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VHF TOTAL LIGHTNING MAPPING DATA USE FOR THUNDERSTORM NOWCASTING AT WEATHER FORECAST OFFICES

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1. INTRODUCTION

VHF total lightning mapping is defined as the detection of both cloud and cloud-to-ground (CG) lightning flashes, including the detection and mapping of the horizontal extent of cloud lightning flashes. Data from regional VHF total lightning mapping networks, with detection efficiencies over 90%, can provide a substantial improvement over networks that detect only CG lightning for certain meteorological and safety nowcasting applications. This paper will summarize survey results obtained from forecasters at several different forecast offices aimed at identifying the value of VHF total lightning mapping data for improved weather nowcasts.

Over the past several years, forecasters at the National Weather Service (NWS) Dallas-Fort Worth, Huntsville, Birmingham and Nashville Forecast Offices (FOs) and the Finnish Meteorological Institute (FMI) have been evaluating the use of VHF total lightning mapping data for thunderstorm nowcasting. The program involving the Dallas-Forth Worth and FMI FOs has been directed by Vaisala. Vaisala's motivation for this study is to better understand the role of ground-based VHF total lightning mapping networks in weather and safety nowcasting (Lojou and Cummins, 2006).

The program involving the Huntsville, Birmingham and Nashville FOs has been directed by the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) as part of the Short-term Prediction Research and Transition Center (SPoRT) program. NASA MSFC's motivation for this study is to better understand the role of space-based total lightning mapping data in weather and safety nowcasting in anticipation and support of the Global Lightning Mapper (GLM) planned for launch on GOES-R in 2014 (Walsh and Schmit, 2008).

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2. METHODOLOGY

Vaisala and NASA MSFC worked with NWS and FMI forecasters to develop forecaster surveys that would be filled out, when possible, after severe thunderstorm events or other thunderstorm events that were of interest to the forecasters. The surveys asked forecasters several questions on topics, including: (1) whether or not VHF total lightning mapping data were used during an event, (2) location and time of the event, (3) what kind of warnings were issued during the event, (4) what thunderstorm types occurred, (5) what type of severe weather occurred, if any, and (6) how were VHF total lightning mapping data used during the event.

The surveys also asked forecasters to rank the relative importance of several data types during the nowcasting process. These data types were somewhat different depending on the forecaster group that helped create the survey. The following data types (listed alphabetically) were ranked on a scale of 1 to 10 (with 1 being the least valuable and 10 being the most valuable) by DFW NWS forecasters:

- CG lightning data
- Human spotters
- Radar reflectivity
- Radar velocity
- VHF total lightning mapping data

The following data types (listed alphabetically) were ranked on a scale of 1 to 10 (with 1 being the least valuable and 10 being the most valuable) by Huntsville, Birmingham and Nashville NWS forecasters:

- CG lightning data
- Human report
- Previous human report
- Radar reflectivity
- Radar rotation
- Radar tornado vortex signature
- Surface boundary
- Thunderstorm environment
- VHF total lightning mapping data

The following data types (listed alphabetically) were ranked on a scale of 1 to 10 (with 1 being the least valuable and 10 being the most valuable) by FMI forecasters:

- CG lightning data
- Human spotters
- Radar reflectivity
- VHF total lightning mapping data

3. NOWCASTING USES AT DFW NWS FORECAST OFFICE (FO)

Table 1 summarizes the 13 convective situations when a forecaster filled out a survey after using VHF total lightning mapping data and conventional datasets at Weather Forecast Office (WFO) Fort Worth – Dallas (FWD). The survey asked the forecaster to assign a value to each of five datasets that would reflect the importance of that dataset for that particular convective situation. The results of the survey suggest that VHF total lightning mapping data, which has been available to forecasters at WFO FWD since late 2004, has been a valuable addition to the suite of remote sensing tools available for thunderstorm nowcasting.

