7.4 OPERATIONAL USE OF TOTAL LIGHTNING INFORMATION FOR WEATHER AND AVIATION AT DALLAS-FORT WORTH

Martin J. Murphy*, Ronald L. Holle, and Nicholas W.S. Demetriades
Vaisala Inc., Tucson, Arizona

1. INTRODUCTION

Vaisala is currently participating in an evaluation of the utility of total lightning information in National Weather Service (NWS) weather forecast offices (WFOs) as part of a joint program of NASA and the Southern Region of the NWS to move experimental data sets into operations. The purpose of this paper is to describe this program and our role in it briefly. We also present some of the experimental data products that are being considered for use in the WFO at Fort Worth, TX. We then describe some additional experimental products that might be better suited to aviation users and that could be made available following a model similar to the NASA program.

2. SPoRT and LATEST

The Short-term Prediction Research and Transition (SPoRT) Center is based at the Global Hydrology and Climatology Center (GHCC) at the NASA Marshall Space Flight Center (Goodman, 2004). The purpose of SPoRT is to hasten improvements in 0-24 hour forecasts by providing NWS forecasters with hands-on experience using newer, experimental data sets. Integrating the experimental data into AWIPS is a key component of facilitating its use operationally, as was recognized early in the program. SPoRT also has as an objective to measure the effect of the new data sets by surveying forecasters after an event in which the data may have had an impact on warnings or forecasts. Current data sets being supplied through SPoRT include derived products from the MODIS satellite and three-dimensional total lightning information from a Lightning Mapping Array (LMA; see Rison et al., 1999) in northern Alabama. The total lightning information is available in the Huntsville, AL, Birmingham, AL, and Nashville, TN, WFOs, whose county warning areas are fully or mostly covered by the LMA. An additional user of 3-D total lightning information is the Melbourne, FL, WFO. That office has received data from the Kennedy Space Center LDAR (Lightning Detection And Ranging; see Lennon and Maier, 1991) network for many years as part of a test-bed arrangement worked out prior to the start of the SPoRT program.

There is an ongoing growth in the number of total lightning detection systems deployed for research and operational purposes, and for the moment, all happen to fall within the geographical domain of the NWS Southern Region. This has presented an opportunity for an outgrowth of SPoRT called the Total Lightning Applications, Transition, Evaluation, Science, and Technology (LATEST) demonstration. LATEST is a government-university-industry collaboration that is focused particularly on test beds involving total lightning detection within the NWS Southern Region. Future expansion of the total lightning data test beds will begin in summer 2004 when Vaisala's LDAR II network around Dallas-Ft Worth (DFW) begins providing data in real time to the WFO in Ft Worth. Other total lightning detection systems, such as an LMA in the Oklahoma City area and a future LDAR II network around Houston, will also participate in LATEST.

3. DFW TOTAL LIGHTNING DETECTION SYSTEM

In the DFW area, we have set up a variety of sensors and small networks for test and evaluation purposes. Among these are two total lightning mapping systems, an LDAR II and a SAFIR (Richard and Kononov, 2001). Of the two, the LDAR II network has the longer history at DFW, and its data are what we present in this paper. The DFW LDAR II network is made up of 7 sensors having radial baselines of 20-30 km and is centered on the DFW International Airport. These sensors measure the times of arrival of impulsive bursts or pulses of radiation in the VHF band produced by lightning flashes. These pulses of radiation are used to map, that is, reconstruct the path of, individual cloud and cloud-to-ground (CG) lightning flashes in three dimensions. The expected three-dimensional location accuracy of the system for individual pulses is better than 100

Corresponding author address: Martin J. Murphy, Vaisala Inc., Tucson Operations, 2705 E. Medina Rd., Tucson, AZ, 85706; e-mail: martin.murphy@vaisala.com

m within the network perimeter and better than 2 km out to a range of about 150 km from DFW airport. Because of the large number of pulses produced by each lightning flash, the expected flash detection efficiency of the network is nearly 100% within the perimeter and better than 90% to a range of 100-120 km.

