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Final Report for

Partners Project

Project Title: Total Lightning Observations in the Warning Decision Process for Severe Convection over the Southern Great Plains

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SECTION 1: PROJECT OBJECTIVES

Given the availability of the unique Lightning Detection and Ranging (LDAR II) network over Dallas-Fort Worth (DFW), it is an ideal time to investigate the potential benefit of total lightning information in an operational setting at the Fort Worth-Dallas (FWD) Weather Forecast Office (WFO). As such, the objectives of this Partners Project are

1) to determine the overall benefit of the DFW LDAR II total lightning information in the detection and short-term prediction of severe convective weather in a variety of convective modes (e.g., multicell, supercell, and mesoscale convective system) over the Fort Worth county warning area for the warning decision process,

2) to evaluate the relative effectiveness of the various LDAR II lightning products, such as lightning source, flash initiation, and flash extent density,

3) and to make recommendations regarding the best practices for incorporating LDAR II data effectively into the warning decision process at the WFO FWD.

SECTION 2: PROJECT ACCOMPLISHMENTS AND FINDINGS

The objectives summarized in Section 1 were accomplished through case study analysis of total lightning behavior in a variety of convective modes. *A summary of the key accomplishments during the course of this project is listed below and followed by a more detailed discussion.*

1) the installation of a case study analysis tool, the Weather Event Simulator (WES), including a custom set-up for viewing total lightning data at Texas A&M University,

2) lightning data quality control and preliminary analysis for multiple thunderstorm events during the 2005-2007 convective seasons, including cases that were ultimately rejected due to LDAR II data quality concerns,

3) case study selection and analysis of LDAR II and Weather Surveillance Radar – 1988 Doppler (WSR-88D) data and imagery for multiple events in a variety of convective modes, including two right moving supercells embedded within a severe multicell line (April 25, 2005), a left moving supercell embedded within a multicell line (April 5, 2005), and mesoscale convective systems (MCSs) with embedded HP supercells and bow echoes (April 28, 2006 and April 13, 2007), and

4) the writing of a conference paper entitled "**Total Lightning Observations in the Warning Decision Process over North Central Texas**" to be presented by Texas A&M University (TAMU) graduate student, Chris McKinney, in January 2008 at the AMS *Third Conference on the Meteorological Applications of Lightning Data* (New Orleans), which will ultimately be adapted into a peer-review journal article.

A kick off meeting took place in September 2006 at the NWS FWD WFO and was attended by the TAMU PI (Carey), a TAMU graduate student (Chas Hodapp) and the NWS PI (Greg Patrick). At the meeting, we focused on project planning and coordination, basic WES training, and an overview of some promising 2005 and 2006 season lightning cases on WES. A critical first accomplishment of the project was to install up-to-date versions (first V6.0 and then later V7.1) of WES on a LINUX workstation at Texas A&M University (TAMU) and to confirm functionality with a test case that included the ability to view LDAR II total lightning data. Running a common weather data viewing tool, WES, at both TAMU and the WFO FWD allowed close collaboration on case study analysis between the Partners and was a critical milestone for the success of the project.

In November 2006, the TAMU PI (Larry Carey) and graduate student (Chas Hodapp) visited the NWS WFO in Forth Worth to coordinate data access, analysis, and case study selection with the Fort Worth Office (Greg Patrick) and Vaisala Inc. (Martin Murphy and Nick Demetriades). As a team, we all visited the NOAA NWS Southern Region Headquarters (SRH) in Fort Worth to brief Rusty Billingsley (Division Chief, Science and Technology Services) and Bernard Meisner (Chief, Science and Training Branch) on the Partners Project and future research and operational opportunities using Vaisala's LDAR II.

