2B.6 SALIENT FEATURES OF THE CSU-CHILL RADAR X-BAND CHANNEL UPGRADE

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1. INTRODUCTION

The CSU-CHILL radar has recently gone through a major transformation to add support for simultaneous dual-wavelength (S and X), dual polarization (H and V) radar operation, as well as high polarization purity S and X band stand alone operations. This process started with the installation of a low-sidelobe dual-offset Gregorian antenna capable of supporting three different feeds (S, X and simultaneous S and X all with dual-polarization capability), and culminated with the development and installation of a separate X-band channel dual-polarization radar system. This paper presents the multi-frequency radar architecture as well as an initial evaluation of the performance of the dual-frequency radar system.

2. SYSTEM OVERVIEW

The CSU-CHILL National Weather Radar Facility [1], located in Greeley, CO, is a research facility operated by Colorado State University, under the sponsorship of the National Science Foundation and the University. In recent years, the facility started a major transformation process to upgrade and expand its capabilities, which include the addition of a new X-band dual polarization radar channel to the existing S-band radar. Figure 1 shows a system architecture overview of the dual-frequency system.

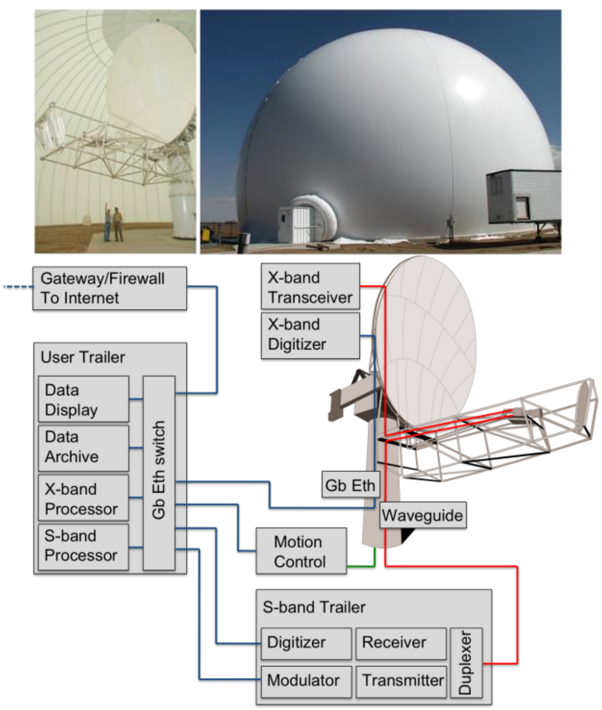

Figure 1 - CSU-CHILL dual-frequency radar system architecture

The radar is housed inside an inflatable radome and uses a 9 m parabolic dual-offset reflector antenna [2] mounted on an elevation over azimuth positioner system. The antenna is illuminated using one of three interchangeable feeds allowing the system to operate at S, X and simultaneous S and X bands as required. This level of flexibility allows to better tailor the radar performance to the intended data purpose; the characteristics of the combined dual-frequency dual-polarization feed, while good in its own metrics, is not as excellent as that of the single frequency units.

The X-band portion of the radar hardware is mounted directly on the antenna structure to minimize waveguide lengths and avoid the use of a waveguide rotary joint. The transmitter, duplexer and receiver subsystems share a single enclosure (transceiver enclosure). A second enclosure houses the data acquisition and timing generation subsystems. The radar control and data streams share a single Ethernet interface that is brought to the signal processor system through a Gbit capable Ethernet slip-ring assembly. The corresponding S-band portion of the radar hardware is located in a trailer adjacent to the radome.

