Meteorological Applications of the Font Range Observational Network Testbed

J.C. Hubbert[1], P. Kennedy[2], M. Dixon[1], W.-C. Lee[1], S. Rutledge[2], T. Weckwerth[1], V. Chandrasekar[2], and E. Loew[1]

[1]*National Center for Atmospheric Research, Boulder CO, USA. hubbert@ucar.edu*
[2]*Colorado State University, Fort Collins CO*

1 September 2014

John Hubbert

1. Introduction

The Front Range Observational Network Testbed is a joint effort by NCAR (the National Center for Atmospheric Research)and CSU (Colorado State University) to provide the research and educational user communities with streamlined access to the EOL S-Pol and CSU-CHILL NSF research radars while they are at their home base locations in Colorado. As part of this effort, a new operating site for S-Pol with improved views of both the eastern slopes of the Rocky Mountains and the greater Denver area was established near Firestone, Colorado during the summer of 2013. This new S-Pol location provides an excellent dual-Doppler baseline configuration with the CSU-CHILL's location near Greeley, CO. (The baseline length is 42 km on an azimuth of 211 degrees from CSU-CHILL). While the CSU-CHILL and EOL S-Pol radars provide the foundation of FRONT, their measurements are complemented by several other meteorological sensor arrays that are resident in the region: (i) The NWS KFTG (Denver-Boulder) and KCYS (Cheyenne, WY) WSR-88D radars, (ii) The single-polarization CSU-Pawnee radar (located 47 km north of CSU-CHILL), (iii) The Northern Colorado Lightning Mapping Array (LMA), (iv) Various surface data networks (highway departments, urban flooding districts, etc. and (v) real-time satellite data.)

The FRONT radar network, shown in Fig. 1, forge a unique research infrastructure for the scientific community. The FRONT domain covers a region from north of Cheyenne, WY to south of Denver CO. FRONT will afford the scientific community a state-of-the-art dual-polarization, dual-Doppler network that will provide a rich set of radar observations for the wide spectrum of weather this region experiences. FRONT will also enhance educational activities by expanding the data archive currently available with CSU-CHILL and by enabling hands on operational experience.

To promote this, S-Pol has recently become fully remotely operable from powering-up the radar, creating, editing and executing scaning strategies, to radar shut down. CSU-CHILL is also remotely controllable and the ability to remotely power up and shut down the radar is scheduled to be completed by the end of 2014. Thus, an approved, remote user will be able to connect to a FRONT server, access the radar control GUI, set up scans and collect data. Shared engineering development between CSU-CHILL and NCAR/EOL (Earth Observing Laboratory) S-Pol research radars provides the scientific community with the following opportunities:

1. target-of-opportunity data collection on weather situations that may be difficult to capture during a short field campaign,
2. use of a long-term mesoscale and climate testbed for testing new instruments and data quality evaluations, studying sensor integration technologies, validating numerical models, and testing advanced networking concepts,
3. a low-cost experimental infrastructure for local field campaigns and,
4. an expanded and diverse hands-on educational/training and outreach experiences.

Correspondingly, FRONT has adopted the following guiding vision and mission statements:
Vision:
FRONT: A testbed for innovative weather, climate and technology exploration; leading, promoting and enabling geoscience research and education.
Mission:
FRONT provides the atmospheric science community with an easily accessible, cost-efficient, observational infrastructure for the collection of comprehensive data sets for hydro-meteorology, mesoscale meteorology, climate process studies and for the advancement of technology.

