Accomplishments 1 November 2012 – 31 October 2013:

Research data collection:

Following test operations with the dual frequency (S and X-band) feed horn during the July – October 2012 period, the single frequency X-band feed horn was installed on the CHILL antenna for the first time in December, 2012. This horn was originally received from the manufacturer in October, 2012. Since this horn was optimized for single frequency operations at X-band (9 GHz), sidelobe levels consistently below 30 dB along with excellent H, V pattern matching was obtained. Also, attenuation-related complications at X-band are generally not significant in winter precipitation, so the 2012 – 2013 cold season offered a good opportunity to test the data collection capabilities of the CSU-CHILL radar in the X-band only feed horn configuration.

Beginning in December, 2012, the initial research data collection with the X-Band was done during the Front Range Orographic STorms (FROST) 20 hr project. This project was requested by Dr. Matt Kumjian (NCAR Postdoctoral Research Fellow), Dr. Roy Rasmussen (Senior Scientist in NCAR's Research Applications Laboratory), and Prof. Steve Rutledge (CSU Atmospheric Science Department). The objective of this project was to document the three dimensional structure and dual-polarization radar characteristics of a wide variety of winter season precipitation. Complementary data was also collected at NCAR's Marshall field site. These measurements included the operation of a scanning dual polarization X-band radar as well as special radiosonde and surface weather observations.

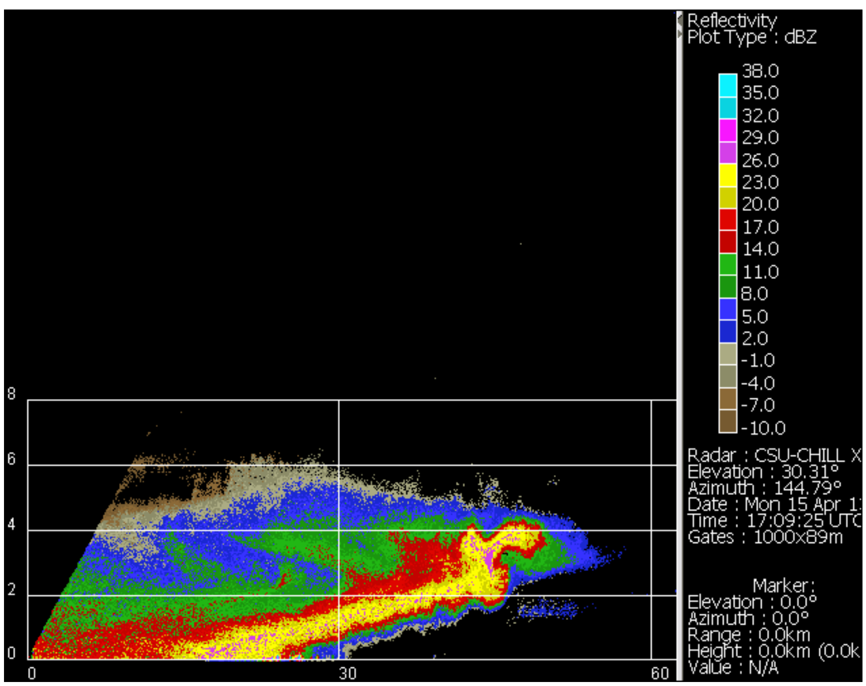

Figure 1: VCHILL plot of the X-band reflectivity data recorded during an RHI scan through the elevated generating cell region associated with a well-define snow band.

A significant result of the FROST project was the documentation of the very frequent occurrence of precipitation generating cells near the cloud top levels in winter precipitation systems. Figure 1 (above) shows an RHI scan through a well-developed elevated generating cell and the associated precipitation "streamer" that descended along a sloping path towards the CHILL radar on 15 April 2013. Dr. Kumjian has submitted a manuscript based upon the FROST observations to the Journal of Applied Meteorology and Climatology. Successful data collection took place during a wide variety of winter precipitation situations during FROST. It is anticipated that additional publications will be developed from this data set.

