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COLORADO LIGHTNING MAPPING ARRAY COLLABORATIONS

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For the past two years, the GOES-R Proving Ground has solicited proposals for its Visiting Scientist Program. NASA's Short-term Prediction Research and Transition (SPoRT) Center has used this opportunity to support the GOES-R Proving Ground by expanding SPoRT's total lightning collaborations. In 2012, this expanded the evaluation of SPoRT's pseudo-geostationary lightning mapper product to the Aviation Weather Center and Storm Prediction Center. This year, SPoRT has collaborated with the Colorado Lightning Mapping Array (COLMA) and potential end users. In particular, SPoRT is collaborating with the Cooperative Institute for Research in the Atmosphere (CIRA) and Colorado State University (CSU) to obtain these data in real-time. From there, SPoRT is supporting the transition of these data to the local forecast offices in Boulder, Colorado and Cheyenne, Wyoming as well as to Proving Ground projects (e.g., the Hazardous Weather Testbed's Spring Program and Aviation Weather Center's Summer Experiment). This presentation will focus on the results of this particular Visiting Scientist Program trip. In particular, the COLMA data are being provided to both forecast offices for initial familiarization. Additionally, several forecast issues have been highlighted as important uses for COLMA data in the operational environment. These include the utility of these data for fire weather situations, situational awareness for both severe weather and lightning safety, and formal evaluations to take place in the spring of 2014.

1. NASA SPoRT AND THE GOES-R PROGRAM

NASA's Short-term Prediction Research and Transition (SPoRT) program (Darden et al. 2002; Goodman et al., 2004) (http://weather.msfc.nasa.gov/sport/) seeks to accelerate the infusion of NASA Earth science observations, data assimilation, and modeling research into weather forecast operations and decision-making. The program is executed in concert with other government, university, and private sector partners. The primary focus is on the regional and local scale, emphasizing forecast improvements on the 0-24 hour time scale. The SPoRT program has facilitated the use of real-time NASA data and products to address critical forecast issues at a number of partner National Weather Service (NWS) Weather Forecast Offices (WFOs) and private weather entities. Numerous techniques have been developed to transform satellite observations into useful parameters that better describe changing weather conditions (Darden et. al. 2002).

A core effort of SPoRT is the transition of ground-based total lightning data into real-time operations. This originally involved the North Alabama Lightning Mapping Array (Goodman et al. 2005 – NALMA), but has since expanded to include ten collaborative networks (Fig. 1). This includes the Colorado Lightning Mapping Array (COLMA), which is the subject of this manuscript. Since the NALMA was first transitioned in 2003, SPoRT has worked with our partners to develop assessments, training, and improved visualizations of these data to our WFO partners (Goodman et al. 2005; Nadler et al. 2009; Darden et al. 2010; Demetriades et al. 2008; Stano et al. 2011a), national center partners (Stano et al. 2013), and proving ground testbeds (Stano et al. 2012). The goal is to provide capabilities that enhance a forecaster's situational awareness that lead to improved severe weather warnings (e.g, the lightning jump algorithm; Schultz et al. 2009, 2011; Gatlin and Goodman 2010), situational awareness, and lightning safety (Hodanish et al. 1998, 2013; Bridenstine et al. 2005; Goodman et al. 2005; Demetriades et al. 2008; Nadler et al. 2009; Stano et al. 2010a; Stano 2012; White et al. 2012). SPoRT's efforts have led to greater utilization of total lightning data operationally and expanded the training on the future uses of the Geostationary Lightning Mapper (GLM; Christian et al. 1989, 1992, 2006; Goodman et al. 2013).

As part of SPoRT's efforts with the GOES-R Proving Ground (PG), SPoRT has created the Pseudo-Geostationary Lightning Mapper (PGLM) products (Stano et al. 2010b, 2011, 2012). These data have been used with the Hazardous Weather Testbed's Spring Program and Aviation Weather Center's Summer Experiment. Given the short range of the ground-based lightning mapping arrays (i.e., ~250 km radius), it is important to collaborate with as many ground networks as possible. This expands the number of users who can evaluate the data, allow for more opportunities to observe active weather, and provide varied domains to investigate regional differences. In order to facilitate an expansion of collaborations, SPoRT has participated with the GOES-R Proving Ground's Visiting Scientist Program (VSP).

