Attachment 1: Extreme Rainfall Event Climate Pattern

Extreme Rainfall Event Climate Pattern Analysis

July 16 and August 17, 2024

Toronto and Region Conservation Authority

Project Number: 60753521

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Table of Contents

1. Introduction 9
1.1 Toronto and Region Conservation Authority 9
1.2 Rainfall in Summer of 2024 10

2. Methodology 12
2.1 Analysis of Station Data 12
2.2 Manipulation of Spatial Data 12
2.2.1 Generation of Gridded Data 12
2.2.2 Isolines 12
2.2.3 Integration of Gridded Data 13
2.3 Heat Island Model 13
2.4 Climate Projections 13
2.5 Intensity-Duration-Frequency Updates 13

3. Background Information 15
3.1 Rainfall 15
3.2 Modelling 17
3.3 Mapping 17
3.4 Reports 17

4. Extreme Rainfall of July 16, 2024 18
4.1 Storm Overview 18
4.1.1 Chronology of the Event 18
4.1.1.1 METAR 18
4.1.1.2 Warnings and Bulletins 18
4.1.1.3 Meteograms 27
4.1.2 Atmospheric Context 28
4.1.2.1 Hurricane Beryl 29
4.1.2.2 Precipitable Water 30
4.1.2.3 Upper-Level Charts 31
4.1.2.4 Tephigram Soundings 33
4.1.2.5 Satellite Imagery 36
4.1.3 Severe Weather Event 37
4.1.3.1 Radar Images 37
4.1.3.2 Low-Level Data 40
4.1.4 Numerical Forecasting 41
4.2 Rainfall Analysis 47
4.2.1 Total Precipitation and Isohyets 47
4.2.2 Duration 49
4.2.3 Intensities 51
4.3 Plain-Language Summary 55

5. Extreme Rainfall of August 17, 2024 56
5.1 Storm Overview 56
5.1.1 Chronology of the Event 56
5.1.1.1 METAR 56
5.1.1.1 Warnings and Bulletins 56
5.1.1.2 Meteograms 69
5.1.2 Atmospheric Context 70
5.1.2.1 Hurricane Debby 70

5.1.2.1 Precipitable Water 71
5.1.2.2 Upper-Level Charts 73
5.1.2.3 Tephigram Soundings 76
5.1.3 Severe Weather Event 77
5.1.4 Numerical Forecasting 83
5.2 Rainfall Analysis 89
5.2.1 Total Precipitation and Isohyets 89
5.2.2 Duration 91
5.2.3 Intensities 93
5.3 Plain-language Summary 97
6. IDF Update 98
7. Topographical Analysis 101
7.1 Heat Island Effect 101
7.1.1 Study Area and Scenarios 101
7.1.2 Simulation 104
7.1.3 Results 104
7.1.3.1 July 16, 2024 104
7.1.3.2 August 17, 2024 105
7.1.4 Influence Factors on Urban Heat Island 107
7.1.5 Effect on Storm Development and Intensity 107
7.2 Lake Ontario 107
7.2.1 Moisture Source 108
7.2.2 Temperature Modulation 110
7.2.3 Lake Breeze 112
7.3 Niagara Escarpment and Oak Ridges Moraine 113
7.3.1 Wind Channeling 115
7.3.2 Orographic Lift 115
7.3.3 Lee Waves 118
8. Major Storm Comparison 119
8.1 August 4, 2014 121
8.2 July 8, 2013 124
8.3 August 4, 2009 128
8.4 August 19, 2005 132
8.5 July 19-20, 1989 (Harrow, Ontario) 136
8.6 August 27-28, 1976 138
8.7 Summary 142
9. Climate Change Impact 145
9.1 Temperature and Precipitation 145
9.2 Hurricanes and Extratropical Cyclones 145
9.3 Thunderstorms 147
10. Summary and Recommendations 148
10.1 Summary 148
10.2 Recommendations 149
11. References 151

Figures

Figure 1-1: Map of the Nine Watersheds in TRCA's Jurisdiction 9
Figure 1-2: Daily Rainfall Totals in Toronto (Pearson Airport) 10
Figure 1-3: Flooded Don Valley Parkway on July 16, 2024 11
Figure 3-1: Selected Precipitation Gauge Stations in the TRCA Region 16
Figure 4-1: Total Precipitation Meteogram at Toronto City Centre (CYTZ; July 15-16, 2024) 28
Figure 4-2: Total Precipitation Meteogram at Rathwood station (July 16, 2024) 28
Figure 4-3: Track of Hurricane Beryl from National Hurricane Center Public Advisories 30
Figure 4-4: Precipitable Water Observational Chart (July 11, 2024, 12Z) 31
Figure 4-5: 500 hPa Height and Absolute Vorticity Observational Chart (July 16, 2024, 12Z) 32
Figure 4-6: 500 hPa Height Contours Observational Chart (July 16, 2024, 12Z) 33
Figure 4-7: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (July 15, 2024, 12Z) 34
Figure 4-8: Tephigram Sounding at the Buffalo/Greater Buffalo International Radiosonde Site (July 16, 2024, 12Z) 35
Figure 4-9: Visible Satellite Image Captured by GOES-16 (July 16, 2024, 00Z) 37
Figure 4-10: Radar Reflectivity Composite (July 15, 2024, 2030Z) 38
Figure 4-11: Radar Reflectivity Composite (July 16, 2024, 0745Z) 39
Figure 4-12: Dual Polarization Quantitative Precipitation Estimation (DPQPE) King City Radar (July 16, 2024, 1348 UTC / 09:48 EDT) 40
Figure 4-13: Air Pressure Meteogram at Toronto City Centre (CYTZ; July 15-16, 2024) 41
Figure 4-14: Temperature and Dew Point Meteogram at Toronto City Centre (CYTZ; July 15-16, 2024) 41
Figure 4-15: Forecasted Three-hour Accumulated Precipitation from 15Z to 18Z (July 16, 2024) 43
Figure 4-16: Forecasted One-hour Accumulated Precipitation from 15Z to 16Z (July 16, 2024) 44
Figure 4-17: HREF 6-hour Ensemble Maximum Accumulated Precipitation from 12Z to 18Z (July 16, 2024) 45
Figure 4-18: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport starting at July 15, 00Z 46
Figure 4-19: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport starting at July 16, 00Z 46
Figure 4-20: Map of Total Precipitation across the TRCA Region (July 16, 2024) 48
Figure 4-21: Map of Precipitation Duration across the TRCA Region (July 16, 2024) 50
Figure 4-22: Map of Average Precipitation Intensity over the TRCA Region (July 16, 2024) 52
Figure 4-23: Map of Maximum 5-minutes Rainfall Intensity in the TRCA Jurisdiction (July 16, 2024) 53
Figure 4-24: Map of Maximum 1-hour Rainfall Intensity in the TRCA Jurisdiction (July 16, 2024) 54
Figure 5-1: Total Precipitation Meteogram at Rathwood station (August 17, 2024) 69
Figure 5-2: Hurricane Debby Track, 3-8 August 2024 71
Figure 5-3: Precipitable Water Observational Chart (August 9, 2024, 12Z) 72
Figure 5-4: Precipitable Water Observational Chart (August 16, 2024, 12Z) 73
Figure 5-5: 500 hPa Height and Absolute Vorticity Observational Chart (August 17, 2024, 12Z) 74
Figure 5-6: 500 hPa Height Contours Observational Chart (August 17, 2024, 12Z) 75
Figure 5-7: 250 hPa Height Contours Observational Chart (August 17, 2024, 12Z) 76
Figure 5-8: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 17, 2024, 12Z) 77
Figure 5-9: Surface Frontal Analysis (August 14, 2024, 15Z) 78
Figure 5-10: Surface Frontal Analysis (August 15, 2024, 6Z) 79
Figure 5-11: Radar Reflectivity Composite (August 15, 2024, 06Z) 80
Figure 5-12: Surface Frontal Analysis (August 17, 2024, 12Z) 81
Figure 5-13: Air Pressure Meteogram at Toronto International Airport (CYYZ; August 16-19, 2024) 81

Figure 5-14: Temperature and Dew Point Meteogram at Toronto International Airport (CYYZ; August 16-19, 2024) 82
Figure 5-15: Dual Polarization Quantitative Precipitation Estimation (DPQPE) King City Radar (August 17, 2024, 1324 UTC / 0924 EDT) 83
Figure 5-16: Forecasted Three-hour Accumulated Precipitation from 15Z to 18Z (August 17, 2024) 84
Figure 5-17: Forecasted One-hour Accumulated Precipitation from 16Z to 17Z (August 17, 2024) 85
Figure 5-18: Forecasted One-hour Accumulated Precipitation from 17Z to 18Z (August 17, 2024) 86
Figure 5-19: HREF 24-hour ensemble maximum accumulated precipitation from 12Z to 12Z (August 17-18, 2024) 87
Figure 5-20: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport Starting at August 16, 00Z 88
Figure 5-21: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport Starting at August 17, 00Z 88
Figure 5-22: Map of Total Precipitation across the TRCA Region (August 17, 2024) 90
Figure 5-23: Map of Precipitation Duration over the TRCA Region (August 17, 2024) 92
Figure 5-24: Map of Precipitation Intensity over the TRCA Region (August 17, 2024) 94
Figure 5-25: Map of Maximum 5-minutes Rainfall Intensity in the TRCA Jurisdiction (August 17, 2024) 95
Figure 5-26: Map of Maximum 1-hour Rainfall Intensity in the TRCA Jurisdiction (August 17, 2024) 96
Figure 6-1: Rainfall to IDF Comparison 2024 99
Figure 6-2: Existing and Updated IDF Curves for the TORONTO CITY and TORONTO INTL A Stations 100
Figure 7-1: Map of Study Area for UHI Modeling 101
Figure 7-2: Historical Aerial Photograph of the Study Area in 1976 102
Figure 7-3: Urban 2025 Model (Top), Urban 1976 Model (Middle), and Rural Model (Bottom) (Simulation) 103
Figure 7-4: Simulated Hourly Air Temperature for Urban 2025, Urban 1976, and Rural Models (July 13 to 17, 2024) 104
Figure 7-5: Simulated Hourly Air Temperature for Urban 2025, Urban 1976, and Rural Models (July 14 to 16, 2024) 105
Figure 7-6: Simulated Hourly Air Temperature for Urban 2025, Urban 1976, and Rural Environments (August 14 to 18, 2024) 106
Figure 7-7: Simulated Hourly Air Temperature for Urban 2025, Urban 1976, and Rural Environments (August 16 to 17, 2024) 107
Figure 7-8: Annual Cycles of Average Lake Ontario Meteorology and Evaporation 108
Figure 7-9: Surface Wind Conditions (16-July-2024, 01 UTC) 110
Figure 7-10: Annual Cycles of Average Lake Ontario Heat Fluxes 111
Figure 7-11: Water Temperature Lake Ontario 112
Figure 7-12: Surface Conditions at 12Z for July 16, 2024 (Left) and August 17, 2024 (Right) 113
Figure 7-13: Elevation Map for the Ontario Peninsula 114
Figure 7-14: Approximate Storm Path for the July 16 and August 17, 2024 117
Figure 8-1: Map of ECCC Stations for the AMC Calculations 120
Figure 8-2: Total Rainfall Accumulation across the Conservation Halton Area (August 4, 2014) 121
Figure 8-3: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 5, 2014, 00Z) 122
Figure 8-4: Surface Map (August 4, 2014, 21Z) 123
Figure 8-5: Model Forecasts of Cumulative Precipitation at Hamilton Munro International Airport Starting at August 4, 2014, 12Z 124
Figure 8-6: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport Starting at August 4, 2014, 12Z 124
Figure 8-7: Total Rainfall Accumulation over the TRCA Jurisdiction (July 8, 2013) 125
Figure 8-8: 21-hour NAM Model Forecast Sounding over Toronto valid at July 8, 2013, 21Z with the NAM Initialized July 8, 2013, 00Z 126
Figure 8-9: Surface Map (July 8, 2013, 21Z) 127

