Title: **Recent Advancements in Lightning Jump Algorithm Work**

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In the past year, the primary objectives were to show the usefulness of total lightning as compared to traditional cloud-to-ground (CG) networks, test the lightning jump algorithm configurations in other regions of the country, increase the number of thunderstorms within our thunderstorm database, and to pinpoint environments that could prove difficult for any lightning jump configuration. A total of 561 thunderstorms have been examined in the past year (409 non-severe, 152 severe) from four regions of the country (North Alabama, Washington D.C., High Plains of CO/KS, and Oklahoma).

Results continue to indicate that the 2σ lightning jump algorithm configuration holds the most promise in terms of prospective operational lightning jump algorithms, with a probability of detection (POD) at 81%, a false alarm rate (FAR) of 45%, a critical success index (CSI) of 49% and a Heidke Skill Score (HSS) of 0.66. The second best performing algorithm configuration was the Threshold 4 algorithm, which had a POD of 72%, FAR of 51%, a CSI of 41% and an HSS of 0.58. Because a more complex algorithm configuration shows the most promise in terms of prospective operational lightning jump algorithms, accurate thunderstorm cell tracking work must be undertaken to track lightning trends on an individual thunderstorm basis over time.

While these numbers for the 2σ configuration are impressive, the algorithm does have its weaknesses. Specifically, low-topped and tropical cyclone thunderstorm environments are present issues for the 2σ lightning jump algorithm, because of the suppressed vertical depth impact on overall flash counts (i.e., a relative dearth in lightning). For example, in a sample of 120 thunderstorms from northern Alabama that contained 72 missed events by the 2σ algorithm 36% of the misses were associated with these two environments (17 storms).

Out of the larger sample of 561 thunderstorms, 30 storms were chosen to compare total lightning trends to CG trends in order to demonstrate the added utility that total lightning information provides. Thunderstorms were chosen based on their high total flash rates, region of the country, and type of thunderstorm. The 2σ lightning jump configuration was used for identification of lightning jumps in the total lightning and CG lightning datasets. Results clearly indicate that total lightning trends outperform CG lightning trends, especially during the early stages of the thunderstorm.

There were two main examples that stood out in this comparison. The first example was from a severe thunderstorm from June 20, 2000 in Eastern Colorado and Western Kansas. Total lightning trends for this thunderstorm indicate that there were 7 lightning jumps indicated during the lifetime of the thunderstorm, with a peak total flash rate of 108 flashes per minute. Meanwhile, the CG data trends indicated zero lightning jumps during this same period of time with a peak CG flash rate of 2 flashes per minute. Four instances of severe weather were reported with this storm, all high wind damage. The total lightning jumps averaged 33 minutes of lead time prior to the high wind events, while there was not a single CG lightning jump during the entire period, leading to four missed events.

A second notable example occurred in Eastern AL on April, 18, 2006. Here total lightning trends indicated that there were four lightning jumps, with a peak total flash rate of 56 flashes per minute. Meanwhile, the CG lightning trends again indicated zero CG lightning jumps, with a peak CG flash rate of 2 flashes per minute. Six instances of severe weather were observed, including hail to the size of golfballs. The total lightning trend information was able to detect all six instances with an average lead time of 28 minutes. Meanwhile, the CG lightning trend data indicated zero lightning jumps; therefore, all 6 events were missed.

For the total lightning trends, the probability of detection (POD) was 93%, a false alarm rate (FAR) of 26%, a critical success index of 70% and a Heidke Skill Score of 0.82. For the same thunderstorm samples using CG data the POD was 66%, FAR of 25%, CSI of 54% and a HSS of 0.70. Thus, total lightning information has distinct advantages over CG lightning information.

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Recent Emphases

Over the past year we have performed the following analysis to expand upon the previous lightning jump algorithm work:

1) Demonstrated the usefulness of total lightning information as compared to traditional cloud-to-Ground (CG) lightning information.

2) Tested the lightning jump algorithms developed previously in four additional regions of the country.

3) Increased the number of thunderstorm cases within the North Alabama region.

4) Identified environments that could prove difficult for any lightning jump algorithm configuration.