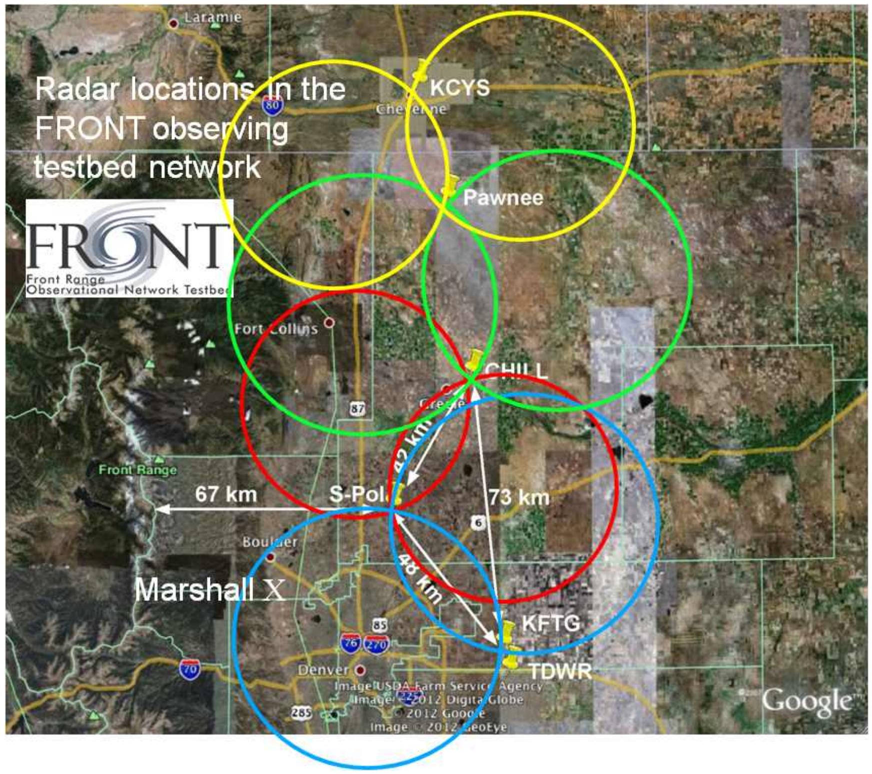

Figure 1: *The FRONT radars' locations and dual-Doppler lobes.*

2. FRONT Example Data Cases

a. *Tornado on 21 May 2014*

The initial FRONT support for a National Science Foundation (NSF) supported project took place during the Radar Observations of Storms for Education (ROSE) experiment conducted by Prof. Sandra Yuter (North Carolina State University) between 20 May and 20 June 2014. The data collection procedures developed for the NCAR S-Pol and CSU-CHILL radars in the ROSE project were designed to provide constant cycle time, synchronized volume scans for input to multiple Doppler wind field synthesis software. On the second day of ROSE operations (21 May 2014), a supercell thunderstorm moved across the northeastern portion of the greater Denver metropolitan area. Figures 2–4 provide preliminary analyses of some of the FRONT data collected during this operation.

At 2003 UTC, the storm was centered over the northeastern corner of the city of Denver. This location was outside of the S-Pol CHILL dual Doppler coverage area. However, suitable beam intersection geometry was provided by the nearby NWS WSR-88D KFTG radar. Figure 2 (top) shows the Earth-relative horizontal wind field synthesized from the S-Pol and KFTG radial velocity data plotted on the color-coded S-Pol reflectivity data at a height of 7.5 km MSL. Interactions between the storm-related and environmental flow fields produced curved, locally accelerated flow around the flanks of the high reflectivity core. Updraft velocities (obtained from a variationally-adjusted vertical integration of the horizontal convergence profile) only exceeded 15 ms^{-1} in localized areas. Figure 2 (bottom) shows the location lightning radiation sources detected by the Northern Colorado Lightning Mapping Array (LMA) in the 7 to 8 km MSL height layer during a three minute time period corresponding to the radar volume scan. At this time, the lightning sources were primarily located within the echo core and also in the immediate downstream anvil region. At 2115 UTC, the storm had intensified as it moved into the S-Pol CHILL dual-Doppler coverage area. The dual-Doppler wind synthesis showed an appreciably larger, more organized region of > 15 ms^{-1} updrafts (Fig. 2 (top)). This strong updraft lofted the growing hydrometeors into the upper troposphere, producing a bounded weak echo region (BWER, Krauss and Marwitz (1984)) at 7.5 km MSL. Due to the reduced concentration of charge-carrying hydrometeors in the BWER, a "lightning hole" (Krehbiel et al. 2000) was apparent in association with the BWER / updraft region at the 7.5 km MSL height level (Fig. 2 (bottom)). The persistence of the locally accelerated flow around the flanks of the main updraft apparently helped advect the charged ice particles, and the associated LMA-detected discharge activity, into a forked pattern that extended several tens of km into the downstream anvil.