Over the course of several months (November 2006 – February 2007), multiple WES data sets and installation scripts of promising lightning events were then identified, summarized, and created by Greg Patrick and evaluated at both the WFO FWD and TAMU for use in this project, including potential cases from 2005 (April 5, 10, 25) and 2006 (April 20, 28; May 6, 9; December 29). Finally, a teleconference in February 2007 between Vaisala, TAMU, and the FWD WFO narrowed down this list of eight potential days to three final cases on which to focus from 2005 (April 5, 25 – supercell cases embedded in multicell squall lines) and 2006 (April 28 - supercell/bow echo on the southern end of an MCS) based on 1) LDAR II data quality, and 2) meteorological significance to the WFO, including the severity and diversity of events. Additionally, our goal was to include at least one lightning case study from the 2007 convective season. After consideration of several possible days from Spring 2007, the April 13th case (MCS with embedded supercell) was chosen based on the same criteria as the earlier 2005/2006 cases.

Detailed analyses of these four case studies were conducted using the WES at TAMU and the FWD WFO (Greg Patrick) both separately and jointly, including a visit by TAMU (Larry Carey and graduate student, Chris McKinney) to the WFO FWD in June 2007. At Texas A&M University, Chas Hodapp led the analysis of the April 28th case from 2006 while Chris McKinney led the analysis of the April 5th and 25th cases from 2005 and the April 13th case from 2007, under the supervision of their graduate advisor and TAMU PI (Larry Carey). In addition to the visits described above, the Project team utilized e-mail and phone calls to exchange ideas, resolve problems, and discuss details of the case studies.

A summary of key findings from the case studies is as follows:

1) From our case studies and past results, it appears that NWS forecasters can use qualitative aspects of total lightning data, including Flash Extent Density (FED) and Gridded Source Density (GSD), in conjunction with WSR-88D in D2D as a secondary indication of the presence

of a strong updraft and the potential for severe weather such as large hail, straight line winds, and tornadoes associated with a particular cell. Examples of qualitative features indicative of a strengthening updraft that can be used to increase situational awareness include the total lightning hole, notch, and hook echo. Each of these features were associated in time and space to well-known WSR-88D signatures of intense and severe weather (e.g., hook echo, bounded weak echo region (BWER), Doppler velocity couplets) and severe weather reports.

2) The development of a notch in the FED and subsequent bowing of the FED lightning pattern in two HP supercells/bow echoes embedded within MCSs were apparent in advance of severe straight line winds observed at the surface. Rear inflow notches in and bowing of FED may be a precursor to severe wind events in some MCSs. This finding is promising but requires further study before utilized in operations.

3) Another very interesting result from this study was the occurrence of FED appendages that appear to signal a tendency for deviant motion with a supercell. Each of these appendages developed to the right or left of right and left-moving supercells, respectively, at approximately the same time as the cell motion became more deviant. After the development of each of these appendages, the highest values of FED appeared to “roll” towards these appendages, placing the highest FED values above the strongest reflectivity gradient with the cell. The ability to highlight updraft development or propagation on a timescale faster than the update time of the WSR-88D makes the LDAR II data an important resource for forecasters to maintain situational awareness during warning operations.

4) Consistent with past studies, our results demonstrated that jumps in the total lightning flash rate, or in our case rapidly increasing trends in the maximum FED inferred from imagery, typically preceded severe weather (hail, straight line winds, and tornadoes) by several to ten’s of minutes for the supercells in our study. While this is encouraging evidence that the lightning data can aid in the warning decision process, the FED values with each case varied substantially throughout the entire study period, sometimes without producing severe weather. More research is needed to quantify what rates of change of FED or GSD are significant in order to reduce the false alarm potential associated with jumps in the lightning data.

5) GSD was typically complementary to FED in the information conveyed to the forecaster. However, significant signatures of storm intensification or propagation were sometimes present in GSD first and sometimes in FED first, depending on the details of the lightning pattern. Because GSD is highly dependent upon source detection efficiency, which drops rapidly with range, our study suggests that GSD should be used with caution outside of the center of the LDAR II network. As a result, FED is currently the favored parameter for use in the weather decision process and for situational awareness at the FWD WFO.

