83 A LIGHTNING MAPPING ARRAY IN SOUTHERN ONTARIO, CANADA: USES FOR SEVERE WEATHER NOWCASTING

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1. INTRODUCTION

Lightning Mapping Array (LMA) technology was developed at the New Mexico Institute of Mining and Technology to locate sources of impulsive very high frequency (VHF, typically ~63 MHz) radiation produced by lightning flashes in three spatial dimensions and time (Rison et al. 1999). Radiation arrival times are measured at a network of ground stations using an accurate time base provided by Global Positioning System receivers. Both cloud-to-ground and in-cloud lightning flashes are detected (i.e., 'total lightning').

LMAs have been installed in a number of countries including the United States, Brazil, France and Japan for severe thunderstorm nowcasting and lightning research purposes. 'Jumps' in total lightning, such as those detected by LMAs, have been associated with increases in thunderstorm intensity and can therefore be used to improve the lead time for operational severe weather warnings (Darden et al. 2010).

In 2014, Environment Canada contracted LMA Technologies LLC to install an LMA in southern Ontario. There are four objectives related to this initiative:

1. Make use of total lightning source density and rate change data to improve the nowcasting of thunderstorm intensity,

2. Use the LMA to evaluate lightning data from model parameterizations and other lightning detection networks including the Canadian Lightning Detection Network (CLDN),

3. Become familiar with the use and benefits of total lightning in advance of its availability via the Geostationary Lightning Mapper (GLM) aboard the GOES-R satellite in coming years,

4. Generally increase knowledge of lightning characteristics in the southern Ontario area, including winter lightning often associated with intense lake-effect snow events, and compare to other regions with LMAs.

2. DATA AND METHODS

The Southern Ontario LMA (SOLMA) is composed of 14 solar-powered ground stations (see Figs. 1 and 2) that were installed in the spring of 2014. These stations receive radio-frequency radiation at successive 80-μs intervals. However, to allow real-time processing, the data are decimated to 400-μs intervals before being sent to the central server via

Figure 1. Lead author Dave Sills with an LMA ground station at Pearson International Airport near Toronto.

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cellular modem. The full dataset must be manually downloaded during station visits.

The VHF sources that make up each lightning flash (often hundreds to thousands) can be plotted to map 3-D spatial and temporal extent (Fig. 3). The LMA sources can also be combined to produce lightning source density products (Fig. 4).

The source detection efficiency and accuracy decrease with distance from the array. The radius for effective 3-D detection (horizontal and vertical accuracy both less than 100 m) is approximately 150 km (Fig. 5 and 6). SOLMA station baselines range from 10 km to 40 km, with most near 20 km.

3. PRELIMINARY RESULTS

Lightning activity was detected by SOLMA on 101 days in 2014 between April 12 and November 30. The most active month was August with 20 days having lightning activity detected. What follows are brief descriptions of events of interest captured by SOLMA.

3.1 September 5/6

This most active event of the season occurred when a strong cold front triggered the development of a squall line across the region. In the one-hour period from 00 UTC to 01 UTC (8 pm to 9 pm local time) on September 6th, more than 1 million LMA sources (decimated) were detected.

3.2 June 12

SOLMA recorded many lightning flashes with considerable horizontal extent. The decimated data that were available in real time are shown in Fig. 3.

3.3 October 16

SOLMA detected a compact area of lightning over the City of Toronto. As shown in Fig. 4, lightning activity, particularly in-cloud lightning, intensified rapidly between 23:30 UTC and 23:40 UTC. Approximately ten minutes later, the storm that generated this lightning ‘jump’ was producing flash flooding and exhibiting a strong mesocyclone on the King City Doppler radar (not shown).

3.4 November 20

SOLMA recorded the first known 3-D detection of total lightning generated by lake-effect snow. This was part of the historic, multi-day lake-effect snow event affecting Buffalo, NY, with more than 2 m of accumulated snow in some locations. One such flash, shown in Fig. 7, lasted less than 0.5 sec and propagated along dendritic-appearing branches across more than 20 km.