The GOES-R VSP solicits collaborators to submit proposals for travel funding. This travel is to allow collaborators to meet face-to-face to establish,

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enhance, or improve collaborations. The VSP does not directly support large work initiatives. Given SPoRT's expertise with manipulating and transitioning total lightning data to operations, the VSP offers an excellent opportunity to establish new collaborations. SPoRT had previous success with a lightning VSP in 2012 in order to meet with the Aviation Weather Center and Storm Prediction Center and to transition total lightning observations to each center in N-AWIPS (Stano et al. 2013). SPoRT contacted Dr. Steven Rutledge (Colorado State University) who owns the Colorado Lightning Mapping Array, and the two local WFOs who would benefit from COLMA data; Boulder, Colorado and Cheyenne, Wyoming. With these collaborators, SPoRT submitted a VSP in late 2012 in order to establish collaboration with COLMA, transition these data to WFOs Boulder and Cheyenne, and to add these data to the N-AWIPS product at the national centers. This VSP was accepted and SPoRT conducted the VSP visits in March 2013. The following sections discuss the results and future work that have evolved out of this initial collaboration.

2. GOALS OF THE COLMA COLLABORATION

The COLMA VSP project for SPoRT to visit with WFOs Boulder and Cheyenne, as well as CIRA / Colorado State was an excellent opportunity for a small level of effort to lead to big results. The primary objective was to establish the initial collaboration. This would set up the initial data feed from COLMA to SPoRT, which would allow for SPoRT to generate real-time products for this network. With a data feed established, the product generation would be relatively simple as it would clone the work SPoRT is already performing for other collaborative lightning mapping arrays. The actual data feed included New Mexico Tech University (NMT), as NMT built and currently operates the COLMA. The overall benefit of this visit would allow for direct interactions between all collaborators and for SPoRT to establish additional data for use with the GOES-R Proving Ground.

The visit proposed several goals. First and foremost, this would initiate a brand new collaboration with COLMA, including the network owners and the potential end users. This would then result in establishing a real-time data feed, which was established prior to the actual visit. The bulk of the visit's objectives centered on science sharing and training. The SPoRT scientist would provide training sessions to discuss the benefits of total lightning (e.g., severe weather decision support, situational awareness, lightning safety, aviation, and impact-based decision support), how the activity relates to the GOES-R Proving Ground, and allow for forecasters to participate in a question and answer session. In addition, SPoRT would have the opportunity to shadow forecasters at each participating WFO. This, as well as the question and answer session, would allow SPoRT to learn about the unique forecast issues and concerns and each WFO. One key item that was discussed regularly was how the COLMA data may be able to supplement radar observations, as radar coverage is less dense than in other regions with access to total lightning data.

Finally, SPoRT and NMT established the data feed prior to the visit. This allowed SPoRT to begin processing the data and providing the data on the local data manager stream to provide COLMA data to the new partner WFOs. The visit would be used to confirm the data ingest and display.

3. INITIAL RESULTS

WFOs Boulder and Cheyenne, as of the American Meteorological Society meeting in February 2014, have had access to the COLMA data for ten months. This initial period has been an informal evaluation period for two reasons. First, there were unexpected difficulties ingesting the COLMA data in AWIPS I for WFO Cheyenne, which limited the opportunity for forecasters to observe the data in real-time. These have been solved and WFO Cheyenne has full access to the data in AWIPS I. Secondly, WFO Boulder was participating in an extended performance evaluation of AWIPS II. This evaluation did not permit the transition of SPoRT's LMA visualization plug-in until late 2013. As a result, WFO Boulder was using the NMT web page (Fig. 2) and SPoRT's Google Earth display (Fig. 3).

In spite of these initial difficulties, both WFOs expressed a great deal of interest and excitement in the COLMA data. This has only increased now that the displays in AWIPS I and AWIPS II are fully functional. The COLMA data are also now part of the data feed being provided to the Aviation Weather Center and Storm Prediction Center. Also, the following, interesting cases have been presented.

3.1 Cheyenne Tornado (29 July 2013)

This was one of the first severe weather opportunities to use the COLMA data for WFO Cheyenne. This particular case showed a lightning jump approximately 10 min prior to a small tornado touched down northwest of the city of Cheyenne. This particular example was useful in two ways. First, it demonstrated the utility of the COLMA data (e.g., rapid temporal update, lightning jump, and complementary nature with respect to radar) and highlighted an operational issue that needed to be addressed to use these data.