Figure 8-10: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport Starting at July 8, 2013, 12Z 128
Figure 8-11: Total Rainfall Accumulation over Cooksville, Ontario (August 4, 2009) 129
Figure 8-12: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 5, 2009, 00Z) 130
Figure 8-13: Surface Map (August 4, 2009, 21Z) 131
Figure 8-14: 24-hour Precipitation Forecast from August 4, 2009, 12Z to August 5, 2009, 12Z by the NAM Model Initialized August 4, 2009, 12Z 132
Figure 8-15: Total Rainfall Accumulation (August 19, 2005) 133
Figure 8-16: Surface Map (August 19, 2005, 21Z) 134
Figure 8-17: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 20, 2005, 00Z) 134
Figure 8-18: 24-hour Precipitation Forecast from August 19, 2005, 12Z to August 20, 2005, 12Z by the NAM Model Initialized August 19, 2005, 12Z 135
Figure 8-19: Rainfall Accumulation (Harrow, Ontario Storm of July 19-20, 1989) 136
Figure 8-20: Surface Map (July 20, 1989, 00Z) 137
Figure 8-21: Tephigram Sounding at the Flint Airport Radiosonde Site (July 20, 1989, 00Z) 137
Figure 8-22: Surface Map (August 27, 1976, 18Z) 138
Figure 8-23: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 28, 1976, 00Z) 139
Figure 8-24: Total Rainfall Accumulation (August 27, 1976) 140
Figure 8-25: Surface Map (August 28, 1976, 18Z) 141
Figure 8-26: Total Rainfall Accumulation Map (August 28, 1976) 141

Tables

Table 3-1: Summary of Rainfall Gauge Stations 15
Table 4-1: Chronological List of Forecasts, Weather Warnings, Alerts, and Bulletins (July 16, 2024) 18
Table 4-2: TRCA's Assessment of Predicted Rainfall and Runoff Amounts on the Morning of July 16 47
Table 4-3: Number of Stations with Data on July 16, 2024 47
Table 4-4: Total Precipitation across the TRCA Watersheds (July 16, 2024) 49
Table 5-1: Chronological List of Forecasts, Weather Warnings, Alerts, and Bulletins (August 17, 2024) 56
Table 5-2: TRCA's Assessment of Predicted Rainfall and Runoff Amounts on the Morning of August 17 89
Table 5-3: Number of Station with Data on August 17, 2024 89
Table 5-4: Total Precipitation across the TRCA Watersheds (August 17, 2024) 91
Table 6-1: Precipitation at the IDF Stations during Both Events and Nearest High-resolution Stations 98
Table 7-1: Temperature and Humidity Measurements at TORONTO INTL A Station (Late Hours of July 15 and Early Hours of July 16, 2024) 109
Table 7-2: Temperature, Dew Temperature and Precipitation at SARNIA Station (July 16, 2024) 116
Table 8-1: Summary of Storm Comparison by Characteristics 143
Table 9-1: Extratropical Cyclones of Tropical Origin that Tracked within 150 km of the TRCA Region 146

Appendices

Appendix A. Data Completeness
- A.1 Rainfall
  - A.1.1 TRCA
  - A.1.2 ECCC
  - A.1.3 City of Toronto
  - A.1.4 City of Mississauga

Appendix B. Supplementary Material for Storms
- B.1 July 16, 2024
  - B.1.1 METAR – Toronto City Airport
  - B.1.2 METAR – Toronto Pearson Airport
  - B.1.3 Soundings
  - B.1.4 Radar Images
- B.2 August 17, 2024
  - B.2.1 METAR – Toronto City Airport
  - B.2.2 METAR – Toronto Pearson Airport
  - B.2.3 Radar Images

Appendix C. Numerical Forecast
- C.1 July 16, 2024
  - C.1.1 HRRR Model
- C.2 August 17, 2024
  - C.2.1 NAM12 Model

Appendix D. Cumulative Event-day Precipitation
- D.1 July 16, 2024
  - D.1.1 TRCA
  - D.1.2 ECCC
  - D.1.3 City of Toronto
  - D.1.4 City of Mississauga
- D.2 August 17, 2024
  - D.2.1 TRCA
  - D.2.2 ECCC
  - D.2.3 City of Toronto
  - D.2.4 City of Mississauga

Appendix E. Data for IDF curves
- E.1 TORONTO CITY
- E.2 TORONTO INTL A

Appendix F. Storm Comparison
- F.1 August 4, 2014
  - F.1.1 Weather Maps
  - F.1.2 Radar Images
  - F.1.3 Model Precipitation Maps
- F.2 July 8, 2013
  - F.2.1 Weather Maps
  - F.2.2 Tephigram Soundings
  - F.2.3 Radar Images
  - F.2.4 Model Precipitation Maps
- F.3 August 4, 2009
  - F.3.1 Weather Maps
  - F.3.2 Radar Images
  - F.3.3 Model Precipitation Maps
- F.4 August 19, 2005

F.4.1 Weather Maps
F.4.2 Radar Images
F.4.3 Model Precipitation Maps
F.5 July 19-20, 1989
F.5.1 Weather maps
F.6 August 27-28, 1976
F.6.1 Tephigram Soundings
F.6.2 Radar Images

Acronyms, Terms and/or Abbreviations

CAPE	Convective Available Potential Energy
CYTZ	Airport code for Billy Bishop Toronto City Airport
CYYZ	Airport code for Toronto Pearson International Airport
DPQPE	Dual Polarization Quantitative Precipitation Estimation
ECCC	Environment and Climate Change Canada
EL	Equilibrium Level
GIS	Geographic Information System
GTA	Greater Toronto Area
hPa	Hectopascal
IDF	Intensity-Duration-Frequency
IDW	Inverse Distance Weighting
LBF	Lake Breeze Front
LCL	Lifting Condensation Level
LFC	Level of Free Convection
MCS	Mesoscale Convective System
MCV	Mesoscale Convective Vortex
METAR	Meteorological Terminal Aviation Routine Weather Reports
MSC	Meteorological Service of Canada
MSL	Mean Sea Level
NAM	North American Mesoscale (with a 12 km spatial resolution)
NOAA	National Oceanic and Atmospheric Administration
OSPC	Ontario Storm Prediction Centre
RH	Relative Humidity
T	Temperature
T_d	Dew point Temperature
TRCA	Toronto and Region Conservation Authority
UHI	Urban Heat Island
UTC	Coordinated Universal Time
Z	Zulu
Γ_d	Lapse rate for dry adiabatic ascent
Γ_{dew}	Lapse rate for moist adiabatic ascent

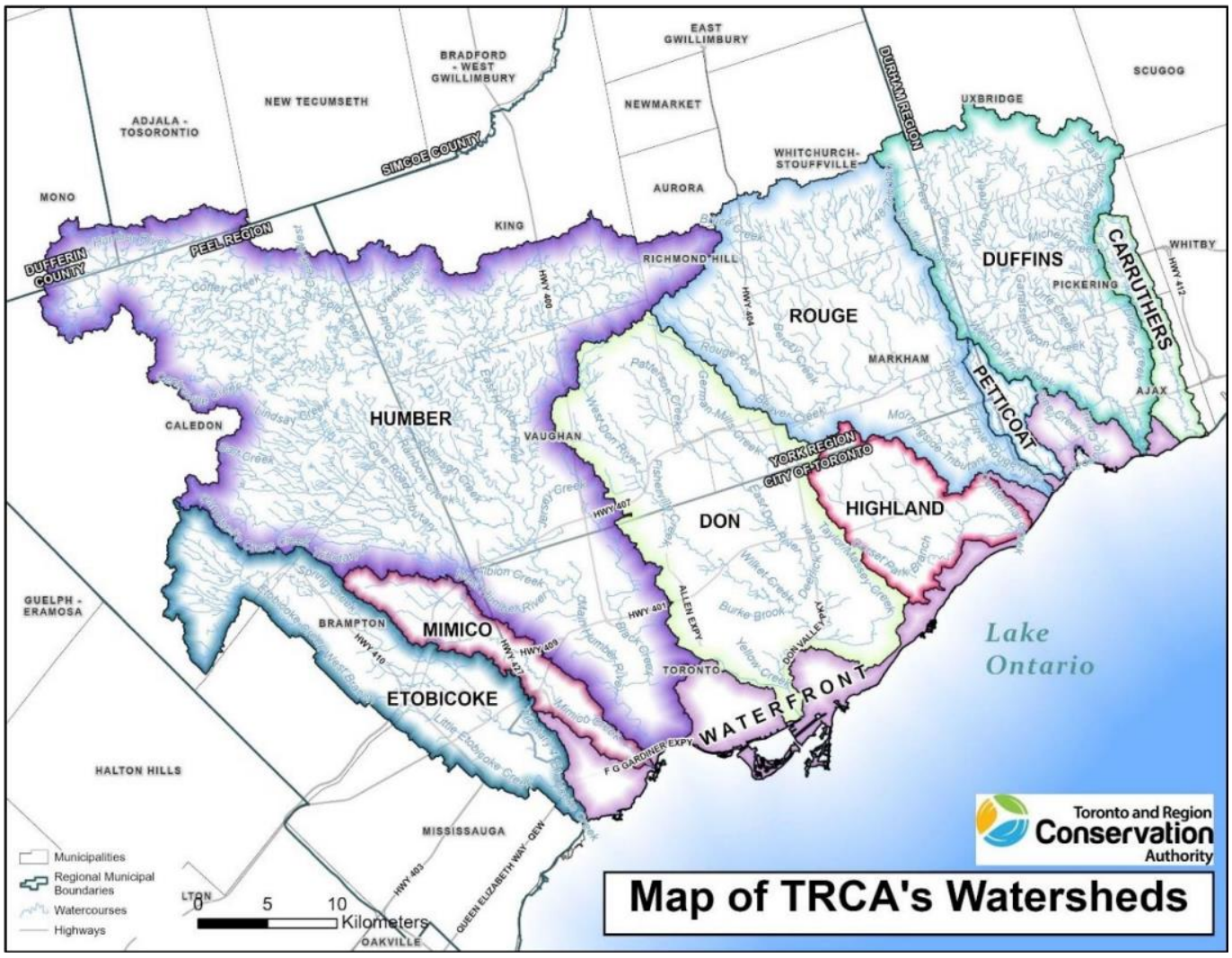
METAR code

BR	Mist
M	No observation (missing)
RA	Rain
SH	Showers
TS	Thunderstorm
VC	In the vicinity
-	Light intensity
+	Heavy intensity

1. Introduction

1.1 Toronto and Region Conservation Authority

Since its establishment in 1946, the Toronto and Region Conservation Authority (TRCA) has been dedicated to safeguarding the natural environment and resources of the Toronto region, home to nearly five million residents (TRCA, 2025a). Governed by the Conservation Authorities Act since 1957, TRCA plays a pivotal role in mitigating natural hazards and protecting infrastructure to ensure public health and safety (TRCA, 2024a). This responsibility includes safeguarding people and property within its jurisdiction, which spans several significant waterways such as Carruthers Creek, Don River, Duffins Creek, Etobicoke Creek, Highland Creek, Humber River, Mimico Creek, Petticoat Creek, and Rouge River (Figure 1-1). These efforts are vital for maintaining the ecological integrity and safety of these areas for the community.



Source: TRCA, 2024b

Figure 1-1: Map of the Nine Watersheds in TRCA's Jurisdiction

Under the Conservation Authorities Act, TRCA provides strategic guidance to ensure the health of watersheds and waterways. Rainfall accumulation, a critical component of water resource management, necessitates that TRCA analyze extreme rainfall events that significantly impact the region (TRCA, 2024b). The frequency and intensity of these events have increased substantially since the pre-industrial era, a trend expected to continue through the end of the century (Mladjic, et al. 2011; Vasseur et al., 2017, Zhang et al., 2019). Consequently, a thorough understanding of the weather context and critical elements of past extreme precipitation events is essential for anticipating future

occurrences. To address these challenges, TRCA may employ such analyses to develop adaptation strategies and infrastructure mitigation measures, ensuring preparedness for future rainfall events.

