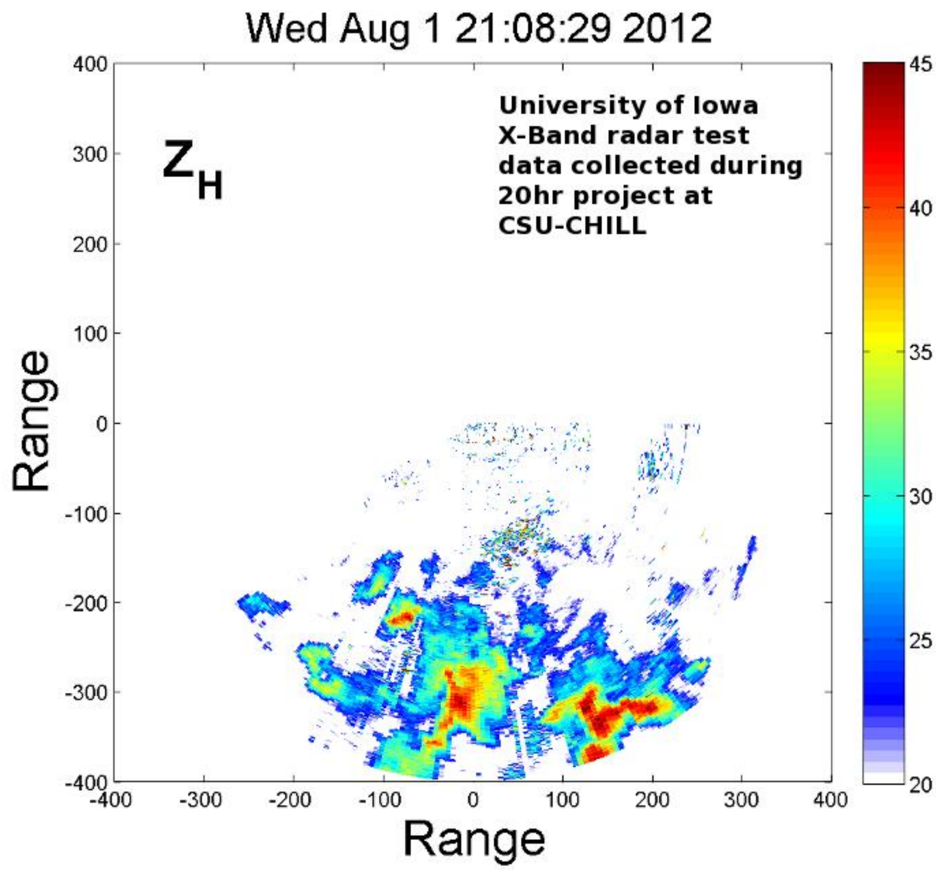

Figure 7: Example reflectivity data collected by the University of Iowa transportable X-Band radar following its initial set up at the CSU-CHILL radar site on 1 August 2012. (Image provided by Piotr Domaszczynski (NASA))

Target of Opportunity / Dual Freq test:

The dual frequency (9 GHz/X-band and 3 GHz/S-Band) feed horn for the CSU-CHILL offset feed antenna began test operations in January, 2012. Basic test operations continued through early April 2012 when the single frequency S-band horn was re-installed as requested by the DC3 project PI's. Unseasonably dry weather prevailed through much of this initial dual frequency test period. The dual frequency horn was returned to service in July, 2012; warm season convective storms provided a variety of echo types and intensities for continuing test dual frequency horn test operations.

Examples of dual frequency data collected during one of these July 2012 test operations are shown in Figure 8. Figures 8a and b show the reflectivity fields observed at the two radar frequencies. The narrower beamwidth of the X-Band channel (0.33^o vs. 1.0^o at S-Band) contributes to the improved resolution of small scale echo features. The X-Band data in Fig. 8b has not been corrected for attenuation effects, this causes the reflectivities observed at the shorter wavelength to consistently fall below the 11 cm wavelength dBZ values with increasing range.