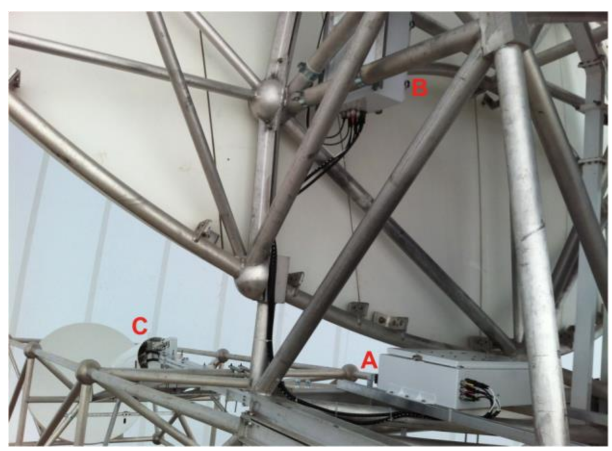

Figure 2 - CSU-CHILL radar X-band channel components. (A) is the transceiver enclosure, (B) is the data acquisition enclosure, (C) is the dual-frequency dual-polarization feed.

The user trailer houses the X-band and S-band signal processor computers. The X-band signal processor gathers the radar I and Q data stream from

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the data acquisition system and the position data stream from the motion control system and computes the Doppler spectrum moments according to the system configuration. The real-time output of the signal processor is then passed to the data archive and display servers, which are common to both the S-band and X-band systems. This allows leveraging the same tools for data display and analysis for both frequencies. Internet access to the signal processor computers allows remote control and operation of the radar through graphical user interfaces and/or command line programs, enabling overnight and unattended system operation.

The X-band subsystem (shown in Figure 3 below) uses a magnetron transmitter that is split to create simultaneous H and V polarization signals. A low-noise, high dynamic range dual-channel parallel receiver is used to bring the analog signal to the system IF centered around 150 MHz in a single down-conversion stage.

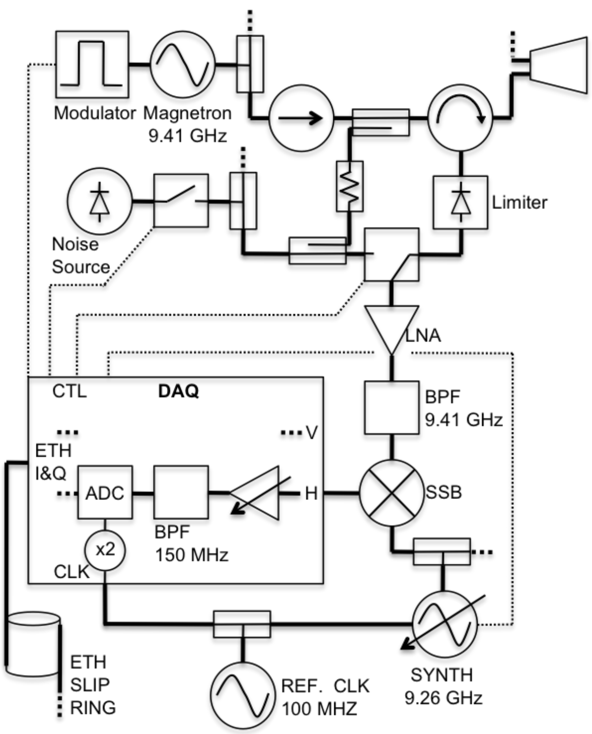

Figure 3 - CSU-CHILL radar X-band channel block diagram.

A sample of the transmitted pulse is coupled through a dedicated circuit and fed to the receiver through a front-end switch. An on-board noise source is used as an absolute power reference to calibrate the receiver gain over its entire band of operation (120-180 MHz). A high-speed digitizer is employed to sample and digitally down-convert the IF signal to base band. The digitizer incorporates an IF programmable gain stage and broad anti-aliasing filters. The transmitted pulse sample is kept at the native sampling resolution of 200 MHz and used to estimate the transmitted pulse duration, power, and frequency. The estimated IF frequency of the transmitted pulse sample is then used to tune the digital down-conversion. This simple digital Automatic Frequency Control loop allows tracking any magnetron frequency changes and keeping the down-conversion process tuned to the current transmitted frequency. This is illustrated in Figure 4 below.