The dual frequency feed horn was put back in service in mid-May, 2013 in anticipation of several convective season data collection efforts. The NSF-supported REU 2013 project took place under the direction of Prof. V. Chandrasekar (CSU Electrical and Computer Engineering Department). Six students from Y institutions came to the main CSU campus to participate in the REU program between 20 May and 18 July 2013 (Fig. 2) (verify). These students all received introductory lectures regarding the CSU-CHILL radar's technical characteristics and general applications of dual-polarization radars to meteorological observations. The objective of the REU project was to provide the students with hands-on experience in the conduct research involving various topics related to meteorological radars. Mentors from the staff of the CSU ECE Department and from the CSU-CHILL Facility guided the student's research efforts. Table 1 summarizes REU 2013 student's activities:

Student	Home institution	Project title	Mentor
J. Marquis	University of Louisiana Monroe	Radar Data Objective Analysis	J. Hardin
M. Wiesner	McGill University	Machine Learning for Classification of Radar Data	J. Hardin
D. Silva	UPRM	MRI X-band Radar Observations: Comparison Between Colorado and Puerto Rico	M. Chaturvedi and H. Chen
E. Marreo	UPRM	MRI X-band Radar Observations: Comparison Between Colorado and Puerto Rico	M. Chaturvedi and H. Chen
J. Costello	University of Illinois	Meteorological Interpretation of S and X-band Warm Season Echoes using the CSU-CHILL Dual-frequency Radar	P. Kennedy
E. Dougherty	University of Virginia	Meteorological Interpretation of S and X-band Warm Season Echoes using the CSU-CHILL Dual-frequency Radar	P. Kennedy

Table 1: Summary of REU2013 students and their research projects

Figure 2: Five of the six REU 2013 students; rightmost individual is Mr. Steven Swenson, an ECE graduate student.

An example outcome of the REU activities is shown in Figure 3. One activity of REU students Erin Dougherty and Jacqueline Costello involved the comparison of various dual wavelength polarimetric radar signatures with visual cumulonimbus cloud development. Figure 3 shows data from an RHI scan whose azimuth angle was selected to intercept an area of visually active cloud development. Several of the REU students expect to use their summer 2013 research project efforts as the basis of senior year projects done at their home institutions.

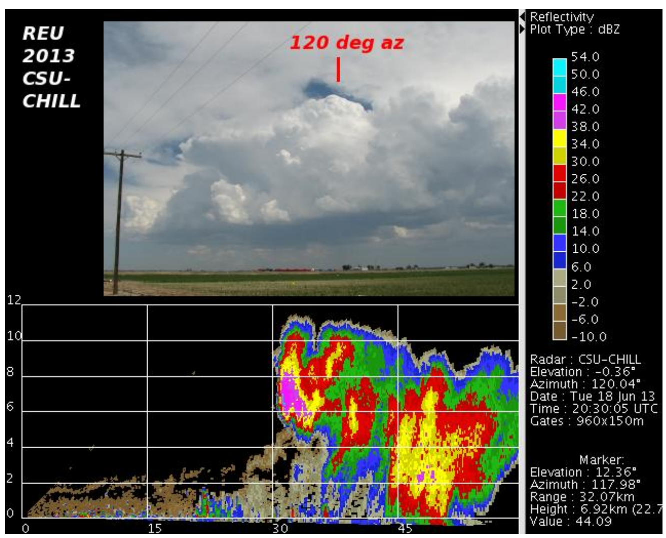

Figure 3: RHI scan directed by REU2013 students to collect dual frequency CSU-CHILL data in a visually developing convective cloud top on 18 June 2013.

Prof. Adam Houston (University of Nebraska Lincoln), conducted a 20hr project for a one week period in June, 2013. The goal of this project was to collect radar data from the boundary layer where an instrumented unmanned aircraft (UAS) was being flown. FAA requirements restricted these UAS flights to the sparsely populated Pawnee National Grasslands area. Low elevation angle PPI scans conducted by CSU-CHILL documented the passage of an outflow boundary across the UAS flight region on 21 June

2013 (Fig. 4). Analyses are currently in progress to correlate the various airborne *in-situ* UAS measurements with the radar-documented boundary layer echo features.