As of summer 2004, the communications system for the LDAR II network is being upgraded so that the system provides data in real time. A local wireless microwave ISP service operating at 5 GHz and providing a data bandwidth of approximately 600 kbps is being used for all sites. This communications rate is sufficient to allow each sensor to detect up to 10000 pulses per second (one pulse every 100 μsec) and transmit these pulses to the central analyzer with little or no buffering and no saturation of the communications link. The central analyzer is located at the main office of the ISP and collects the data from the seven sensors over the ISP's internal local network. Processed locations of VHF sources are passed from the central analyzer to a product generator that will eventually also receive CG flash data from the U.S. National Lightning Detection Network (NLDN) and use the combined lightning information to produce a number of derived products. For the moment, these derived products are destined primarily for the NWS weather forecast office (WFO) at Fort Worth. Eventually, the product generator will also ingest radar data from the WSR-88D radar at Ft. Worth and future derived products will be based on a combination of radar and lightning information. In the next sections, we provide examples of existing or proposed derived products for the NWS as well as for possible use in aviation.

4. PRODUCTS SPECIFICALLY RELATED TO THE NWS

The WFOs at Huntsville, Birmingham, and Nashville receive grids of the density of VHF pulses, or radiation "sources," in 17 horizontal slices through the troposphere. The first 16 slices give the source density in layers of 1-km thickness going from 2-17 km MSL in altitude. Each layer is presented as a grid with horizontal resolution of 2 km by 2 km. The final slice is the total density throughout the troposphere, that is, the sum of the densities in the first 16 slices. An example of the total source density for severe storms near DFW is shown in Figure 1. One of the key features of interest is the relative minimum, or hole, in the source density in the western cell. This hole is due to a very strong updraft that does not permit the growth of precipitation-sized particles or the accumulation of separated charge. All of the precipitation growth and charge separation occur on the fringes of the strong updraft. Lightning propagates only in areas of separated charge, thereby allowing the strong updraft region to be delineated clearly. The supercell storm shown in Figure 1 produced 10-cm hailstones during the time when these lightning data were collected.

Early participants in the SPoRT program have indicated that the distinction between flashes and the individual VHF sources is not yet regarded as important operationally. However, most lightning flashes produce a large number of sources. Furthermore, flashes are initiated primarily in regions of high electric field, which are typically confined to convective cores. With this information, we can supplement the source density plot in Figure 1 by noting which of the grid squares also contain the locations of flash initiation points. This is shown in Figure 2, where the source densities are color-coded as in Figure 1, but in addition, any grid squares containing flash initiation locations are further marked by a white X. This plot clearly shows that flash initiation locations are concentrated in the area surrounding the strong updraft in the western cell. They are generally not found outside the main convective areas. However, when storms are at long distance from the network, the detection efficiency for individual VHF sources is low and, therefore, many flashes are represented by only one source. This effect can be seen at the eastern edge of Fig. 2.

5. POSSIBLE PRODUCTS FOR USE IN AVIATION

5.1 Early detection of thunderstorms

The lightning activity in most thunderstorms begins with cloud flashes, which can be detected with a total lightning detection system, such as LDAR II or SAFIR, but not by the NLDN. Therefore, a total lightning detection system can provide the earliest possible confirmation of lightning activity in a developing storm. For ease of presentation, the total lightning data may be associated to specific convective cells as identified by radar, and the information may be displayed on a radar image. Figure 3 shows an example from June 30, 2001. The cell identifiers shown in Figure 3 are taken from the Storm Cell Identification and Tracking (SCIT) algorithm that runs as part of the NEXRAD Open-systems Radar Product Generator (ORPG). On this particular day, a number of convective showers produced no lightning discharges, while others eventually produced lightning. In Fig. 3, those cells that had lightning at the time shown are surrounded by a pink box. Note that, although the base reflectivity and cell tracking information from NEXRAD are only updated once every 5 minutes, the cell highlighting on this radar-based display may be updated continuously because of the continuous data stream provided by the total lightning detection system.

5.2 Lightning warnings for ground operations

In certain storm situations, lightning warnings for airport ground operations can be very tricky, and a combination of total lightning and radar information can enhance safety in these difficult situations. A particularly difficult case was presented by an MCS that passed over DFW airport on August 17, 2001. The Ft. Worth NEXRAD base reflectivity data at 15:12 UTC on that day is shown in Figure 4 together with the locations of CG lightning flashes detected by the NLDN between 15:05-15:15. Although this MCS was falling apart at the time, it still had a small but reasonably intact convective zone that was generating the majority of CG lightning, as well as a significant stratiform rain region that also produced CG lightning.