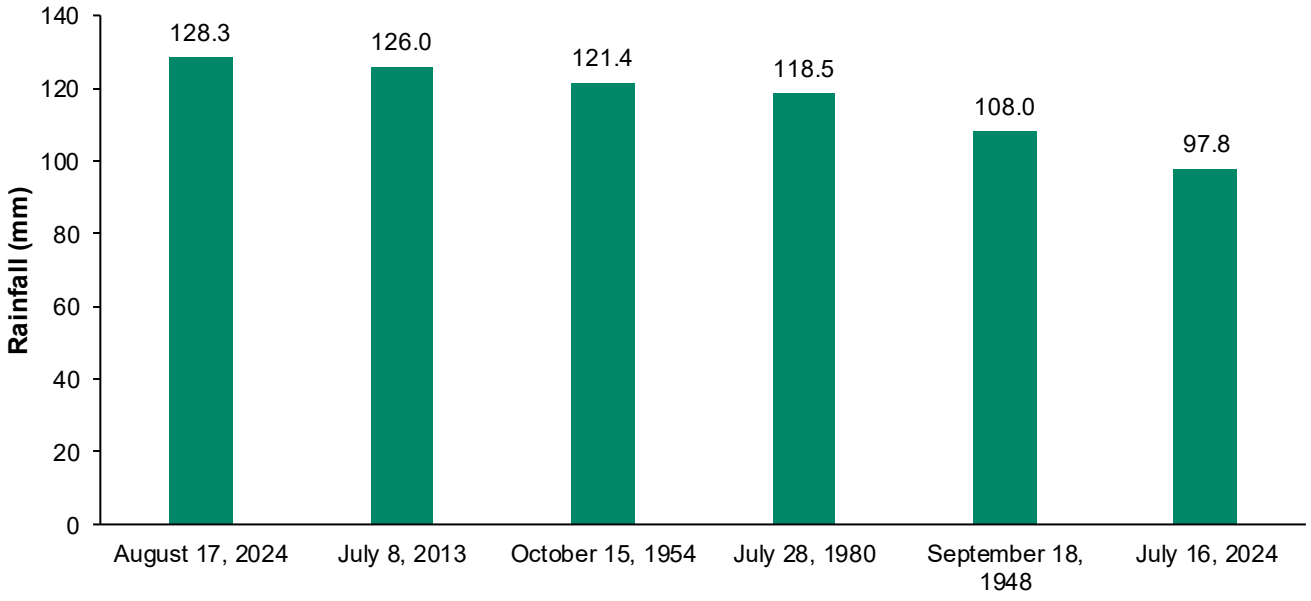
Additionally, TRCA's mandate includes protecting the safety of people and property, which are increasingly vulnerable during extreme rainfall events that can lead to flooding. The rising frequency of such flooding and extreme precipitation events has made them Ontario's leading cause of public emergencies (TRCA, 2024b). To mitigate these risks, TRCA operates a Flood Forecasting and Warning Program as part of the mandated programs and services under the Conservation Authorities Act, which monitors weather and watershed conditions for flood risks within its jurisdiction. These initiatives underscore TRCA's commitment to proactive and comprehensive hazard management, ensuring the resilience and safety of the Toronto region.

1.2 Rainfall in Summer of 2024

Over the course of the summer (June, July, August) 2024, the Greater Toronto Area (GTA) received over 510 mm of precipitation surpassing the previous record set in 2008 by over 100 mm, measured at the Pearson International Airport meteorological station, (Environment and Climate Change Canada (ECCC), 2025a, D'Andrea, 2024). According to the ECCC records, over half of the precipitation fell on three days:

- June 20: 50.8 mm
- July 16: 97.8 mm
- August 17: 128.3 mm

The event on August 17 brought 186% of the average August rainfall and broke the previous record for daily extreme rainfall. The event on July 16 also surpassed the monthly average rainfall by about 30% and brought the sixth highest rainfall amount measured at Pearson International Airport (Figure 1-2).



Source: Weather Network 2024; ECCC, 2025a

Figure 1-2: Daily Rainfall Totals in Toronto (Pearson Airport)

Both events led to major flooding across the GTA due to extreme rainfall accumulation. Across Toronto and Mississauga, several highways (e.g., 400, 401, 403, 404) and the Don Valley Parkway were flooded leading to dozens of stranded vehicles and numerous water rescues (Figure 1-3). In addition to flooded roads, parks, and buildings, the underground transit system was also flooded, requiring the rescue and relocation of people. Especially during the July 16 event, the GTA experienced significant power outages that lasted for hours. On August 17, Pearson International Airport was particularly impacted by grounded flights and substantial delays. The two events combined resulted in over $1 billion of insured damages for the GTA and southern Ontario as estimated by Catastrophe Indices and Quantification Inc. (Government of Canada, 2025).



Source: Oakville News, 2024

Figure 1-3: Flooded Don Valley Parkway on July 16, 2024

2. Methodology

2.1 Analysis of Station Data

Data from a network of gauge stations (Section 3.1) with time resolutions of 5-minutes or one hour were used to create a spatial dataset of total rainfall, rainfall duration, and rainfall intensity at each station during the days of the July 16, 2024 and August 17, 2024 storms. Total rainfall (Sections 4.2.1 and 5.2.1) was calculated by adding the measured precipitation during the sub-daily time intervals during the days of the events. Rainfall duration (Sections 4.2.2 and 5.2.2) was calculated by adding the length of all the 5-minute time intervals with precipitation larger than zero during the days of the events, excluding the hourly data to avoid its high uncertainty. The average rainfall intensity (Sections 4.2.3 and 5.2.3) was calculated by dividing total rainfall by rainfall duration, for stations where both are available. The maximum intensities for different rainfall durations (5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours, 6 hours, 12 hours and 24 hours) were calculated by adding 5-minute values through a moving window of the respective duration and selecting the maximum among all possible positions of the window (Sections 4.2.3 and 5.2.3).

Gaps in station data were identified and addressed to ensure the quality of the analysis. In the case of gauge stations, stations with less than 95% available data were dismissed from the analysis as precipitation is a discontinuous variable whose instant values cannot be straightforwardly derived (Section 3.1).

2.2 Manipulation of Spatial Data

The Geographic Information System (GIS) software QGIS is used to manipulate spatial data for the assessment of precipitation data in the TRCA jurisdiction during the July 16, 2024 and August 17, 2024 storms (Sections 4.2 and 5.2).

2.2.1 Generation of Gridded Data

To generate a spatial distribution from scattered data points, the QGIS “rasterize” algorithm is first used to generate an empty raster (a grid of cells/pixels) and fill the cells where the data points are located. Subsequently, the “Fill NoData” algorithm is used to fill-in the empty cells. This algorithm uses Inverse Distance Weighting (IDW) interpolation to estimate the value of the empty pixel based on surrounding pixels with data and then applies smoothing iterations to reduce artifacts. The distance from which data pixels can be used to fill an empty pixel and the number of smoothing iterations is controlled by the user and was set to the recommended values of 100-pixel distance and 3 smoothing iterations. The IDW interpolations was tested and compared against other interpolation techniques on a similar dataset in 2014 and was found to be the best performing method (AMEC, 2014).

2.2.2 Isolines

QGIS was used to create isolines (lines connecting points of equal numerical value in a spatial distribution) from gridded data, using the QGIS “contour” algorithm. This algorithm uses linear interpolation between grid cell values to determine the spatial location of the isolines, for specific values given by the user. The isoline intervals were chosen to facilitate the reading of the gradients in the maps, for which the spatial separation between isolines has to be large enough to avoid cluttering, but low enough to allow an intuitive perception of the gradients. The algorithm was used to calculate the following isolines:

- Isohyets: Lines of equal precipitation, applied to the total precipitation during the storms of July 16, 2024 and of August 17, 2024. Lines were calculated at intervals of 10 mm.
- Duration isolines: Lines of equal duration, applied to the duration of precipitation during the storms of July 16, 2024 and of August 17, 2024. Lines were calculated at intervals of 30 min.
- Intensity isolines: Lines of equal rainfall intensity/rate, applied to the intensity of precipitation during the storms of July 16, 2024 and of August 17, 2024. Lines were calculated at intervals of 5 mm/h.

- Contour lines: Lines of equal elevation, applied to the elevation map of the Ontario Peninsula. Lines were calculated at intervals of 50 m, and additionally to define the contours of Lake Ontario at 73 m and of Lake Huron and Lake Erie at 175 m.

2.2.3 Integration of Gridded Data

Gridded data for the total precipitation during the days of the storms was integrated over the watersheds under the TRCA jurisdiction. This was done using R software with the "sf" and "terra" packages to manipulate spatial data. The pixels / grid cells of the gridded data were compared to the outline of the watersheds to determine the fraction of area of the pixel within each watershed. Then, the total precipitation for the pixel was multiplied by the area of the pixel within each watershed and added to the total precipitation for the respective watershed.

2.3 Heat Island Model

The microclimate simulations of the Urban Heat Island (UHI) effect presented in this study (Section 7.1) were conducted using Ladybug Tools, an open-source suite of environmental modeling plugins developed for use within the Grasshopper parametric design environment in Rhinoceros 3D. The Ladybug Tools gives the ability to integrate climate data with three-dimensional models to simulate urban environmental conditions across spatial and temporal scales. Rhino-Grasshopper environment allows precise 3D modeling of building geometry, surface materials, and vegetations that directly influence microclimate conditions. The tool facilitates hourly simulation of the thermal performance of different geometry configurations, allowing for a fine-scale assessment of microclimate variation within the urban landscape. In addition, the integration of the tool with other Grasshopper Tool, enables further expansion of simulation into building energy modeling and large-scale urban analyses.

Several studies have evaluated the reliability of Ladybug Tools for analyzing urban microclimates and the environment. Its daylight and solar radiation modeling function have been evaluated against empirical measurements and standardized benchmarks (Ibrahim et al., 2020). Modifications to its microclimate workflow have also contributed to improved accuracy and applicability in outdoor thermal comfort assessment at the urban scale (Kavari, 2020; Aguilar-Carrasco et al., 2023).

In this study, Ladybug Tools was used to simulate hourly outdoor air temperature across two land use models in Mississauga, under identical weather conditions, to quantify the intensity of the UHI effect over a six-day period for both July and August 2024. The simulation was applied to three different 3D domains:

- Vegetated rural area in Mississauga in about 1958,
- Transition period of 1976, and
- Built-up industrial area as it is today.

2.4 Climate Projections

Climate change impacts on the TRCA jurisdiction were researched using a bibliographical approach (Section 9). Numerous reports and scientific articles were analyzed to obtain a comprehensive picture of potential future climate change across the TRCA jurisdiction obtained from various climate projections. Temperature and precipitation averages, as well as extreme events of precipitation, hurricanes, extratropical cyclones, and thunderstorms, were the main focus of this bibliographical research.

2.5 Intensity-Duration-Frequency Updates

New Intensity-Duration-Frequency (IDF) curves that incorporate the 2024 data were created (Section 6) following ECCC's methodology for IDF curve analyses (ECCC, 2025d). The Gumbel distribution (method of moments) was applied to annual datasets of maximum rainfall amounts for different durations (i.e., 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours, 6 hours, 12 hours, and 24 hours) to calculate the IDF curves. The corresponding data for 2024 was calculated from the July 16, 2024 and August 17, 2024 storms and added to this dataset to updated IDF curves.

The IDF curves were updated at two locations within the TRCA jurisdiction: Toronto City and Toronto Pearson International Airport. These two locations were chosen based on their relevancy, as they are located in the area most affected by the 2024 storms and are still active. Other available IDF curves in the TRCA jurisdiction from stations have been discontinued and were excluded from this analysis.

