P686 Vertically Integrated Ice – A New Lightning Nowcasting Tool

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1. BACKGROUND AND METHODOLOGY

Lightning is a frequent and dangerous phenomenon, especially in the summer along the Gulf Coast where numerous thunderstorms occur daily. Over the past 30 years, lightning is second only to flooding in the number of average deaths it has caused (NWS 2009). Since 1940, lightning has caused more deaths than any other weather event. Despite its dangers, very few techniques exist to accurately nowcast lightning. The most widely practiced technique uses a specific radar reflectivity value (i.e. 40 dBZ) at a specific environmental isotherm (i.e. -10° C) as forecast criteria. However, this data can be hard to obtain in real-time, especially when thunderstorms are numerous. Therefore, an additional radar-derived parameter, known as vertically integrated ice (VII), was developed and tested to determine its viability in lightning nowcasting. The equation for VII, first proposed by Carey and Rutledge (2000), is

$$VII = 1000\pi\rho_i N_0^{3/7}\left(\frac{5.28\times10^{-18}}{720}\right)^{4/7}\int_{H_{-10}}^{H_{-40}} Z^{4/7}\,dH$$

where H_{-10} and H_{-40} indicate the heights of the -10 and -40 °C environmental levels in meters, respectively, ρ_i is the density of ice (917 kg m^{-3}) and N_0 is the intercept parameter (4 x 10^6 m^{-4}) of an exponential size distribution of precipitation-sized ice. For the development and testing of VII, ten years (1997 – 2006) of Level II Houston (KHGX) Weather Surveillance Radar – 1988 Doppler (WSR-88D) data were analyzed. Only summer time (June, July and August) daylight hours (14 – 00 UTC, 09 CDT – 19 CDT) data were considered, amounting to a total of 85,603 radar volumes. All cells within 150 km from the radar site (Figure 1) were analyzed.

Convective cells were tracked using a modified version of the Storm Cell Identification and Tracking (SCIT) algorithm, called the Constant Altitude Plan Position Indicator (CAPPI)-SCIT algorithm, and then correlated to cloud-to-ground (CG) lightning data from the National Lightning Detection Network (NLDN). This study objectively analyzed 65,399 unique cells and 1,028,510 lightning flashes to find the best lightning forecast criteria.

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Lightning forecasts were made on a cell-by-cell basis. A forecast was a yes-no product on whether or not the cell was expected to produce CG lightning. The forecast process involved first identifying and tracking convective cells using CAPPI-SCIT and then determining a cell-based VII. This cell-based VII value was then compared to various VII threshold values. If the cell-based VII values were greater than a given threshold, a "yes" forecast was made. The statistics on these forecasts were then computed using a standard 2 x 2 contingency table. Additionally, a lead time was calculated for comparison with previous studies of lightning forecast and to determine VII viability in National Weather Service (NWS) operations.

Fig. 1. Location of the study area. KHGX indicates the location of the WSR-88D. The range rings are at a distance of 75, 100, 125, and 150 km. IAH is the location of Bush Intercontential Airport, HOU is the location of Hobby Airport, and GLS is location of Galveston Scholes Field.

2. RESULTS

a. VII forecast method

The analysis of the entire dataset using the VII forecast method is shown in Figures 2– 4. The VII forecast method compares the cell-based VII values to the probability distribution function percentile values (Table 1) to make a lightning forecast. The forecasts are separated by range from the radar and how many times a cell was tracked by the CAPPI-SCIT algorithm. In Figures 2 – 4, only those cells with a minimum track count of 2 were considered since it