Figure 4 shows the radar reflectivity from the Cheyenne, Wyoming Doppler radar at ~2350 UTC, which was about 15 min prior to the tornado. The reflectivity observed a cluster of storms northwest of Cheyenne with a boundary south and southeast of the main cluster of storms. Figure 5 shows the corresponding storm relative velocity at the same time as Fig. 4 that shows an intersection of the thunderstorm outflow and the pre-existing boundary. The LAPS surface based CAPE was weak with less than 300 J / kg while the LAPS 0-3 km surface based lapse rates were approximately 8.5° C / km. All of these factors were converging just to the northeast of Federal, Wyoming and indicated favorable conditions for a potential landspout tornado. Figure 6 shows the (A) storm relative velocity and (B) radar reflectivity at the time of the tornado at 0005 UTC on 30 July 2013. These observations show a strong thunderstorm in the location of the tornado with a weak velocity couplet. Taken alone there could be uncertainty in whether or not a tornado warning should be issued as the radar observation is using the 6.4 degree scan. Figure 7 shows a series of COLMA, 1-min observations of total lightning source densities. The total lightning observations show very little total lightning prior to 2355 UTC. This rapidly changes about 10 min prior to the tornado touchdown with the total lightning observations surging from close to zero to over 40 sources in one minute on a 1×1 km grid.

This surge in lightning activity at 2355 UTC did occur approximately 10 min prior to the tornado's touchdown at 0005 UTC. This case was highlighted by WFO Cheyenne for two reasons. First, the surge in activity occurred for a landspout tornado, which traditionally can be difficult to observe and provide a warning. Secondly, the magnitude of the surge was relatively low. From cases using the North Alabama Lightning Mapping Array (NALMA), a severe weather event is usually preceded by at least 100 sources. However, the NALMA data are available every 2 min and with a 2×2 km grid resolution. This suggested that the COLMA observations may require a 2×2 km grid as opposed to the current 1×1 km grid, or use a modified color curve, as was implemented by WFO Cheyenne as seen in Fig. 7.

3.2 Long flash event (25 July 2013)

The second example better illustrates the use of COLMA observations for lightning safety. On the afternoon of 25 July 2013 several thunderstorm cells were moving roughly to the south, paralleling the Front Range to the west and Interstate 25 to the east in WFO Boulder's county warning area. At the time WFO Boulder did not have COLMA data in AWIPS II and relied on the various real-time web pages. During the afternoon, the thunderstorms exhibited active lightning, but not enough for a lightning jump and indicate severe weather. NASA SPoRT was monitoring the storms via the Google Earth web display to test that data processing was working appropriately during this event.

By 1900 UTC most of the cells were observed with total lightning and most of the activity was confined to the vicinity of the main storm updraft, as is typical. By 1920 UTC there were a few flashes that were observed extending several miles from the storm core, but nothing unusual was observed. Figure 8 shows a close up view of one storm in particular just west of Loveland, Colorado (south of Ft. Collins) at 1927 UTC using the 1×1 km source density product. A dramatic change is observed one minute later at 1928 UTC (Fig. 9). Here, a single flash has been observed initiating in the storm cell west of Loveland and then extending eastward towards Greeley, Colorado, which is approximately the center of the COLMA network.

A post-event analysis was performed on viewed the same storm in AWIPS II, representing was WFO Boulder would see once allowed to install the LMA visualization plug-in (Fig. 10). Figure 10 shows the same long flash observed by the source density product, but also indicates the importance of incorporating COLMA data into the end users decision support system (i.e., AWIPS II). Instead of looking at the source density product by itself, it can immediately be compared to the radar reflectivity at a single scan level (e.g., 0.9° here) or with the composite reflectivity. This particular case showed that the flash extended for nearly 67.5 km (42 miles). In addition, when compared to the composite reflectivity in Fig. 10, the flash appears to travel along the anvil portion of the storm, following a weak maximum of composite reflectivity values.

There were no cloud-to-ground strikes associated with this particular flash. However, this event demonstrates that very long flashes can and do occur. Being able to show an image like Fig. 10 allows forecasters to starkly demonstrate the importance of heeding lightning safety instructions in forecasts. Later discussions with the forecast office have indicated that investigation of other such events like this would be useful to help determine when long flashes may be more likely to occur and to determine how this information can better be applied to lightning safety issues, incident support, and fire weather situations.

4. CONCLUSIONS AND FUTURE WORK

In the fall of 2012, NASA's Short-term Prediction Research and Transition (SPoRT) Center submitted a GOES-R Visiting Scientist Program proposal with WFOs Boulder and Cheyenne as well as Colorado State University with the aid of the Colorado Institute for Research in the Atmosphere (CIRA). The objective was to initiate collaborations between each of the listed entities. The proposal called for CIRA and Colorado State, who owns the Colorado Lightning Mapping Array (COLMA), to coordinate with New Mexico Tech University (current handlers for COLMA) to provide a real-time data feed of COLMA data to NASA SPoRT. In return, SPoRT would meet with each WFO to train them on the use of total lightning, building on SPoRT's previous total lightning expertise, and transition COLMA data to operations.