3. Background Information

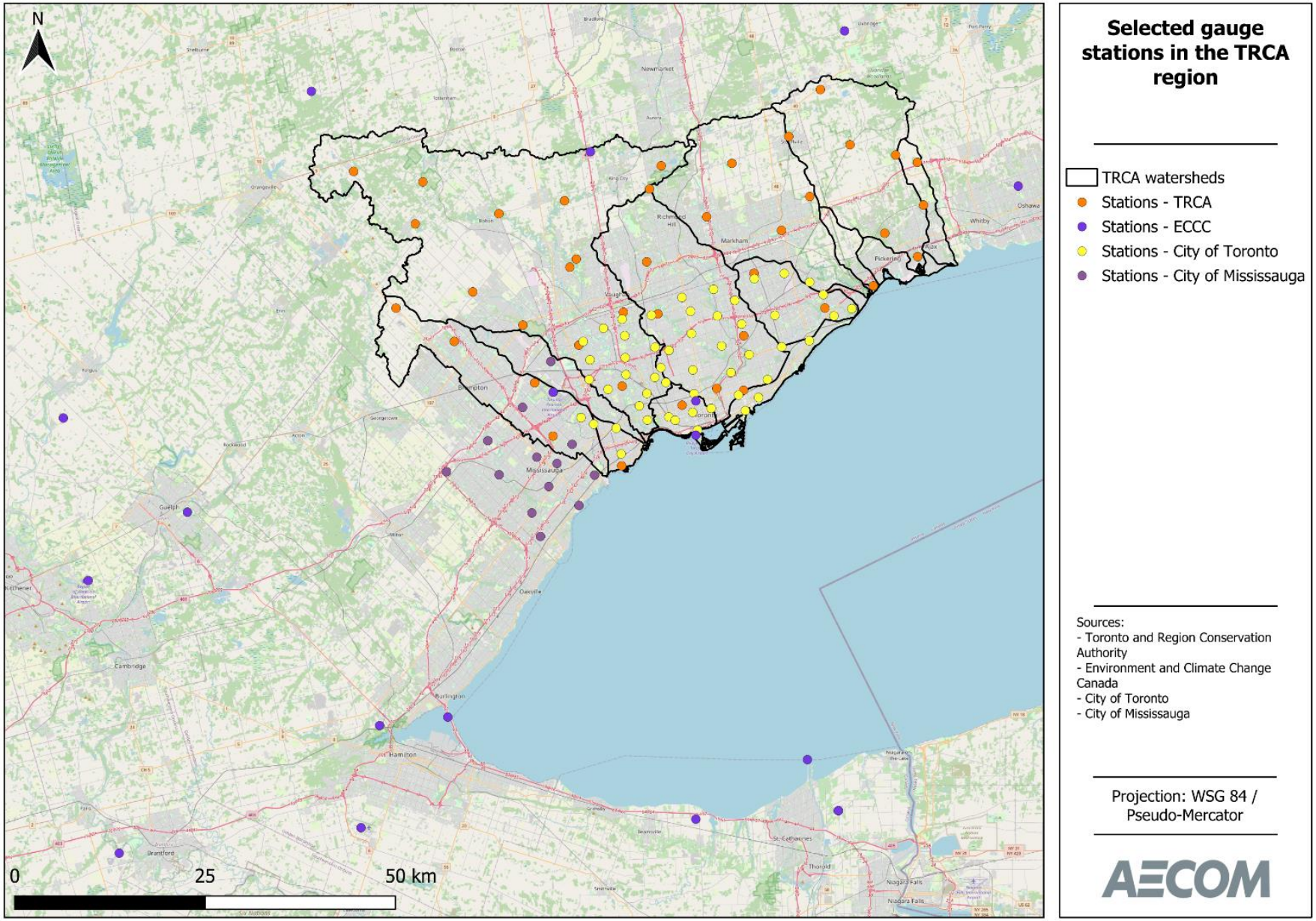
3.1 Rainfall

Rainfall data has been retrieved from rain gauges provided by TRCA, ECCC, City of Toronto, and City of Mississauga. The data provider, their number of stations and time interval of the rainfall measurements are presented in Table 3-1.

Table 3-1: Summary of Rainfall Gauge Stations

Provider	Number of Gauges	Time Interval
TRCA	40	5 minutes
ECCC	18	1 hour
City of Toronto	52	5 minutes
City of Mississauga	13	5 minutes
Total	123	-

The selected gauge stations are shown in Figure 3-1. The gauge stations were selected with the aim of providing a spatial assessment of the precipitation totals on the days of the July 16 and August 17, 2024 events in the TRCA region. As discussed in Section 2.2.1, this assessment requires the spatial interpolation between the available data points to fill the gaps in between. The high density of stations in the TRCA region (mainly from TRCA and City of Toronto) allows for a reliable assessment of precipitation in the centre of the region, while the stations outside the region (from ECCC and City of Mississauga) allow the spatial analysis to be extended to the periphery of the TRCA region.



Note: Only stations with data completeness above 95% were selected.

Figure 3-1: Selected Precipitation Gauge Stations in the TRCA Region

A quality control process was performed on the gauge stations to determine the completeness or percentage of available observations during the days of the July 16, 2024 and August 17, 2024 storms (Appendix A). Data with completeness below 95% were dismissed. In the case of ECCC station data, hourly and daily data can be available for the same station, therefore in those stations without available hourly data, the daily data was used to create a spatial dataset of total precipitation during the days of the storm events. For the calculation of rainfall duration, the ECCC data was excluded as their coarse temporal resolution of hourly or daily data frequency introduces a bias when the results are compared to the 5-minute data of all other datasets.

3.2 Modelling

In support of increasing the understanding of influence factors on the pathway, intensity, and duration of the storms modelling efforts were undertaking. These efforts include heat island modelling using the Ladybug Tool.

3.3 Mapping

The software QGIS was used to create the maps shown in this report. A street map from the OpenStreetMap Foundation (OpenStreetMap contributors, 2025) was used to provide the base reference map on which to add the map features. A surface elevation map from NASA (NASA Shuttle Radar Topography Mission (SRTM), 2013) with a spatial resolution of 30 m was used to create topographical gradients and contour lines.

For the heat island analysis and the visual representation of rainfall distribution several GIS layers have been provided including:

- TRCA watersheds and sub-watersheds
- TRCA watercourses
- Highways and major roads in the study area
- Building footprint
- Aerial photography

3.4 Reports

The analysis includes the review of reports for major historic storm events that have impacted the GTA and Southern Ontario. The methodologies, storm characteristics, and consequence profiles have been compared. The storm reports include:

- August 4, 2014 Storm Event, Burlington, Conservation Halton, 2015
- July 8, 2013, Extreme Rainfall Event, Summary and Analysis Report, TRCA, 2014
- Cooksville Creek – August 2009 Flooding, Credit Valley Conservation, 2010
- Summary of Rainfall Analysis Completed for the August 19th, 2005 Storm Event, TRCA, 2006
- Harrow Storm and Flood Study, Ministry of Natural Resources, 1990
- The Storms of August 27 and 28, 1976 and Subsequent Flooding on the Highland Creek, Metropolitan Toronto and Region Conservation Authority, 1977

4. Extreme Rainfall of July 16, 2024

4.1 Storm Overview

In this section, the preceding weather conditions and the formation and development of the storm that led to the extreme rainfall event on July 16, 2024, over the GTA are discussed. First, to provide a comprehensive understanding, the meteorological context leading up to the storm was examined. This includes an analysis of the chronology of events using flood messages issued by the TRCA and severe weather forecasts from the Meteorological Service of Canada (MSC) of ECCC. Thereafter, multiparameter weather maps, radar imagery, tephigram soundings, surface observations, and past forecasts were analyzed. This analysis aims to provide a deeper understanding of the storm's development and the extreme weather conditions it caused, which were only briefly addressed in the public weather warnings and bulletins.

4.1.1 Chronology of the Event

Based on radar imagery and severe weather warnings, the onset of rainfall can be traced back to July 16 at 8:42 AM on the far western side of the TRCA jurisdiction, specifically in the City of Brampton. The storm lasted slightly over four hours, concluding at 1:54 PM over the eastern part of the TRCA jurisdiction. Although the most intense part of the storm occurred between 9:48 AM and 10:36 AM, the damage was long-lasting as flash flooding ensued shortly thereafter.

4.1.1.1 METAR

The chronology of the event can be effectively reconstructed using Meteorological Terminal Aviation Routine Weather Reports (METAR), which are provided by most airports. These observation reports include hourly codes and annotations that facilitate the sharing of weather data, particularly for the aviation industry to inform nearby pilots of prevailing weather conditions. METAR reports relay information on temperature, pressure, wind, visibility, cloud coverage, and present weather phenomena. Pearson International Airport (CYYZ) reported thunderstorms on July 16, 2024 at 8:43 AM, while the Toronto City Centre Airport (CYTZ) first reported thunderstorms in the vicinity at 9:01 AM, indicating the observation of nearby thunderstorms. Four minutes later, the METAR reported thunderstorms, followed by thunderstorms with light rainfall at 9:08 AM, and thunderstorms with heavy rainfall observed from 9:16 AM to 9:34 AM. Rainfall intensity then decreased to light until 10:00 AM, before increasing again between 10:09 AM and 10:30 AM. Subsequently, the thunderstorm dissipated, leaving behind primarily rainfall and mist until 1:00 PM (Appendices B.1.1 and B.1.2).

4.1.1.2 Warnings and Bulletins

The chronology of the event can further be described by reviewing the publicly available information from the day leading up to and of the event. To provide this perspective, severe weather warnings and bulletins issued by the MSC, along with flood warnings by TRCA were utilized (Table 4-1). TRCA's Flood Forecasting and Warning Program, issues flood messages to local agencies and the public, based on continuous monitoring of weather conditions and flood forecasts.

Table 4-1: Chronological List of Forecasts, Weather Warnings, Alerts, and Bulletins (July 16, 2024)

Date and Time	Type	Description
Monday, July 15, 2024, 5:00 AM	Public forecasts issued by Environment Canada	CITY OF TORONTO. TUESDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. BECOMING A MIX OF SUN AND CLOUD IN THE AFTERNOON. RISK OF A THUNDERSTORM IN THE MORNING. WIND BECOMING SOUTHWEST 20 KM/H GUSTING TO 40 NEAR NOON. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH. MISSISSAUGA - BRAMPTON. TUESDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. BECOMING A MIX OF SUN AND CLOUD IN THE

Date and Time	Type	Description
		AFTERNOON. RISK OF A THUNDERSTORM IN THE MORNING. WIND BECOMING WEST 20 KM/H GUSTING TO 40 IN THE MORNING. HIGH 29. HUMIDEX 34. UV INDEX 7 OR HIGH. CALEDON. TUESDAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING WITH RISK OF A THUNDERSTORM. WIND BECOMING WEST 30 KM/H GUSTING TO 50 IN THE MORNING. HIGH 29. HUMIDEX 34. UV INDEX 7 OR HIGH. VAUGHAN - RICHMOND HILL - MARKHAM. TUESDAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING WITH RISK OF A THUNDERSTORM. WIND SOUTHWEST 20 KM/H GUSTING TO 40. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH. PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TUESDAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING WITH RISK OF A THUNDERSTORM. WIND BECOMING SOUTHWEST 30 KM/H GUSTING TO 50 NEAR NOON. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH.
Monday, July 15, 2024, 11:00 AM	Public forecasts issued by Environment Canada	CITY OF TORONTO. TUESDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. BECOMING A MIX OF SUN AND CLOUD IN THE AFTERNOON. RISK OF A THUNDERSTORM IN THE MORNING. WIND BECOMING SOUTHWEST 20 KM/H GUSTING TO 40 NEAR NOON. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH. MISSISSAUGA - BRAMPTON. TUESDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. BECOMING A MIX OF SUN AND CLOUD IN THE AFTERNOON. RISK OF A THUNDERSTORM IN THE MORNING. WIND BECOMING WEST 20 KM/H GUSTING TO 40 IN THE MORNING. HIGH 29. HUMIDEX 34. UV INDEX 7 OR HIGH. CALEDON. TUESDAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING WITH RISK OF A THUNDERSTORM. WIND BECOMING WEST 30 KM/H GUSTING TO 50 IN THE MORNING. HIGH 29. HUMIDEX 34. UV INDEX 7 OR HIGH. VAUGHAN - RICHMOND HILL - MARKHAM. TUESDAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING WITH RISK OF A THUNDERSTORM. WIND SOUTHWEST 20 KM/H GUSTING TO 40. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH. PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TUESDAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING WITH RISK OF A THUNDERSTORM. WIND BECOMING SOUTHWEST 30 KM/H GUSTING TO 50 NEAR NOON. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH.
Monday, July 15, 2024, 11:25 AM	TRCA Flood Message Issuance: Watershed Conditions Statement – Water Safety	TRCA issued Watershed Conditions Statement for Water Safety, for thunderstorm activity for July 15. Water levels in most of TRCA watercourses are normal or slightly above normal.
Monday, July 15, 2024, 12:40 PM	Updated forecasts issued by Environment Canada	CITY OF TORONTO. TUESDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. BECOMING A MIX OF SUN AND CLOUD IN THE AFTERNOON. RISK OF A THUNDERSTORM IN THE MORNING. WIND