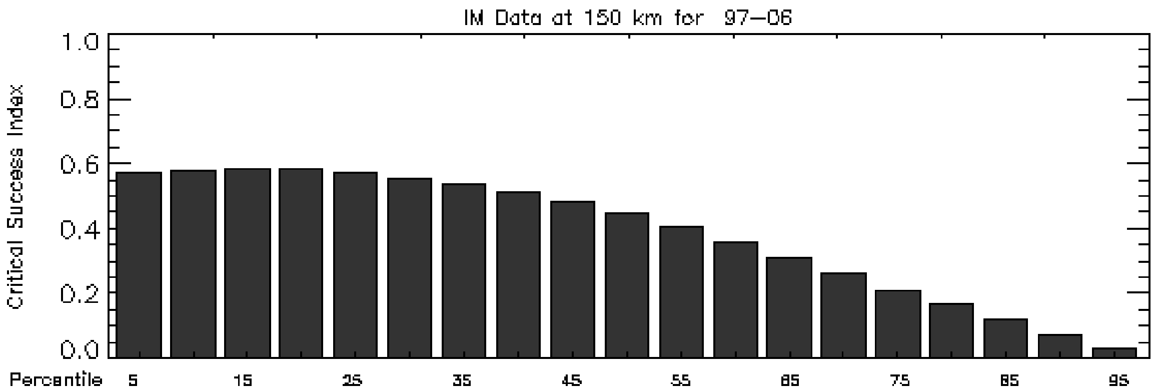

Fig. 2. CSI values using the vertically integrated ice (VII) percentile values for the entire dataset (1997-2006) when considering only cells with a minimum track count of 2. Data including all cells within 150 km.

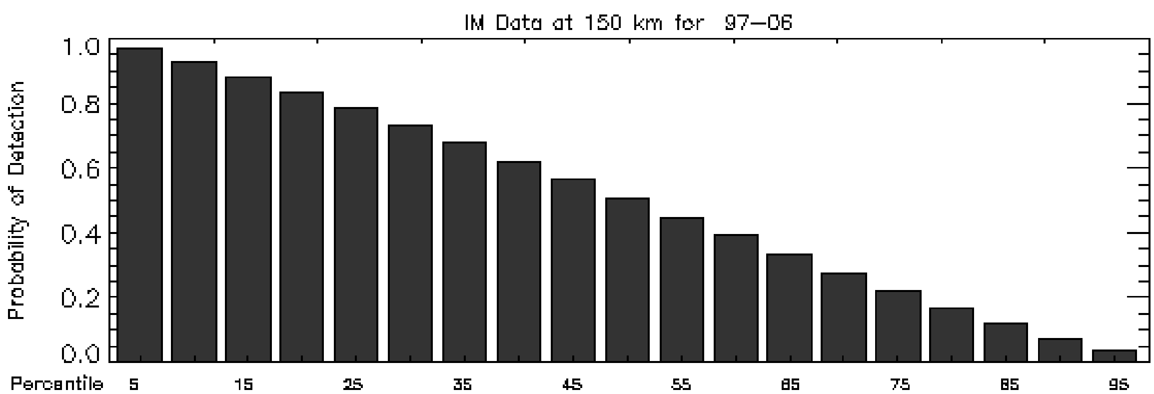

Fig. 3. Same as Fig. 2 for the POD values.

was determined to provide the most accurate forecasts. Forecast variations by range from the radar and VII percentile value will be considered.

The best VII predictors were found when using forecast values of 0.42 kg m^{-2} (10th percentile) and 0.58 kg m^{-2} (15th percentile) in cells within 75 km of the radar, resulting in a CSI of 0.68. Figure 2 shows a gradual increase in the CSI values from the lowest VII percentile (i.e., > 0.25 kg m^{-2}) to the 15th VII percentile (i.e., > 0.58 kg m^{-2}), a gradual decrease from the 15th percentile to the 40th percentile (1.50 kg m^{-2}) and then a sharper decrease thereafter. The VII percentiles used are shown in Table 1. This plateau likely represents the optimum amount of precipitation ice mass needed for lightning production. The assumptions made in creating this product likely restrict its ability to measure the *actual* amount of precipitation ice mass between -10 and -40°C. Therefore, though the plateau occurs near 1.0 kg m^{-2}, it is more important to note the plateau instead of the actual values. The lower percentile (below 50 percent) forecasts show approximately the same skill as previous CG forecast methods using radar reflectivity, resulting from high POD instead of low FAR (Fig. 3 and 4). VII-based CSI values indicate only a small range dependency, i.e., CSI increases slightly as the range decreases. This result suggests that while considering range is beneficial, it is a secondary consideration. If a maximization of CSI is desired, only cells within 75 km should be analyzed.

