Differences in Lightning Flash Characteristics During the Lake-Effect Electrification (LEE) 17-20 November 2022 Event

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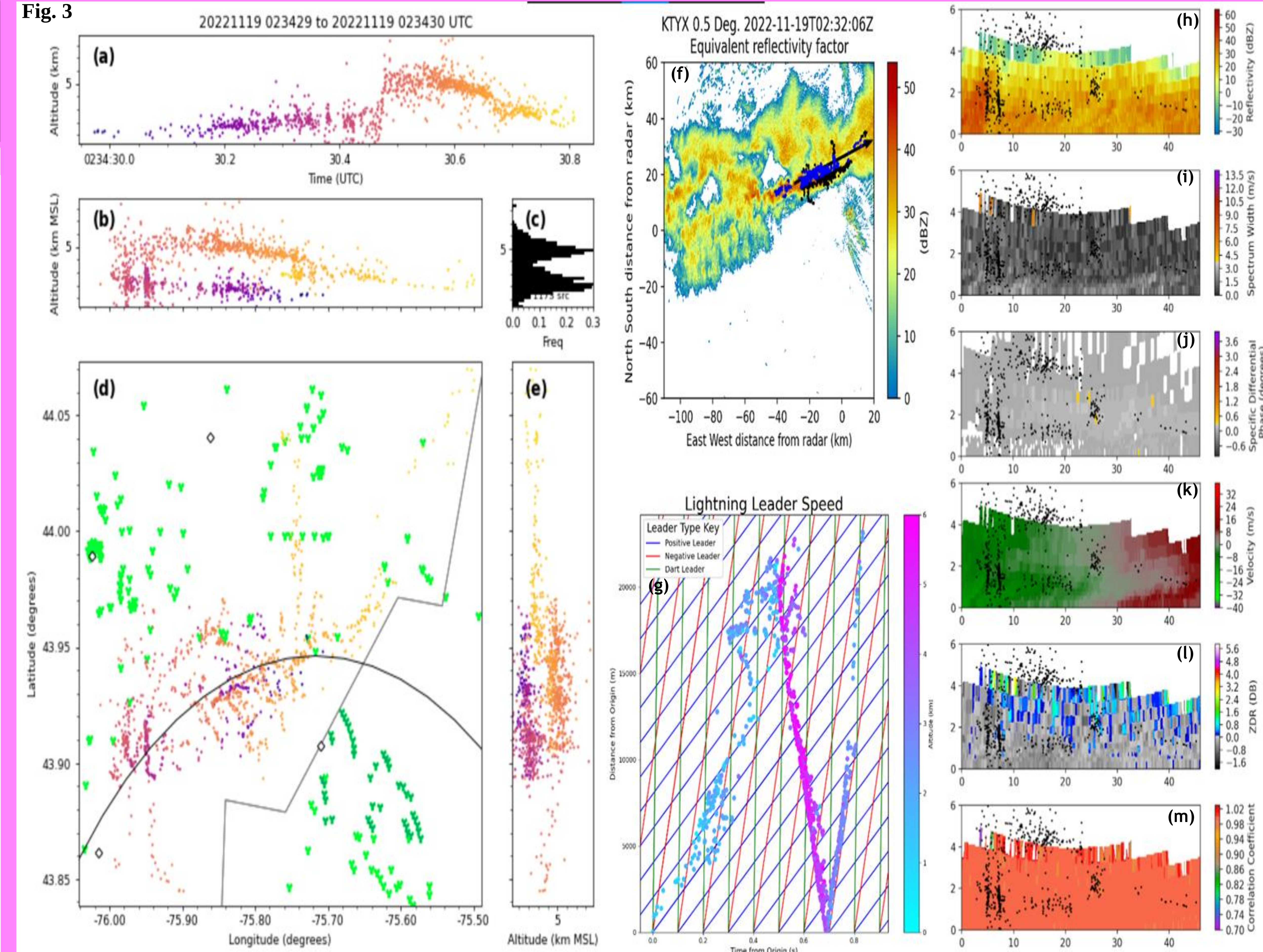
Background