Date and Time	Type	Description
		BECOMING SOUTHWEST 20 KM/H GUSTING TO 40 NEAR NOON. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH. MISSISSAUGA - BRAMPTON. TUESDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. BECOMING A MIX OF SUN AND CLOUD IN THE AFTERNOON. RISK OF A THUNDERSTORM IN THE MORNING. WIND BECOMING WEST 20 KM/H GUSTING TO 40 IN THE MORNING. HIGH 29. HUMIDEX 34. UV INDEX 7 OR HIGH. VAUGHAN - RICHMOND HILL - MARKHAM. TUESDAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING WITH RISK OF A THUNDERSTORM. WIND SOUTHWEST 20 KM/H GUSTING TO 40. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH.
Monday, July 15, 2024, 12:52 PM	Updated forecasts issued by Environment Canada	CITY OF TORONTO. TUESDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. BECOMING A MIX OF SUN AND CLOUD IN THE AFTERNOON. RISK OF A THUNDERSTORM IN THE MORNING. WIND BECOMING SOUTHWEST 20 KM/H GUSTING TO 40 NEAR NOON. HIGH 29. HUMIDEX 36. UV INDEX 7 OR HIGH MISSISSAUGA - BRAMPTON. TUESDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. BECOMING A MIX OF SUN AND CLOUD IN THE AFTERNOON. RISK OF A THUNDERSTORM IN THE MORNING. WIND BECOMING WEST 20 KM/H GUSTING TO 40 IN THE MORNING. HIGH 29. HUMIDEX 34. UV INDEX 7 OR HIGH.
Monday, July 15, 2024, 3:30 PM	Public forecasts issued by Environment Canada	CITY OF TORONTO. TUESDAY..SHOWERS ENDING NEAR NOON THEN CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE MORNING. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTH 20 KM/H GUSTING TO 40 IN THE MORNING THEN BECOMING WEST 20 GUSTING TO 40 IN THE AFTERNOON. HIGH 29. HUMIDEX 38. UV INDEX 6 OR HIGH. TUESDAY NIGHT..PARTLY CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS EARLY IN THE EVENING THEN CLEAR. WIND WEST 20 KM/H GUSTING TO 40 BECOMING LIGHT AFTER MIDNIGHT. LOW 17. MISSISSAUGA - BRAMPTON. TUESDAY..SHOWERS ENDING LATE IN THE MORNING THEN MAINLY CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE MORNING. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 IN THE MORNING. HIGH 28. HUMIDEX 36. UV INDEX 7 OR HIGH. TUESDAY NIGHT..PARTLY CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS EARLY IN THE EVENING. OTHERWISE CLEAR. WIND WEST 20 KM/H GUSTING TO 40 BECOMING LIGHT IN THE EVENING. LOW 17. VAUGHAN - RICHMOND HILL - MARKHAM. TUESDAY..SHOWERS ENDING NEAR NOON THEN CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE MORNING. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 IN THE AFTERNOON. HIGH 28. HUMIDEX 37. UV INDEX 7 OR HIGH. TUESDAY NIGHT..PARTLY CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS EARLY IN THE EVENING THEN CLEAR. WIND WEST 20 KM/H GUSTING TO 40 BECOMING LIGHT IN THE EVENING. LOW 15.

Date and Time	Type	Description
		PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TUESDAY..SHOWERS ENDING NEAR NOON THEN CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE MORNING. LOCAL AMOUNT 10 TO 20 MM. WIND SOUTHWEST 20 KM/H GUSTING TO 40 BECOMING LIGHT LATE IN THE MORNING. WIND BECOMING WEST 20 GUSTING TO 40 IN THE AFTERNOON. HIGH 28. HUMIDEX 37. UV INDEX 7 OR HIGH. TUESDAY NIGHT..PARTLY CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS EARLY IN THE EVENING. CLEARING IN THE EVENING. WIND WEST 20 KM/H GUSTING TO 40 BECOMING LIGHT IN THE EVENING. LOW 15. CALEDON. TUESDAY..SHOWERS ENDING LATE IN THE MORNING THEN CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE MORNING. LOCAL AMOUNT 10 TO 20 MM. WIND SOUTHWEST 20 KM/H BECOMING LIGHT IN THE MORNING. WIND BECOMING WEST 30 GUSTING TO 50 LATE IN THE MORNING. HIGH 27. HUMIDEX 35. UV INDEX 7 OR HIGH. TUESDAY NIGHT..PARTLY CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS EARLY IN THE EVENING. CLEARING IN THE EVENING. WIND WEST 20 KM/H GUSTING TO 40 BECOMING LIGHT IN THE EVENING. LOW 15.
Tuesday, July 16, 2024, 5:00 AM	Public forecasts issued by Environment Canada	CITY OF TORONTO. TODAY..MAINLY CLOUDY. SHOWERS BEGINNING EARLY THIS MORNING AND ENDING THIS AFTERNOON THEN 40 PERCENT CHANCE OF SHOWERS LATER THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 15 TO 25 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 LATE THIS MORNING THEN LIGHT THIS AFTERNOON. HIGH 29. HUMIDEX 38. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 LATE THIS EVENING THEN LIGHT AFTER MIDNIGHT. LOW 19. MISSISSAUGA - BRAMPTON. TODAY..MAINLY CLOUDY. SHOWERS BEGINNING EARLY THIS MORNING AND ENDING THIS AFTERNOON THEN 30 PERCENT CHANCE OF SHOWERS LATER THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 15 TO 25 MM. WIND BECOMING SOUTHWEST 20 KM/H GUSTING TO 40 THIS AFTERNOON. HIGH 28. HUMIDEX 36. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. CLEARING BEFORE MORNING. WIND SOUTHWEST 20 KM/H GUSTING TO 40 BECOMING LIGHT AFTER MIDNIGHT. LOW 19. CALEDON. TODAY..MAINLY CLOUDY. SHOWERS BEGINNING EARLY THIS MORNING AND ENDING THIS AFTERNOON THEN 30 PERCENT CHANCE OF SHOWERS LATER THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 15 TO 25 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 LATE THIS MORNING. HIGH 27. HUMIDEX 35. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. CLEARING BEFORE MORNING. WIND BECOMING WEST 20 KM/H BEFORE MORNING. LOW 15. VAUGHAN - RICHMOND HILL - MARKHAM.

Date and Time	Type	Description
		TODAY..MAINLY CLOUDY. SHOWERS BEGINNING EARLY THIS MORNING AND ENDING THIS AFTERNOON THEN 40 PERCENT CHANCE OF SHOWERS LATER THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 15 TO 25 MM. WIND BECOMING SOUTHWEST 30 KM/H THIS AFTERNOON. HIGH 28. HUMIDEX 37. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND WEST 30 KM/H BECOMING LIGHT THIS EVENING. LOW 19. PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TODAY..MAINLY CLOUDY. SHOWERS BEGINNING EARLY THIS MORNING AND ENDING THIS AFTERNOON THEN 40 PERCENT CHANCE OF SHOWERS LATER THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 15 TO 25 MM. FOG PATCHES DISSIPATING THIS MORNING. WIND NORTHWEST 20 KM/H BECOMING SOUTHWEST 20 THIS AFTERNOON. HIGH 27. HUMIDEX 36. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. LOW 18.
Tuesday, July 16, 2024, 8:22 AM	Severe Thunderstorm Watch issued by Environment Canada for City of Toronto, Mississauga – Brampton, Caledon, York – Durham	HAZARDS: WIND GUSTS UP TO 90 KM/H. LOCAL RAINFALL AMOUNTS UP TO 50 MM POSSIBLE. UP TO NICKEL SIZE HAIL. TIMING: THIS MORNING INTO EARLY THIS AFTERNOON. DISCUSSION: THUNDERSTORMS ARE TRACKING EASTWARD OVER SOUTHERN ONTARIO AND MAY PRODUCE ISOLATED DAMAGING WIND GUSTS, TORRENTIAL DOWNPOURS AND LARGE HAIL. THE LINE IS CURRENTLY JUST WEST OF LAKE ONTARIO.
Tuesday, July 16, 2024, 8:43 AM	Updated forecasts issued by Environment Canada	MISSISSAUGA - BRAMPTON. TODAY..SHOWERS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND BECOMING SOUTHWEST 20 KM/H GUSTING TO 40 THIS AFTERNOON. HIGH 28. HUMIDEX 36. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. CLEARING BEFORE MORNING. WIND SOUTHWEST 20 KM/H GUSTING TO 40 BECOMING LIGHT AFTER MIDNIGHT. LOW 19. CALEDON. TODAY..SHOWERS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 15 TO 25 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 LATE THIS MORNING. HIGH 27. HUMIDEX 35. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. CLEARING BEFORE MORNING. WIND BECOMING WEST 20 KM/H BEFORE MORNING. LOW 15.
Tuesday, July 16, 2024, 8:53 AM	Updated forecasts issued by Environment Canada	CITY OF TORONTO. TODAY..SHOWERS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND

Date and Time	Type	Description
		BECOMING WEST 20 KM/H GUSTING TO 40 THEN LIGHT THIS AFTERNOON. HIGH 29. HUMIDEX 38. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 LATE THIS EVENING THEN LIGHT AFTER MIDNIGHT. LOW 19. MISSISSAUGA - BRAMPTON. TODAY..SHOWERS WITH THUNDERSTORMS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS AFTERNOON. LOCAL AMOUNT 20 TO 30 MM. WIND BECOMING SOUTHWEST 20 KM/H GUSTING TO 40 THIS AFTERNOON. HIGH 28. HUMIDEX 36. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. CLEARING BEFORE MORNING. WIND SOUTHWEST 20 KM/H GUSTING TO 40 BECOMING LIGHT AFTER MIDNIGHT. LOW 19. CALEDON. TODAY..SHOWERS WITH THUNDERSTORMS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS AFTERNOON. LOCAL AMOUNT 15 TO 25 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 LATE THIS MORNING. HIGH 27. HUMIDEX 35. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. CLEARING BEFORE MORNING. WIND BECOMING WEST 20 KM/H BEFORE MORNING. LOW 15. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..SHOWERS WITH THUNDERSTORMS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS AFTERNOON. LOCAL AMOUNT 15 TO 25 MM. WIND BECOMING SOUTHWEST 30 KM/H THIS AFTERNOON. HIGH 28. HUMIDEX 37. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND WEST 30 KM/H BECOMING LIGHT THIS EVENING. LOW 19.
Tuesday, July 16, 2024, 9:23 AM	TRCA Flood –Message Issuance: Flood Watch	TRCA issued Flood Watch, heads up for potential flooding and municipalities, emergency services, individual landowners in flood-prone areas should prepare.
Tuesday, July 16, 2024, 9:35 AM	Rainfall Warning issued by Environment Canada for City of Toronto, Halton – Peel, Vaughan – Richmond Hill - Markham	RAIN, AT TIMES HEAVY, CONTINUES. HAZARDS: RAINFALL AMOUNTS UP TO 75 MM. RAINFALL RATES OF 40 MM AN HOUR. TIMING: THIS MORNING. DISCUSSION: HEAVY RAIN IS EXPECTED THIS MORNING WITH SHOWERS AND THUNDERSTORMS. TOTAL RAINFALL AMOUNTS OF 50 TO 75 MM ARE POSSIBLE WITH RAINFALL RATES OF 40 MM WITHIN AN HOUR.