Only 8 of 14 stations were operational during this period due to insufficient solar power (currently being addressed), so a reduced vertical accuracy of approximately 500 m was attained. The initial leader appears to have initiated near 6 km altitude, with the majority of sources detected between 1 km and 8 km altitude after that time. A small number of sources were detected to 12 km altitude. These sources are relatively localized and unbranched, and likely have significant positional errors due to the occasional incorporation of random local noise events, as suggested by Thomas et al. (2004). Enhanced echo top data from the BUF NEXRAD Doppler radar (not shown) did not exceed 6 km at the time of, and in the hours leading up to, the source detections though low reflectivity precipitation and cloud likely extended to high altitudes.

Fig. 8 shows the low-level reflectivity structure associated with the lake-effect snow band at 23:00 UTC, with the SOLMA sources from Fig. 7 superimposed. Interestingly, the flash occurred in a region of ~20 dBZ echoes and not in the vicinity of stronger echoes to the west reaching ~27 dBZ.

4. FUTURE WORK

SOLMA is expected to collect research data through 2018. Over this period, a number of related initiatives are planned.

Work is underway to implement LMA total lightning data into a severe thunderstorm nowcasting prototype system (iCAST, Sills et al. 2009) that will be demonstrated in real time during the Pan Am / ParaPan Am Games in the Toronto area in summer 2015. The LMA source density and rate of change will be incorporated into a storm tracking and trending algorithm that ranks storms in a storm attribute table and generates first-guess threat areas for cells with an intensity that is nowcast to exceed severe thresholds.

Methods will be developed to validate CLDN performance using LMA data and evaluate the performance of new lightning parameterization approaches in EC's high-resolution deterministic prediction system (with horizontal grid spacing typically between 250 m and 2.5 km).

Opportunities also exist to integrate LMA data with a dual-polarization radar particle classification algorithm used with the King City radar, to collaborate with Ryerson University researchers studying lightning discharges at Toronto's CN Tower (height 457 m AGL), and to collaborate with US colleagues studying winter lightning generated by lake-effect snowsqualls.

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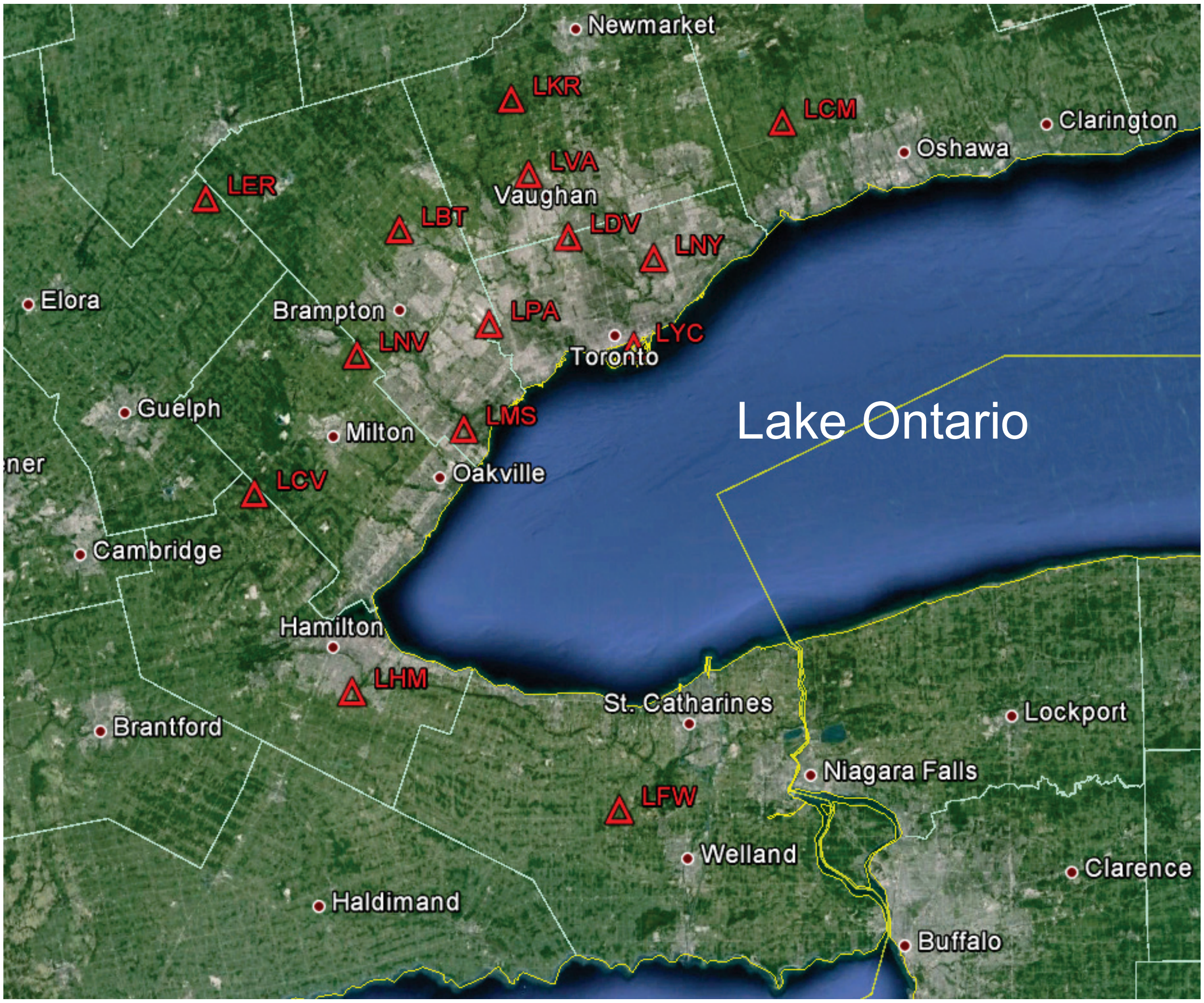

