P12.194 FRONT: The FRONT RANGE OBSERVATIONAL NETWORK TESTBED

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1. INTRODUCTION

Since 2008 the personnel of the Colorado State University CSU-CHILL National Radar Facility and the National Center for Atmospheric Research S-Pol Radar Facility have been developing, with guidance from the National Science Foundation, a plan to more closely align the two radar's architectures so that operation, development, maintenance and management of the two facilities would become more efficient. Initially, the radar groups focused on adopting common software and hardware structures including antenna control, radar process control, signal processing, calibration, and data display capabilities. These common structures allow the two radars to be more streamlined in their operation, which easily enables shared development. Another highlight of this joint activity paradigm is the Front Range Operational Network Testbed (FRONT). The common streamlined infrastructure enables close networking of these systems forming the anchor points of an experimental infrastructure. FRONT, formed by S-Pol, CSU-CHILL and CSU-Pawnee S-band radars, along with nearby NEXRAD radars, brings a new observational capability to the community.

An important aspect of the envisioned FRONT mission is moving S-Pol to a new site in Weld County, called the Firestone Site (near the intersection of Weld County Roads 18 and 19), in order to create a dual-Doppler, dual-polarization radar configuration. It is planned that radar data from the NEXRADs KFTG (Denver Airport) and KCYS (Cheyenne) will be integrated with CSU-CHILL, S-Pol and Pawnee (located near Nunn, CO) data thereby forging a unique research infrastructure for the scientific community. See Fig. 1 for the location of the radars in FRONT. An important aspect of the plan is that S-Pol will adopt an operational strategy successfully used at CSU-CHILL: S-Pol will be maintained in an operational configuration when not remotely deployed on NSF field experiments.

Similar to CSU-CHILL, S-Pol will be available to the scientific community while at its FRONT home base in part for small data collection efforts roughly defined as 20 hour projects. More significant collection efforts will still need to go through the OFAP (Observing Facilities Assessment Panel) process. A FRONT request form can be found at at http://www.eol.ucar.edu/front; however, FRONT as a network will not be available until Fall of 2012.

The 42-kilometer baseline of Firestone field site and CSU-CHILL has excellent dual- Doppler geometry. It is our vision that 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, both CSU-CHILL and S-Pol will become remotely operable. 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 will provide 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 such as Virtual Operations Center (VOC),

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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 and climate technology development; leading, promoting and enabling geoscience research and education.
Mission:
FRONT provides the atmospheric science community with a cost-efficient observational infrastructure for the collection of comprehensive mesoscale data sets that include the unique dual-polarization and multi-wavelength remote sensing capabilities of the NCAR S-Pol and CSU-CHILL radars.
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1.1. *FRONT Measurement Capabilities*

FRONT is anchored by two advanced, dual-polarimetric radars, the CSU-CHILL and S-Pol; however, FRONT offers much more measurement capability than just the main S-band frequencies of these radars. Both CSU-CHILL and S-Pol are adding second frequencies: for CSU-CHILL, X-band and for S-Pol, Ka-band. This combination of two high quality S-band polarimetric radars with two additional frequencies for expanded microphysical profiling will establish a unique measurement capability. The X-band component on CSU-CHILL will feature an aligned common-axis, very narrow main antenna beam (0.33 degree) enabling high resolution measurements that are precisely collocated with the S-band measurements. This will be accomplished by employing a new dual-frequency horn on CSU-CHILL. In contrast, the dual-frequency capability of S-Pol is achieved by the addition of a Ka-band antenna mounted to the edge of the S-Pol's center-fed, parabolic reflector antenna. The dual-frequency capability of S-Pol enables the retrieval of humidity and cloud liquid water content (Ellis and Vivekanandan 2010, 2011).

FRONT will be augmented by a VHF 3-D lightning network. The Lightning Mapping Array (LMA) is a three-dimensional total lightning location system that uses time of arrival of the lightning caused, electromagnetic pulses at a network of receiver stations (Rison et al. 1999). Paul Krehbiel and colleagues will be installing the LMA network as part of the proposed NSF DC3 (Deep Convective Clouds and Chemistry) project. At the conclusion of DC3 the LMA network will become part of FRONT. Figure 2 shows the planned locations of the individual LMA receivers.

In the future, FRONT will continue to be augmented by real-time satellite data feeds, lidars, radiometers, surface stations, GPS receivers, rain gauges, profilers and other observational platforms as collaborative opportunities and funding become available. Such a comprehensive network would result in a unique observational test-bed from a worldwide perspective.