For severe thunderstorm episodes, it was clear from the surveys that radar reflectivity data from WSR-88D was the single most important dataset in the convective nowcasting and warning decision making process. However, data from the VHF total lightning mapping network ranked 3rd out of the 5 datasets for relative importance and received a higher average rating than traditional CG lightning data from the National Lightning Detection Network (NLDN). There are several reasons for VHF total lightning mapping data being ranked higher than NLDN data for severe thunderstorm episodes. Two possible reasons include 1) flash rate trends with VHF total lightning mapping data are more valuable and easier to visualize on an AWIPS D2D display, and 2) when compared with NLDN graphics of CG flashes, patterns of Flash Extent Density (FED) imagery from VHF total lightning mapping data are more likely to provide evidence of important changes in thunderstorm intensity (Lojou and Cummins, 2006). The FED product has been provided by Vaisala for use at the DFW FO and is the primary way forecasters visualize the VHF total lightning mapping data. FED is defined as the number of total (cloud plus CG) lightning flashes that pass through a 1 km by 1 km grid box per 2-minute time interval.

For thunderstorm events when severe weather was not reported, VHF total lightning mapping data received the highest average rating of the 5 datasets. The use of radar reflectivity and CG lightning data from NLDN ranked 2nd and 3rd in importance in the 9 surveys submitted. When severe weather was not occurring, the VHF total lightning mapping data gained importance as a nowcasting tool. Lightning data, whether it is from the NLDN or the VHF total lightning mapping network, can be used in the preparation of several product issuances, including Short Term Forecasts (text product identifier NOW), Terminal Aerodrome Forecasts (TAF), Special Weather Statements (SPS), and Airport Weather Warnings (AWW). Being able to visualize the extent of cloud and CG lightning using FED imagery from the VHF total lightning mapping network was important when a forecaster provided services related to public or aviation safety.

The use of FED imagery from the VHF total lightning mapping network during non-severe convective events can be grouped into three product issuance categories: 1) SPSs and NOWs - to help convey the CG threat, including anvil lightning; 2) AWWs - for CG lightning activity within 10 nm of DFW airport; and 3) TAF issuances or amendments - to provide data as input into the decision to include or exclude thunderstorms in the terminal forecasts for airports in the Dallas – Fort Worth metroplex. The vertical and horizontal extent of radar reflectivity can also be used as data for each of these three issuance categories, but the FED imagery often provides a better and more direct synopsis of current lightning activity. NLDN data also has an important role in the issuance of products in the three categories, but the additional information included in FED imagery can improve those issuances. For example, the threat of CG lightning from the anvil region of supercell thunderstorms can be more easily visualized using FED imagery which offers a more consistent display of cloud anvil lightning when compared to the sporadic anvil CG flashes from NLDN displays.

4. NOWCASTING USES AT HUNTSVILLE, BIRMINGHAM AND NASHVILLE NWS FORECAST OFFICES

The North Alabama Lightning Mapping Array (NALMA) became operational in November 2001 and has been used by nearby NWS offices in the short-term forecasting of severe and hazardous weather (Goodman et al., 2005). This section focuses on the NALMA and its use by the Huntsville (HUN), Birmingham (BMX), and Nashville (OHX) NWS offices.

The NALMA is based on the Lightning Mapping Array (LMA) developed at New Mexico Tech (e.g., Rison et al., 1999) and consists of 10 VHF receivers deployed across north Alabama. A base station is located at the National Space Science and Technology Center (NSSTC), which is on the campus of the University of Alabama in Huntsville. The network has been providing VHF total lightning mapping observations to HUN since its inception in Jan 2003, when the lightning data was viewed by the forecasters with a stand-alone display. The forecasters strongly supported a system whereby the VHF total lightning mapping data could be ingested into their Advanced Weather Interactive Processing System (AWIPS) workstations, where the lightning data could be displayed along with other products. A netCDF file of VHF total lightning mapping source density, binned onto a 2 km by 2 km horizontal, 1 km vertical grid is computed every two minutes from the NALMA observations. This 3-D grid (460 by 460 by 16 km) is then provided to the NWS offices for ingest into their AWIPS system. The data latency is less than 20 s. This capability was provided to the HUN office in May 2003, and to BMX and OHX later in 2003. The 2 min time scale results in at least half the time of the radar information, thus providing more rapid updates to storm updraft intensification.