About 30 minutes before the radar image in Fig. 4, the convective region was beginning to move away from the airport and for a time no longer produced CG flashes within 10 km of the airport. However, as is typical in MCSs, the stratiform region produced a number of CG flashes that were scattered over much the region, as seen in Fig. 4. Just after the time of the radar image in Fig. 4, one CG flash struck ground near where a DFW grounds crew employee was working, causing serious injury to the employee. The lightning warning that had been in effect as the convective region of the MCS was passing over the airport had expired because no CG flashes were detected close to the airport for nearly 30 minutes, and therefore, employees were allowed to return to work. During the 30 minutes after the last CG flash occurred within 10 km of the airport, however, many lightning discharges occurred within the clouds, including a number of flashes that passed directly over the airport. This is shown in Figure 5, where the total lightning activity detected by the LDAR II system between 15:05-15:15 is overlaid on the reflectivity image from 15:12. We note that most of the lightning activity is observed where stratiform region reflectivity values are at least 20 or 25 dBZ. This is typical of other MCSs near DFW that have been observed with the LDAR II network. However, note that not all stratiform areas where reflectivity exceeds 20-25 dBZ have lightning.

With knowledge of the locations of both substantial reflectivity and lightning activity, we have developed a prototype derived product involving the following data sets: base reflectivity, total lightning activity from the LDAR II network, and CG flash locations from the NLDN. This prototype is shown in Figure 6 using the same reflectivity and lightning data used in Figures 4 and 5. In Figure 6, areas in green show where reflectivity exceeded 15 dBZ but no lightning activity was detected, dark blue shows where there was in-cloud lightning and reflectivity values below 25 dBZ, yellow shows where there was in-cloud lightning with reflectivity values of 25 dBZ or more, and red shows where there was CG lightning detected by the NLDN. Figure 6 shows that, just prior to the strike that injured the grounds crew employee at DFW, the airport was within the yellow area. This supports the suggestion that this combination of radar and lightning information represents the area of elevated risk of CG flashes. The details of the radar-total lightning relationship to CG strike risk will be quantified in a future study.

5.3 Use of three-dimensional information

Regional volumetric (three-dimensional) total lightning data near major international airports can potentially allow for safer and more efficient air traffic management. In general, aircraft are routed around the convective cores (>40 dBZ) of thunderstorm cells because of the turbulence created by updrafts strong enough to produce radar reflectivities over 40 dBZ. Radar measurements define the major updraft areas indirectly via observations of high reflectivity and convergence zones. The high-density cores of lightning activity delineate these areas more directly because large updraft speeds are necessary for the development of precipitation-sized ice in a mixed-phase cloud, charge separation, and ultimately, lightning initiation. Because of the vertical development, the lightning activity extends to high altitudes in the regions of strong convection.

We suggest that the altitude of lightning activity can be a very important parameter. Observations from the DFW LDAR II network have shown that cloud lightning has preferred paths of propagation through anvils and stratiform rain regions that are attached to active thunderstorm cells. These paths slope downward with increasing distance from the convective cores as shown by Carey et al. (2003). Three-dimensional total lightning information can therefore be used to identify just the convective cores for aircraft flying at cruising altitude. This was illustrated clearly by a storm system on May 27, 2002. Figure 7 shows the NEXRAD base reflectivity image from 21:52 UTC. Two convective cells were located south of Fort Worth, and both of these were attached to a large stratiform rain region covering the DFW area and extending to the Oklahoma border. Figure 8 shows the LDAR II data classified by altitude, with sources below 10 km altitude plotted in light blue and sources at or above 10 km plotted in red. Lightning sources produced within the convective cores south of Fort Worth extended to 10 km or more in altitude, but those sources associated with cloud flashes that propagated through the attached stratiform region were exclusively below 10 km.

6. CONCLUSIONS

The purpose of this paper has been to present, at the conceptual level, ideas for derived products based on lightning and radar information. The infrastructure necessary to be able to produce this type of derived information is being put in place at DFW. The test-bed model established under the LATEST group could readily be extended to aviation users.