Figure 2. Distribution of 14 LMA ground stations in the Toronto area. Base map source: "Western Lake Ontario." 43.6N, 79.3W. **Google Earth**. Imagery date 4/9/2013. Accessed 5/12/2014.

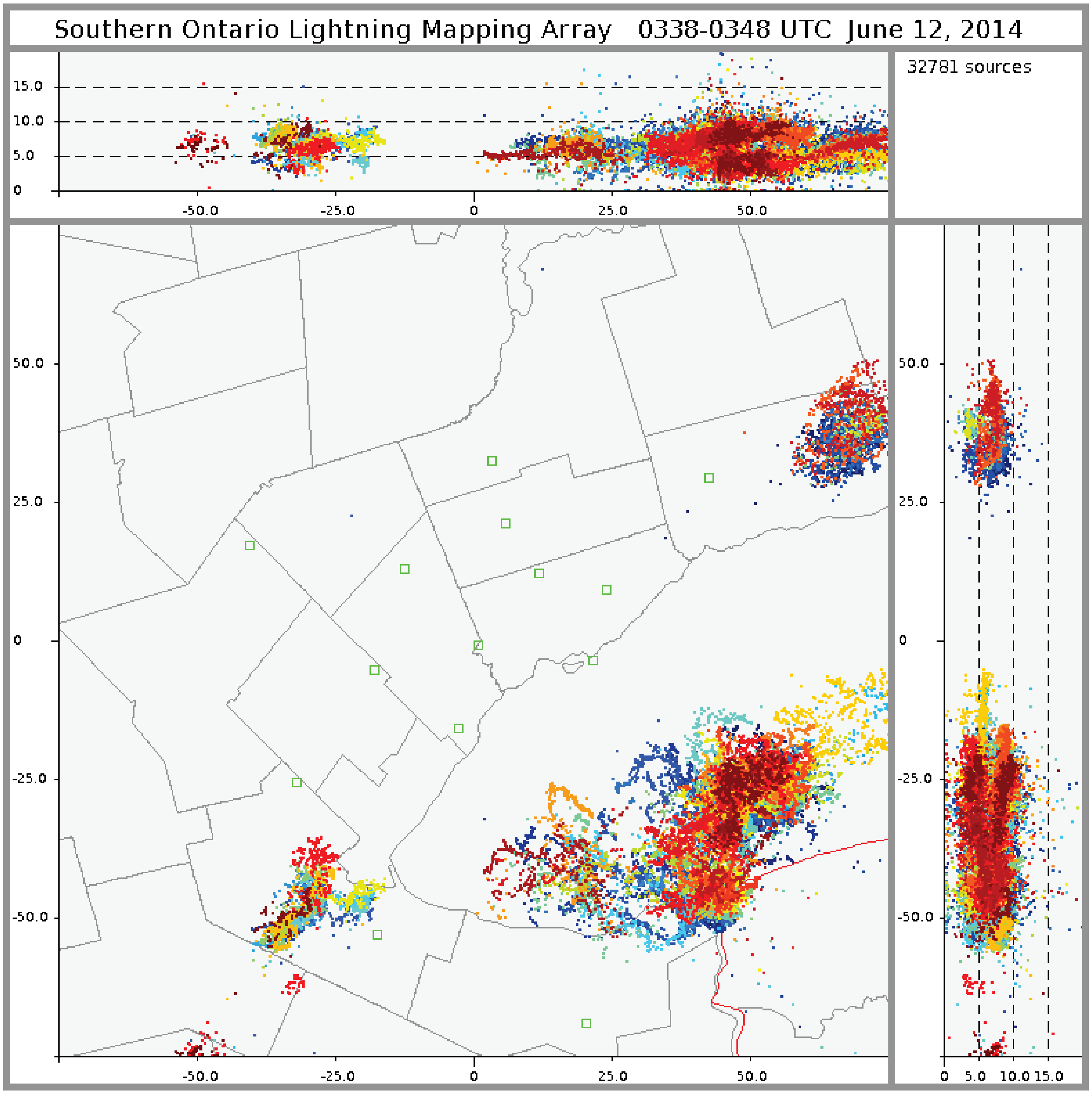

Figure 3. Multi-dimensional plot of individual SOLMA sources (decimated) over a period of 10 minutes (and available in real time) on June 12, 2014. Red is the most recent and blue the least recent in the period.