The proposal was accepted by the GOES-R program and the actual visit was conducted in mid-March of 2013. The resulting visit has led to the initial collaboration defined by the proposal. The actual transition of data to each WFO was delayed for different reasons, but has since been accomplished. Even with the limited opportunity to view COLMA data in AWIPS or AWIPS II, the COLMA data have proven popular and several local events have been highlighted for further investigation in the future. Two have been outlined here, including a weak tornado to the northwest of Cheyenne, Wyoming and a long flash event between Boulder and Ft. Collins, Colorado in the Boulder county warning area.

The initial feedback of these data has been very valuable. As expected, forecasters have preferred the availability of these data in AWIPS and AWIPS II. With the performance evaluation completed, the data are now available in AWIPS II. Additionally, both WFOs have indicated that the color curves initially used in the transition and derived from those used in Huntsville, Alabama for the North Alabama Lightning Mapping Array, may be too high in magnitude. This may partly be due to COLMA using 1 min updates with a 1×1 km grid versus the 2 min updates and 2×2 km grid used by the North Alabama Lightning Mapping Array. Changing the grid resolution is one avenue of discussion. Another quick response will be to modify the existing color curve to better highlight lower intensity storms.

In addition to these results, the collaborators submitted a follow-up GOES-R Visiting Scientist Program proposal in the fall of 2013, which has been accepted. This particular visit will build on last year's collaborations. This will allow for a review of the past year to determine what has worked and what needs to be improved for the collaborations. Also, this will pave the way for a formal spring 2014 evaluation, now that the data are fully available in AWIPS and AWIPS II. Furthermore, this new proposal with incorporate the Denver Center Weather Service Unit to expand the collaborations to the aviation community. Ultimately, the GOES-R Visiting Scientist Program has provided the initial kick start to a strong and productive collaboration with NASA SPoRT, the Colorado Lightning Mapping Array, and WFOs Boulder and Cheyenne.

Acknowledgements: The authors wish to again thank the GOES-R program for funding the visiting scientist proposal. In addition, Dr. Steven Rutledge from Colorado State University and New Mexico Tech University have been instrumental in sharing these data in real-time to NASA SPoRT in order to produce the products used in this collaboration.

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6. FIGURES

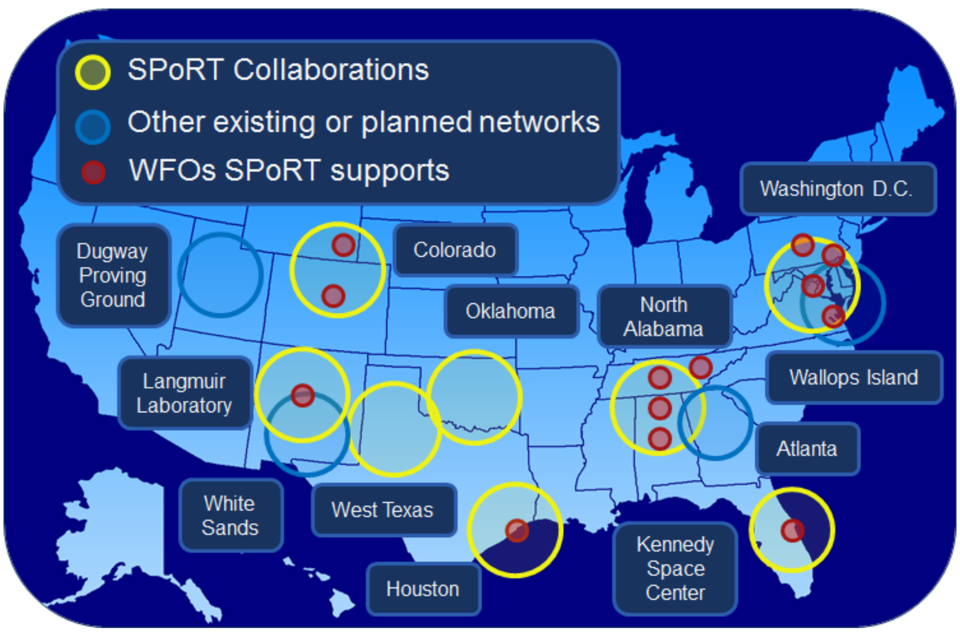

Figure 1. This map shows the locations of the various lightning mapping arrays across the United States. The rings indicate the approximate range of each lightning mapping array with yellow rings indicating networks collaborating with NASA SPoRT and blue rings indicating other networks that are net yet available for collaborations. The red circles highlight the local National Weather Service Offices that are receiving total lightning observations from SPoRT via these collaborations.