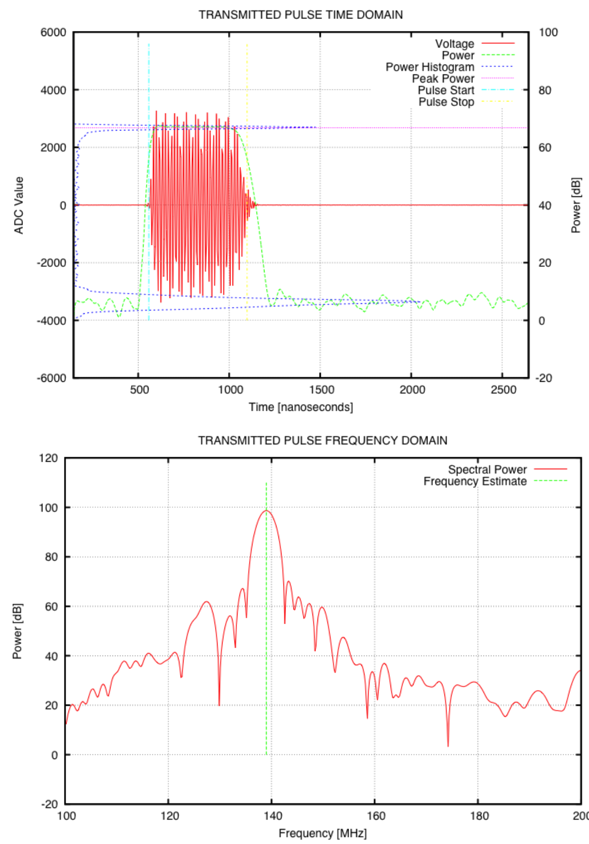

Figure 4 – Transmitted pulse sample data at 200 MHz sampling rate. Top is time domain view and bottom is frequency domain view.

The main characteristics of the CSU-CHILL radar both for the X-band component and the S-band component are listed in Table 1 below.

Table 1 - CSU-CHILL dual-frequency radar system main specifications

Parameter	S-Band	X-Band
Antenna		
Reflector Type	8.5 meter dual-offset Gregorian parabolic	
Feed Type	Scalar, symmetric OMT	
Polarization	Linear H and V	
Gain	43 dBi	53 dBi
Beam Width	1.0 deg	0.3 deg
Sidelobe Level	< -27 dB	< -36 dB
Cross-Pol Level	< -43 dB	< -23 dB
Scan Type	PPI (360°, sector), RHI, Fixed pointing, Vertically pointing	

Scan Rate	< 18 deg/sec	
Transmitters		
Frequency	2.725 GHz	9.41 GHz +/- 30 MHz
Type	Dual Klystron	Magnetron
Power	1 MW	25 kW
Transmit Modes	Single-pol, Simultaneous, Alternating	Simultaneous
Duty Cycle	< 0.16 %	< 0.16 %
PRF	1.25 KHz	2.00 KHz
Receivers		
Sensitivity	-10 dBz, 30 km	-10 dBz, 30 km
Noise Figure	3.4 dB	4.0 dB
Dynamic Range	80 dB	90 dB
Range Sampling	30 – 150 m	1.5 – 192 m
Signal Processing and Products		
Processing Modes	Pulse Pair, Spectral Clutter Filter, Second Trip Suppression, Dual-Doppler velocity unfolding	
Polarization Processing	Hydrometeor ID, attenuation correction, K_{DP} estimation	
Data Products	Z, Z_{DR}, V, W, ρ_{HV}, NCP, ϕ_{DP}, K_{DP}, SNR	

3. SELECTED DATA CASES

Selected data examples representative of the radar capabilities are shown in this section. These data examples were obtained during routine radar operation in support of user requests.