The first case of a successful warning attributed to VHF total lightning mapping data occurred on 6 May 2003 from forecasters at HUN. Then, on 27 August 2003, the VHF total lightning mapping data was a major factor in the decision not to issue a warning (again from the HUN office). These cases demonstrated the potential use of VHF total lightning data in improving warning lead times and reducing false alarms. Comments from the forecasters' included: "*..the NALMA density map gives you a great overall view of where storms with intensifying updrafts are located. So it gives you a good map of where to concentrate attention*" and "*the NALMA tips the scales towards issuing a warning".*

The forecasters mainly focused on using trends in VHF total lightning mapping data for nowcasting severe weather. Williams et al. (1999) studied 30 severe cases in Florida and found that increases in VHF total lightning mapping activity (termed lightning 'jumps') preceded the severe weather by 5-30 minutes. Since the lightning data were provided as gridded fields of lightning sources, the forecasters used AWIPS to determine the source number at various times to determine the trend. In conversations with the forecasters, they used the data in a number of cases and reported good results. To quantify the usefulness, a web-based survey was developed with input from the HUN SOO and Chris Darden. The SOO felt that forecasters would be able to complete this survey after a shift in which the lightning data was considered for use in their forecasting warning decision(s).

Table 2 shows the results of the 42 surveys completed by HUN, BMX, or OHX from November 2003 through June 2007. These surveys spanned many different types of events, i.e., supercells, linear convective events, tornadoes, pulse-type storms, microbursts, and hailstorms. The most important tool used by forecasters for these events was radar reflectivity (average rating of 8.8), followed by VHF total lightning mapping density maps (6.9). The average improvement in lead time provided by VHF total lightning mapping was estimated by forecasters to be 2.5-3.2 min.

The surveys were then divided into two groups: one where at least one tornado warning was issued, and another in which only severe (no tornado warnings) were issued (not shown). In the severe-only surveys (31 surveys, 151 warnings), the rankings were very similar to the overall results. The average improvement in lead time was 3.0-3.8 min. However, in the surveys that included tornado warnings (11 surveys, 68 warnings), the radar velocity data (strong rotation) was the most important factor in the warning decision, followed by radar reflectivity (2^{nd} in importance), near storm environmental factors (3^{rd}), and VHF total lightning mapping data (4^{th}). The average lead time improvement was only 1.0-1.2 min for the tornadic warning group. This suggests that the VHF total lightning mapping data are more important in marginally severe events. A large supercell would not require additional data to improve the situational awareness of the forecaster, but in marginal bow echo or summertime convective situations, the VHF total lightning mapping data seems to increase the forecaster's confidence in making the warning decision sooner.

Another result of the surveys was learning of other ways the forecasters use the VHF total lightning mapping data. In addition to being useful in low-to-moderate severe weather situations, HUN has found that VHF total lightning mapping precedes CG lightning by 3-5 min. This enables them to increase lead times for Terminal Aviation Forecasts updates and Airport Weather Warnings. The forecasters also noted that the VHF total lightning mapping data provides additional information on storm severity at farther ranges from the radar. The more frequent updates provided by VHF total lightning mapping when compared to radar volume scan information was useful because forecasters didn't have to wait for the next radar update to decide whether or not to issue a warning.

Further work relating VHF total lightning trend relationships to severe weather is ongoing. Gatlin (2007) recently studied 20 spring-time thunderstorms (6 tornadic supercells, 1 non-tornadic supercell, 12 non-tornadic nonsupercells, and 1 non severe storm). Using a 2-min cell-based moving average VHF total lightning mapping threshold, he found a severe event probability of detection of .985 with a false alarm rate of .446. Further studies are following up on these results, as well as finding a method to provide cell-based trending information in real-time to the forecaster.

5. SUMMARY OF FMI STATISTICS AND APPLICATIONS

The VHF total lightning mapping network of FMI consists of three SAFIR-type sensors. These sensors are combined with a total of 29 Improved Accuracy through Combined Technology (IMPACT) sensors and newer types located in Finland and in neighboring countries (Sweden, Norway and Estonia) for CG lightning detection. Therefore, the VHF total lightning information is available from a limited area covering the southwest corner of Finland and the surrounding sea areas. The Helsinki-Vantaa International Airport is also covered. The coverage area for CG lightning is much larger.