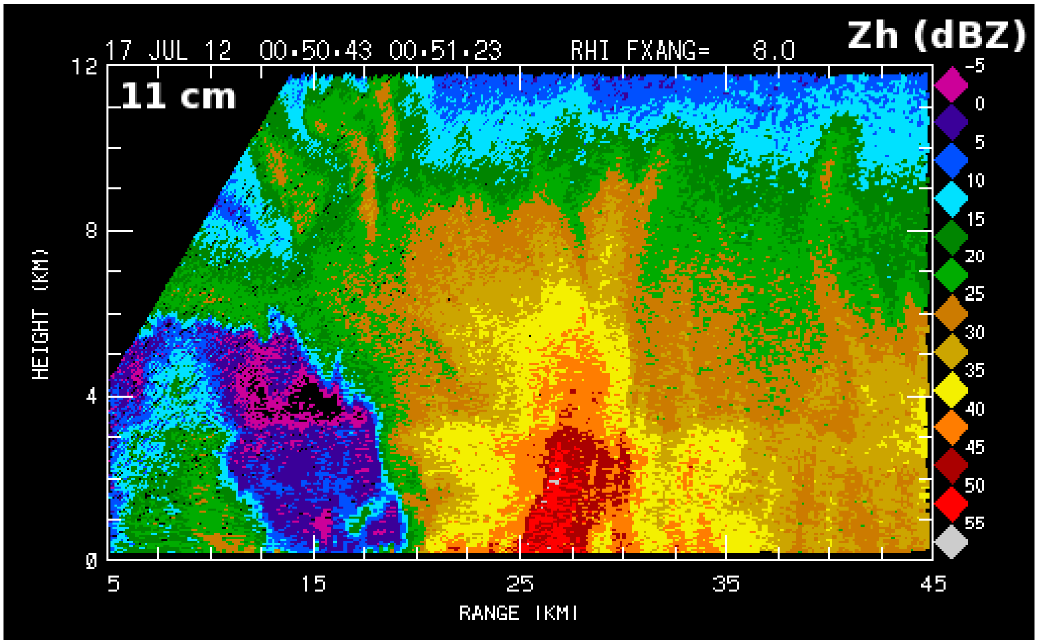

Figure 8: Example dual frequency test data collected in thunderstorm precipitation on 17 July 2012. (a) Reflectivity data observed at S-Band.

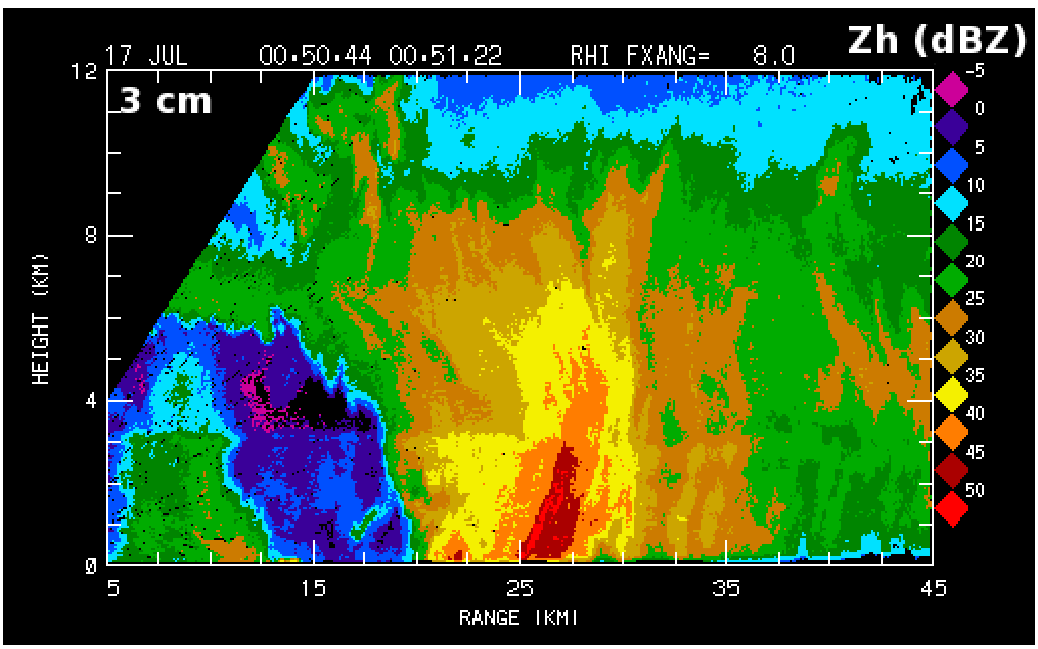

Fig. 8b: Reflectivity data (without attenuation correction) at X-Band.