Dual polarization data collected in Range Height Indicator (RHI) scans conducted by the CHILL and S-Pol radars during the ROSE project provided additional information on the three dimensional structure of the 21 May 2014 supercell. Figure 4 shows selected data fields observed in an RHI scan done by the S-Pol radar through the BWER at 2123 UTC (roughly 8 minutes after the data shown in Fig. 3). The BWER and associated maximum echo top are apparent near the 55 km range point (Fig. 4a). The de-aliased radial velocity pattern showed an updraft-related divergence pattern co-located with the echo summit (Fig. 4b). At lower heights near the 55 km range point, a positive Z_{dr} column extended up to heights of about 6 km MSL, indicative of the updrafts capabilities to loft and size sort the raindrops that were being swept up from lower levels (Fig. 4c). At the lowest heights in the differential propagation phase field, the increased retardation of the H waves relative to the V waves due to the high concentration of oblate raindrops in the echo core was evidenced by the rightward (green towards red) progression along the color scale with increasing range (Fig. 4d). In the upper, sub-freezing portion of the echo, phase shifts in the opposite sense (i.e., green towards blue) indicated the presence of ice crystals whose long axes had become oriented towards the vertical due to the presence of strong electric fields. These negative phase shifts occurred in regions that were displaced from the BWER in general agreement with the horizontal distributions of the LMA discharge source and reflectivity fields shown in Fig. 3 (bottom).

b. *Polarimetric signatures in the ice phase, 15 July 2014*

During July 2014 a NSF supported project called FRONT-DE (demonstration experiment) which examined and compared polarimetric signatures among CSU-CHILL, S-Pol and KFTG radars. On 15 July a convective complex passed through the eastern portion of the FRONT domain and was captured by these three radars. The storms were electrified and the ice phase contained an abundance of ice particles with significant axis ratios. Such ice crystals, in the presence of strong electric field, can be aligned and canted such that cross coupling between the H and V polarized components of the radar signal occurs (Hubbert et al. 2014a,b). Having three polarimetric radars with the LMA described above provides a unique opportunity to study ice crystal microphysics and electrification.

The S-Pol high power transmit network has the capability to broadcast either fast alternating H and V pulses or simultaneous H and V pules. Less than 10s is required to switch between these two polarization modes. During July 2014 S-Pol alternated between SHV and FHV volume and RHI scans. Figure 5 shows a PPI of S-Pol Z, ϕ_{dp}, Z_{dr}^{fhv}, Z_{dr}^{shv}, ρ_x and LDR all at 5.5° elevation. The data is taken above the ice phase. At 5.5° and 50 km range gives about 4.8 km AGL. The top of the melting level is roughly 3 km AGL as estimated from the polarimetric variables (RHIs not shown). The ϕ_{dp} of Fig. 5 shows that there is about 20° of total phase shift in the ice phase at about the 100° azimuth radial. Modeling studies show that ice crystals causing the this amount of phase shift should have Z_{dr} in excess of several dB (Hubbert et al. 2014a,b). The Z_{dr}^{fhv} shows that intrinsic Z_{dr} is only slightly positive. Thus we conclude that oriented ice crystals causing the large ϕ_{dp} accumulation likely coexist with larger polarimetrically isotropic ice particles that dominate the Z_{dr}^{fhv}. Theory and experimental measurements have verified that if the particles in a radar resolution have a mean canting angle of zero deg. and if the particles and their canting angles are symmetrically distributed around the zero mean angle, then cross coupling of the transmitted H and V electric fields doesn't occur. Thus cross-coupling signatures in the ice phase are evidence of canted ice particles (Ryzhkov and Zrnić 2007; Hubbert et al. 2010, 2014a,b).

The Z_{dr}^{shv} of Fig. 5 show the well know radial streaks caused by cross coupling. This data was gathered at about 10 min. later than the Z_{dr}^{fhv} data. The ϕ_{dp}^{shv} (not given) shows that a comparable amount of phase shift was present as shown in the ϕ_{dp}^{fhv} of Fig. 5. The ρ_x and LDR in Fig. 5 also show evidence of canted ice crystals and cross coupling. ρ_x is the correlation coefficient of the copolar H and the accompanying crosspolar V signals for FHV data. The radial higher value streaks in red are caused by canted and aligned ice particles. LDR also shows similarly streaks (increased values). Figure 6 shows the ρ_x data of Fig. 5 with lightning flash counts as recorded by the LMA at the 8.9 to 9.5 km MSL region. Charge separation was indeed occurring in this storm which likely aligned the ice particles which interned caused the observed cross coupling. CHILL and KFTG corroborate these signatures but are not shown here.