Date and Time	Type	Description
		HEAVY DOWNPOURS CAN CAUSE FLASH FLOODS AND WATER POOLING ON ROADS. LOCALIZED FLOODING IN LOW-LYING AREAS IS POSSIBLE. WATCH FOR POSSIBLE WASHOUTS NEAR RIVERS, CREEKS AND CULVERTS.
Tuesday, July 16, 2024, 9:52 AM	Updated forecasts issued by Environment Canada	CITY OF TORONTO. TODAY..SHOWERS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 50 TO 70 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 THEN LIGHT THIS AFTERNOON. HIGH 29. HUMIDEX 38. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 LATE THIS EVENING THEN LIGHT AFTER MIDNIGHT. LOW 19. MISSISSAUGA - BRAMPTON. TODAY..SHOWERS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 50 TO 70 MM. WIND BECOMING SOUTHWEST 20 KM/H GUSTING TO 40 THIS AFTERNOON. HIGH 28. HUMIDEX 36. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. CLEARING BEFORE MORNING. WIND SOUTHWEST 20 KM/H GUSTING TO 40 BECOMING LIGHT AFTER MIDNIGHT. LOW 19. CALEDON. TODAY..SHOWERS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 50 TO 70 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 LATE THIS MORNING. HIGH 27. HUMIDEX 35. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. CLEARING BEFORE MORNING. WIND BECOMING WEST 20 KM/H BEFORE MORNING. LOW 15. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..SHOWERS ENDING EARLY THIS AFTERNOON THEN A MIX OF SUN AND CLOUD WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 50 TO 70 MM. WIND BECOMING SOUTHWEST 30 KM/H THIS AFTERNOON. HIGH 28. HUMIDEX 37. UV INDEX 9 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND WEST 30 KM/H BECOMING LIGHT THIS EVENING. LOW 19.
Tuesday, July 16, 2024, 9:56 AM	Severe Thunderstorm Watch update issued by Environment Canada for City of Toronto, Mississauga – Brampton, Vaughan – Richmond Hill – Markham, Pickering – Oshawa – Southern Durham Region Severe Thunderstorm Watch end issued by Environment Canada for Caledon	CONDITIONS ARE FAVOURABLE FOR THE DEVELOPMENT OF DANGEROUS THUNDERSTORMS THAT MAY BE CAPABLE OF PRODUCING STRONG WIND GUSTS, LARGE HAIL AND TORRENTIAL RAIN. HAZARDS: WIND GUSTS UP TO 90 KM/H. LOCAL RAINFALL AMOUNTS UP TO 50 MM POSSIBLE. UP TO NICKEL SIZE HAIL. TIMING: THIS MORNING INTO EARLY THIS AFTERNOON.

Date and Time	Type	Description
		DISCUSSION: THUNDERSTORMS ARE TRACKING EASTWARD OVER SOUTHERN ONTARIO AND MAY PRODUCE ISOLATED DAMAGING WIND GUSTS, TORRENTIAL DOWNPOURS AND LARGE HAIL. THUNDERSTORMS WILL MOVE EAST OF THE AREA BY MID DAY, HOWEVER, THE THREAT OF HEAVY RAIN WILL PERSIST FOR MUCH OF THE DAY.
Tuesday, July 16, 2024, 10:43 AM	Rainfall Warning update issued by Environment Canada for City of Toronto, Halton – Peel, Vaughan – Richmond Hill - Markham	HEAVY RAIN IS EXPECTED, CONTINUES. HAZARDS: RAINFALL AMOUNTS UP TO 100 MM. RAINFALL RATES OF 40 MM AN HOUR. TIMING: THIS MORNING INTO EARLY THIS AFTERNOON. DISCUSSION: HEAVY RAIN IS EXPECTED THIS MORNING WITH SHOWERS AND THUNDERSTORMS. TOTAL RAINFALL AMOUNTS OF 100 MM ARE POSSIBLE WITH RAINFALL RATES OF 40 MM WITHIN AN HOUR. LOCALIZED FLOODING IN LOW-LYING AREAS IS POSSIBLE. ABANDON STALLED CARS IF WATER IS RISING RAPIDLY. DON'T APPROACH WASHOUTS NEAR RIVERS, CREEKS AND CULVERTS. KEEP CHILDREN AND PETS AWAY FROM CREEKS AND RIVER BANKS. CONSIDER MOVING VALUABLE ITEMS TO HIGHER LEVELS.
Tuesday, July 16, 2024, 10:46 AM	Rainfall Warning issued by Environment Canada for Pickering – Oshawa – Southern Durham Region	RAIN, AT TIMES HEAVY, IS EXPECTED. HAZARDS: RAINFALL AMOUNTS UP TO 50 MM. RAINFALL RATES OF 30 MM AN HOUR. TIMING: LATE THIS MORNING INTO EARLY THIS AFTERNOON. DISCUSSION: HEAVY RAIN IS EXPECTED WITH SHOWERS AND THUNDERSTORMS. TOTAL RAINFALL AMOUNTS NEAR 50 MM ARE POSSIBLE WITH RAINFALL RATES OF 30 MM WITHIN AN HOUR. HEAVY DOWNPOURS CAN CAUSE FLASH FLOODS AND WATER POOLING ON ROADS. LOCALIZED FLOODING IN LOW-LYING AREAS IS POSSIBLE. WATCH FOR POSSIBLE WASHOUTS NEAR RIVERS, CREEKS AND CULVERTS.
Tuesday, July 16, 2024, 10:48 AM	Severe Thunderstorm Watch end issued by Environment Canada for City of Toronto, Mississauga – Brampton, Caledon, York – Durham, Vaughan – Richmond Hill - Markham	
Tuesday, July 16, 2024, 11:00 AM	Public Forecasts by Environment Canada	CITY OF TORONTO. TODAY..SHOWERS AT TIMES HEAVY ENDING EARLY THIS AFTERNOON THEN MAINLY CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 80 TO 110 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 THIS AFTERNOON. HIGH 26. HUMIDEX 35. UV INDEX 8 OR VERY HIGH. TONIGHT. PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND SOUTHWEST 20 KM/H GUSTING TO 40 BECOMING LIGHT LATE THIS EVENING. LOW 19.

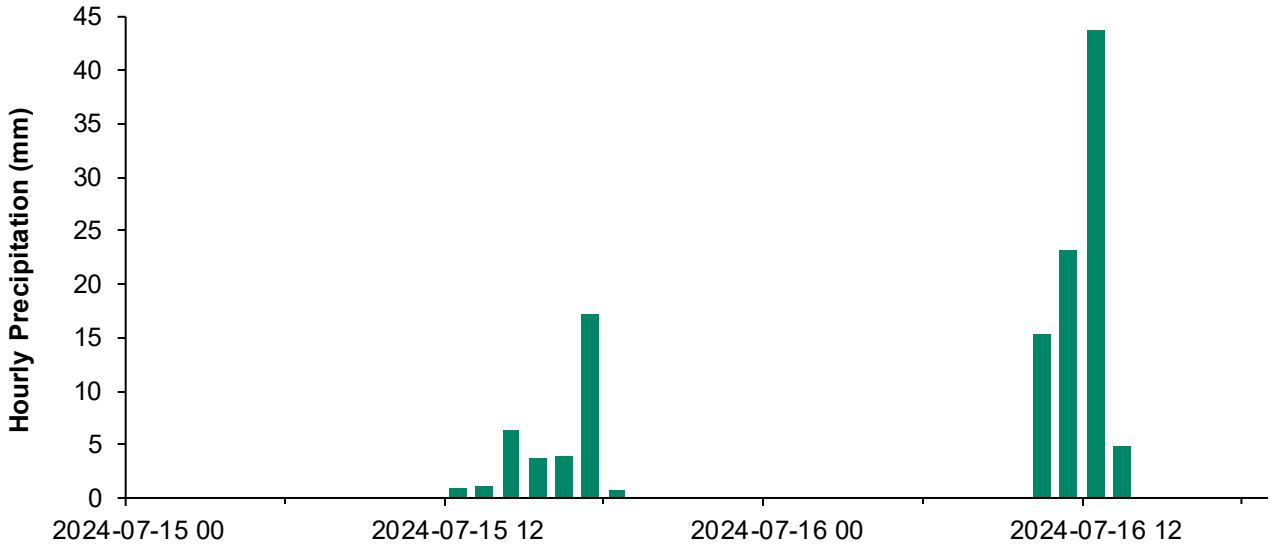
Date and Time	Type	Description
		MISSISSAUGA - BRAMPTON. TODAY..SHOWERS AT TIMES HEAVY ENDING EARLY THIS AFTERNOON THEN MAINLY CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. AMOUNT 80 TO 110 MM. WIND BECOMING WEST 30 KM/H GUSTING TO 50 THIS AFTERNOON. HIGH 26. HUMIDEX 34. UV INDEX 8 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND SOUTHWEST 20 KM/H GUSTING TO 40 BECOMING LIGHT THIS EVENING. LOW 19. CALEDON. TODAY..SHOWERS AT TIMES HEAVY ENDING EARLY THIS AFTERNOON THEN MAINLY CLOUDY WITH 30 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 50 TO 70 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 THIS AFTERNOON. HIGH 26. HUMIDEX 34. UV INDEX 8 OR VERY HIGH. TONIGHT..PARTLY CLOUDY. 30 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND WEST 20 KM/H GUSTING TO 40 BECOMING LIGHT THIS EVENING. LOW 15. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..SHOWERS AT TIMES HEAVY ENDING EARLY THIS AFTERNOON THEN MAINLY CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 80 TO 110 MM. WIND BECOMING WEST 20 KM/H GUSTING TO 40 THIS AFTERNOON. HIGH 26. HUMIDEX 35. UV INDEX 7 OR HIGH. TONIGHT..PARTLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. WIND WEST 20 KM/H BECOMING LIGHT THIS EVENING. LOW 19. PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TODAY..SHOWERS AT TIMES HEAVY ENDING EARLY THIS AFTERNOON THEN MAINLY CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM. LOCAL AMOUNT 50 MM. HIGH 27. HUMIDEX 36. UV INDEX 7 OR HIGH. TONIGHT..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS THIS EVENING AND AFTER MIDNIGHT WITH RISK OF A THUNDERSTORM. LOW 18.
Tuesday, July 16, 2024, 11:05 AM	Update to Rainfall Warning issued by Environment Canada for City of Toronto, Mississauga – Brampton, Vaughan – Richmond Hill - Markham	EXTREMELY HEAVY RAIN IS EXPECTED. THE GROUND, ALREADY NEAR SATURATION, HAS LITTLE ABILITY TO ABSORB FURTHER RAINFALL. HAZARDS: RAINFALL AMOUNTS UP TO 125 MM. RAINFALL RATES OF 40 MM AN HOUR. TIMING: THIS MORNING INTO EARLY THIS AFTERNOON. DISCUSSION: HEAVY RAIN CONTINUES WITH SHOWERS AND THUNDERSTORMS. TOTAL RAINFALL AMOUNTS OF UP TO 125 MM ARE POSSIBLE WITH RAINFALL RATES OF 40 MM WITHIN AN HOUR. THIS EXTREMELY HEAVY WILL GRADUALLY TAPER OVER THE NEXT FEW HOURS. ABANDON STALLED CARS IF WATER IS RISING RAPIDLY. RAPIDLY RISING RIVERS AND CREEKS CAN SWEEP AWAY BRIDGES, CULVERTS, BUILDINGS, AND PEOPLE. KEEP CHILDREN AND PETS

Date and Time	Type	Description
		AWAY FROM CREEKS AND RIVER BANKS. CONSIDER MOVING VALUABLE ITEMS TO HIGHER LEVELS.
Tuesday, July 16, 2024, 11:46 AM	Severe Thunderstorm Watch end issued by Environment Canada for Pickering – Oshawa – Southern Durham Region	CONDITIONS ARE NO LONGER FAVOURABLE FOR THE DEVELOPMENT OF SEVERE THUNDERSTORMS.
Tuesday, July 16, 2024, 11:52 AM	TRCA Flood Message Issuance – Flood Warning	TRCA issued Flood Warning, TRCA watersheds have received up to 60 mm since this morning. Water levels in the lower portion of TRCA watercourses are running very high and the water levels in the remaining watercourses are rising as well.
Tuesday, July 16, 2024, 12:50 PM	Rainfall Warning end issued by Environment Canada for Caledon	
Tuesday, July 16, 2024, 12:57 PM	Rainfall Warning end issued by Environment Canada for Mississauga – Brampton	
Tuesday, July 16, 2024, 1:34 PM	Rainfall Warning end issued by Environment Canada for City of Toronto, Vaughan – Richmond Hill - Markham	SIGNIFICANT RAINFALL IS NO LONGER EXPECTED.
Tuesday, July 16, 2024, 2:31 PM	Rainfall Warning end issued by Environment Canada for Pickering – Oshawa – Southern Durham Region	
Tuesday, July 16, 2024, 11:05 PM	TRCA Flood Message Issuance – Cancellation of Flood Warning	TRCA cancelled Flood Warning and downgraded to Watershed Conditions Statement – Water Safety, TRCA rain gauges have recorded 8 to 105 mm of rainfall from this morning to the afternoon within TRCA's jurisdiction.