The corresponding differential propagation phase data are shown in Figures 8c and d. When significant quantities of oblate raindrops exist along the radar beam path, the propagation of the horizontally-polarized radar waves is slowed relative to the propagation of the vertically polarized waves. This increasing phase difference is indicated by the shift downward along the color scale with range that is evident at near surface levels where significant rain rates exits. Since the magnitude of the differential propagation phase shift is inversely proportional to wavelength, larger excursions along the color scale are present in the X-Band data than in the S-Band data. This increased X-Band sensitivity also makes the region of reversed phase shift sense (i.e. movement upward along the color scale from green to blue) just above the 30 dBZ reflectivity contour more evident in the X-Band data. This reversed differential propagation phase (vertically polarized wave retarded more than the horizontal wave) is due to ice crystals whose major axes have been oriented towards a vertical alignment by electric field effects. Dual frequency test operations are continuing to explore the various applications of this technology to cloud physics and precipitation characterization topics.

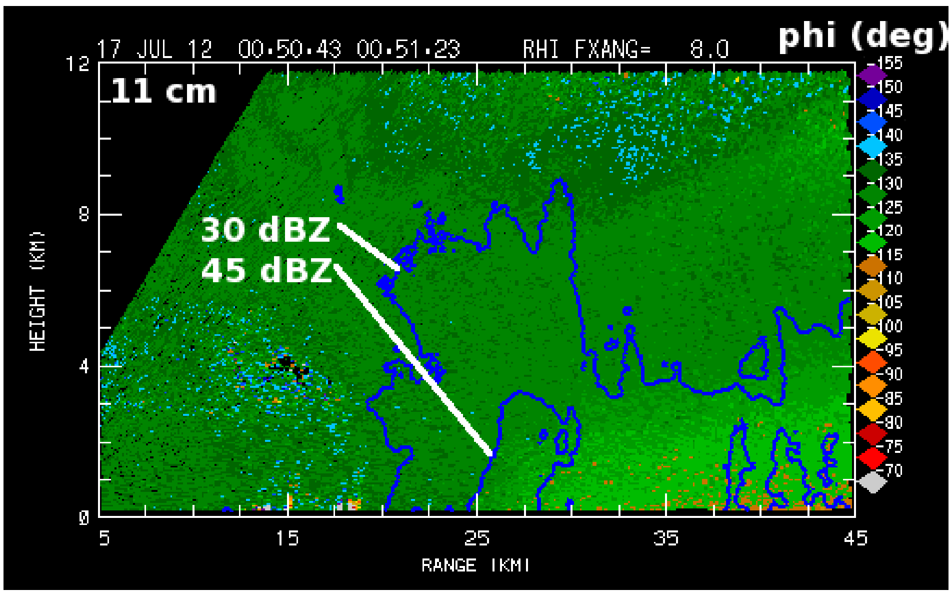

Fig. 8c: Differential propagation phase observed at S-Band. Blue contour lines are the 30 and 45 dBZ S-Band levels.