3.1 *Dual-Frequency Scans on Convective Storm*

During the month of June 2013 the CSU-CHILL radar operated in simultaneous X-band and S-band dual-frequency mode, collecting data on a number of convective storms during the CHILL Microphysical Investigation of Electrification (CHILL-MIE) 20-hour project. The presented RHI scan shows good agreement between the observed Reflectivity at both frequencies, with the expected Differential Phase increase after the high Reflectivity areas.

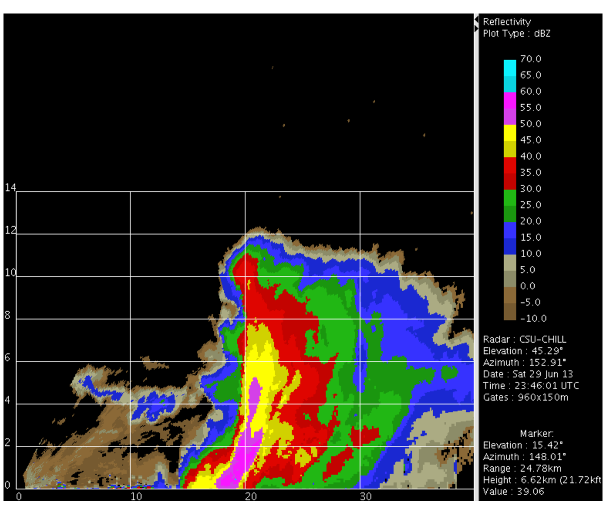

Figure 5 - S-band Reflectivity

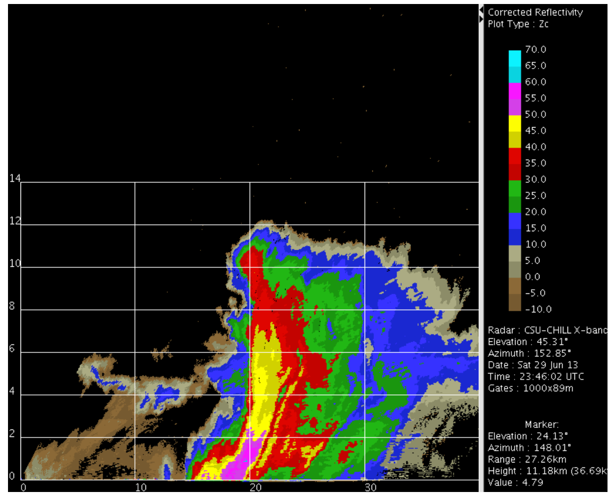

Figure 6 – X-band Reflectivity (corrected for attenuation)