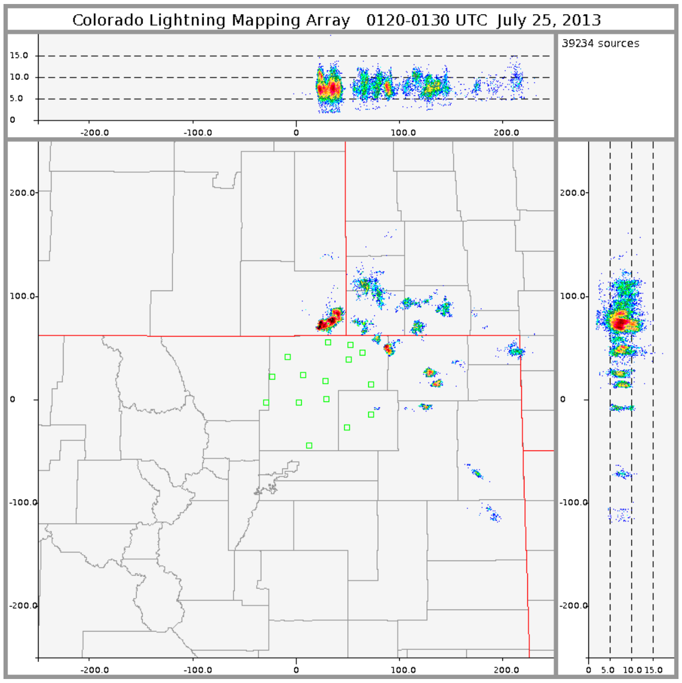

Figure 2. This is an example web display from New Mexico Tech University of the Colorado Lightning Mapping Array between 0120-0130 UTC on 25 July 2013. The image displays a 10 min summary of all of the sources observed in the domain. The green boxes are the locations of the individual lightning mapping array sensors. The main display shows the 10 min source density in the x-y plan. The smaller display at the top is the 10 min source density in the x-z plane, while the display to the right is the 10 min source density in the y-z plane.

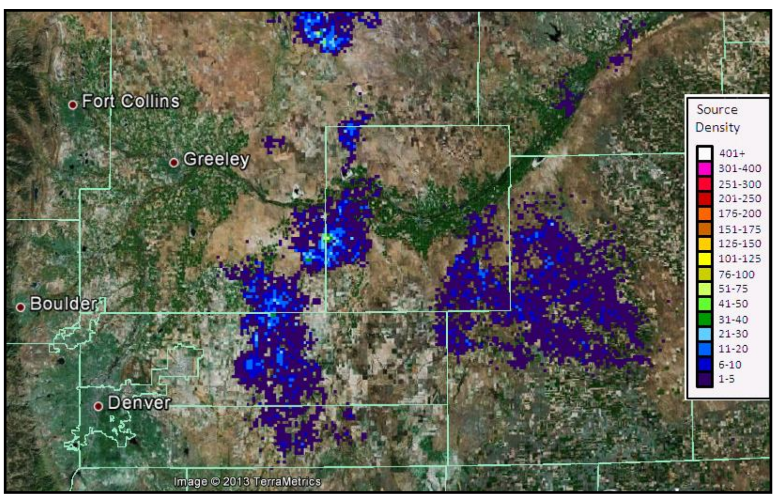

Figure 3. A sample image of the NASA SPoRT Google Earth web display (zoomed in over the north central portion of WFO Boulder's county warning area) for the Colorado Lightning Mapping Array showing the 1 min source density at 0100 UTC on 9 April 2013.