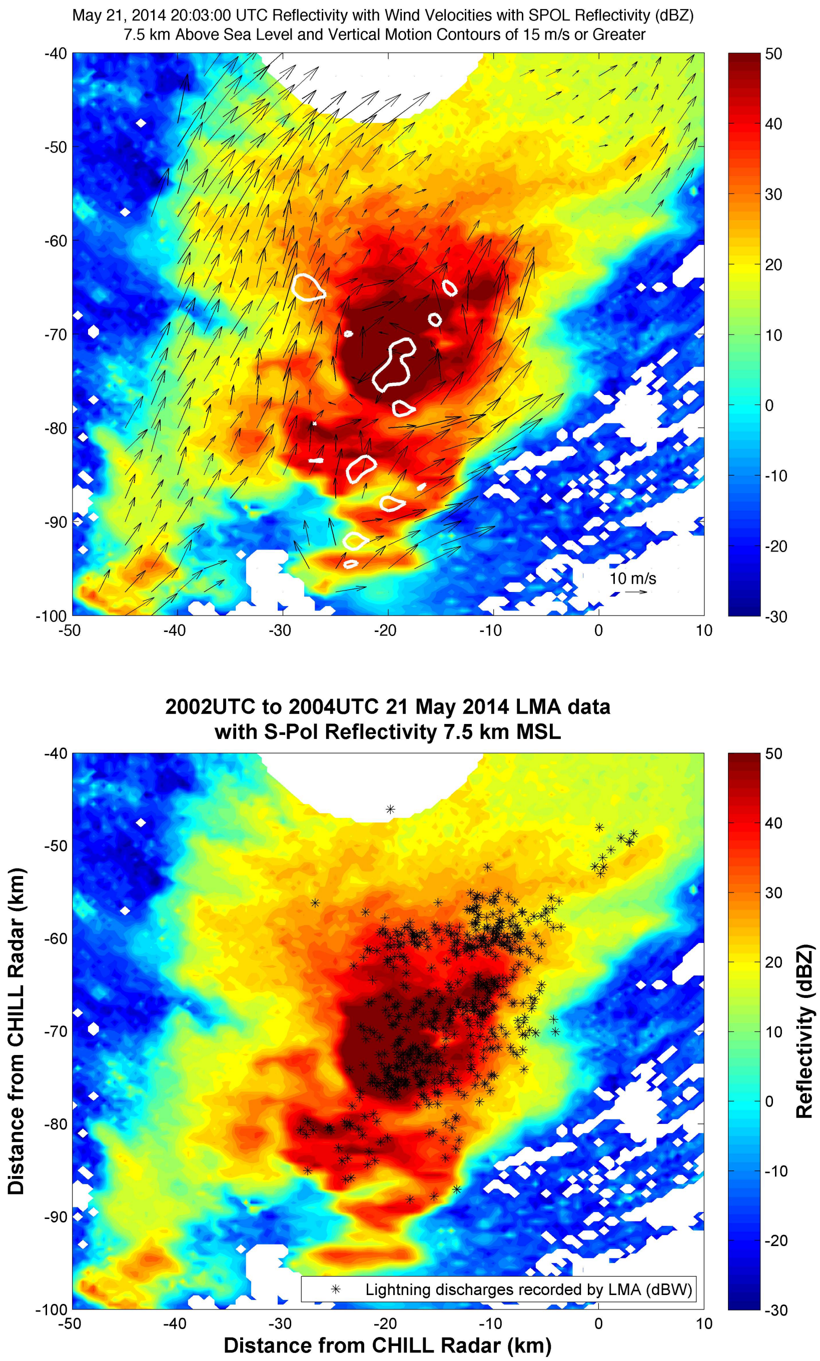

Figure 2: *FRONT radar data. Top panel: Earth-relative horizontal winds (arrows) and updrafts of 15 ms^{-1} or more (solid white contour) at the 7.5 km MSL level synthesized from radial the velocities observed by the NCAR S-Pol and NWS KFTG radars at 2003 UTC on 21 May 2014. Analysis grid X, Y distances are in km relative to the CSU-CHILL radar. Color fill is S-Pol reflectivity field in dBZ. Bottom panel: Locations of lightning-related discharges detected by the Northern Colorado Lightning Mapping Array (LMA) system between 2002 and 2004 UTC in the 7 to 8 km MSL height range on 21 May 2014. Color fill is S-Pol reflectivity levels as in the top panel*