- The Lake-Effect Electrification (LEE) field project was conducted from September 2022 until March 2023
- Our goal is to understand the electrical charge structure of cool season lake-effect storms east of Lake Ontario and the associated lightning
- 2013-14 Ontario Winter Lake-Effect Systems (OWLeS) project saw most lightning flashes east of the lake, contra over water as climatologically expected, prompting LEE (Kristovitch et al. 2017, Steiger et al. 2009)
- During the 17-20 Nov 2022 storm, 148 lightning flashes were observed by the lightning mapping array (LMA) network (246 total flashes)
- These flashes were sorted into three categories based on where they were located: past the Canadian border, < 15 km from the NY lake shore, and > 15 km from the shore
- Based on those criteria, 12 Canada flashes, 25 near-shore flashes, and 109 inland flashes were documented. Two flashes occurred on the border between near-shore and inland
  - Canada flashes were not studied due to low visibility from the KTYX NEXRAD

Fig 3: An LMA plot showing a single lightning flash with alt vs time (a), vs long (b), vs frequency of points (c), vs lat (e), lat vs long (d), KTYX radar plan view (f), speed of individual leaders (g), reflectivity (h), spectrum width (i), specific differential phase (j), radial velocity (k), ZDR (l), CC (m) vertical cross sections. The color transition from blue to yellow represents the passage of time (a) corresponding to the rest of the figure b-e. The LMA plot demonstrates how the flash traveled both directions along the band and it's bi-level characteristic. The bi-level characteristic is backed-up by the leader speed plot. The plan view from KTYX (f) shows an arrow traveling through the flash. All LMA points ≦ 2.5 km of the arrow (shown in blue) and plotted on the cross sections.

Fig. 3



Methodology

- Made plots using data from KTYX radar and joint Georgia Tech Research Institute and National Severe Storms Laboratory LMA network (Chmielewski et al. 2023)
- Analyzed characteristics (Fig. 1) such as:
  - Flash extent density plots to determine where flashes primarily occurred (Fig. 2)
  - Altitude mode on LMA plot (Fig. 3c)
  - Predominant leader speed determined using a velocity map derived from LMA network (Fig. 3g)
    - Positive leaders follow $2*10^4$ m s^{-1}, negative leaders follow 10^5 m s^{-1}, dart leaders follow 10^6 m s^{-1} (Valde et al. 2013)
  - Direction in relation to lake-effect band
    - Toward or away from the lake (up band/down band)
  - If the flash stayed in a region with higher reflectivity (Fig. 3f)

Results

- 80% of lightning occurred inland during this storm (Fig. 1)
- 74% of inland lightning was predominantly positive leaders, 48% of shore lightning was predominantly negative leaders (Fig. 1)
- *Up band lightning occurred most frequently for inland lightning, down band for near shore lightning (Fig. 1)*
- Shore flashes (30%) showed more bi-level traits than inland flashes (14%) (Fig. 1)
- 84% of the overall flashes stayed near regions with greater reflectivity (Fig. 1)
- The most common altitude for LMA sources was 1.9 km MSL inland and 2.5 km MSL on shore (Fig. 4)