6) The usefulness of the LDAR network also appears to be highly dependent upon the distance of the cell from the network and the performance ability of the network on a given day. While the ongoing installation of two more LDAR sensors on the southern side of the DFW LDAR II network should help mitigate range effects and other network artifacts such as communications drop outs, forecasters at WFO FWD must be educated on both the strengths and weaknesses of the LDAR data if they are to be able to accurately apply the lightning data into the warning

decision process in real time. Additionally, issues such as precipitation induced phase distortion, which can disrupt telecommunication paths and result in the loss of real time data, must also be understood by forecasters if they are to correctly interpret the lightning products. While sharp decreases in FED values for one particular cell should signal a forecaster that a severe weather event may be imminent, a similar decrease with all cells across the domain of the LDAR II is more likely a network detection issue, and not the harbinger of widespread severe weather. As detection ability can vary day to day (or even during the course of an event) given the status of the network sensors, forecasters should be kept aware of any situations (maintenance, communication problems, etc.) that would affect the data being sent to the WFO, so that artificial signals are not treated as indicative of the actual convective or severe activity within a given cell.

7) Although the total lightning images often exhibit trends that are quite similar to Doppler radar images in D2D, the LDAR II network does present one clear advantage over the WSR-88D, which is the ability to rapidly update images during an event. The total lightning data can be updated on any time step required, whether two minutes or every 30 seconds, as opposed to the radar, which currently updates each scan every four and a half to six minutes. This increased temporal sampling of the LDAR II lightning data can allow forecasters to see details of rapidly changing convective structure that may be smoothed out in the coarse temporal sampling of the WSR-88D, improving situational awareness. In some cases, the lightning signature precedes the radar signature of storm intensity and severity by several to ten minutes because of the faster temporal sampling and possibly because of a closer physical connection of total lightning to storm properties that cause severe weather (e.g., updrafts and downdrafts).

SECTION 3: BENEFITS AND LESSONS LEARNED: OPERATIONAL PARTNER PERSPECTIVE

The Partner's Project was ongoing during an active convective season in north Texas. As a result of the enhanced focus on the total lightning data during and after several significant convective events, more of the WFO FWD forecast staff has been exposed to the potential value of the LDAR II dataset. Informal discussions of total lightning trends during and after convective events have affected a renewed interest in viewing real-time total lightning data in AWIPS D2D. As a direct result of the project, more forecasters are using the dataset operationally.

The findings helped highlight or reinforce several important characteristics of LDAR II data. First, the value of total lightning data is not wholly related to monitoring trends in flash rates. This project showed that significant value can be derived by observing the morphology of convection using FED maps in D2D; depending on the environment, the value could include important clues related to updraft intensity or location of damaging downburst development. These types of indicators could aid the decision process related to severe thunderstorm and tornado warnings.

Second, some of the findings were discovered after intense investigations of LDAR II data in a research environment and may not be transferable to an operational environment. Although all NWS operational forecasters in the NWS have extensive training and experience in the interpretation of weather radar data, few have been exposed to real-time total lightning data. The findings from this project suggest that meteorologists would benefit from more extensive training in the interpretation and uses of total lightning data. For the NWS, the value of datasets such as LDAR II may be maximized only after forecasters undertake a more robust training program and after they are exposed to data during a large variety of convective events.

SECTION 4: BENEFITS AND LESSONS LEARNED: UNIVERSITY PARTNER PERSPECTIVE

The project has given Texas A&M University faculty (Larry Carey) and graduate students (Chas Hodapp and Chris McKinney) unique access to the Vaisala Inc. DFW LDAR II network data in an operational forecasting setting. Through multiple visits to the WFO FWD and informal exchanges over phone and e-mail, TAMU faculty and graduate students have benefited from exposure to operational forecasting at the WFO and the operational experience that Mr. Greg Patrick brings to the interpretation and use of the total lightning and WSR-88D data in the warning decision process. Furthermore, TAMU has benefited from the expertise of Mr. Patrick in installing and operating WES software in a mode that includes total lightning data. WES has been and will continue to be an invaluable lightning and radar research tool at TAMU in general and in collaborative projects with the NOAA-NWS in particular. Finally, the project has allowed two TAMU graduate students to pursue collaborative research on applied topics with relevance to the NOAA-NWS. The networking and knowledge gained by the graduate students during this project is invaluable. From the University perspective, the collaborative research was a success both in the benefits and lessons learned.