2. FRONT ENABLED SCIENCE

The Front Range of Colorado has hosted many field projects in the past spanning studies of warm season and cool season weather events. A partial list of these projects includes: JAWS (Joint Airport Weather Studies), CLAWS (Classify, Locate and Avoid Wind Shear), CINDE (The Convection Initiation and Downburst Experiment), POWS (Polarimetric Observations of Winter Storms), WISP (Winter Icing and Storms Project; two field seasons), STERAO-A (Stratosphere-Troposphere Experiments: Radiation, Aerosols and Ozone), The Front Range Pilot Project (for NASA Global Precipitation Measurement ground validation), and REFRACTT (Refractivity Experiment for H2O Research and Collaborative Operational Technology Transfer). Each of these projects utilized Doppler wind measurements, as well as polarimetric measurements as this technology became available. However, these projects did not have access to advanced multiparameter measurements (dual-polarization and multi-frequency) in the context of high quality 3-D wind fields such as will be provided by FRONT. We believe this infrastructure, enhanced by other measurements as described in the previous section, will motivate a series of experiments afforded by this advanced technology. Below we provide a list of potential scientific projects that would be possible with the FRONT. These projects are envisioned to be of interest to the broader science community.

Numerical model data assimilation The routine availability of high-resolution observations would provide an excellent test-bed for high-resolution numerical forecast models that assimilate observations, such as that used by the NCAR Short Term Explicit Prediction (STEP) program. Improvement resulting from new forecast model developments can be evaluated systematically, which cannot be done by one-time field observations. It is also envisioned that the combination of S-Pol and CSU-CHILL into a radar network will help focus resources and institutional expertise so that dual-polarimetric data are finally integrated into numerical models.

Automated Data Quality and Advanced Signal Processing The collection of data by a well-calibrated radar, while crucial, is only the initial step in providing the scientific community with meaningful meteorological data – data artifacts must either be eliminated or identified and censored via signal processing to achieve high data quality. Effective and reliable use of radar data for quantitative precipitation estimation (QPE), Nowcasting, data assimilation into weather models, hydrometeor classification and severe weather identification, depends directly on high quality radar data. There are many factors that affect radar data quality some of which include: radar calibration, NP (normal propagation) and AP (anomalous propagation) ground clutter, low SNR (signal-to-noise-ratio), multiple trip echoes, radar malfunction, 3-body scattering, attenuation, beam blockage, partial beam filling, biological scatterers, RF (radio frequency) interference, and data measurement uncertainty (i.e., error statistics).

Various signal-processing techniques have been developed to effectively mitigate these data-contaminating effects, or at least to identify the contaminated data so that it can be classified as non-meteorological echo; however, these techniques and algorithms are still evolving and represent current areas of intense research. Furthermore, with the advances in fast digital radar technology, computers and gigabit Ethernet speeds, it is now possible to over sample radar return signals down to 20 m in range, or better, and transmit these I and Q samples to fast computers. The flexible, easy-to-program PC environment is then used to execute signal processing algorithms for data quality and radar product generation. This new radar processing technology, which exists on both CSU-CHILL and S-Pol, also makes possible real-time spectral processing especially for dual-polarization measurements, a research area that has only begun to be explored.

The integrated facility would provide an excellent opportunity for developing and testing real-time automated radar quality control techniques. The lack of such techniques limits the accuracy and utility of real-time retrievals such as rain rate, cloud water content, humidity and wind. Furthermore, effective real-time data quality control is essential for the assimilation of these observations and retrievals into numerical models and nowcasting algorithms. The various radars at different wavelengths collecting large amounts of data would be an excellent laboratory for developing and verifying calibration methods, attenuation and scattering effect correction techniques, range and velocity ambiguity mitigation techniques, ground clutter detection and removal algorithms and precipitation identification algorithms. The expected outcomes of improved real-time data quality are improved QPE and QPF.

Orographic impacts The location of the radars affords an excellent opportunity to study orographic precipitation and mountain waves. The relationship between orography and its impacts on precipitation are an ongoing research topic and have important hydrologic implications. The orography affects both summer and winter precipitation, as well as generating frequent mountain waves and turbulence. FRONT would be well suited to sample numerous events throughout the year. Measurements of winds and polarimetric variables would provide insight into precipitation formation processes in complex terrain.