Fig. 1

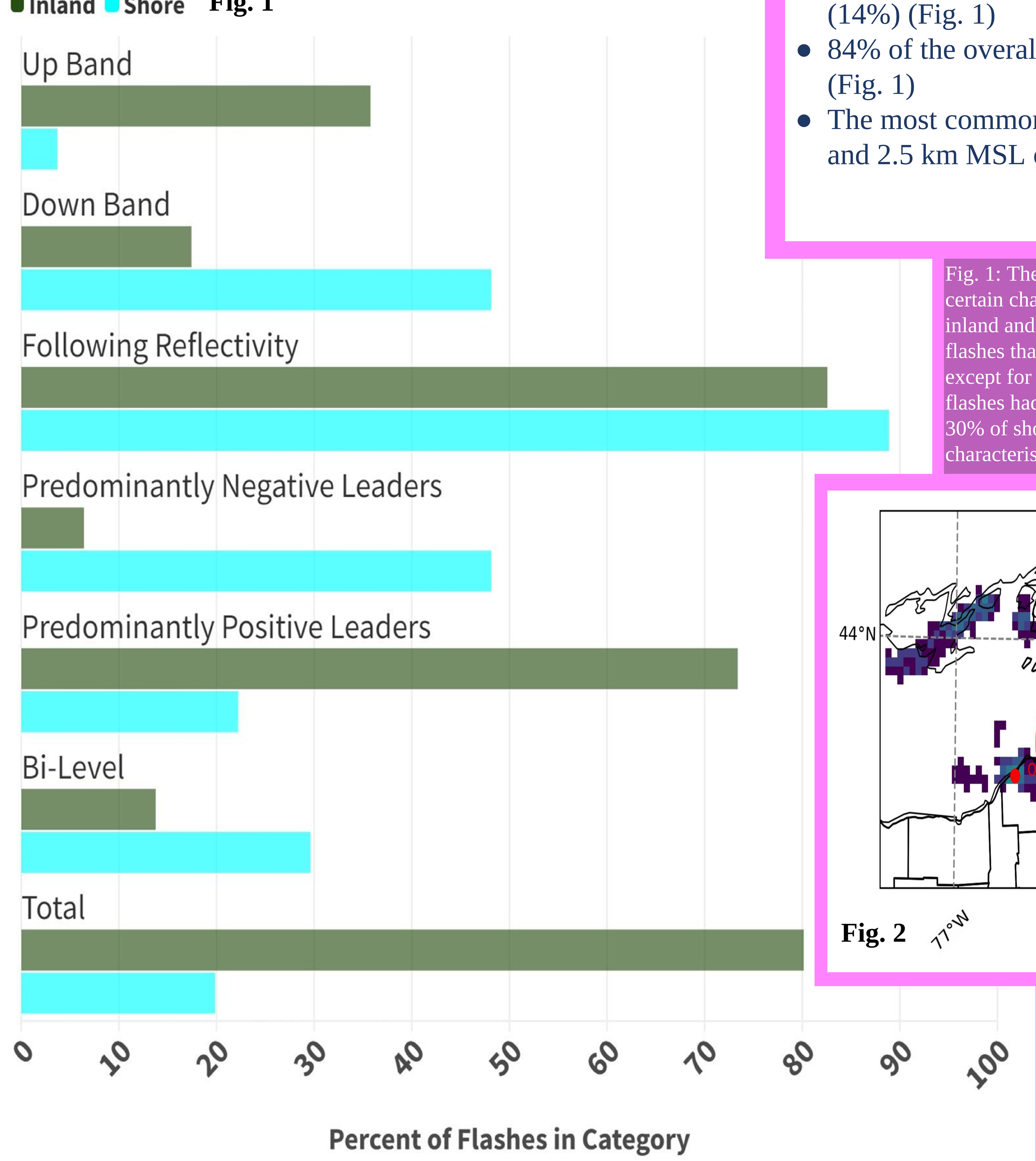


Fig. 1: The percentage of flashes observed with certain characteristics is split into two categories: inland and shore. Each row shows the percentage of flashes that exhibited the specified characteristic, except for the total flash row. Ex. 14% of inland flashes had bi-level characteristics (86% did not). 30% of shore flashes showed bi-level characteristics (70% did not).