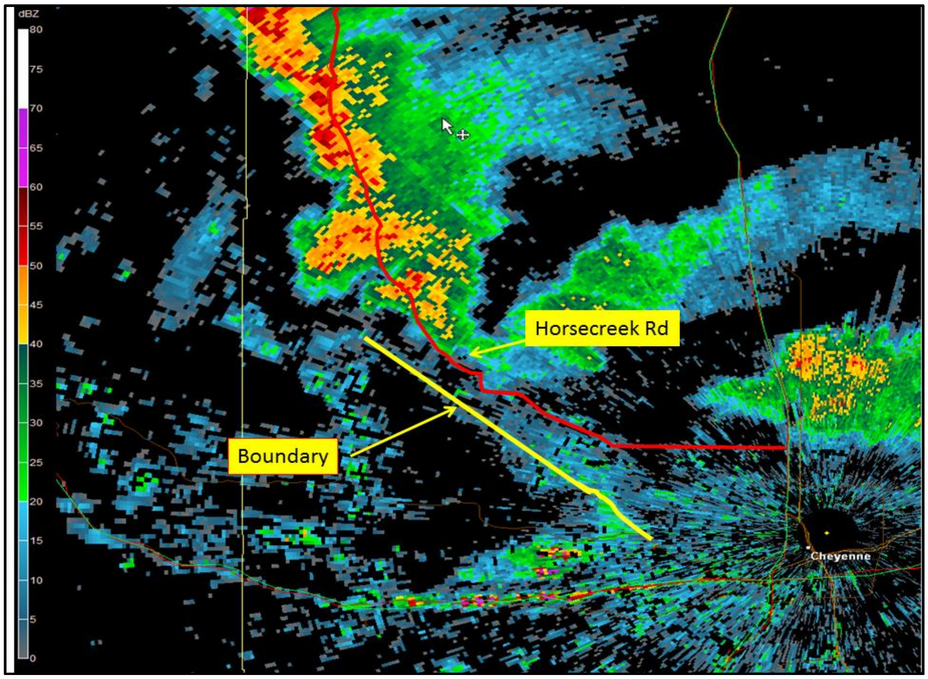

Figure 4. The Cheyenne Doppler radar reflectivity at 2350 UTC on 29 July 2013 approximately 15 min prior to the touchdown of the tornado at 0005 UTC on 30 July 2013. The yellow line indicates the pre-existing boundary extending northwest from Cheyenne, Wyoming through Federal, Wyoming. (Image courtesy of WFO Cheyenne.)

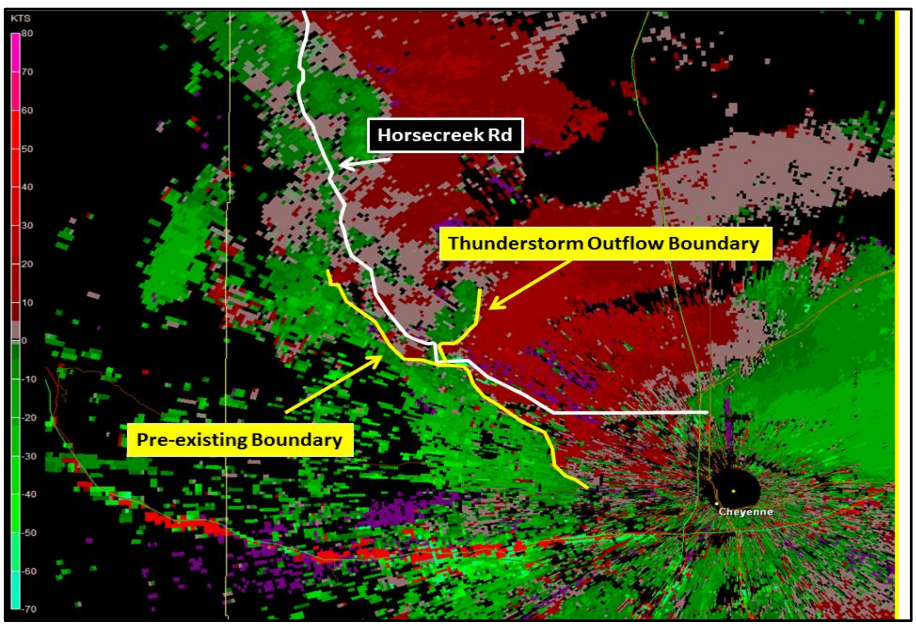

Figure 5. This is the same time as Fig. 4, but shows the Cheyenne Doppler radar storm relative velocity. The pre-existing boundary is noted again, along with a thunderstorm outflow boundary that intersects with the pre-existing boundary to the northeast of Federal, Wyoming. (Image courtesy of WFO Cheyenne.)