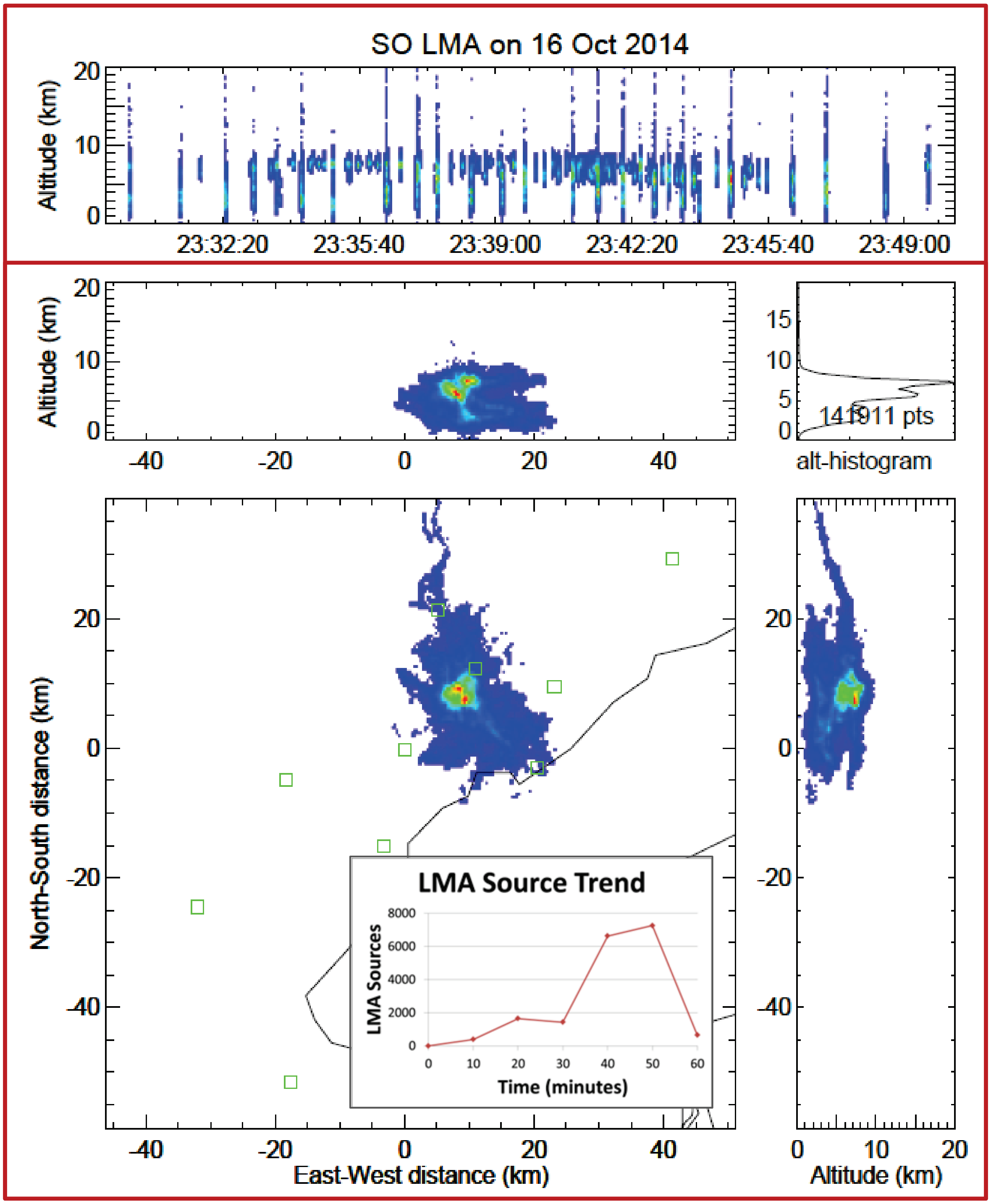

Figure 4. Multi-dimensional plot of source density (red indicates more than 500 sources per km^2) over a period of 20 minutes (23:29:50 - 23:49:50 UTC) on October 16, 2014. The top box shows source density altitude over time. The bottom box shows the spatial distribution of source density with plan view (including outline of Lake Ontario and green boxes indicating station locations), vertical projections and vertical source count. Inset shows the source trend (decimated) over 60 minutes with 'jump' between 30 and 40 minutes (23:30 and 23:40 UTC, respectively).

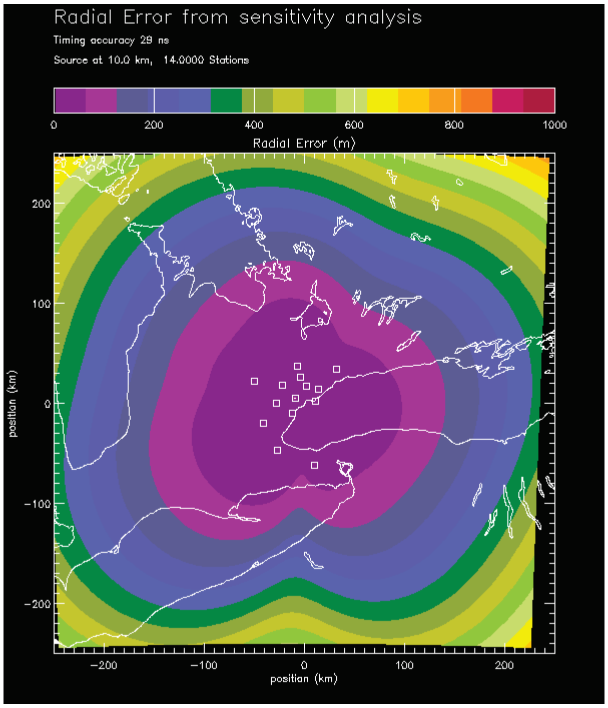

Figure 5. A map showing the radial error in metres assuming a source height of 10 km.