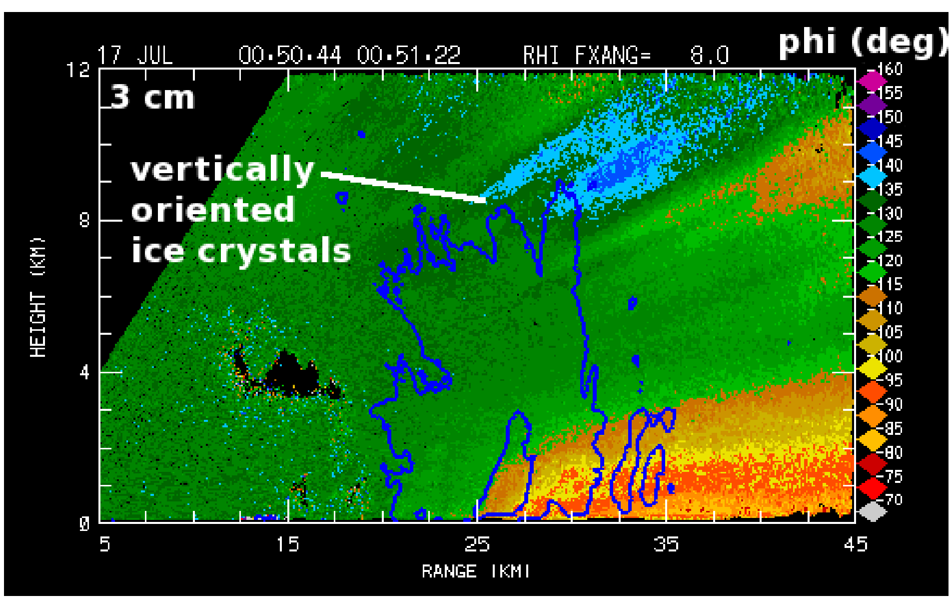

Fig. 8d: Differential propagation phase at X-Band. Contours are 30 and 45 dBZ X-Band levels.

TRAINING & DEVELOPMENT:

YEAR 1: 11/15/2011 – 10/31/2012

Training:

The REU 2012 project provided the various participating students with training to advance their skills in the development of software and hardware, and in the interpretation of polarimetric radar data. The REU student's research project activities are summarized in the following table:

Name	**Home institution**	**Major**	**REU Project Topic**
Allison Manhard	Clemson University	Electrical Eng.	Automating radar calibration sphere tracking with GPS.
Samantha Strong-Henninger	U. Nebraska	Atmos. Sci.	Testing of a tornado detection algorithm using input data from the CASA and CSU-CHILL radars.
Jelena Notaros	U. Colorado	Electrical Eng.	Comparison of the electromagnetic scattering properties of hailstones as simulated by several numerical modeling techniques.
Michael Rausch	Ripon College	Computer Science	Adding a map server interface to the VCHILL basemap options.
Peter Marinescu	Stony Book University	Atmos. Sci.	Applying image processing techniques to the analysis of hailpads.
Barry Windschitl	St. Cloud State	Atmos. Sci.	Verification of the performance of a polarimetric radar technique for the differentiation of small and large diameter hail.

Figure 9 shows an example of the results of one of this summer's REU projects; the VCHILL base map improvement work done by Michael Rausch. He added a map server interface to greatly improve the variety of base map information (i.e., population density, etc.) that can be presented in VCHILL. In Figure 9, the map server has provided detailed depictions of the runways and roadways in the vicinity of Denver International Airport overlaid on CSU-CHILL reflectivity data collected as a damaging hailstorm struck the airport. The increased base map functionality provided by Michael's REU efforts will be made available as a standard feature available to all VCHILL users.