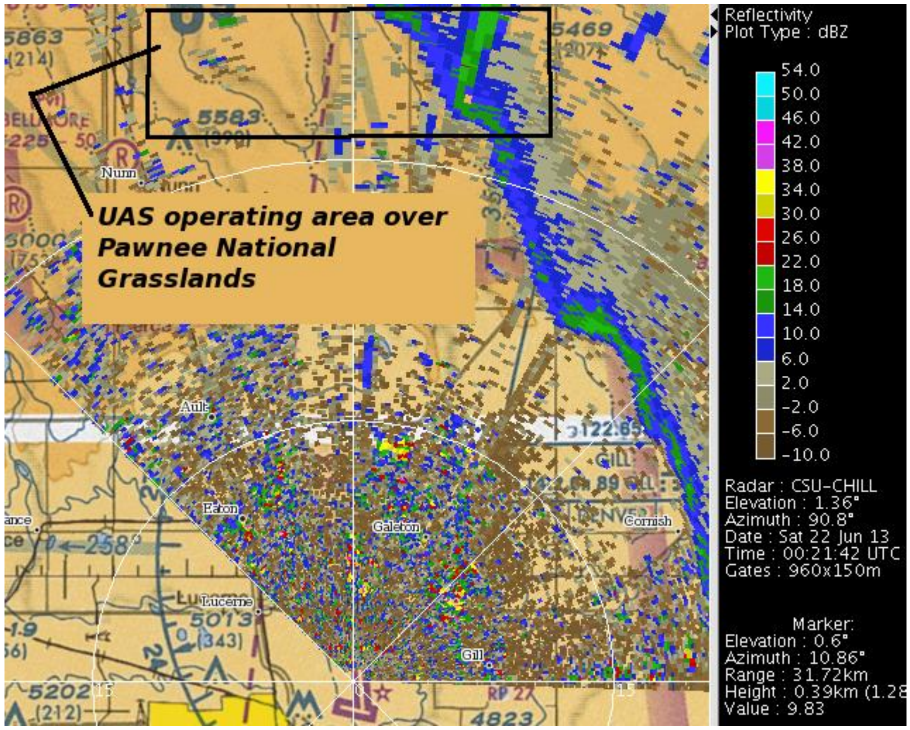

Figure 4: CSU-CHILL reflectivity data collected during a UAS flight through the fine line echo associated with an outflow boundary.

Mr. Brody Fuchs, a graduate student in the CSU Atmospheric Science Department conducted the CHILL Microphysical Investigation of Electrification (CHILL-MIE) 20hr project during the June to mid-July 2013 period. The objective of this project was to collect data sets that can be analyzed as a part of Brody's PhD dissertation dealing with thunderstorm electrification. The CSU-CHILL's dual frequency capabilities are critical to this research. The increased differential propagation sensitivity offered by the CSU-CHILL X-band system provides enhanced capabilities for the identification of regions where the atmospheric electric field strength has become strong enough to influence ice particle orientation (Fig. 5). Additionally, regions where preferential differences in the S and X-band measurements of reflectivity, co-polar correlation coefficient (ρHV), etc. can be used to map regions where hydrometeor sizes have become large enough to cause Mie scattering effects to develop in the shorter wavelength X-band data.

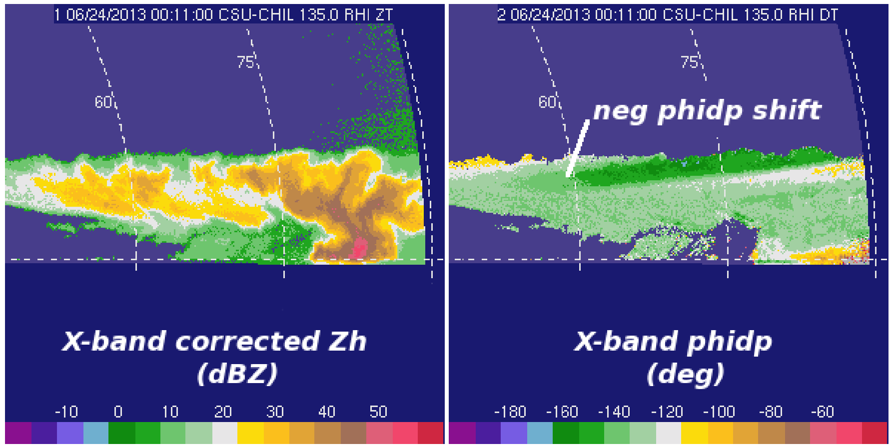

Figure 5: X-band reflectivity (left) and differential propagation phase (right) in an RHI scan through the trailing anvil region of a thunderstorm obtained during the CHILL-MIE 20hr project. The phidp indication of a strong electric field area is marked.