Summer convective storms Flash floods resulting from terrain-induced heavy precipitation during warm seasons are extreme hazards in the U.S. The Front Range experiences numerous summertime convective storms. FRONT could support research interests requiring nearly continuous observations of convection initiation, evolution, and precipitation production within the radar domain, resources permitting. The real-time refractivity retrieval would provide valuable low-level moisture information, which shows promise for convection initiation and evolution studies. Hail formation processes could also be studied with the combined polarimetric data from S-Pol and CSU-CHILL

Winter storms Front Range winter storms are complex with both critical synoptic and mesoscale dynamic and microphysical processes occurring simultaneously. Each must be better understood to improve forecasts and scientific research on precipitation production. Historically, Doppler radar-based studies of heavy winter storms in the Front Range are few and far between and most have been with single conventional radar data. Research on blocking effects on winter storms and barrier jet evolution would benefit greatly from multi-Doppler polarimetric radar data. High-resolution wind and hydrometeor fields would help to assess the large north-south variations in precipitation along the urban corridor. The value of radar refractivity in winter storms could be evaluated. The polarization fields would also yield insight into the role of the dendritic zone and how its location and evolution and depth contribute to precipitation production in these storms. In combination with data on the riming structure of the storms, the precipitation process from start to finish could be analyzed. Such information would yield immediate forecast benefits. Studies of winter storms are expected to benefit significantly from the short wavelength observations of S-Pol (Ka band) and CSU-CHILL (X-band).

Radar retrieval development and testing The Front Range laboratory would provide an excellent opportunity to develop and test radar retrieval algorithms. This may include dual-Doppler processing to obtain the three-dimensional wind fields in real-time, particle identification algorithms to study microphysics, radar refractivity to obtain surface moisture maps, dual-wavelength retrieval developments for water vapor and cloud liquid water retrievals and single-Doppler kinematic and thermodynamic retrievals, such as currently used by the Variational Doppler Radar Analysis System.

Dual-polarimetric radar studies The close proximity of two research polarimetric radars provides a unique opportunity to study overlapping observations of polarimetric variables. Possible applications are automated data quality control, the development of advanced signal processing techniques and improved use of polarimetric variables for the identification and understanding of precipitation microphysical variables. With the imminent polarimetric upgrade of the nations WSR-88D radars, we expect the CSU-CHILL and S-Pol radars to be in demand as development and demonstration platforms for polarimetric-based algorithms. Indeed, once the KFTG and KCYS WSR-88Ds are upgraded, CSU-CHILL and S-Pol data can be used to validate the their measurements. In general, we anticipate a number of demands placed on CSU-CHILL and S-Pol once the nations WSR-88D radars are upgraded. While the WSR-88D network will make dual-polarized data available nation wide, the scanning strategies used by the NWS are fixed and are not at the discretion of NSF scientific research community. In addition, the NEXRADs will use the simultaneous horizontal and vertical (SHV) transmit technique which does not provide the full set of polarimetric variables and furthermore, the data quality of the NEXRAD radars will not be on par with S-Pol and CSU-CHILL due to cross-polar coupling that occurs in SHV mode operation (Wang and Chandrasekar 2006; Hubbert et al. 2010a,b). Thus, we envision the continued need for high quality, S-band, dual-polarization measurements that CSU-CHILL and S-Pol can provide.

Triple Doppler operations Given the radar baselines of CSU-CHILL, S-Pol and KFTG (near Denver International Airport) in FRONT, triple-Doppler measurements are possible. Other triple-Doppler configurations could also be created. For example, a mobile C-band radar could be located east or west of the baseline formed by CSU-CHILL and S-Pol. Inter-comparisons of dual-Doppler and triple-Doppler solutions could therefore be done.

3. EDUCATION, TRAINING and OUTREACH

As noted earlier in this document, a primary result of the collaborative efforts between the NCAR and CSU radar groups will be the development of a local operational structure that supports the efficient collection of data while the S-Pol and CSU-CHILL radars are located at their institutional home bases. Historically, the costs of conducting field projects that do not involve relocating these large S-Band radar systems have been modest (REFRACTT, STERAO-A, etc.). Also, the local availability of additional observing instrumentation (CSU-Pawnee, KFTG and KCYS WSR-88D radars; NCAR portable sounding systems, etc.) will permit the collection of even more comprehensive observations. The overall cost efficiency of home-based radar operations will particularly benefit the small-scale ($50K budget) educationally centered research projects that the NSF has recently targeted for deployment pool funding support.