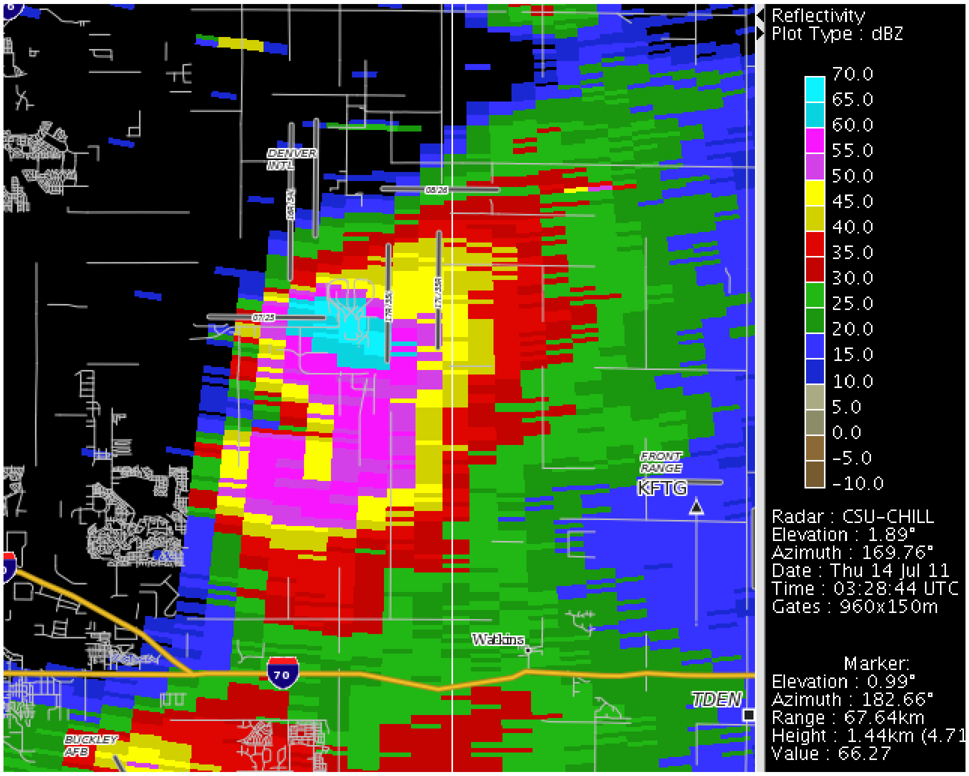

Figure 9: VCHILL presentation of the CSU-CHILL reflectivity data collected as a major hailstorm struck Denver International Airport during the evening of 13 July 2011 (local date). Map overlay of highways and runways provided by the map server interface developed by REU 2012 student Michael Rausch.

Technical Developments

Dual Frequency Horn Initial Installation

The dual frequency feed horn (designed for simultaneous dual polarization operations at 9 GHz / 3 cm wavelength and 3 GHz / 11 cm wavelength) was delivered in October, 2011 (Fig. 10). CSU-CHILL Chief Engineer David Brunkow installed a system of dial indicators and laser-illuminated visual references to ensure that the new feed horn was properly positioned in the antenna feed boom assembly. Mounting arrangements were also developed to secure the X-Band transceiver hardware onto the antenna's feed boom support structure (Fig. 11). As summarized in the Findings section, test operations confirm that the overall CSU-CHILL dual frequency system is operating satisfactorily.

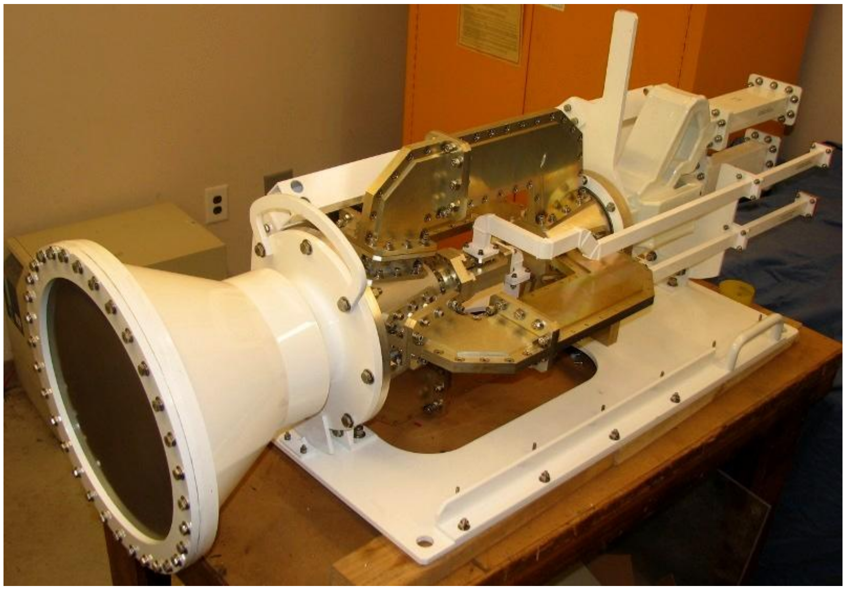

Figure 10: Dual frequency feed horn as received from the manufacturer in October, 2011. The gold-colored waveguide sections route the S-band signals around the centrally located X-Band orothomode transducer. Both the S and X-Band signals are radiated and received though the common corrugated horn aperture at the left edge of the picture.

Figure 11: Dual frequency feed horn (inset) and X-band transmitter hardware installed on the CSU-CHILL offset antenna.

FRONT Collaborations with NCAR

Regular collaborations with the engineering staff of the NCAR S-Pol radar continued throughout this reporting period. The S-Pol radar is expected to become operational at the new Firestone site by early 2012. Planning discussions for initial FRONT network operations are currently underway. Significant staff time was also dedicated to developing a concept paper for FRONT. This white paper is currently nearing completion.