In mid-July 2013 Dr. Sergey Matrosov of NOAA's Earth System Research Laboratory in Boulder, Colorado expressed an interest in the collection of CSU-CHILL data when locally heavy convective rain was occurring over the burn scar left by the June 2012 High Park fire. Specifically, rapid update (~2 minute cycle time), low elevation angle PPI scans were desired from which high spatial resolution maps of the evolving rainfall field could be generated. These rainfall maps would then be used to initialize hydrological model simulations of the streambed runoff responses to locally heavy rains. Since the monsoon precipitation season was imminent, the CSU-CHILL Facility was able to provide expedited approval for Dr. Matrosov's 20 hr request; data from the first heavy rain event was collected within 3 days of the initial project discussions (Fig. 6).

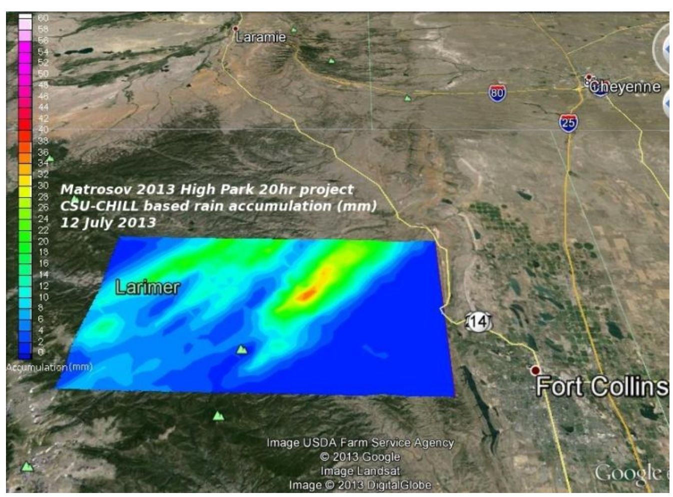

Figure 6: Rain accumulation (mm) estimated from CSU-CHILL dual polarization data collected on 12 July 2013, the first operational day of Dr. Matrosov's 20 hr project. Local rock slides and flash flooding occurred in the vicinity of the >25 mm accumulation area. Most of this rain fell in ~30 minutes. (Basic plot provided by S. Matrosov).

During August of 2013, the FRONT Rainfall and Streamflow Prediction – Testbed of Capabilities 20hr project was conducted for Rita Roberts and Jim Wilson of NCAR's Research Applications laboratory. A primary goal of this project was the collection of coordinated data sets from the available subset of the radars in the Front Range Observational Network Testbed (FRONT) domain. To this end, the volume scan starting times of the CSU-CHILL radar were frequently brought into time synchronization with those of the NWS KFTG radar located near Denver International Airport. This allowed wind field to be synthesized from coordinated radial velocity measurements. Figure 7 shows an example of the low level horizontal wind field observed in the vicinity of a thunderstorm. These low level flow fields are an important component in the project's efforts in nowcasting / forecasting the future evolution of convective storms and their associated rainfall patterns.

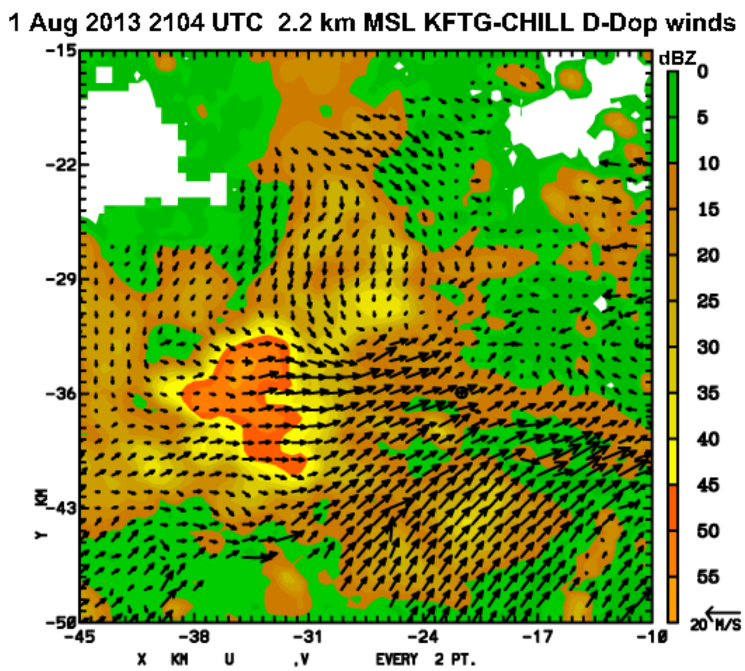

Figure 7: Horizontal Earth-relative wind flow field based on dual Doppler processing of NWS KFTG and CSU-CHILL radial velocity data. Higher wind speeds augmented by thunderstorm outflow effects are evident in the quadrant located southeast of the reflectivity core.