Source: TRCA, 2025b; ECCC, 2025b

4.1.1.3 Meteograms

Meteograms illustrate observational data of various meteorological variables, including temperature, pressure, precipitation accumulation, and cloud fraction, plotted against time on bi-axis graphs. These visual tools are instrumental in analyzing the storm's progression retrospectively. For July 16, 2024, the meteograms provide a detailed temporal depiction of weather conditions before, during, and after the storm. The hourly precipitation accumulation is particularly significant in identifying the timing of the most intense precipitation rates. At the Toronto City Centre weather station, the meteogram shows an onset of precipitation between 9 and 10 AM, a subsequent intensification until 12 PM before the rainfall lessens and stops between 12 and 1 PM (Figure 4-1). The meteogram also shows precipitation on July 15 leading to high soil moisture content limiting its ability to absorb additional precipitation on July 16.



Source: Meteostat, 2025

Figure 4-1: Total Precipitation Meteogram at Toronto City Centre (CYTZ; July 15-16, 2024)

However, Toronto City Centre station did not record the highest rainfall during the event. TRCA operates numerous local stream and rain gauge stations to monitor water levels and precipitation accumulations. This monitoring is integral to their responsibility of gathering data related to hydrological conditions and providing critical insights into potential flooding scenarios. On July 16, 2024, the Rathwood station recorded the highest rainfall within the TRCA jurisdiction, totaling 101.5 mm (Figure 4-2). The most intense rainfall episodes occurred between 10 AM and 12 PM, leading to fast accumulation. The blue bars represent precipitation at 5-minute intervals, while the red shading indicates the cumulative rainfall accumulation.

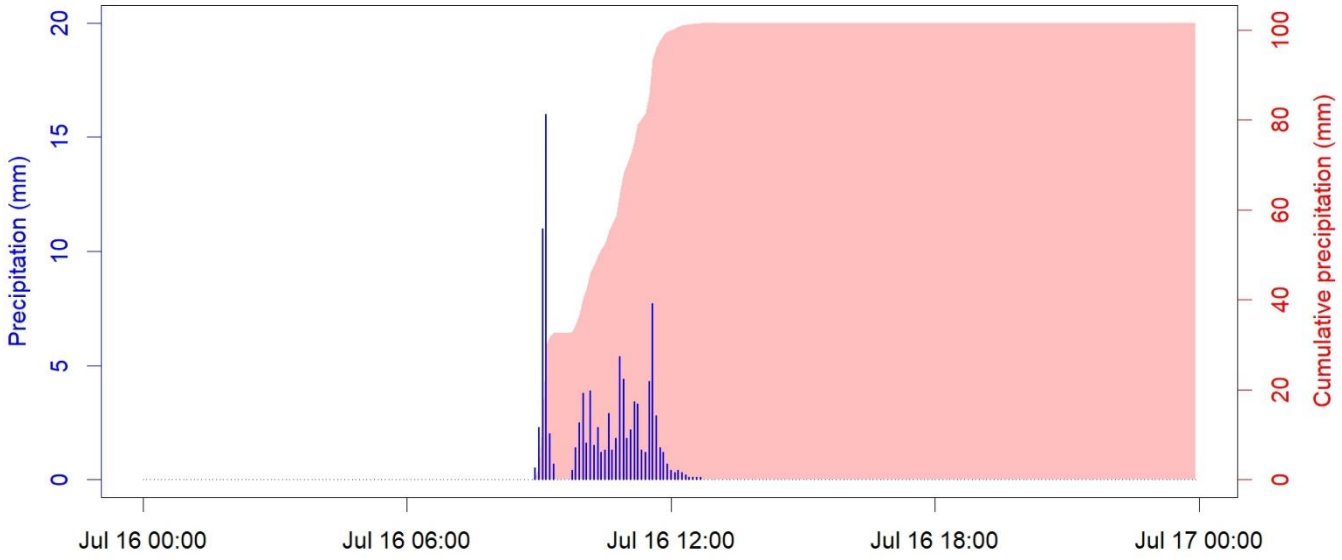


Figure 4-2: Total Precipitation Meteogram at Rathwood station (July 16, 2024)

4.1.2 Atmospheric Context

The atmospheric conditions preceding the extreme rainfall event, which contributed to its magnitude and significant impact on the GTA, were analyzed. This objective was achieved by leveraging a variety of observational tools, including reanalysis maps, soundings, and observational data. The evolution of weather variables leading up to the

storm's passage was examined. The analysis was structured by categorizing weather products into distinct types, such as upper-level maps, low-level maps, tephigram soundings, and radar and satellite imagery.

To account for the fact that meteorological phenomena often span more than one time zone, time stamps of meteorological data products are typically expressed uniformly. Either Zulu (Z) or Coordinated Universal Time (UTC) is used to streamline the sharing of weather forecasts and reanalysis data across time zones and international boundaries. Eastern Time, which is commonly used in Canada, is generally five hours behind UTC. However, during the Northern Hemisphere's summer season, following the spring equinox when daylight saving time is observed, Eastern Time shifts to being four hours behind UTC.

4.1.2.1 Hurricane Beryl

In Canada, particularly in the eastern regions, storms often originate from the prairies or the United States. These storms gather their necessary components as the low-pressure systems move across the landscape. This movement allows meteorologists to track the storm paths several days before they reach the region of interest enabling a thorough analysis to identify the key ingredients and the most significant risks associated with each severe weather event. The extreme rainfall and flooding event on July 16, 2024 was in part shaped by the high relative humidity in the atmosphere and high moisture content of the ground, which had been established in the week prior to the storm. The passage of the remnants of Hurricane Beryl over the GTA and general moisture transport from the Gulf of Mexico contributed at least partly to the intensity of the rainfall that impacted the region.

Hurricane Beryl initially formed as a tropical wave in the Atlantic Basin near the west coast of Africa. As it travelled westward, intensified, becoming a tropical depression on June 28, 2024, and rapidly developed into a tropical storm and subsequently a hurricane by the evening of June 29 (Figure 4-3). The hurricane continued to gain strength, reaching Category 4 on the Saffir-Simpson hurricane wind scale as it made landfall on the island of Carriacou (Grenada) on July 1 (Beven et al., 2025). The following day, Beryl peaked at Category 5 intensity while still moving westward, but it weakened to a Category 2 hurricane just before making landfall on the Yucatán Peninsula on July 5. The hurricane then weakened to a tropical storm over the Yucatán Peninsula, shifted to a northwestern path, and then strengthened back to a Category 1 storm before entering the continental United States through Texas on July 8. Hurricane Beryl weakened to a tropical storm while passing Houston on July 8 and to a tropical depression over northern Texas before transitioning to an extratropical cyclone over central Arkansas on July 9 (Beven et al., 2025). Extratropical cyclones are fueled by temperature contrasts, unlike tropical cyclones, which are fueled by convection in areas of weak temperature contrasts. The fast-approaching extratropical storm reached Toronto on July 10 at 10 PM. While wind shear was weak, heavy rainfall was forecasted to cause local flash flooding in the Great Lakes region and northern New York (National Oceanic and Atmospheric Administration (NOAA), 2024).



Note: *Based on operational National Hurricane Center public advisories.*
Source: *NWS, 2024*

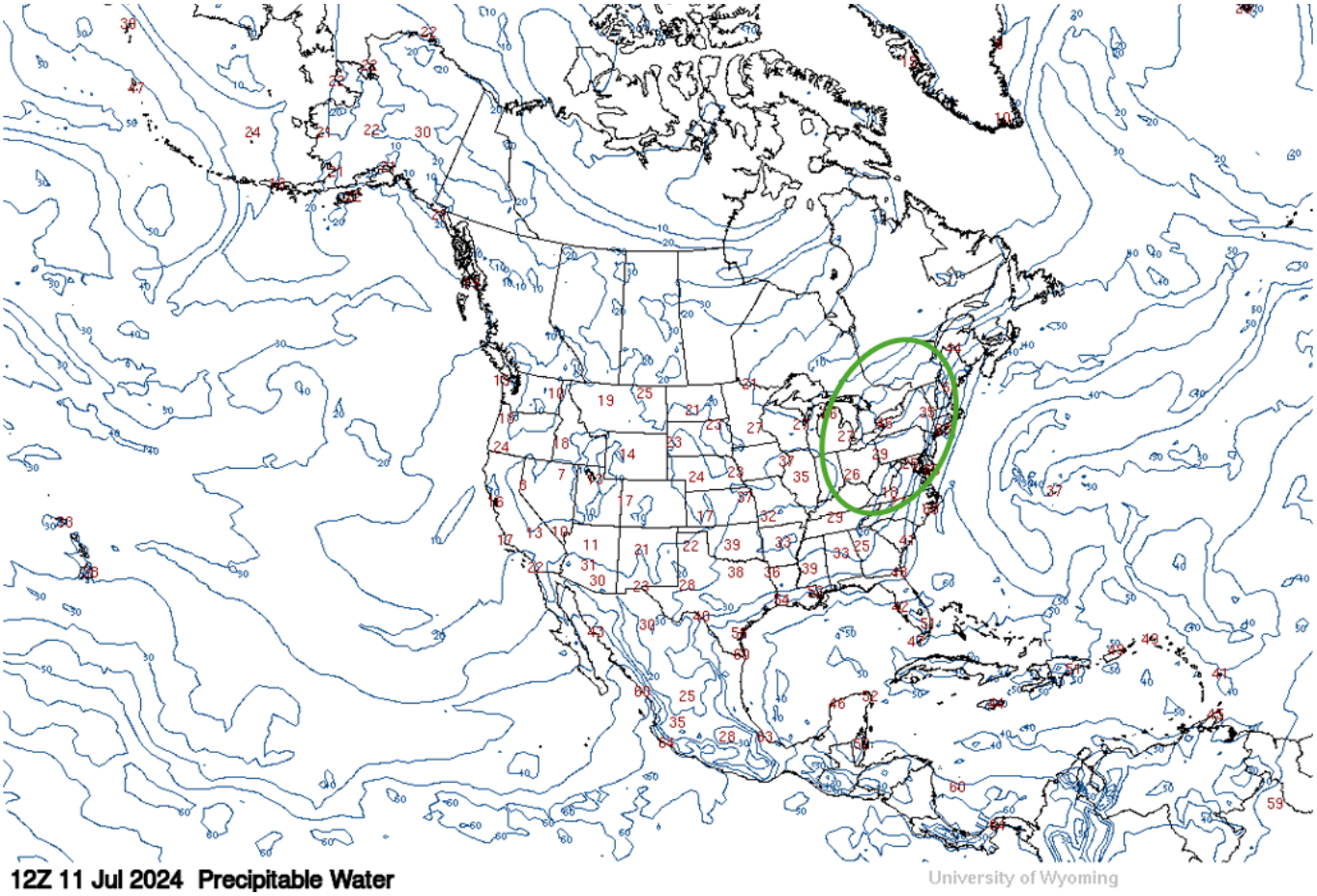
Figure 4-3: Track of Hurricane Beryl from National Hurricane Center Public Advisories

The Toronto City weather station recorded 44.7 mm of rain on July 10, which is slightly below the 2-year return period heavy rainfall threshold of 47 mm (ECCC, 2022 & 2025a). While the remnants of Hurricane Beryl brought significant rainfall, it did not cause major damages in the region. However, the extratropical cyclone's passage left substantial moisture in the atmosphere across North America, which was later steered by strong upper-level wind shear, contributing to the extreme rainfall on July 16.