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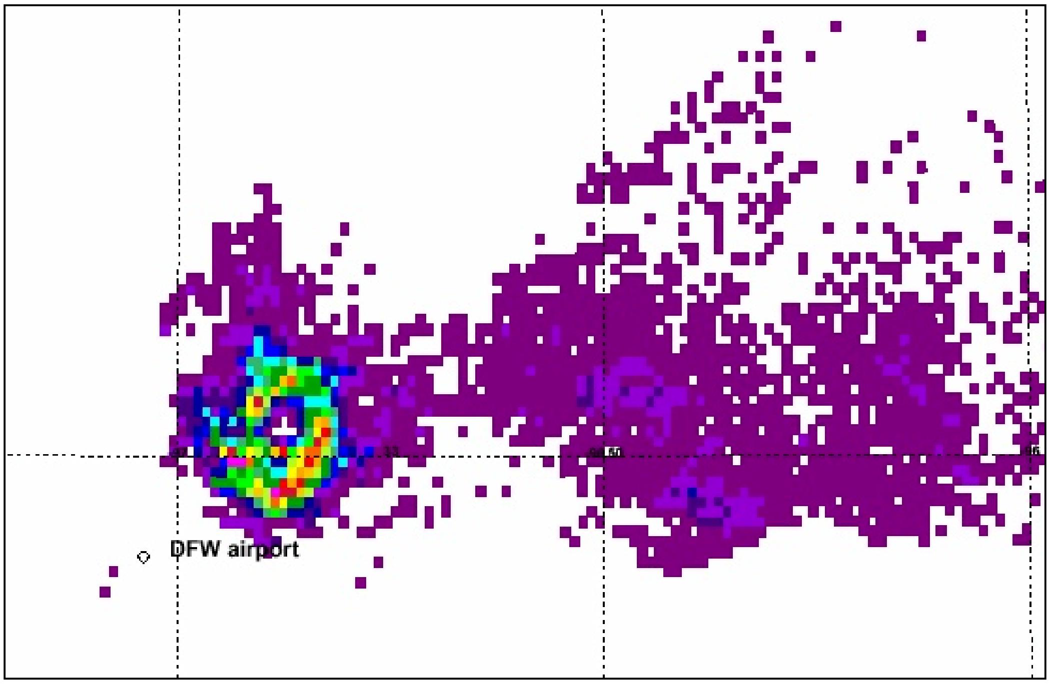

Figure 1. VHF source density (src/km^2) on 1X1 km^2 grid for 04:04-04:07 UTC on April 6, 2003. Each color change represents an additional 10 src/km^2.

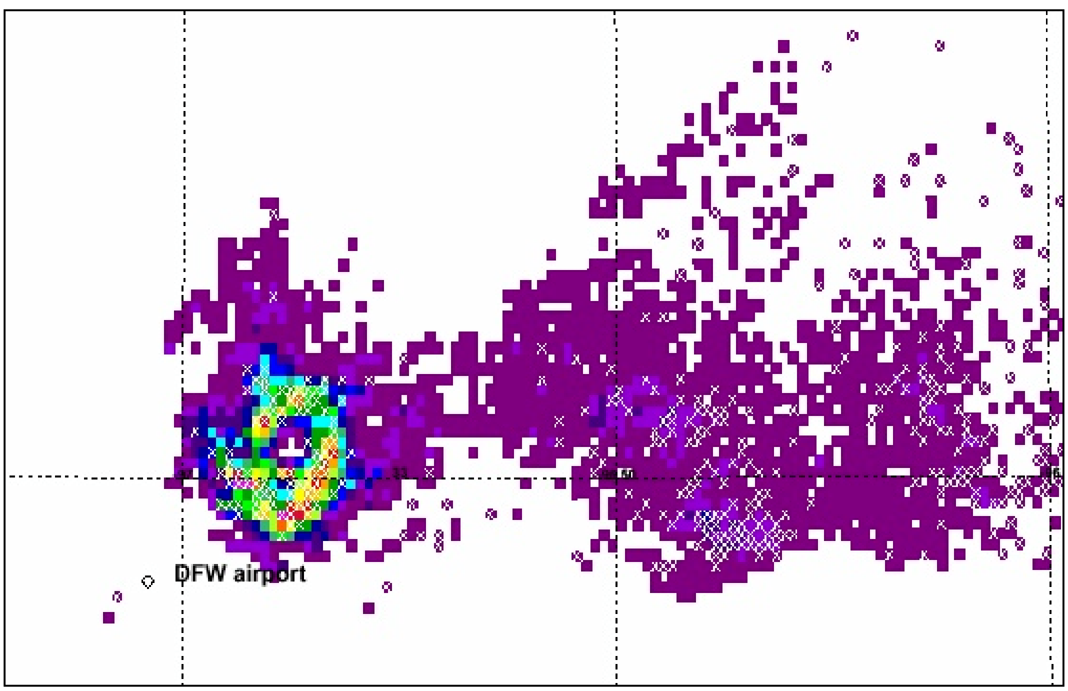

Figure 2. As in Fig. 1 but with white Xs through grid cells that include flash initiation locations.