The final 20hr project of the reporting period was conducted under the direction of Dr. Scott Ellis (NCAR RSF) during September – October 2013. In this time period, the NSF GV research aircraft operated by NCAR was performing a series of test flights to document the performance of several new instrumentation systems. One such instrument was the wing pod-mounted HIAPER Cloud Radar (HCR). During the departure and arrival stages of several of these flights, the GV flew along radial ground tracks with respect to the CSU-CHILL radar location. This flight pattern kept the aircraft in a constant azimuth angle RHI plane. A verification of this flight technique occurs when the echo from the radar's direct illumination of the aircraft is obtained (Fig. 8). The CSU-CHLL data collected during such well-coordinated scans is being used as a reference for the HCR measurements.

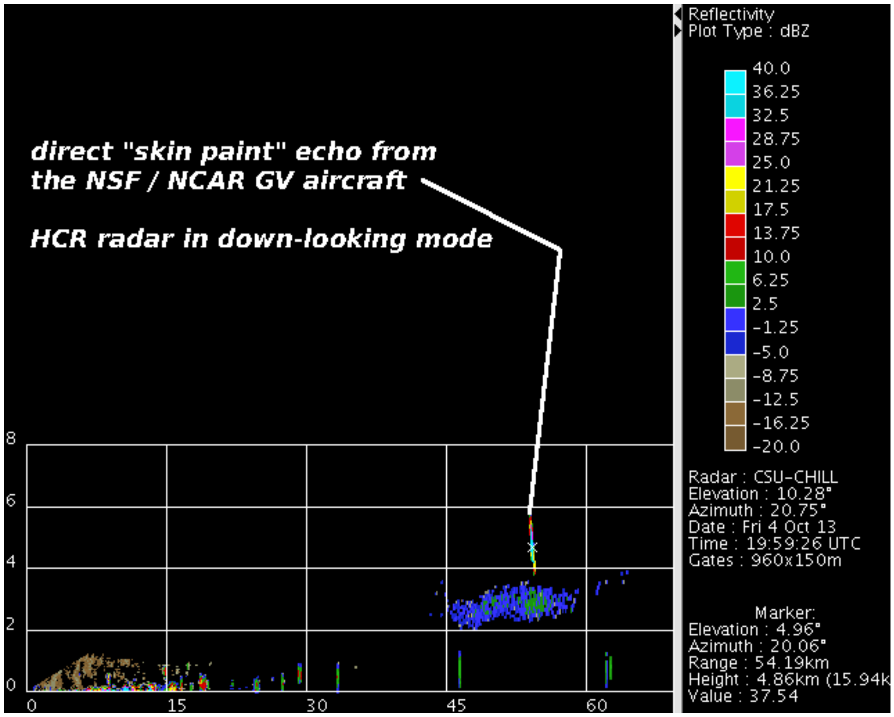

Figure 8: CSU-CHILL RHI scan conducted along an inbound radial being flown by the NSF / NCAR GV research aircraft. The downward-looking HIAPER Cloud Radar (HCR) was making simultaneous observations of the echo layer located between the 45 and 60 km range marks.

In addition to providing dedicated support to NSF-sponsored and 20hr projects, the CSU-CHILL Facility also collected “target of opportunity” data when meteorological events of particular interest occurred. Data sets collected in this mode are a primary source of the archived example cases that support many educational interests. One such event of interest was the widespread flooding rainfall that occurred over portions of the northern Colorado foothills between 12 and 14 September 2013. Following an initial episode of heavy nocturnal convection, less intense but more prolonged showers added several inches of additional rainfall during the daylight hours of 12 September, 2013. Figure 9 shows an example low elevation angle PPI scan that was conducted as a band of heavy rain showers augmented the ongoing flooding conditions in the eastern Denver / Aurora Colorado areas during the mid-day hours of 12 September. Preliminary analyses of the differential reflectivity (Zdr) characteristics of this rain indicate that the raindrop size distributions contained an unusually (for the Colorado high plains) large fraction of small diameter drops. More detailed analyses of the CSU-CHILL data collected during the September 2013 floods are ongoing.