Due to the small VHF total lightning mapping coverage area and the fact that on average only a few severe thunderstorms occur in Finland each year, the yearly number of severe storms within the VHF total lightning mapping area is quite small. But when severe weather occurs in this region, risk for the loss of property or even human life increases because in this part of the country the population density is the highest. Therefore, the forecasters at FMI have noticed that VHF total lightning mapping data combined with weather radar data provides useful information about the severity and lifecycle of a thunderstorm. This is important regarding the possible official announcements for the public.

5.1 Values placed on different datasets

Although the number of surveys is small (second column in Table 3) for both severe and non-severe types, some conclusions can be made.

Weather radar is one of the best and most used tools at FMI to observe any kind of a thunderstorm and estimate its severity. This can be seen from the third column in Table 3 (mean score is 8.8 and 9.4 for non-severe and severe thunderstorm types, respectively).

Interestingly, the mean score for VHF total lightning mapping data is lower for the severe thunderstorm types than for the non-severe types (7.4 and 8.8 in column four in Table 3). The reason is probably the increased importance of weather radar data for observing the severe storm types, which also lowers the mean score of CG lightning data (i.e., forecasters concentrate even more on analyzing radar data). It is also obvious that forecasters put the highest value on those data types that have large coverage. In Finland, these would be weather radar and CG lightning data.

CG lightning data has been used for real-time monitoring at FMI for about 20 years. During this period, forecasters have become very comfortable using CG lightning data for real-time monitoring. But, during the first years of CG lightning data use by forecasters at FMI, it was the same situation as VHF total lightning mapping data at present (operational usage of VHF total lightning mapping data since 2001). People are usually inclined to use the kind of data they are the most familiar with. The high mean scores (9.0 and 8.2 in the fifth column in Table 3) for CG lightning data reflects these aspects; data is available from large areas and forecasters are familiar with using the data. Human spotters (storm chasers, etc.) are considered important in the severe storm type. This is logical because in the case of a severe thunderstorm it is important to know the ground truth in the path of the storm. Furthermore, the more violent the storm, the more eager people are to report it.

5.2 Most common uses of VHF total lightning mapping data

The use of VHF total lightning mapping data at FMI can be divided into two categories: 1) early monitoring and warning, and 2) estimation of thunderstorm intensity. The first category includes the important fact that sometimes the first located lightning events are cloud flashes (detected by the VHF total lightning mapping sensors). With the capability to detect these first cloud flashes, a forecaster receives important information regarding the development stage of a convective cell. The second category consists of the determination of storm severity according to the VHF total lightning mapping densities and flash rates. Operational meteorology, aviation and military are also interested in VHF total lightning mapping because these users want to be aware of the lightning activity as early as possible to minimize their risks and to obtain more detailed information about the electrical structure of the cloud (i.e., not just the ground strike point).

The method used to visualize the VHF total lightning mapping data depends on the user. Because there are different kinds of user groups (i.e., operational meteorology, aviation, military, electric companies, etc.), lightning data can be placed as a layer in different kinds of software. The forecasters at FMI have been using a 3-D visualization of FED with experimental Vaisala-based software during the past two years. This display method provides the normal ground strike point information and also an eye-catching way to reveal the intensity of the thunderstorm. VHF total lightning mapping densities are presented as “flash clouds” whose height and colors depend on the densities. Weather radar data is also displayed simultaneously as one layer in this experimental display.

From the animation of FED, a forecaster may observe several important features, such as how fast the thunderstorm is developing and when it will reach the land areas if approaching from the sea. Combined weather radar data provides information on any adjacent developing cells. According to the surveys, forecasters consider it rather important to easily combine different types of data.