Beyond the support of traditional, OFAP-allocated field projects, local operations can readily be conducted to collect target of opportunity polarimetric radar data sets. For example, experience has shown that having the radars operational during the mid-May through early August period will yield many possibilities for convective storm observations in the Colorado Front Range area providing more opportunities to unravel the challenges of convective initiation. These “target of opportunity” activities will provide two primary benefits: (1) exercising of the radar systems for testing and improvement of their technical capabilities. (i.e. real-time product generation software, remotely-controlled / unattended radar operational modes) (2) the resultant data sets should yield many “classroom case” examples that will be made available to the educational community via the Internet.

To generally improve access to the S-Pol and CSU-CHILL data archives, it is envisioned that one of the eventual results of the collaboration efforts will be the storage of the radar files in a common format at NCARs mass data storage facility. The archived data files from both radars will be organized to allow interactive perusal using VCHILL software. EOL’s current on-line data archive interface will be modified to provide educational interests (as well as scientific investigators) with standardized procedures for selecting and downloading S-Pol and CSU-

CHILL data files of interest.

We will continue to make special efforts to identify classroom case data sets that are recorded during "target of opportunity" operations. This type of archive has been developed and maintained on the CSU-CHILL web site for many years. Links to such events of interest are established in a searchable, on-line data base that allows members of the educational community to easily select archived polarimetric radar data sets for use in lecture presentations, student case studies, etc. Educational programs in both Atmospheric Science and Electrical Engineering (nationwide, and some times worldwide) have utilized data collected by the CSU-CHILL. With the addition of S-Pol, more cases can be captured for these purposes. Cases can now include coordinated polarimetric and Doppler observations.

Beyond the assembly of archived case study data sets, home-based radar operations will also support various "real-time" educational activities. The expanded remote control and data display capabilities planned for S-Pol and CSU-CHILL will make it feasible to both view the data and to control the antenna scanning from remotely located instructional settings. Thus, a mesoscale meteorology course being conducted at a distant university might include laboratory sessions during which the students remotely observe the real-time data streams from CSU-CHILL and S-Pol and make "on-the-fly" adjustment of system scan parameters.

4. FRONT SYNERGY: AIRCRAFT ICING EXAMPLE

A recently-conducted test of NASA's NIRSS (NASA Icing Remote Sensing System) hardware provides an example of the type of research synergy that is enabled by the FRONT infrastructure. NIRSS consists of vertically pointing Doppler K-band radar, a multichannel radiometer and a laser ceilometer (Reehorst et al. 2005, 2006). Collectively, these sensors are designed to detect regions where the presence of supercooled droplets produces conditions conducive to the formation of structural icing on aircraft. During the winter of 2010 – 2011, the NIRSS equipment was installed at NOAA's field site near Platteville, CO. Due to its proximity to Denver International Airport (35 km north-northwest of KDEN), a considerable amount of air traffic transits the Platteville area. Platteville is also located approximately equidistant from CSU-CHILL and from S-Pol's current operating site near Marshall, CO, allowing these research radars to provide dual-polarization / Doppler velocity measurements in the mesoscale region surrounding Platteville.

During the NIRSS project, the CSU-CHILL and S-Pol collected data in local events such as on 30 – 31 December 2010 when widespread clouds and precipitation occurred over northeastern Colorado. The 0045 UTC volume start time for CSU-CHILL and S-Pol was essentially coincident with an operational volume scan conducted by the NWS KFTG (Denver area) WSR-88D radar. Due to the close agreement with the volume starting time of the research radars, a multiple-Doppler wind field synthesis over a large area could be done using the radial velocity data from all three radars. The resultant Earth-relative flow field at a height of 2.8 km MSL is shown in Fig 3b. The background color fill depicts terrain heights in decameters above MSL (150 = 1.5 km). The low level airflow contains a significant upslope component in the Platteville region, the resultant upward vertical air motions aid in the generation of clouds and possible supercooled droplet regions. The same horizontal wind field is plotted along with the CSU-CHILL reflectivity field in Fig. 3b. Reflectivities of 15 – 18 dBZ are present in the Platteville area. The NIRSS observations collected as this same time did not detect significant quantities of supercooled liquid (Serke et al. (2011), Fig. 6). The growth of the large snow particles responsible for appreciable S-Band reflectivity levels had apparently scavenged out any available supercooled liquid.