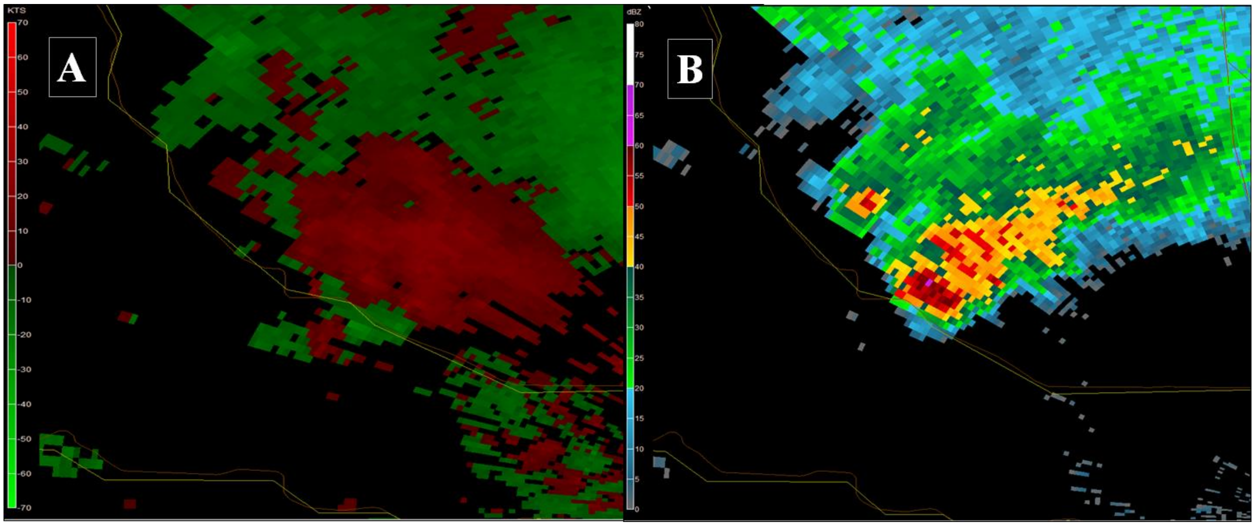

Figure 6. The Cheyenne Doppler radar storm relative velocity (A) and reflectivity (B) at the time of the tornado touchdown at 0005 UTC on 30 July 2013. (Image courtesy of WFO Cheyenne.)

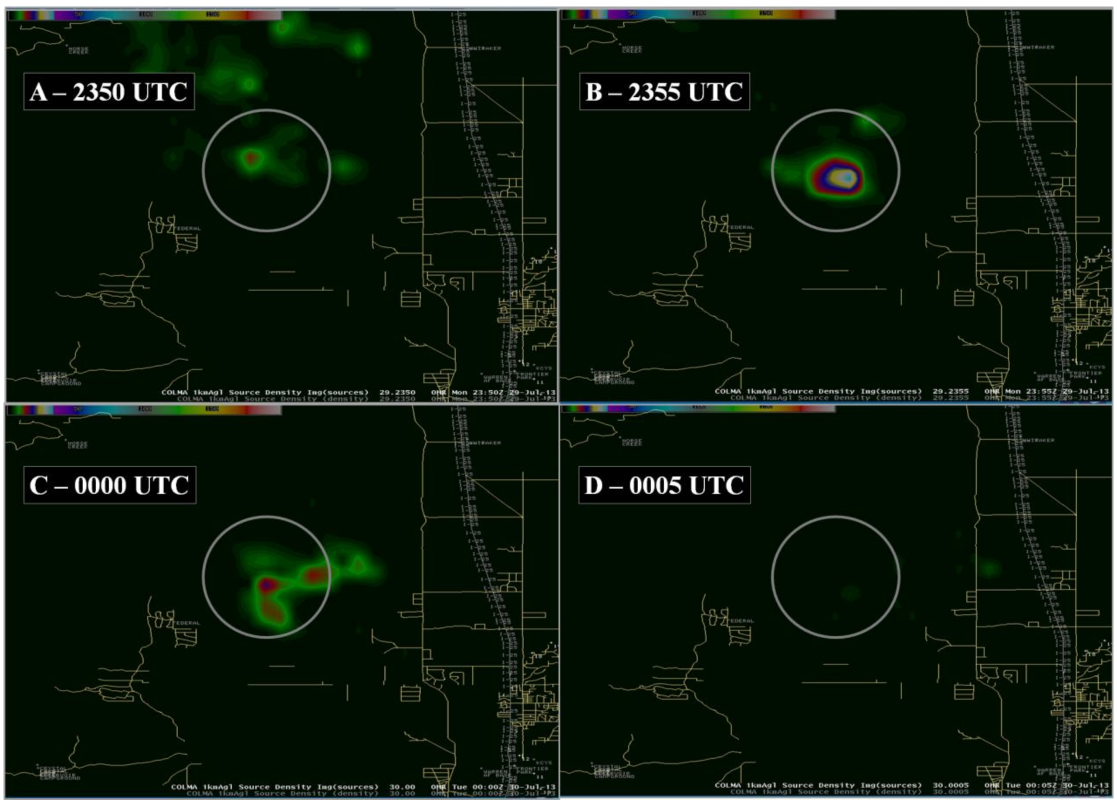

Figure 7. A series of 1 min Colorado Lightning Mapping Array source densities displayed in AWIPS I using a modified color curve to enhance lower values. The images are at 2350 UTC on 29 July 2013 15 min prior to the tornado touchdown (A), 2355 UTC 10 min prior to touchdown (B), 0000 UTC on 30 July 2013 5 min prior to touchdown (C), and 0005 UTC at the time of touchdown. The surge in total lightning activity in B highlights the main storm is strengthening and that severe weather is likely. The lack of total lightning in D observed at the time of the tornado is typical as total lightning activity generally decreases at the time of severe weather. (Image courtesy of WFO Cheyenne.)