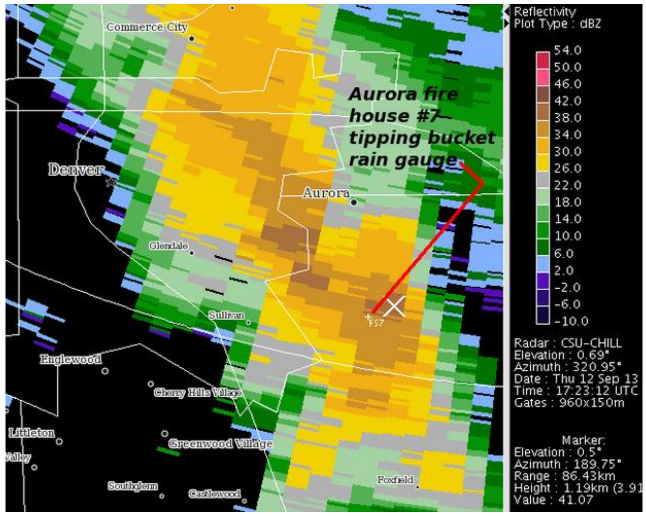

Figure 9: One of multiple bands of moderate to heavy rain that affected the Aurora and Denver areas on 12 September 2013. The marked rain gauge is one of many sites operated by the Denver Urban Drainage and Flood Control District (UDFCD). The ground truth rainfall rates and accumulations provided by this gauge network are being examined in relationship to dual polarization data collected by CSU-CHILL.

Educational Support

a) "Virtual tours" of the CSU-CHILL Facility were provided on several occasions during the reporting period. During these tours, two-way video conferencing software is used to provide an in-room presence for students located at physically distant institutions. Various permanently installed web cameras at the radar are used to provide remote realtime imagery of important system elements (antenna and feed assemblies; transmitter equipment, etc.) CSU-CHILL technical staff members also present more detailed views of specific radar hardware to the students in the distant classrooms (Fig. 10).

Figure 10: CSU-CHILL Senior Electrical Engineer David Brunkow describes the construction features of a VA-87B Klystron microwave power amplifier tube during a virtual tour of the Facility.

c) AMS short course on weather radar calibration:

In conjunction with the 36th American Meteorological Society Weather Radar Conference, the CSU-CHILL Facility hosted a short course on meteorological radar calibration techniques on Saturday, 14 September 2013. Twenty students participated in both lecture and hands-on calibration activities such as tracking a balloon-borne known cross section spherical target and verifying antenna leveling (Fig. 11).

Figure 11: AMS Radar Calibration short course held at CSU-CHILL on 14 September 2013. Upper two photo insets provided by short course participant Timothy Marshall.

d) The Virtual CHILL (VCHILL) software package developed and maintained by CSU continues to provide convenient internet access to the Facility's multi-year on-line data archives. This capability has allowed instructors and students from the international community to interactively replay CSU-CHILL data. Currently more than 700 VCHILL user accounts have been registered with the CSU-CHILL Facility.

Technical Upgrades to the Facility

The primary technical advancement made at the Facility during this reporting period was the arrival in November 2012 of an ASR11 solid state S-band (3 GHz) transmitter from Raytheon Corporation. This equipment was made available through a CSU - industrial collaboration developed by Prof. V. Chandrasekar. ASR11 radars are in current use for terminal area air traffic control purposes (i.e., the detection of discrete aircraft targets). The ASR11 transmitter is currently being mated to in-house designed up-converter / digital receiver subsystems. This integrated transmitter / receiver system will then be spliced into the existing waveguide runs to the CSU-CHILL dual offset feed antenna; initial test operations should begin in early 2014. The goal of these efforts is to verify the feasibility of making research quality dual polarization meteorological (distributed target) measurements by applying pulse compression techniques to a high-powered, solid state S-band transmitter.

Figure 12: Raytheon ASR11 transmitter being moved to its operational housing, a customized 20 ft sea container.

Additional technical upgrades during the reporting period included the design of several auxiliary control systems that will be added to the existing Klystron-based FPS-18 transmitters and antenna drive systems. These additions will make many of the system control and operating status parameters available via standard network communications protocols. This improved system access will support remotely-controlled / unattended CSU-CHILL radar operations, simplifying data collection during weekend and overnight hours. The installation and testing of this new remote control hardware should take place during the first quarter of 2014.