Thunderstorm Cases and Regions of Study

561 Thunderstorms Analyzed:
- 409 non severe
- 152 severe (tornado, wind, hail)*

*224 severe weather reports

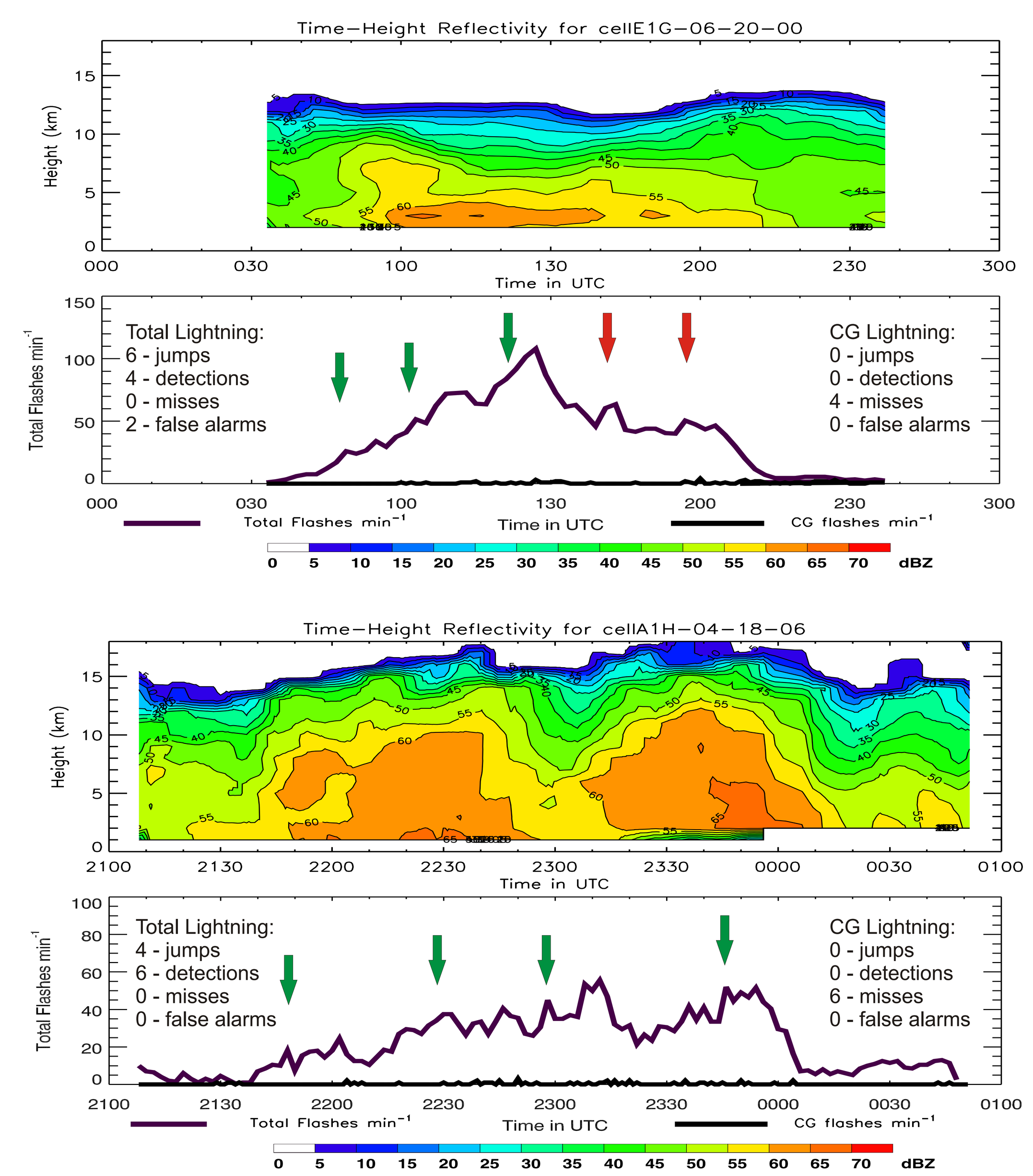
Four Regions of the Country
- North Alabama
- Washington D.C.
- Eastern Colorado/West Central Kansas (STEPS; Lang et al. 2004)
- Oklahoma

Each region has a lightning mapping array (LMA)

Total Lightning vs Cloud-to-Ground Lightning

Total lightning outperforms CG lightning

Comparison Examples



Above: Two examples where total lightning trends outperformed CG lightning trends in the real-time detection of severe weather. In both cases, (June 20, 2000 [top] and April 18, 2006 [bottom]) multiple reports of severe weather were observed, and total lightning trends indicated the potential for severe weather, while CG lightning trends did not. Arrows represent total lightning jump times using the 2σ lightning jump algorithm; ⬇ = detection, ⬇ = false alarm