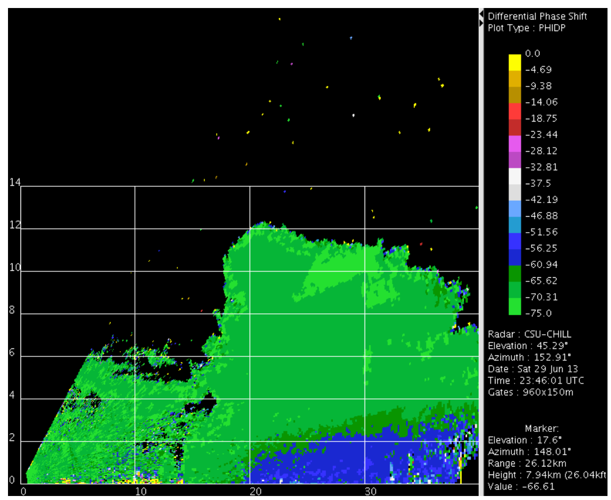

Figure 7 – S-band Differential Phase

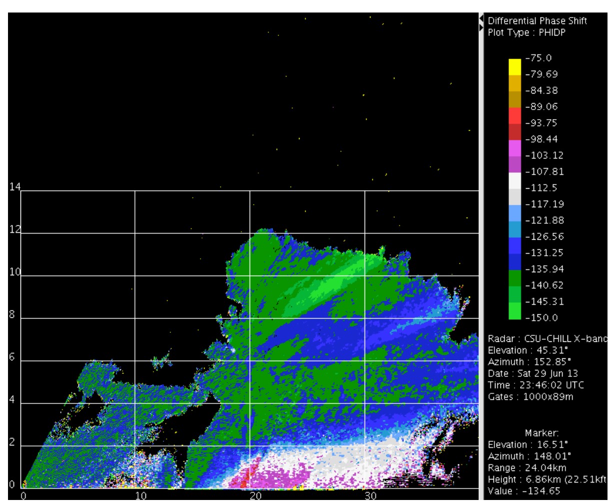

Figure 8 – X-band differential phase

The higher sensitivity of Differential Phase at X-band makes some features such as potential vertical alignment of particles due to electrification (roughly at 30 km range and 10 km height) easier to observe.

The availability of collocated dual-polarization data sets at S and X-band make the CSU-CHILL radar a unique platform for development and verification of dual-frequency and high-frequency data processing algorithms that can be verified with the collocated S-band observations. Figure 9 below shows one such example where an attenuation correction algorithm for X-band data is investigated and compared to the collocated S-band data.

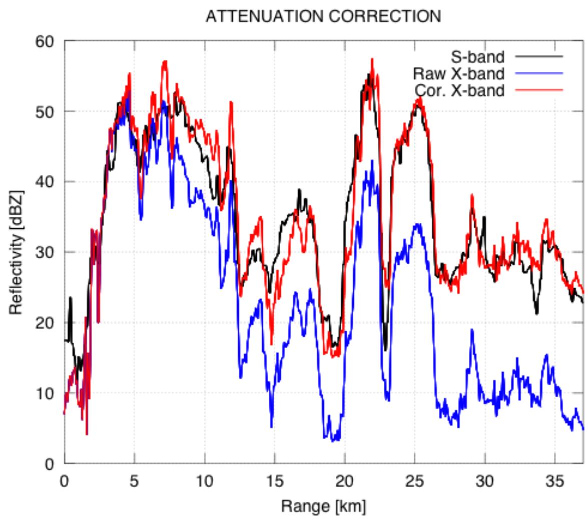

Figure 9 - Comparison of reflectivity at S and X band before and after attenuation correction

3.2 *X-Band Scans on Winter Storm*

During the winter months of 2013 the CSU-CHILL radar operated at X-band only. The increased resolution and sensitivity of the higher frequency, coupled with the potentially less severe attenuation of the winter weather make X-band well suited for this type of observations. The presented scan shows a snow band across the radar's 180 km coverage diameter. Although the radar operated without engaging its clutter filter capability, Figures 10 and 11 show virtually no clutter at short range due to the narrow, low sidelobe beam pattern. Similarly, fine scale banded velocity features are well resolved along the 30 km range ring in the SW az quadrant. In Figure 13 one can see how Differential Phase shifts appear at the further ranges as the beam height gets up into levels of colder temperature and more pristine ice crystals [3].

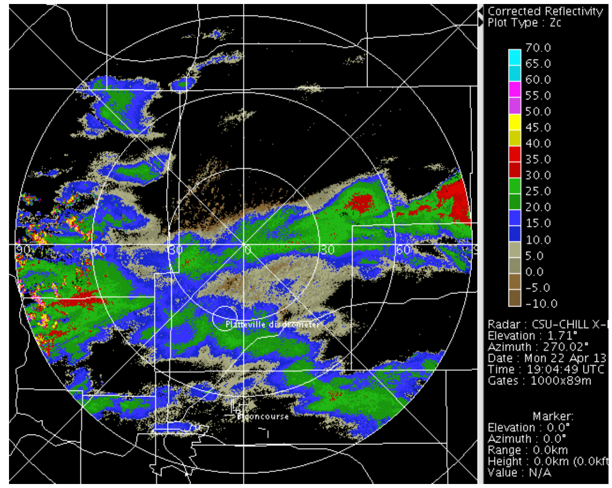

Figure 10 - X-band Reflectivity (corrected for attenuation)