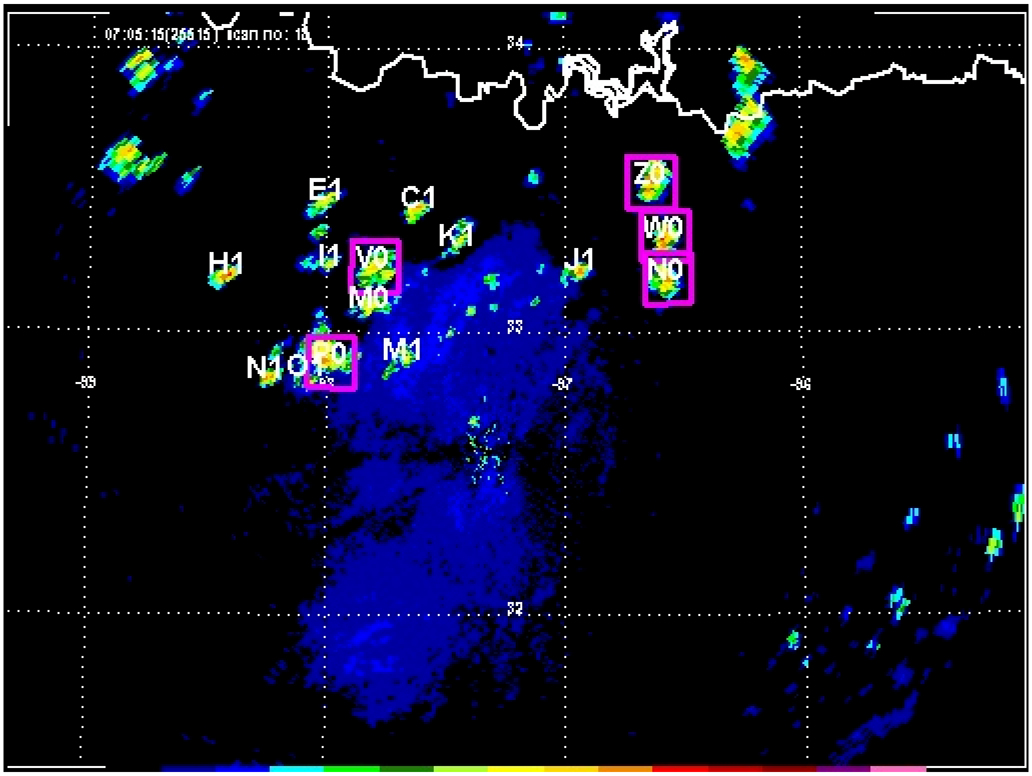

Figure 3. KFWS base reflectivity at 07:05 UTC on June 30, 2001, with cell identifiers from the SCIT algorithm shown in white. Cells with lightning are surrounded by pink boxes.