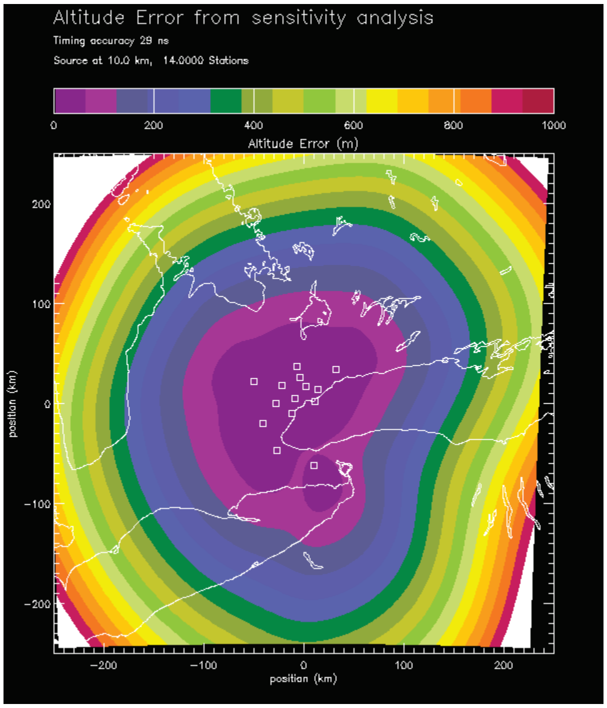

Figure 6. A map showing the altitude error in metres assuming a source height of 10 km.