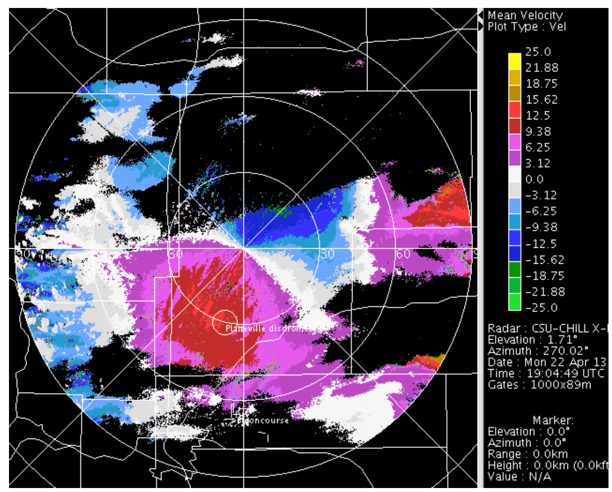

Figure 11 - X-band Doppler Velocity

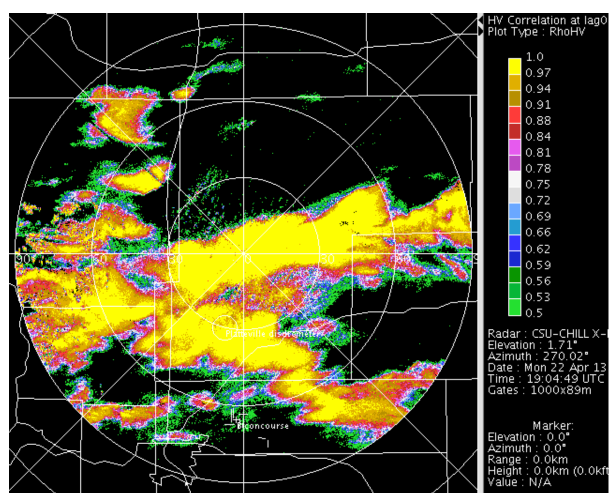

Figure 12 - X-band Co-Pol Cross-Correlation

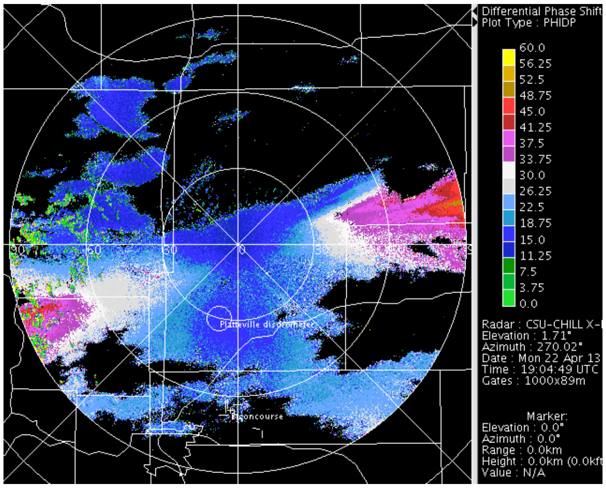

Figure 13 - X-band Differential Phase

3.3 *X-Band Scans on Tornadic Storm*

In the early afternoon of June 18' 2013 a tornado developed over the Denver airport. The selected X-band scan was taken at an elevation of 0.5 deg and shows a very well defined hook-echo signature at a range near 70 km directly south of the radar, owing to the very small antenna beam-width at X-band (0.3 deg). The Doppler velocity field shows a tight velocity couplet collocated with the hook-echo signature. The X-band radar system operated with a dual PRF scheme similar to that described in [4] adapted to the CSU-CHILL radar longer range. This dual PRF scheme allowed to resolve Doppler velocities close to 24 m/s while maintaining an unambiguous range of 100 km. The Co-Pol Cross-Correlation field shows an area of generally lower values inside the contour of higher Reflectivity, which could be indicative of Mie scattering. The area of lower values corresponding to the eye of the hook-echo signature could be indicative of debris as described in [5].