A view of the vertical structure of the echo system is provided by the S-Pol RHI scan data shown in Fig. 4. The general increase in reflectivity towards the surface is indicative of the collection of ice particles into larger size aggregates. The average depth of the precipitation echo increases with range along the RHI plane. An area of positive specific propagation differential phase (K_{dp}) is found at mid-levels in the 90 – 100 km range interval in a snowband where appreciable concentrations of growing dendritic crystals probably exist (Kennedy and Rutledge 2011). The availability of these mesoscale observations synthesized from the FRONT radars provides a useful context for the interpretation of the single-point data collected by NIRSS.

This aircraft-icing case study then serves as an example of the type of research that FRONT can enable. Real-time wind vector fields are a future goal of FRONT.

5. 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. Because of the streamlined subsystem developments in the two radars, they can support each other in development and deployment activities. For example developmental activities in CSU-CHILL can be more readily implemented in S-Pol. Since S-Pol will be operational in between deployments as a part of FRONT, S-Pol will always be in a state of operational readiness for NSF field deployments. FRONT will available to the research community by Fall 2012 and will be requestable for 20-hour projects in a streamlined process. A FRONT request form is available at http://www.eol.ucar.edu/front.

Acknowledgment

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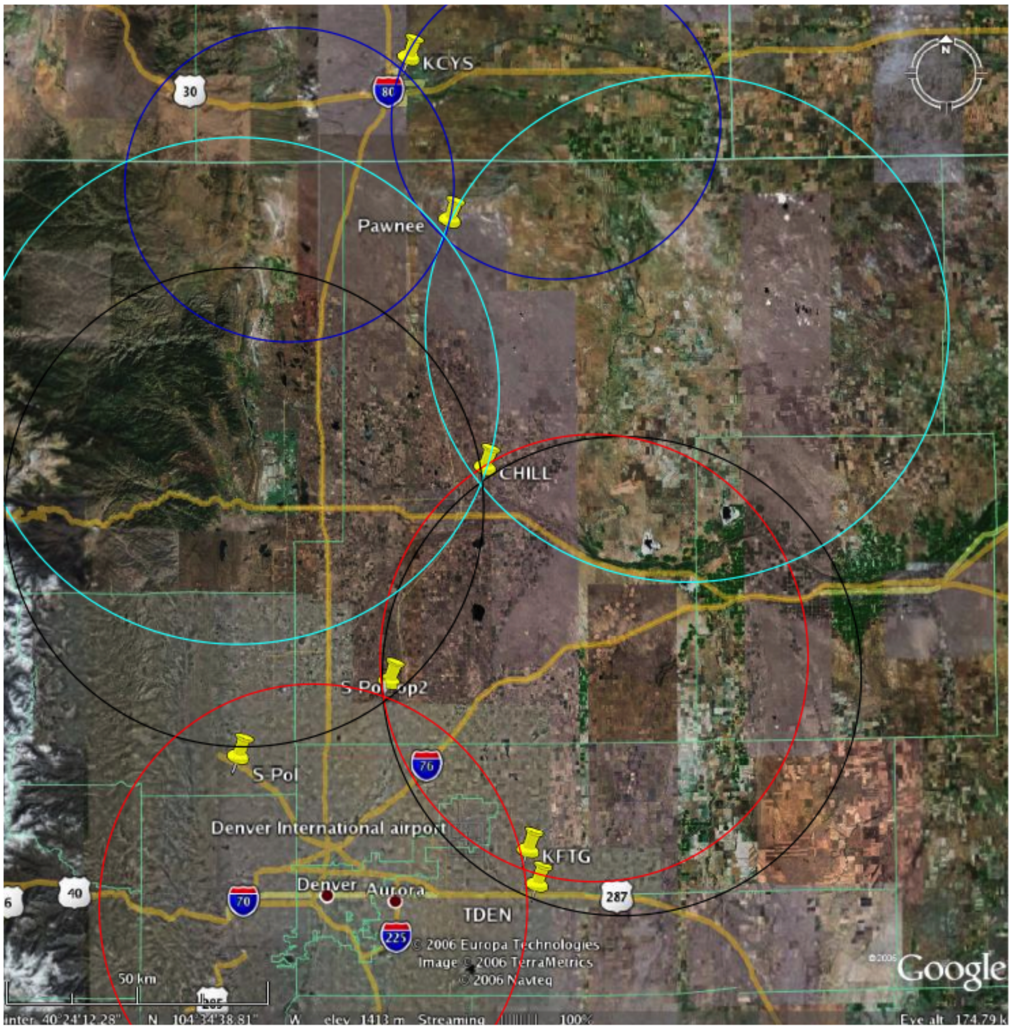