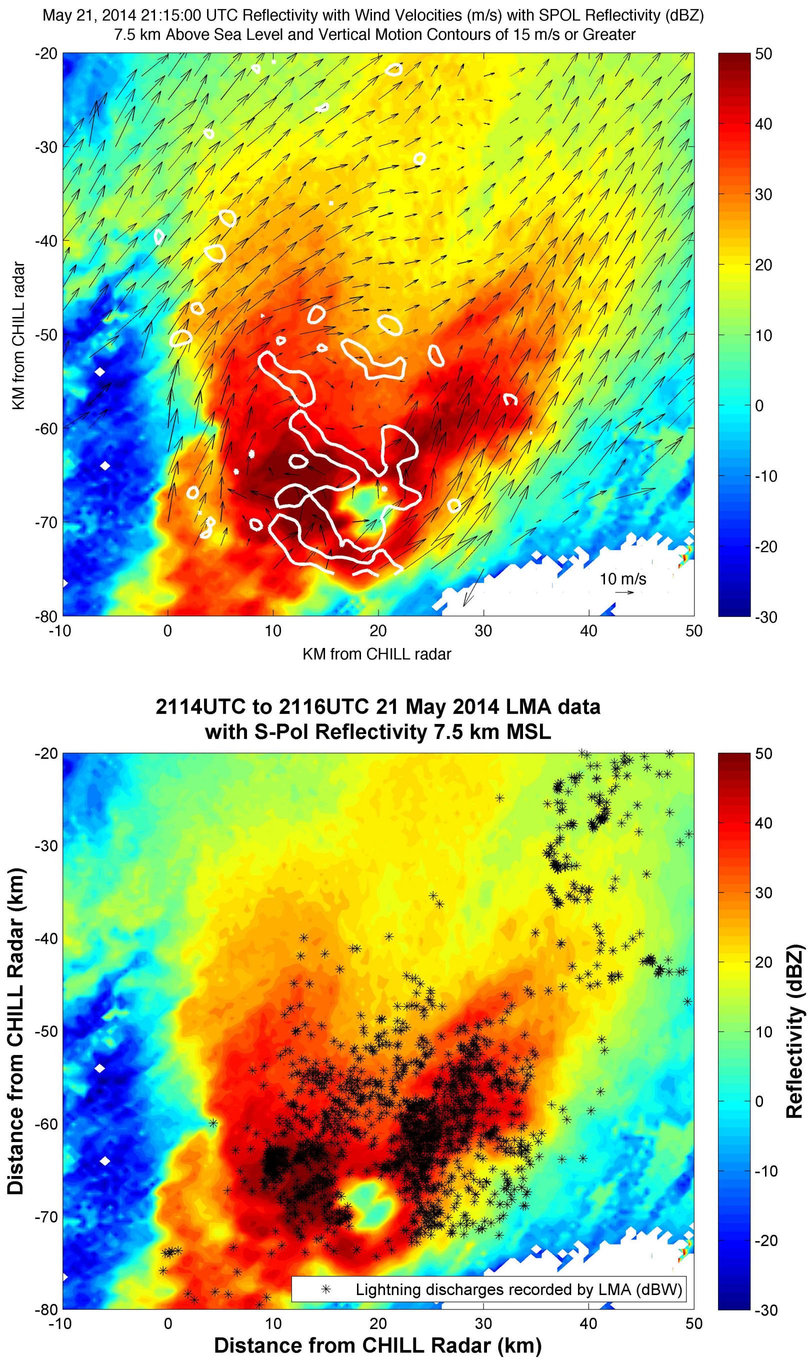

Figure 3: *FRONT radar data. Top panel: As in Fig. 2 except analysis time is 2115 UTC and the contributing radial velocity data was provided by the NCAR S-Pol and CSU-CHILL radars. Bottom panel: As in 2 except the LMA data time interval is 2114 2116 UTC.*