Overall

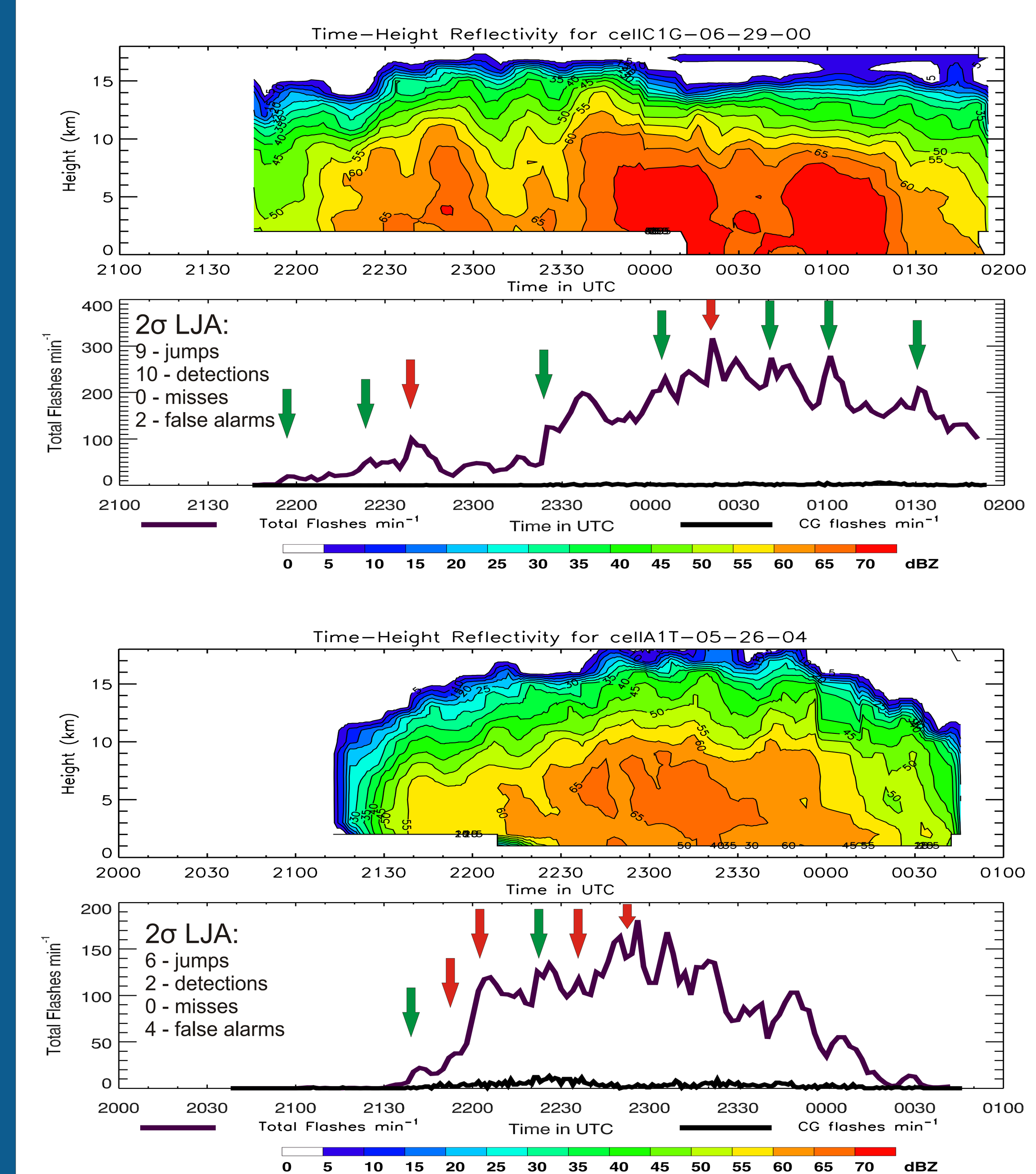
Table 1. Overall lightning jump statistics using total lightning trends and CG lightning trends. Five statistical categories are represented: probability of detection, false alarm rate, critical success index, Heidke Skill Score, and average lead time prior to severe weather occurrence.