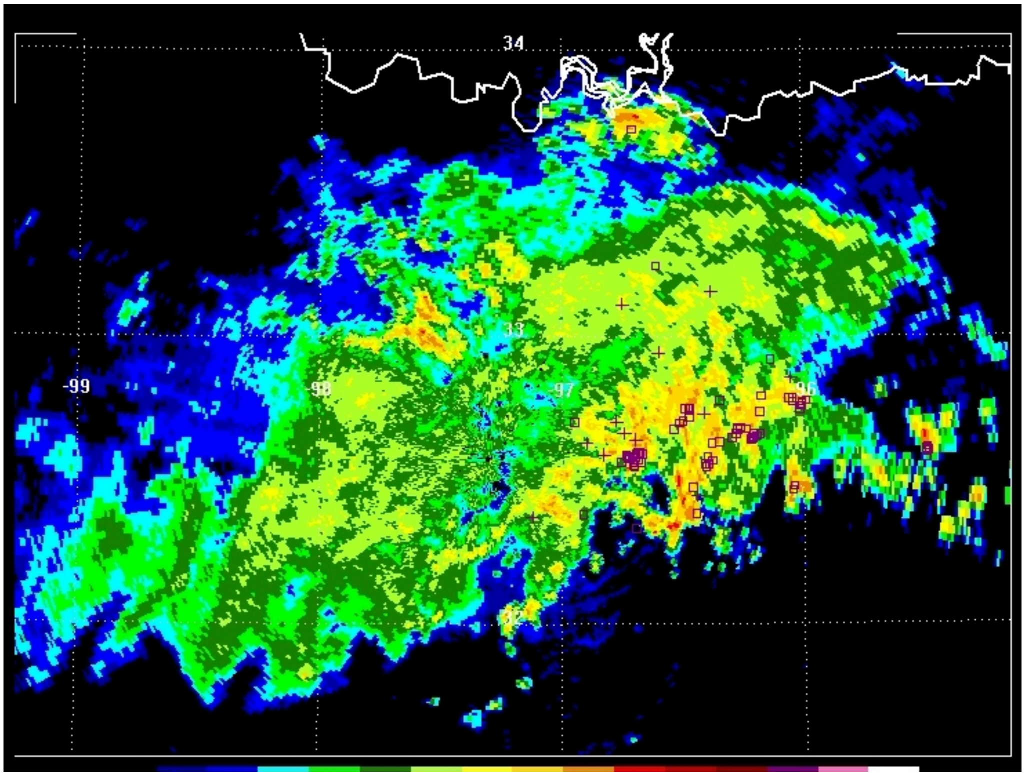

Figure 4. KFWS base reflectivity at 15:12 UTC on August 17, 2001, with CG flashes between 15:05-15:15 plotted with purple symbols (square = negative, plus sign = positive).

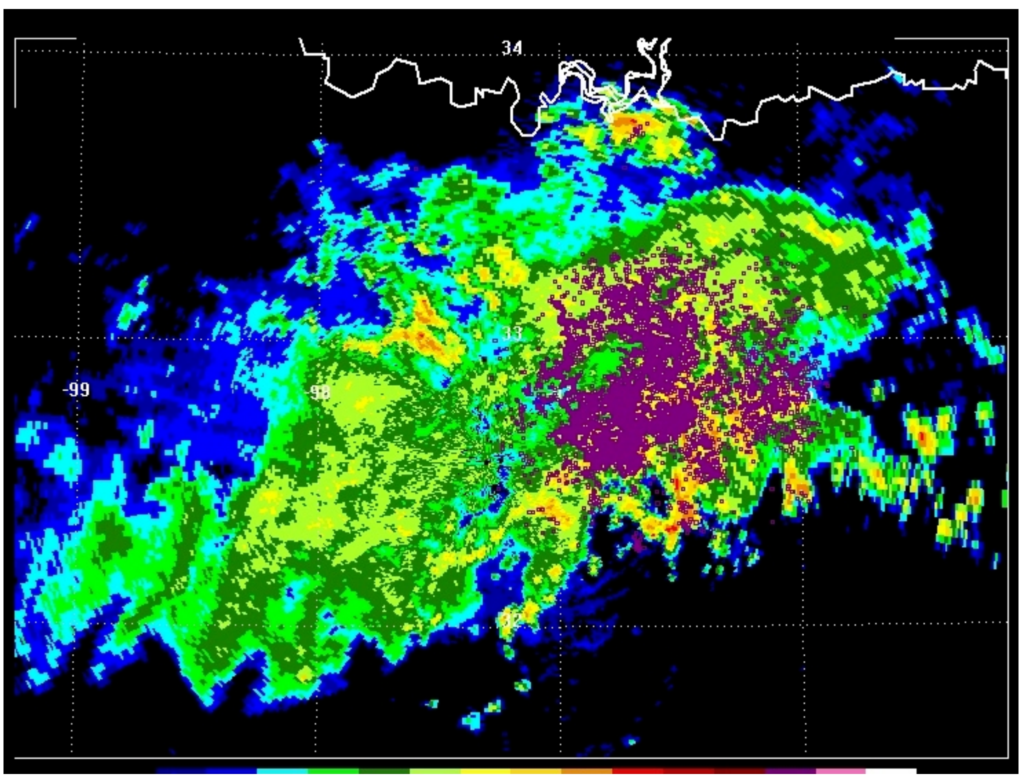

Figure 5. KFWS base reflectivity at 15:12 UTC on August 17, 2001, with LDAR II sources between 15:05-15:15 plotted with purple symbols.