6. SUMMARY OF ALL FORECASTER RESULTS

Table 4 shows the mean values placed on the four datasets that were common to all forecaster surveys for both severe and non-severe cases. These datasets (listed alphabetically) included:

- CG lightning data
- Human spotters (reports)
- Radar reflectivity
- VHF total lightning mapping data

Since the number of severe weather surveys filled out by Huntsville, Birmingham and Nashville forecasters was so large, the values shown in Table 4 represent the mean of the mean values shown in Tables 1-3. This limits the weighting of Huntsville, Birmingham and Nashville surveys to 1/3 of the values shown in Table 4, with DFW and FMI also each contributing 1/3 to the values shown in Table 4.

Table 4 clearly shows that VHF total lightning mapping data has been a valuable addition to the forecasters suite of observational datasets for both severe and non-severe thunderstorm nowcasting. The value of VHF total lightning mapping data is highest for non-severe thunderstorm situations. In fact, it ranked higher than any other dataset available to forecasters for non-severe thunderstorm cases. As stated in this paper, this ranking is mostly due to the ability of VHF total lightning mapping data to (1) provide early warning for CG lightning and (2) properly identify all areas at risk for CG lightning, including thunderstorm anvils and stratiform rain regions. For non-severe thunderstorms, the highest risk to human life and property is typically represented by the CG lightning hazard. Flash flooding can also cause a high risk to human life and property, but it occurs less frequently within thunderstorms.

For severe thunderstorm cases, radar reflectivity data is clearly ranked as the most important dataset for thunderstorm nowcasting (Table 4). This result should be expected since radar reflectivity data has formed the foundation of severe weather nowcasting for several decades. However, VHF total lightning mapping data ranked second and clearly provides a valuable complement to radar reflectivity information for severe weather nowcasting. In fact, it ranked considerably higher than two traditional datasets used for severe weather nowcasting over the last couple of decades; CG lightning data and human spotters. Note also that VHF total lightning mapping data provides valuable information that is more timely (more frequent updates than radar) than radar for rapidly evolving severe weather situations.

In general, forecasters found the following attributes of VHF total lightning mapping data to be the most valuable during thunderstorm nowcasting:

- Early warning of CG lightning hazard by cloud lightning
- Total lightning mapping provides better identification of areas at risk for CG lightning
- Quicker updates than radar for rapidly evolving severe weather situations
- Better indicator of thunderstorm lifecycle than CG lightning data
- Some similar signatures to radar reflectivity data for severe weather identification

7. REFERENCES

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Table 1. Summary of the DFW forecaster survey results. Each number in columns three through seven represents the mean score (or value) attributed to each dataset.

Thunderstorm Type	Number of Surveys	Radar reflectivity	Radar velocity	VHF total lightning mapping data	CG lightning data	Human spotters
Non-severe	9	6.3	2.4	8.0	6.1	4.0
Severe	4	9.5	5.0	4.8	3.3	2.3

Table 2. Summary of the Huntsville, Birmingham and Nashville forecaster severe thunderstorm survey results. Each number in columns three through eleven represents the mean score (or value) attributed to each dataset.

Thunderstorm Type	Number of surveys	Radar reflectivity	Radar rotation	VHF total lightning mapping data	CG lightning data	Radar tornado vortex signature	Human report	Previous human report	Thunderstorm environment	Surface boundary
Severe	42	8.8	4.6	6.9	3.7	1.7	3.8	0.8	5.6	3.5

Table 3. Summary of the FMI forecaster survey results. Each number in columns three through six represents the mean score (or value) attributed to each dataset.

Thunderstorm Type	Number of Surveys	Radar reflectivity	VHF total lightning mapping data	CG lightning data	Human spotters
Non-severe	4	8.8	8.8	9.0	2.0
Severe	5	9.4	7.4	8.2	7.4

Table 4. Summary of all forecaster survey results from the DFW, Huntsville, Birmingham and Nashville NWS FOs and FMI. Each number in columns three through six represents the mean score (or value) attributed to each dataset. The mean scores in this case were calculated as the mean of the mean scores shown in Tables 1-3.

Thunderstorm Type	Number of Surveys	Radar reflectivity	VHF total lightning mapping data	CG lightning data	Human spotters
Non-severe	13	7.6	8.4	7.6	3.0
Severe	51	9.2	6.4	5.1	4.5