An interesting result is the CSI average near 0.65 for the lower percentile values. Since VII is only calculated using radar data between the -10 and -40 °C environmental levels, approximately 7 and 11 km in height, respectively, the results shows that any time echo reaches near 7 km, there is a potential for CG flashes. This is similar to the “Larsen area” from Larsen and Stansbury (1974), which was defined as an area with greater than 43 dBZ above 7 km. This information is very valuable when considering the ease in which a lightning forecast can be made. The plateau of CSI values suggests the daily environmental level does not need to be explicitly known. Instead, climatological heights could be used with sufficient accuracy.

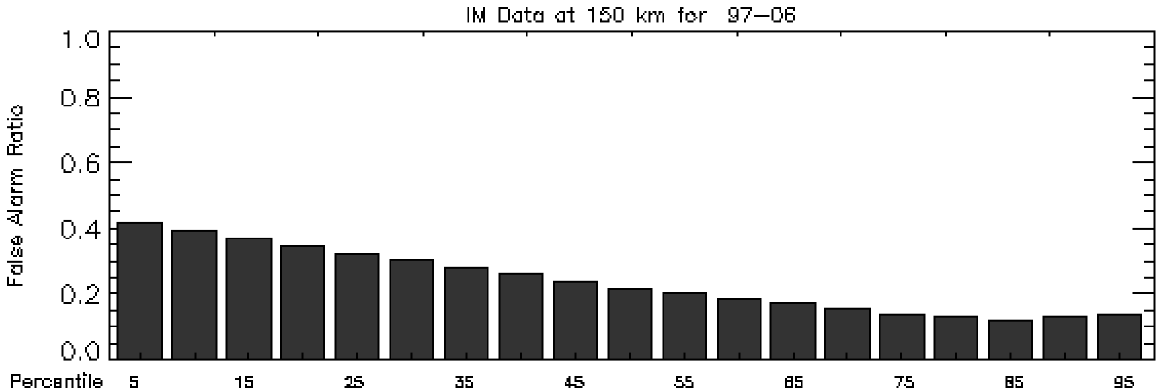

Fig. 4. Same as Fig. 2 for the FAR values.

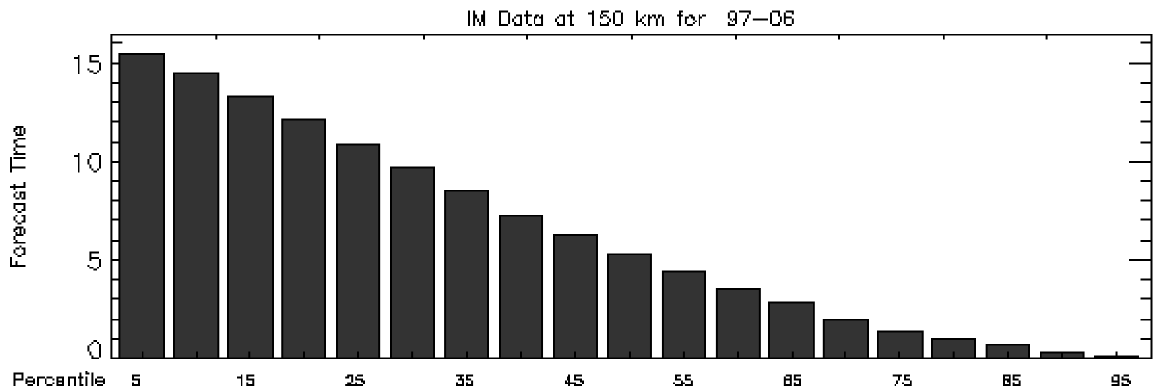

Fig. 5. Average lead time for 1997 to 2006 (in minutes) using the vertically integrated ice (VII) percentile values for the entire dataset (1997-2006) when considering only cells with a minimum track count of 2 for data within 150 km.

b. First flash forecast time

In addition to testing the accuracy of the lightning forecast, the lead time to the first flash was calculated for the VII forecast method (Fig. 5). An average maximum forecast lead time of 13.5 min occurred using the 5th percentile within 150 km of the radar. This value is comparable to previous studies of lightning forecasting. The 5th-25th, 25-50th, 50th – 75th, and 75th-95th percentile VII ranges were averaged and yielded an average forecast time of 11.7, 7.3, 3.6, and 1.4 min, respectively. The forecast times follow the POD values. This is to be expected since higher POD values signal that a predictor is easily met, which in turn creates a longer forecast time.