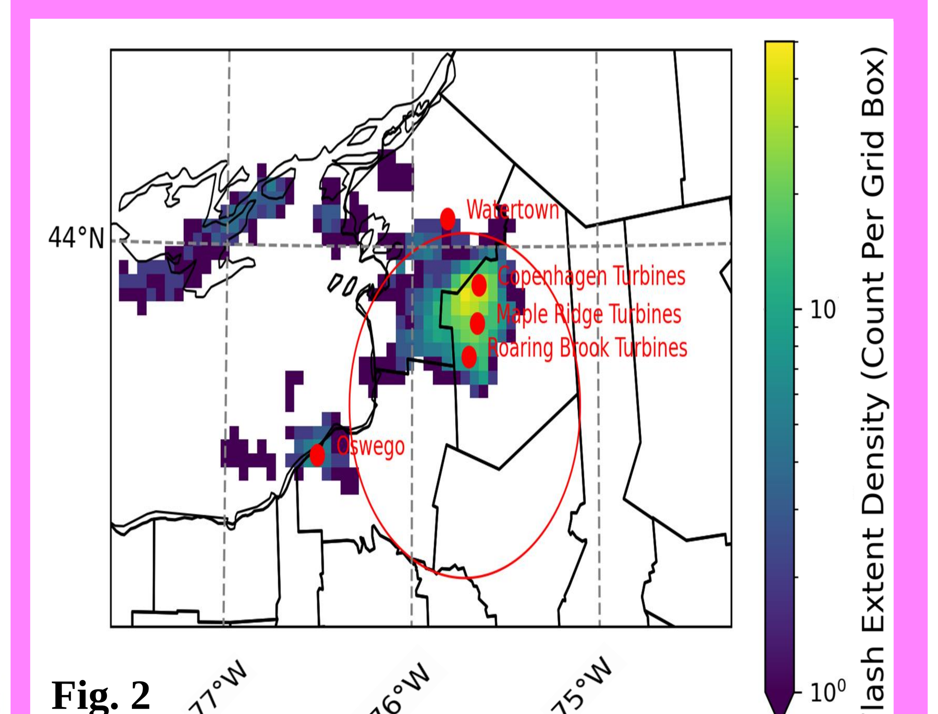


Fig. 2

Fig 2: Flash extent density plot for all 148 flashes recorded during the 17-20 Nov 2022 event. Each grid box increases by one count for each lightning flash occurring within the grid box. This plot demonstrates the significant amount of lightning that occurred over the turbines compared to the rest of the domain.

Results (cont.)

- The Flash Extent Density plot for the event highlights the significant amount of lightning that occurred near the wind turbines (Fig. 2)
- The ability to isolate and observe radar characteristics for one flash helps with understanding lightning as a whole (Fig. 3)
  - In Fig. 3h, the lightning is shown above the radar top, suggesting that the negative leaders are propagating in a screening layer above the storm
- A Lightning Leader Speed plot establishes two specific charge types and the altitudes they occur at (Fig. 3g)
  - The LMA plot helps to display the speed spatially
- Radar cross sections helped to identify different factors that could influence lightning
- Minima in correlation coefficient occasionally lined up with turbulence (greater spectrum width), couplets in velocity, and presence of towers on LMA plot (Fig. 3)
  - Low level radar data were too low-res to conclude

Discussion and Conclusions

- 80% of the lightning from these four days occurred away from the lake shore, opposite of what the climatology suggests (Steiger et al. 2009)
  - The wind turbines were newly constructed at the time of this study and more have been added since, so there is some credence to the hypothesis that the wind turbines are having a substantial effect on the lightning in this storm type (lake-effect)
- 84% of flashes stayed within regions with higher reflectivity. This may have been where the charge separation from colliding particles was strongest (MacGorman and Rust 1998)
- The divide between shore flashes having predominantly negative leaders but inland flashes having predominantly positive leaders demonstrates a difference in the storm environment and the charge regions
- Lightning is awesome!!

Fig. 4

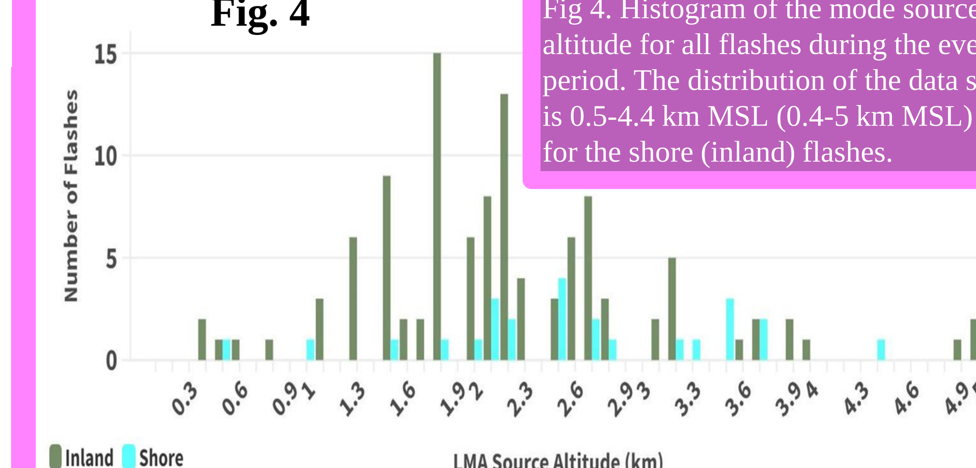


Fig 4. Histogram of the mode source altitude for all flashes during the event period. The distribution of the data set is 0.5-4.4 km MSL (0.4-5 km MSL) for the shore (inland) flashes.

Future Work

- Study more characteristics of inland and shore lightning
- Analyze upward lightning characteristics from LEE with radar and LMA data to determine tower location
- Determine differences between other electrified cold season storms (e.g., cyclones) and lake-effect lightning

Acknowledgements

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