	Probability of Detection	False Alarm	Critical Success	Heidke	Avg. Lead Time
CG Lightning	65%	25%	54%	0.70	19.73 mins
Total Lightning	93%	26%	70%	0.82	24.47 mins

Testing of Regions and Increasing Sample Size

- Number of thunderstorms increased from 85 in Schultz et al. (2009) to 561.
- The increase in storms only lowers the POD by 6%, and increases the FAR by 10% using the 2σ algorithm configuration.

Region Examples



Above: Case examples from two of the four regions studied. The top example is a thunderstorm from Western KS, on June 29, 2000 and the bottom example is from Oklahoma on May 26, 2004. Both thunderstorms produced multiple reports of severe weather, in which total lightning jumps indicated by the 2σ configuration proceeded the observance of severe weather at the surface. Arrows represent total lightning jump times using the 2σ lightning jump algorithm; ⬇ = detection, ⬇ = false alarm

Overall

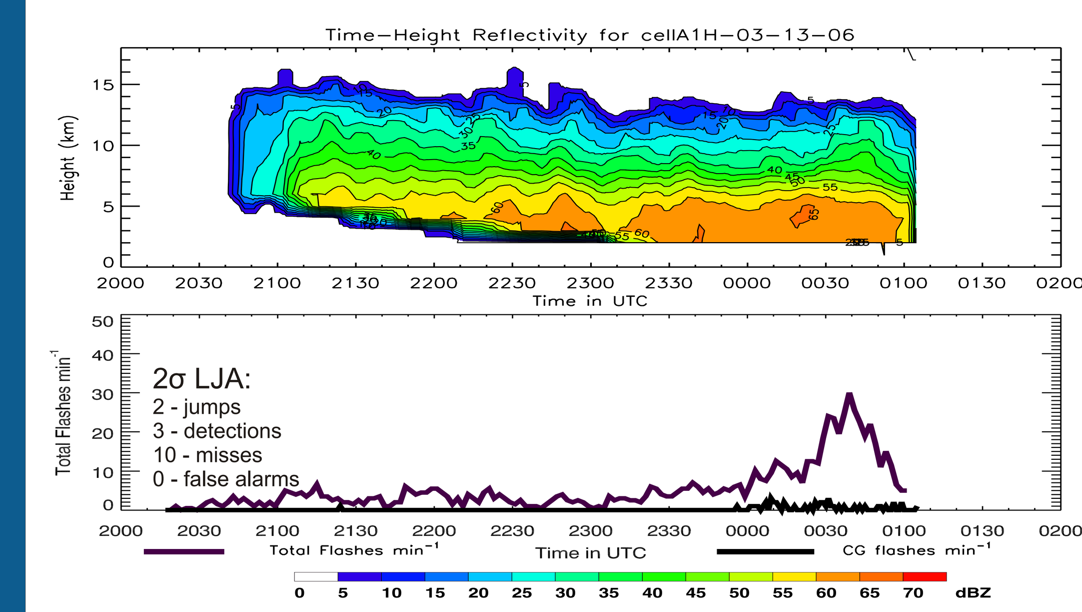
Table 2. Overall lightning jump statistics for the best performing total lightning jump algorithm, the 2σ configuration, on the sample of 561 thunderstorms. Five statistical categories are represented: probability of detection, false alarm rate, critical success index, Heidke Skill Score, and average lead time prior to severe weather occurrence.

	Probability of Detection	False Alarm	Critical Success	Heidke	Avg. Lead Time
2σ	81%	45%	45%	0.62	19.20 mins

Problematic Environments

- Low topped environments
- Tropical cyclone remnants
- Relative lack of lightning can fail to 'turn on' the jump algorithm.

Example



Above: Time height history of reflectivity (top panel), total lightning, and CG lightning (bottom panel) from a tornadic low topped supercell on March 14, 2006 in North Alabama. This thunderstorm produced 13 severe weather events between 2018 UTC and 0053 UTC March 14, including 8 brief tornadoes. Zero lightning jumps were detected prior until 0011 UTC because the total flash rate remained below 10 flashes min^{-1}, which is a requirement to weed false jumps from ordinary thunderstorms.

Conclusions/Future Work

Total lightning trends outperform CG lightning trends prior to severe weather.

Despite the increase in the number of thunderstorms the POD (81%) and FAR (45%) are solid for the 2σ lightning jump algorithm.

Lightning jump algorithms can successfully be used in other regions of the country.

Writing ATBD in the next year.

Prepare testing for the GOES-R proving ground.