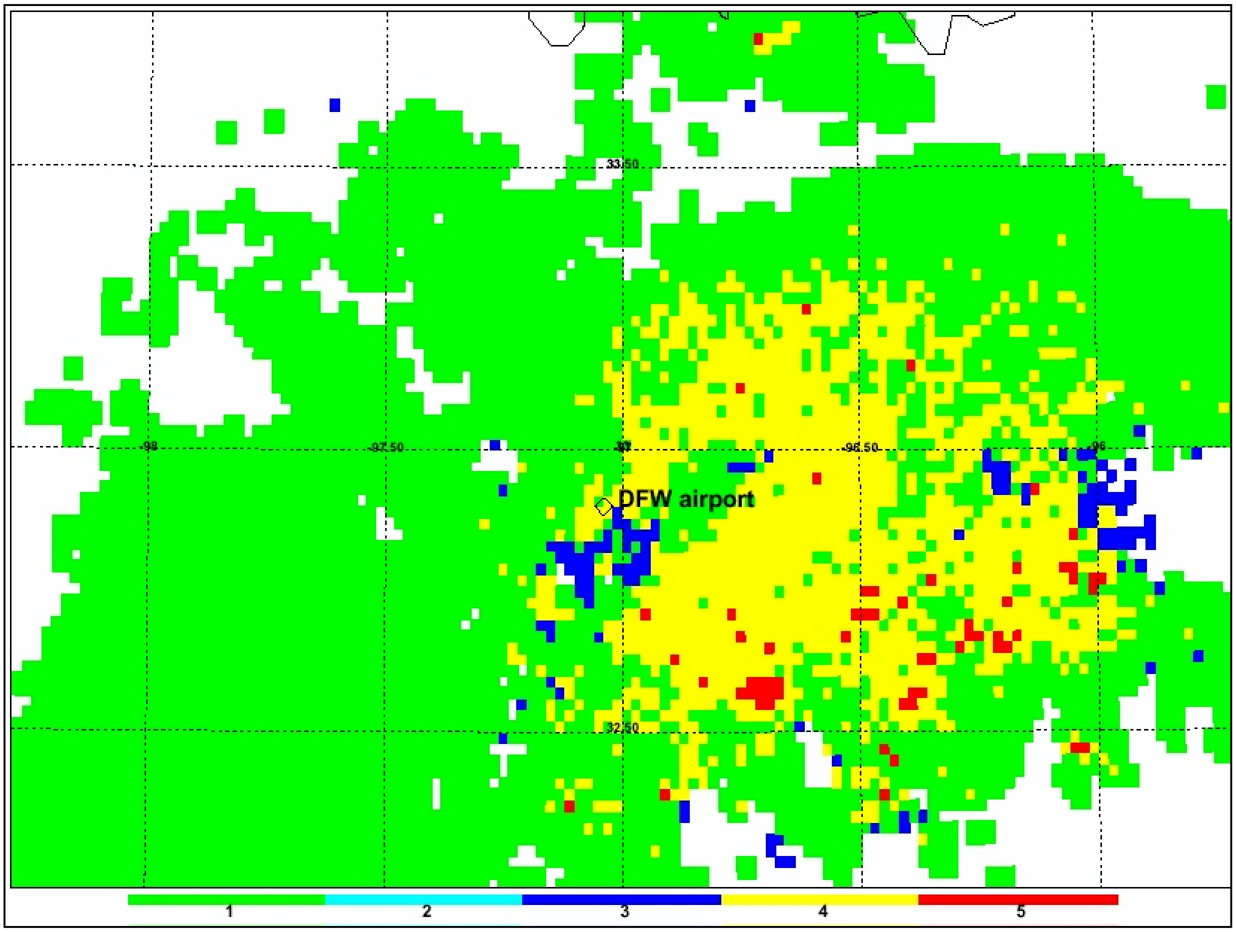

Figure 6. Prototype warning graphic based on combination of radar base reflectivity, in-cloud lightning, and CG flash information. See text for discussion of five color-coded categories.