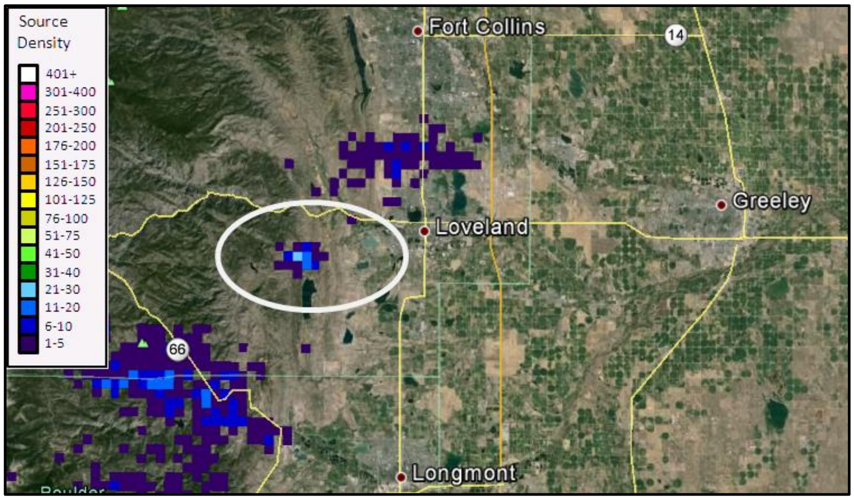

Figure 8. The Google Earth source density display available to WFO Boulder prior to the inclusion of these data in AWIPS II at 1927 UTC on 25 July 2013. The storm of interest has been circled just west of Loveland, Colorado.

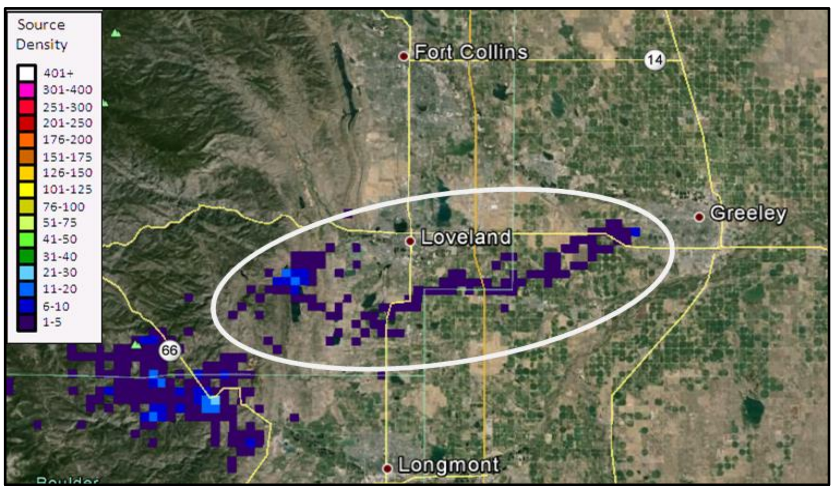

Figure 9. This is the same display as Fig. 8, but one minute later at 1928 UTC. Note that the storm in Fig. 8 has generated a flash that extends almost due east from west of Loveland, Colorado to just outside of Greeley, Colorado.

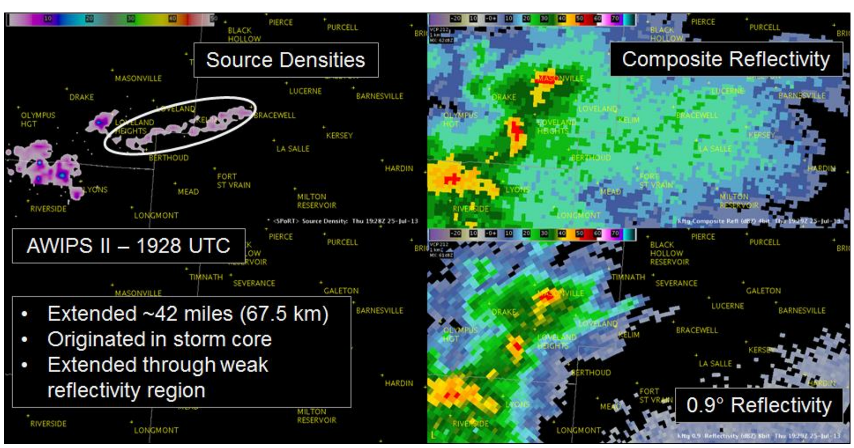

Figure 10. A corresponding AWIPS II display of the source density product (upper left) at the same time as Fig. 9 (1928 UTC on 25 July 2013). Placing the source density data in AWIPS II allows for the observations to be compared to the Denver Doppler radar composite reflectivity (upper right) and 0.9° radar reflectivity (lower right). The flash extended approximately 67.5 km (42 mi) and appeared to move through a region of weak reflectivity observed in the composite reflectivity.