Figure 1: *FRONT radar locations.*

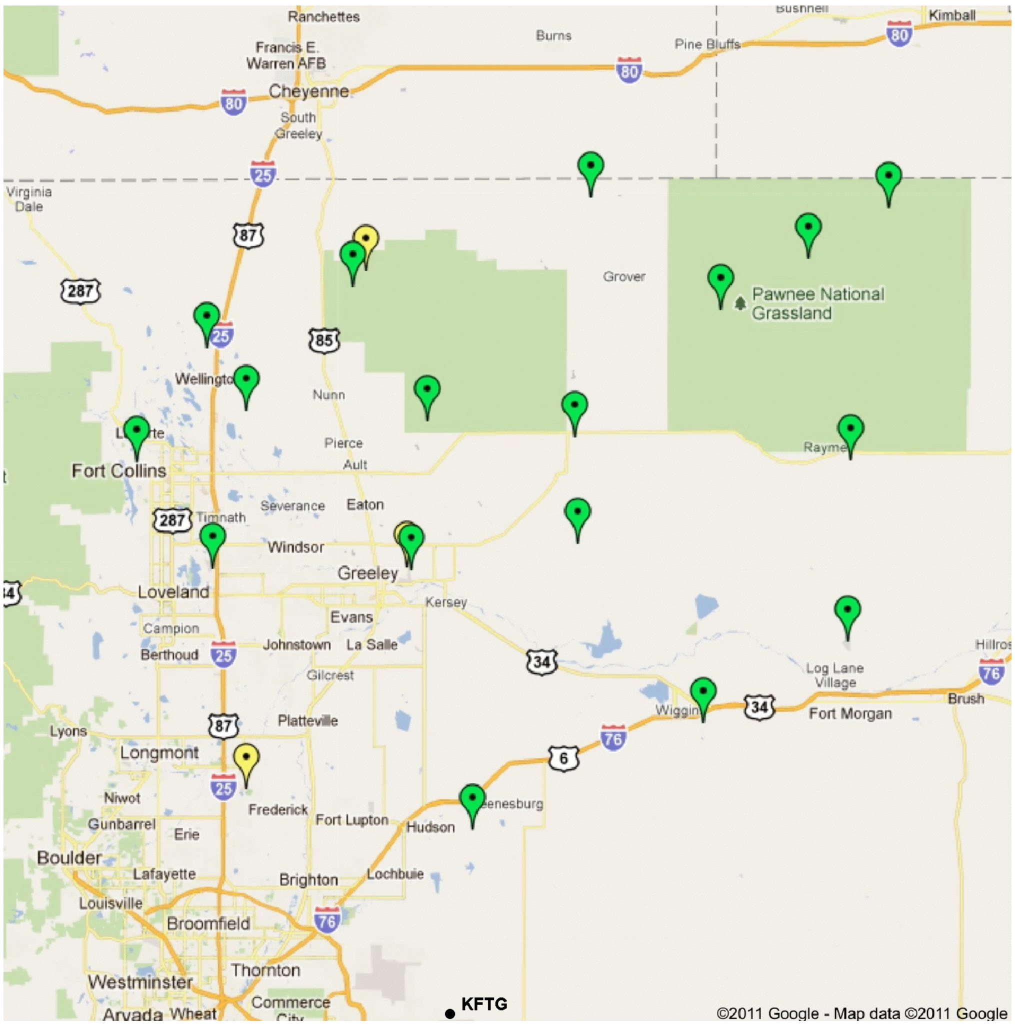