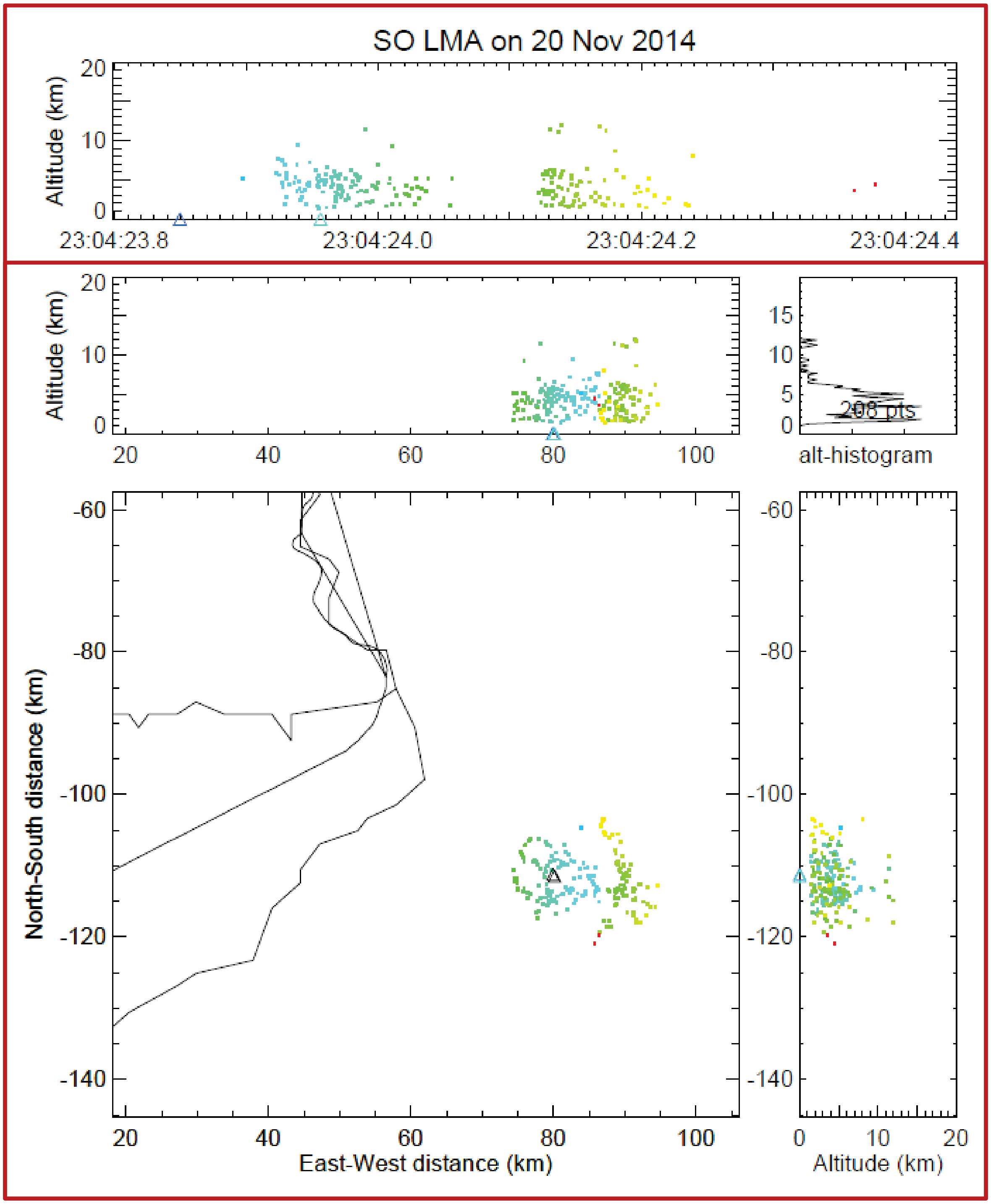

Figure 7. Multi-dimensional plot showing sources detected in association with a lightning flash during a lake-effect snow event on November 20, 2014. The top box shows source altitude over time. The bottom box shows the spatial distribution of sources with plan view (including outline of Lake Erie and the Niagara River with international border), vertical projections and vertical source count. Red is the most recent and blue the least recent in the period (23:04:23.8 - 