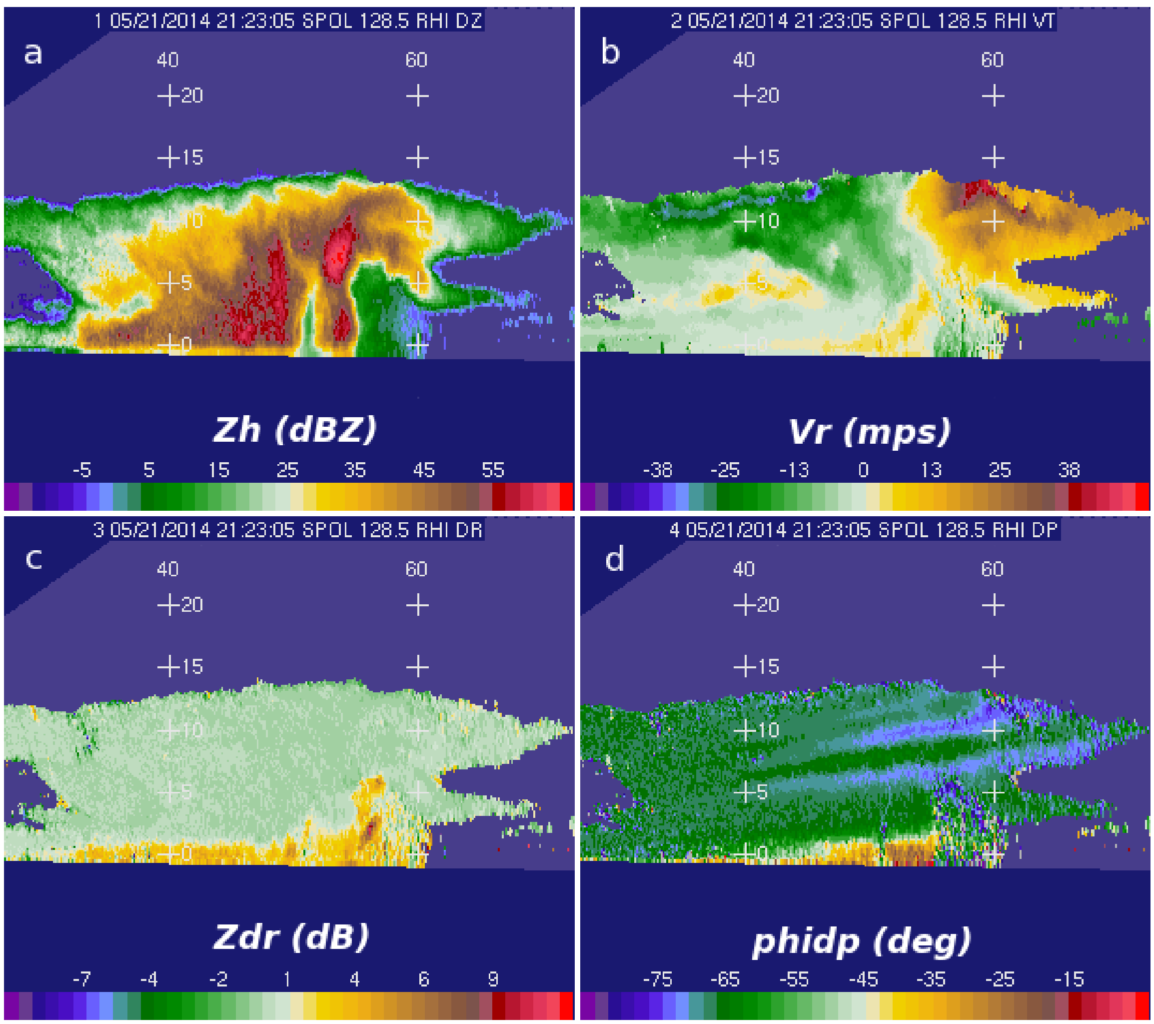

Figure 4: *Selected S-Pol data fields observed in an RHI scan on an azimuth of 128.5° at 2123 UTC on 21 May 2014.*

3. Summary

The CSU-CHILL and NCAR S-POL systems have streamlined operations to form the new FRONT facility. FRONT will provide enhanced service to the science community for not only radar technology demonstration, but also for more general scientific exploration that benefits from easy access to high-quality, dual-Doppler, dual-polarization, multi-frequency radars with the augmentation of other possible measurement platforms. However, S-Pol and CSU-CHILL will continue to support their primary missions of NSF remote deployments as required. In this paper two data cases illustrated some of the features and capabilities of FRONT. One case showed wind vector dual-Doppler analysis for a tornado on 21 May 2015. The second case demonstrated the polarization capabilities of the FRONT. FRONT is available to the research community and is requestable for 20-hour projects in a streamlined process. A FRONT request form can be found at http://www.eol.ucar.edu/front.

Acknowledgment
Both the CSU-CHILL and NCAR S-Pol radars are supported by the National Science Foundation. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation. The author would like to acknowledge Julie Barnum (Missouri State University) and Sarah Murphy (Lyndon State College) who helped assemble several of the figures.

References

Hubbert, J., S. Ellis, W.-Y. Chang, M. Dixon, and Y.-C. Liou, 2014a: X-band polarimetric observations of cross-coupling in the ice phase of convective storms in taiwan. *J. of Applied Meteor. and Clim.*.