As highlighted above, the project demonstrated the utility of interpreting qualitative signatures evident in the rapid update (2-minute frequency) total lightning FED imagery in D2D as proxies for updraft intensification and propagation and as potential precursors to severe weather. This information has obvious benefits in the warning decision process and basic situational awareness when used in conjunction with other information available to the forecaster such as WSR-88D imagery. Some of these findings can be used immediately at the WFO FWD. For example, the use of lightning holes, notches, hooks, and appendages as signatures of updraft intensification and propagation could improve situational awareness of convective activity right now.

However, more applied research is required to understand the relationship between qualitative and quantitative (e.g., lightning jump) signatures in FED and severe weather occurrence before they can be used routinely in operations. In particular, a sufficient number of severe and non-severe cases must be studied in the future in order to quantify basic skill scores of these techniques (e.g., probability of detection, false alarm ratio etc). Finally, the project revealed that performance of the LDAR II network and hence the associated data is sometimes compromised during high impact convective weather that crosses the network. The cause of network wide data dropouts requires further investigation but appears to be associated with real-time microwave communications from the VHF sensors. The ongoing installation of two additional VHF sensors by Vaisala may improve operational performance during these events. Notification of these network communication (or other) sensor outages in real time to the WFO FWD by Vaisala can help mitigate the impact of these data dropouts. To insure proper use of the LDAR data in the warning decision process and in situation awareness, we strongly recommend that forecasters be trained to identify network artifacts and to distinguish them from real evolution in the FED imagery whenever possible.

SECTION 5: PUBLICATIONS AND PRESENTATIONS

McKinney, C. M, L. D. Carey, and G. R. Patrick, 2008: Total lightning observations in the warning decision process over North Central Texas. American Meteorological Society (AMS), *Third Conference on the Meteorological Applications of Lightning Data*, New Orleans, 22-23 January 2008.

(To be given as an oral presentation by TAMU graduate student, Chris McKinney. A draft copy of the conference preprint with technical detail is provided with this final report.)

SECTION 6: SUMMARY OF UNIVERSITY/OPERATIONAL PARTNER INTERACTIONS AND ROLES

Collaborative interaction in this project was handled primarily through e-mail and occasional phone and teleconference calls to resolve more complex issues. These basic communications were generally effective but were supplemented by three visits to the FWD WFO by TAMU faculty and graduate students. The University visits to the WFO were invaluable for project planning and coordination, familiarization with NWS forecasting tools and practices, and collaborative case study analysis.

Partner roles were divided largely as planned in the original Partner's Project proposal. The FWD WFO (Greg Patrick) led the installation of the WES software at TAMU with the assistance of graduate students (Chas Hodapp, Chris McKinney). The FWD WFO also generated the WES case study DVD's and installation scripts that were installed by TAMU graduate students at the University. The FWD WFO also helped TAMU graduate students resolve WES technical issues that occasionally developed with the software and case installations. Despite some minor and fairly typical technical issues, this process was effective and allowed the project to maintain its schedule. The selection of case studies was a collaborative effort between both TAMU (led by Larry Carey with assistance from graduate students) and the FWD WFO with input from Vaisala Inc. on the LDAR II network status. With the use of WES as a common research tool, case study analysis was also truly collaborative. Case study analysis at the University was led by graduate students, Chris McKinney and Chas Hodapp, under the supervision of their graduate advisor, Larry Carey. In parallel, the FWD WFO (Greg Patrick) was able to provide initial and ongoing input, advice, and feedback on all cases studied. Preliminary reports on case study analyses were written at mid-project by Chris McKinney and Chas Hodapp under the direction of Larry Carey. This was an important initial mechanism for providing detailed results to Greg Patrick and for him to provide feedback to the University. Finally, Chris McKinney led the writing of an AMS abstract and conference paper with guidance and feedback from both Larry Carey and Greg Patrick. Mr. McKinney will present the paper orally at the Third Conference on the Meteorological Applications of Lightning Data in January, 2008 at the AMS Annual Meeting in New Orleans.