23:04:24.4 UTC). CLDN detected a negative cloud-to-ground flash first followed by a negative in-cloud flash (shown by triangles).

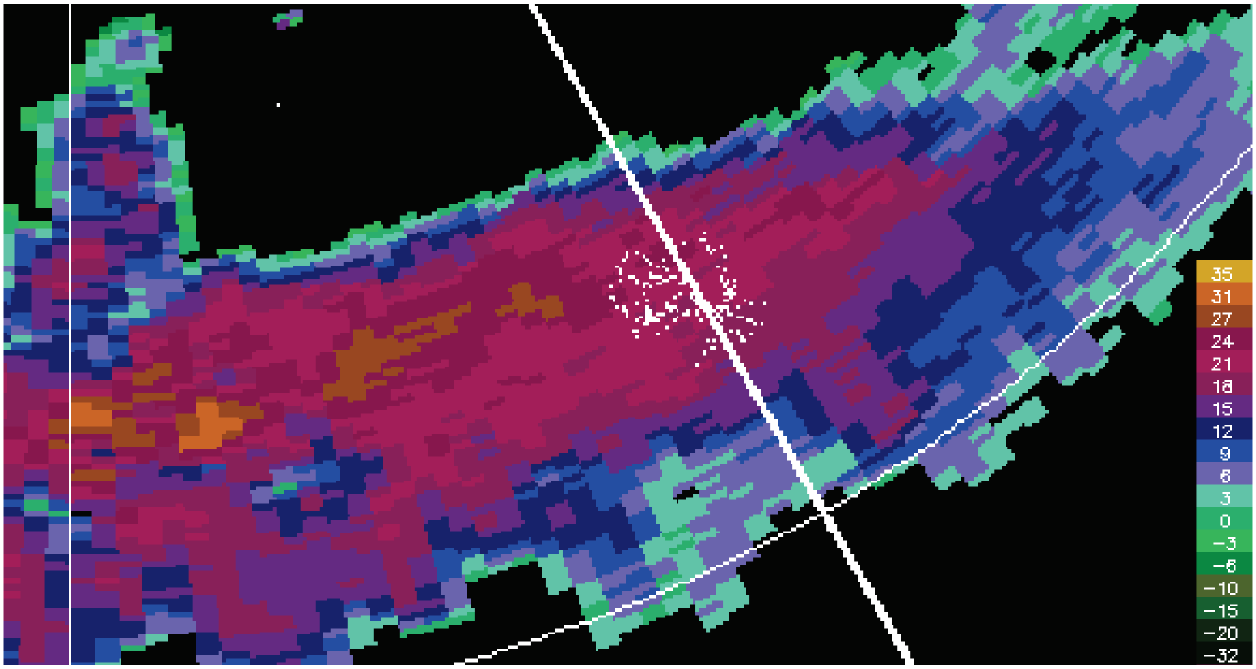

Figure 8. Low-level reflectivity (colour legend in dBZ at right) from the King City radar in Ontario at 23:00 UTC on November 20, 2014, with SOLMA sources superimposed (white dots). As shown in Fig. 7, CLDN detected a negative cloud-to-ground flash followed by a negative in-cloud flash near the same time and location as the SOLMA-detected flash.