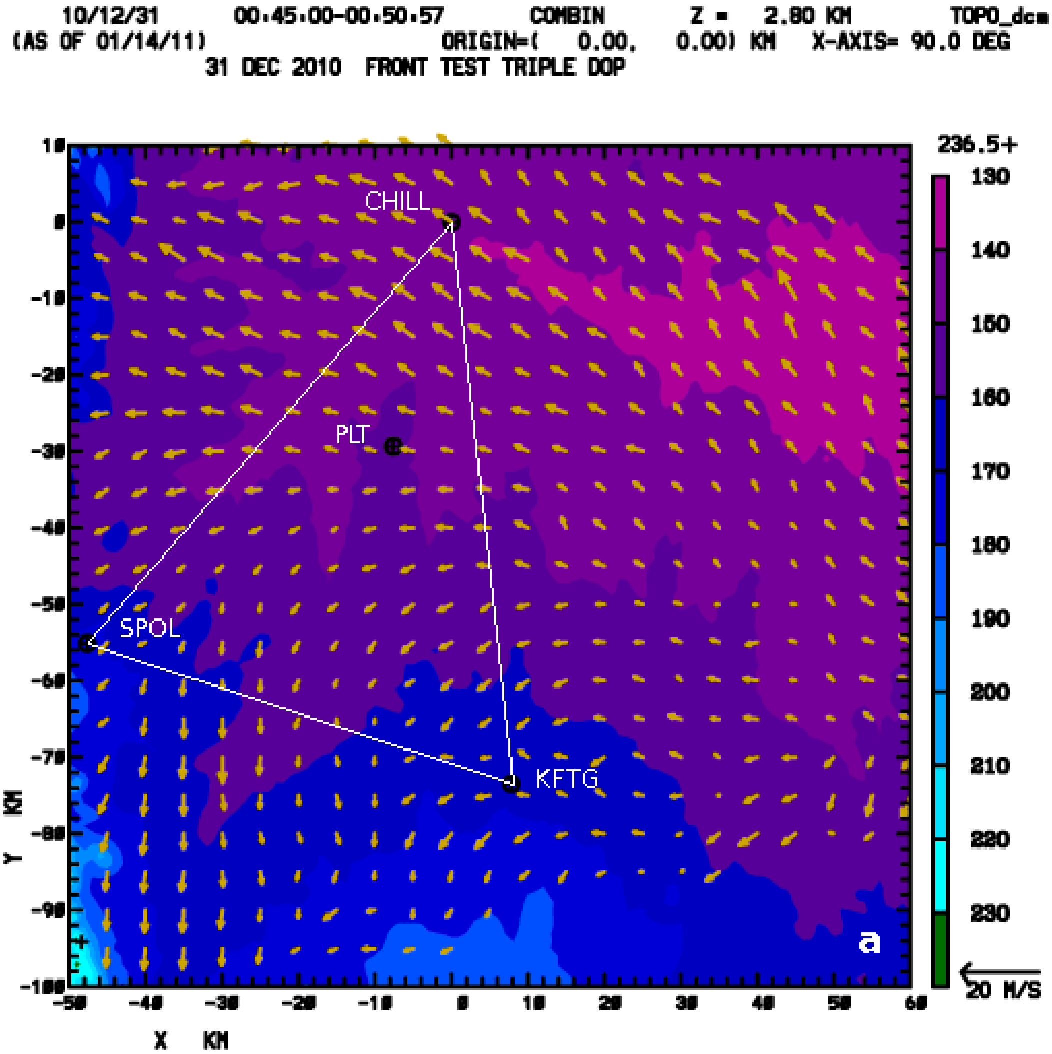