3. VII IN NWS OPERATIONS

a. Background

VII was integrated into the Advanced Weather Interactive Processing System (AWIPS) at Weather Forecast Office (WFO) HGX during the summer of 2008, at WFO Fort Worth (FWD) in August 2009, and at the Spaceflight Meteorology Group (SMG) at Johnson Space Center (JSC) in Houston in June 2010. Figure 6 shows a screenshot of VII from a severe storm near Houston, TX. The NWS does not publicly produce lightning watches or warnings, although this process is in experimental phases at WFOs Jacksonville (Wolf 2006) and Melbourne (Herzog 2011), Florida.

Training on VII was produced in August of 2010 and has been viewed by all the forecasters at FWD as part of required training as well as forecasters at HGX and SMG. Currently plans are to make the training available to all NWS employees during the spring or summer of 2011.

b. Example Use – Airport Weather Warning

At FWD, VII is used most often for Airport Weather Warnings (AWWs). AWWs are issued for lightning within 10 nm of the airport. The lead time goal for an AWW is 30 min. VII is most beneficial for AWWs issued during the early summer, when pulse convection occurs frequently. VII can help distinguish strong storms with the threat of imminent lighting from those which are still too weak for sufficient mixed-phase microphysics. Figure 7 shows example

Table 1. Vertically integrated ice (VII) percentiles (in kg m^{-2})

Percentile	5	10	15	20	25	30	35	40	45	50	60	70	80	90
VII	0.25	0.42	0.58	0.74	0.91	1.09	1.29	1.5	1.73	1.99	2.57	3.33	4.42	6.35

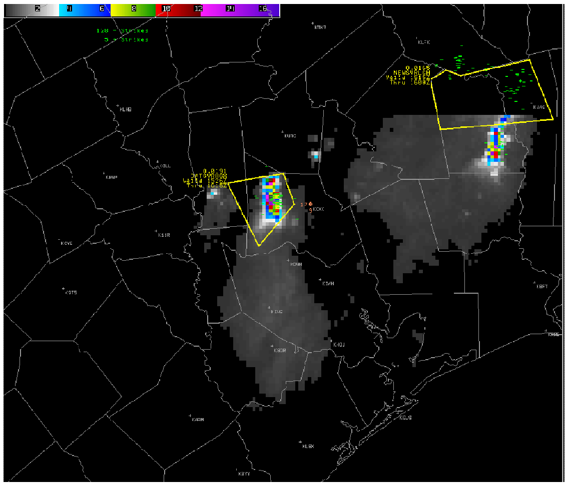

Fig. 6 – Screenshot of VII in AWIPS on a severe storm near Houston, TX

screenshots of VII for a thunderstorm near DFW airport. For this case, a strong thunderstorm developed quickly near DFW airport. Based on the statistics found during the research portion of this study, a VII value of 1 kg m^{-2} is most commonly used as the threshold for an imminent CG strike. If this threshold is used for the case shown in Figure 7, the AWW would be issued at 1647 UTC, which is approximately 15 mins before the first CG strike. Additional example can be found in Hoeth (2011), where examples of how SMG uses the product to aid in their lightning watch and warning products at JSC are provided.