Hubbert, J., S. Ellis, W.-Y. Chang, S. Rutledge, and M. Dixon, 2014b: Microphysical interpretation of S-band simultaneous horizontal and vertical polarization transmit radar data. *J. of Applied Meteor.and Clim.*.

Hubbert, J., S. Ellis, M. Dixon, and G. Meymaris, 2010: Modeling, error analysis and evaluation of dual polarization variables obtained from simultaneous horizontal and vertical polarization transmit radar. Part II: Experimental data. *J. Atmos. Oceanic Technol.*, **27**, 1599–1607.

Krauss, T. and J. Marwitz, 1984: Precipitation processes in an alberta supercell hailstorm. *J. Atmos. Sci.*, **41**, 1025–1035.

Krehbiel, P., R. J. Thomas, W. Rison, T. Hamlin, J. Harlin, and M. Davis, 2000: Gps-based mapping system reveals lightning inside storms. *Eos, Trans. Amer. Geophys. Union*, **81**, 21–25.

Ryzhkov, A. and D. Zrnić, 2007: Depolarization in ice crystals and its effect on radar polarimetric measurements. *J. Atmos. Oceanic Tech.*, **24**, 1256–1267.

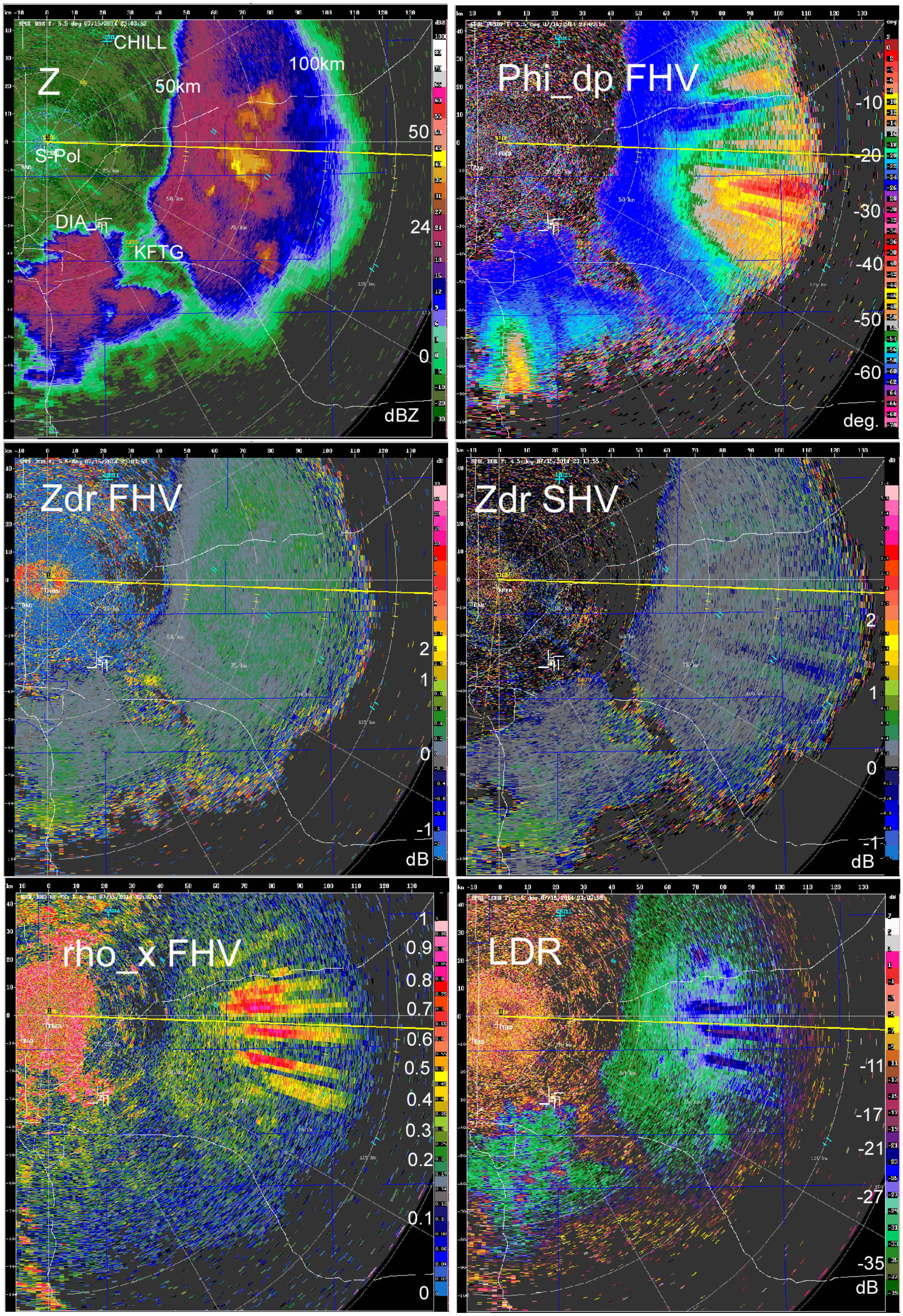

Figure 5: *S-Pol PPI data at 5.5° elevation on 15 July 2014. Z, ϕ_{dp}, Z_{dr}^{fhv}, ρ_x, and LDR were gathered at 23:03:52 UTC while Z_{dr}^{shv} was collected at 23:13:55.*

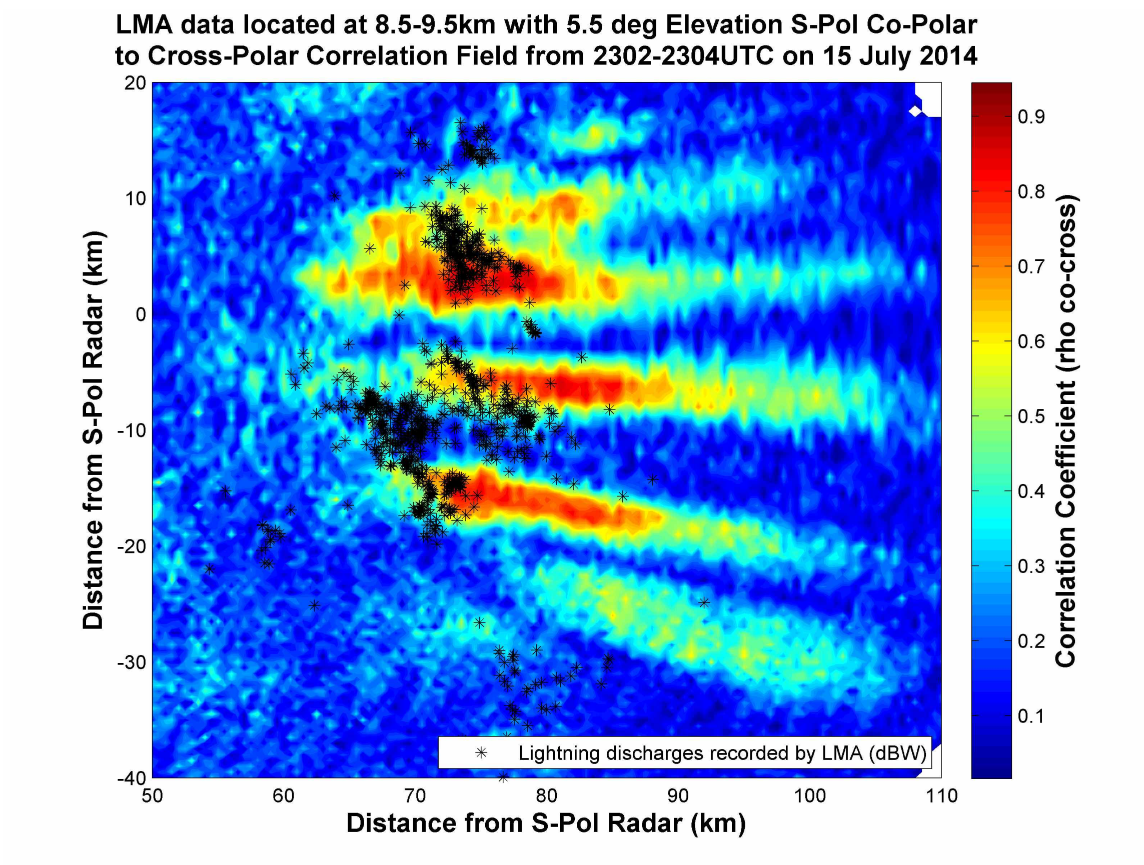

Figure 6: *The ρ_x data of Fig. 5 with lightning flash counts as recorded by the LMA at the 8.9 to 9.5 km MSL region.*