Figure 2: *The locations, marked in green, of the receivers for the LMA to be deployed in the FRONT domain. The yellow markers, from top to bottom, show the location of the Pawnee, CSU-CHILL and S-Pol radars. The CSU-CHILL marker is located close to Greeley and is obscured by a LMA marker. Figure supplied by New Mexico Tech.*



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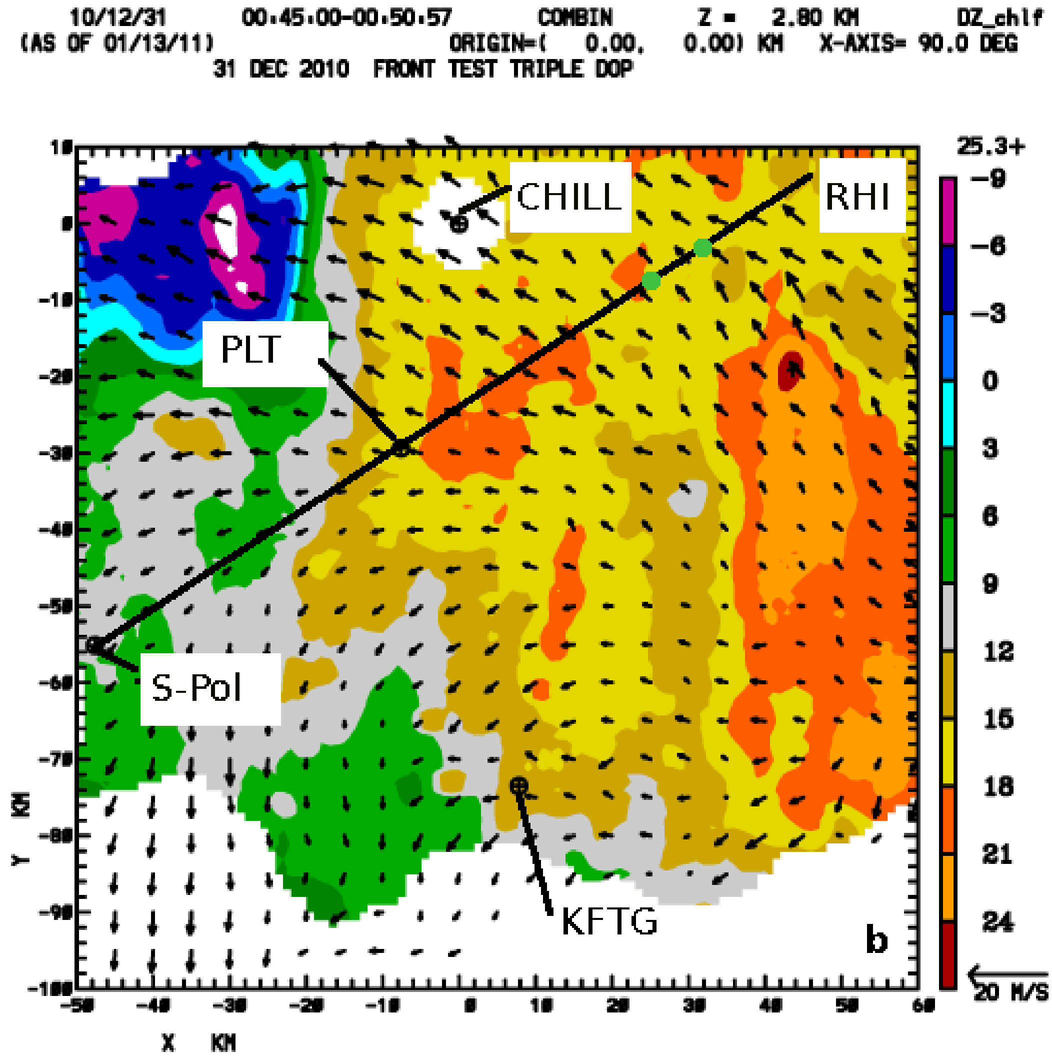

Figure 3: *Panel a: Earth-relative horizontal wind vectors at 2.8 km MSL at 0045 UTC on 31 December 2010. These vectors were synthesized from radial velocity data collected by the NCAR S-Pol, CSU-CHILL, and NWS KFTG radars. Background color fill is terrain heights above sea level in decameters (150 = 1.5 km MSL). NIRSS site at Platteville is marked as PLT. Location of the S-Pol RHI shown in Fig. 4 is marked. Green dots on the RHI line indicated the location of the* K_{dp} *maxima shown in Fig. 3a. Panel b: Wind vectors as in Panel a; color fill is CSU-CHILL reflectivity in dBZ.*

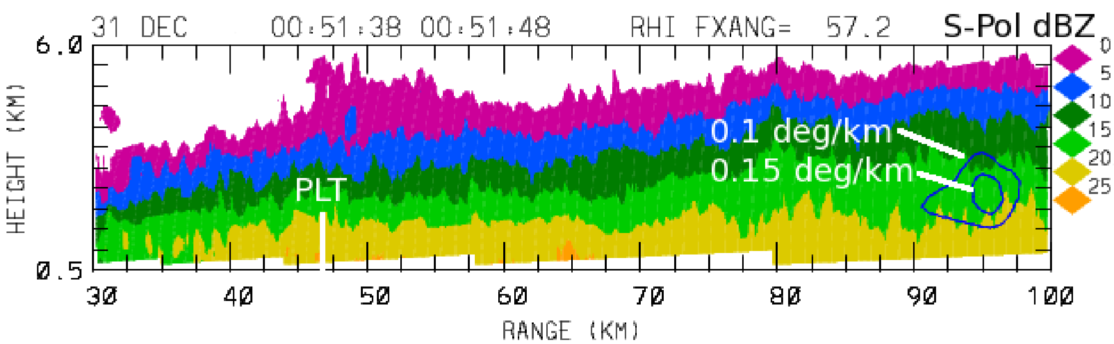

Figure 4: *S-Pol RHI scan data collected on an azimuth of 57.2^o at 0051:38 UTC on 31 December 2010. Color fill is reflectivity level in dBZ. Contour lines are one-way specific propagation phase (Kdp) in $^\circ$ km^{-1}.*