4. CONCLUSIONS

Previous research has shown the potential of forecasting CG lightning using radar reflectivity. thresholds at various isothermal heights. This study incorporates a new radar-derived parameter, vertically integrated ice (VII), into the radar-based first flash CG lightning forecasting method. VII-based CSI values were often comparable to the reflectivity threshold method and the ease of the VII forecast method provides the NWS an easy to implement and effective method of forecasting CG lightning. Forecasts made using VII value greater than 0.25 kg m^{-2}, produced an average CSI of 0.65. The best forecast values for this study were using the 10^{th} percentile value of 0.42 kg m^{-2} or 15^{th} percentile value of 0.58 kg m^{-2}, which both produced an average CSI of 0.67. The CSI values stay above 0.60 until after the 35^{th} percentile VII value. Since VII only considers reflectivity above the -10°C environmental level, any time VII is greater than zero, precipitation mass (i.e., rain, snow, graupel, and/or hail) has reached a height needed for cloud electrification, while any increase of VII over 0.42 kg m^{-2} is shown to represent a sufficient amount of precipitation mass for cloud electrification. The average forecast time when using the 5^{th}-25^{th} percentile VII values was 11.7 min.

VII was incorporated into the National Weather Service's Advanced Weather Interactive Processing System (AWIPS) at Weather Forecast Office Houston (HGX) and Fort Worth (FWD) as well as NASA's Spaceflight Meteorology Group (SMG). This integration has proved beneficial to each office involved. An example was provided that showed how VII could be used to provide 15 min lead time on a CG strike at Dallas-Fort Worth (DFW) International Airport. As a result of the research presented here and two years of operational use in NWS WFOs, a few best practices have been developed:

- To maximize POD – use a low (10th percentile or less) value, such as 0.1 kg m^{-2}
- To minimize FAR – use a high value (above 50th percentile)
- To maximize CSI – use a low (10th percentile or less) value
- To maximize lead time - use a low (10th percentile or less) value

Additional research on VII may yield more operational uses. Correlation of VII with various atmospheric parameters such as convective available potential energy (CAPE), lifted index, and wind shear may provide longer forecast times. Forecast products such as lightning "outlooks" for "frequent" or "numerous" lightning events may also be possible. Carey and Rutledge (2000) found a strong correlation between the total lightning flash rate and total mixed-phase ice mass. Therefore, VII, which is a measure of mixed-phase ice mass, particularly graupel mass, could be used to nowcast "frequent" or "numerous" lightning events once local criteria are established for those types of events. Additionally, more work is needed with rapid changes in VII. Case studies of this dataset showed VII "jumps" often precede cloud-to-ground flashes. There is also a possibility that rapid decreases in VII could signal lightning cessation.

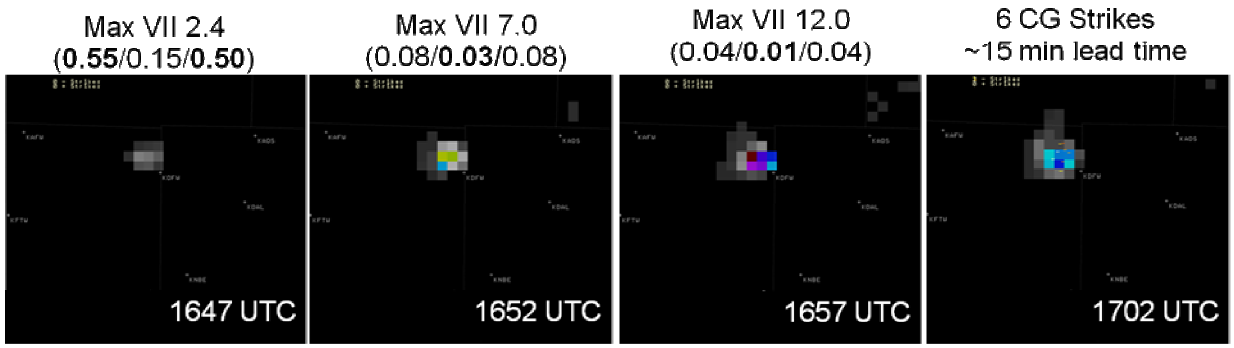

Fig. 7 – Time series of VII images for a thunderstorm near DFW Airport. Maximum VII value is listed as well as the corresponding contingency table parameters in this form: (CSI / POD / FAR).

5. ACKNOWLEDGEMENTS

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