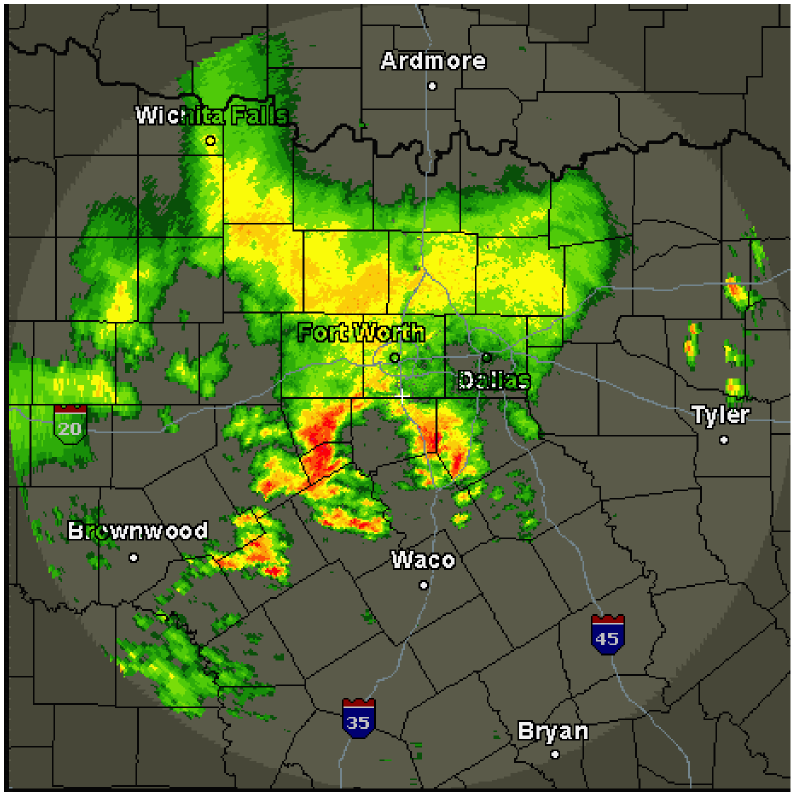

Figure 7. KFWS base reflectivity image at 21:52 UTC, May 27, 2002.

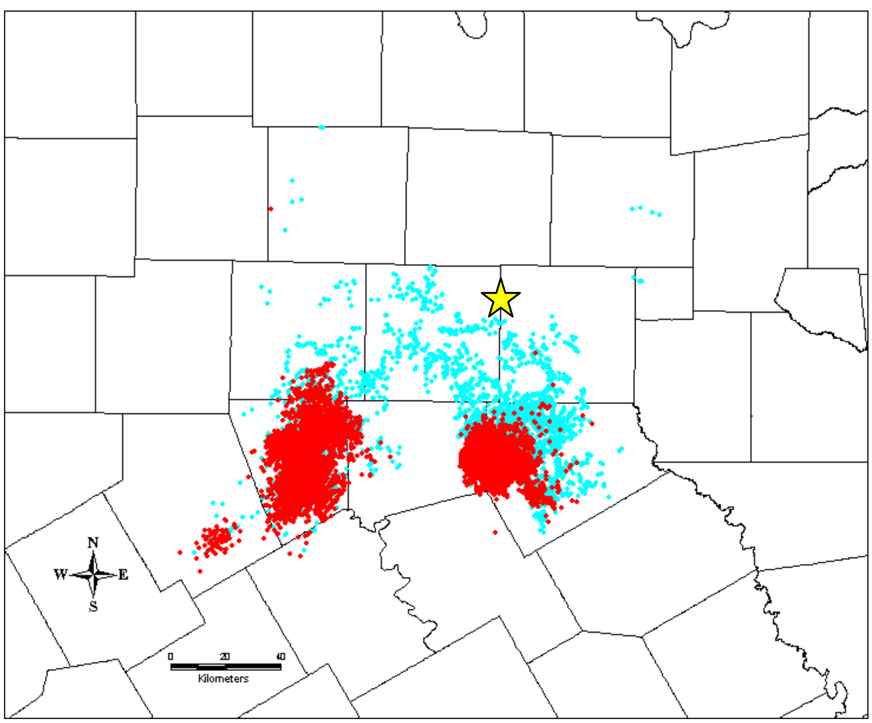

Figure 8. LDAR II sources corresponding to radar data in Fig. 7. Red: above 10 km MSL altitude; cyan: below 10 km MSL. Position of DFW airport indicated by star. County boundaries included (c.f. Fig. 7).