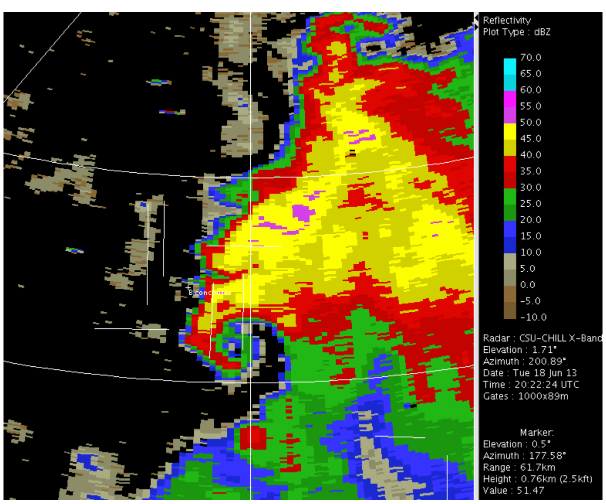

Figure 14 – X-band Reflectivity

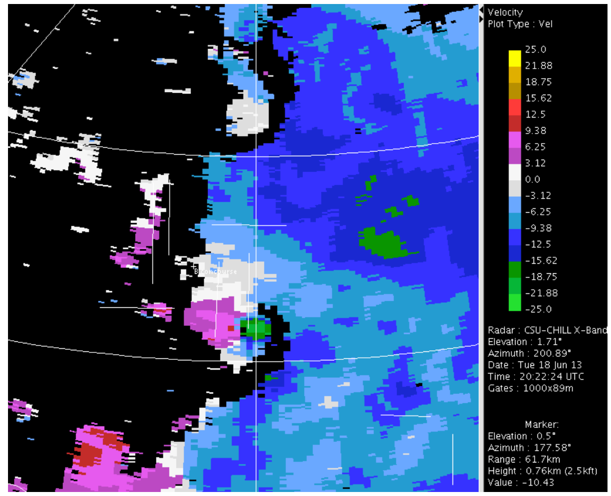

Figure 15– X-band Doppler Velocity

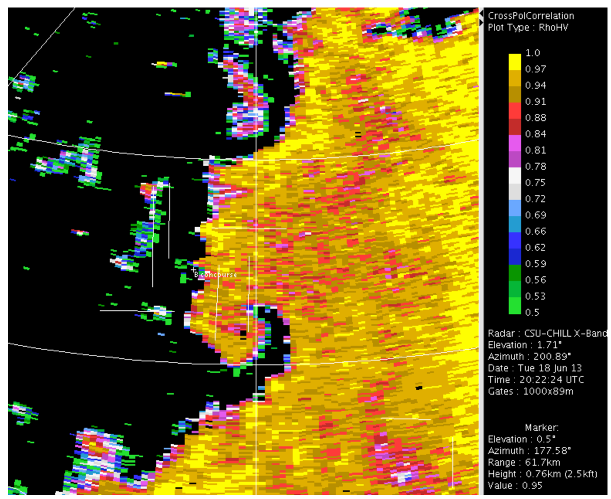

Figure 16 - X-band Co-Pol Cross-Correlation

4. CONCLUSIONS

The small antenna beam-width at X-band (0.3 deg) and simultaneous availability of dual-polarization, dual-wavelength (S and X-band) make the CSU-CHILL radar a unique platform for meteorological observations supporting both research and education. Furthermore, the radar also contributes to the development of processing techniques for higher frequency radars that can be verified with the collocated low-frequency observations at S-band

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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