4.1.2.2 Precipitable Water

In weather forecasting, precipitable water is a useful metric used to assess the moisture content within the atmosphere. It measures the total amount of water vapour in a column of air from the surface to the 300 hPa level, expressed in mm. This metric helps forecasters predict potential rainfall by indicating how much water could potentially fall if all the moisture in the air column were to condense and precipitate.

Following the conclusion of the precipitation events associated with the remnants of Beryl over the GTA, a significant reduction in atmospheric moisture content was anticipated due to the precipitation. Before the passage of the remnants of Hurricane Beryl, the Buffalo International Airport radiosonde site, which measures atmospheric conditions through the whole vertical column of the atmosphere and situated ~100 km southeast of Toronto, recorded a precipitable water of 57 mm on July 10 at 8 AM (12Z). One day later, the precipitable water at Buffalo was reduced to 46 mm (Figure 4-4). The figure illustrates the precipitable water contours and weather station measurements recorded on July 11 at 8 AM (12Z). Although the atmospheric moisture was reduced by the precipitation, it was not entirely depleted, as evidenced by the dense contour lines over the northeastern United States. These contours, highlighted by the green oval, indicate relatively higher atmospheric water content compared to other regions of North America. While the moisture content fluctuated in the days leading up to the event on July 16, it generally remained elevated compared to levels observed prior to the passage of Beryl as an extratropical cyclone.



Note: *Blues lines denote constant precipitable water values, red numbers indicate radiosonde observations (in mm), and the green oval emphasizes regions of elevated precipitable water.*

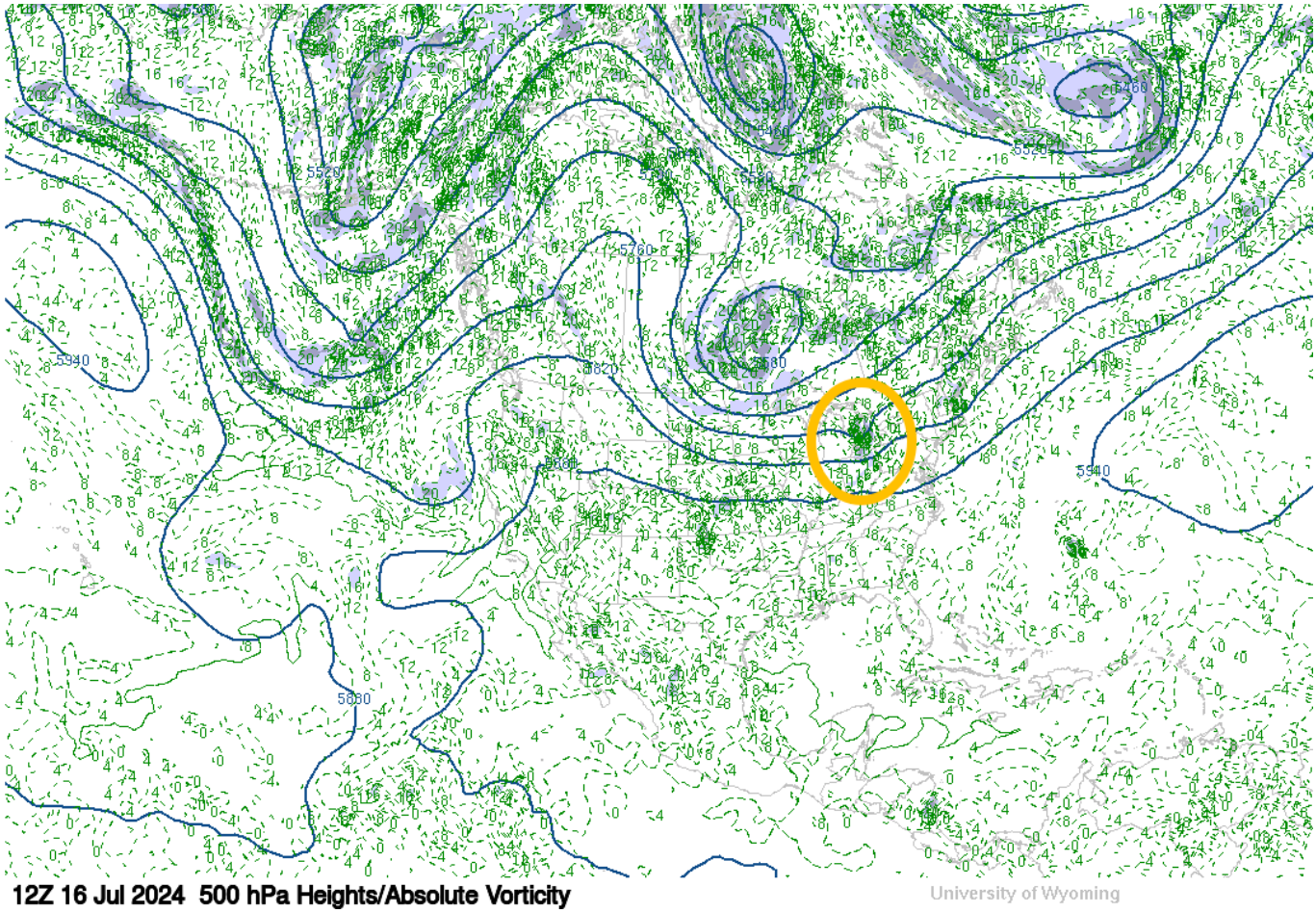
Source: *University of Wyoming, 2025*

Figure 4-4: Precipitable Water Observational Chart (July 11, 2024, 12Z)

4.1.2.3 Upper-Level Charts

Upper-level charts are analytical products representing the upper layers of the atmospheric column, specifically pressure levels below 500 hPa, which correspond to a vertical height of approximately 6 km and above. To get a comprehensive overview of the pre-existing atmospheric conditions, 500 hPa charts at 12-hour intervals are particularly useful for tracking absolute vorticity, which quantifies local spin by incorporating both rotation vorticity and shear vorticity. While the absolute value of vorticity, expressed in units of 10^{-5}/sec, is informative, the trend it exhibits—whether increasing or decreasing—is often more significant.

Regarding this storm, between July 15 at 8 PM (00Z) and July 16 at 8 AM (12Z), the vorticity values increased from 8 to $20 \cdot 10^{-5}$/sec in southern Ontario just west of the GTA, highlighted by the cluster of green dotted lines within the orange circle in the 500 hPa chart for July 16 at 8 AM (12Z), signifying a vorticity maximum (Figure 4-5). Immediately to the east of the vorticity maximum, which is over the GTA, there is strong divergence aloft which necessitates compensation by a corresponding strong convergence at the surface level leading to rising air and the potential for heavy precipitation in the subsequent hours.



Note: *Blue lines depict constant 500 hPa pressure heights, while green dotted lines represent absolute vorticity values. The orange circle highlights the region of interest, showcasing strong positive shear vorticity extending from Lake Ontario to Lake Huron.*

Source: *University of Wyoming, 2025*

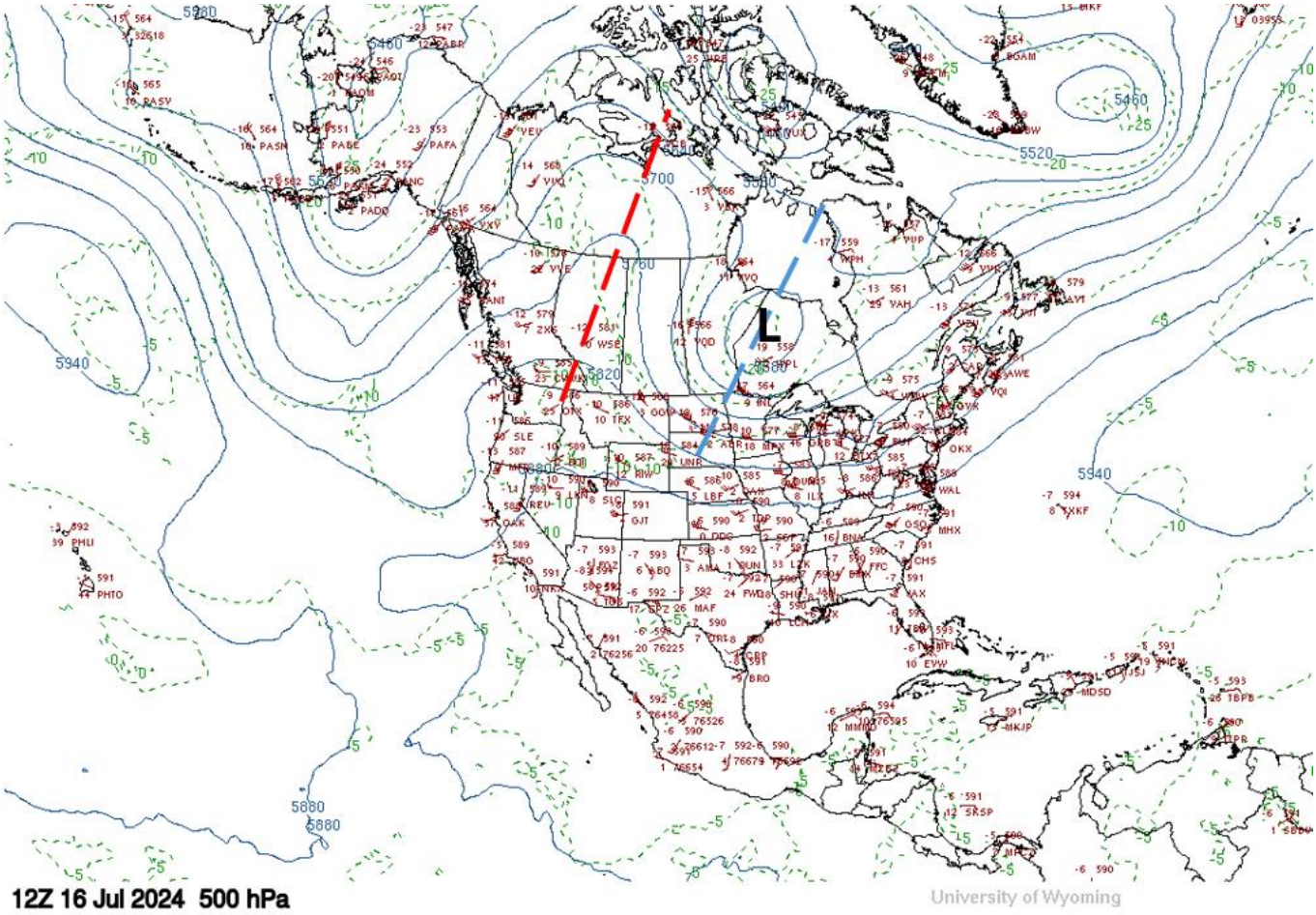
Figure 4-5: 500 hPa Height and Absolute Vorticity Observational Chart (July 16, 2024, 12Z)

The upper-level charts can further be utilized to identify upper-level low- and high-pressure areas. The 500 hPa height contour chart illustrates the altitude of the constant pressure level at 500 hPa. Temperature variations cause the atmospheric column to contract or expand; warmer air temperatures result in higher altitudes as the air becomes less dense and expands upwards, forming a ridge pattern at the 500 hPa pressure level. Conversely, cooler temperatures lead to contraction, lowering the vertical column's height and creating a trough in the upper-level airflow, as depicted by the contour lines. This upper-air analysis also allows for the identification of low-pressure systems at the 500 hPa level, represented by closed circles formed by the constant 500 hPa pressure contours, which are usually associated with troughs.

For clarity, Figure 4-6 shows the 500 hPa level contours on July 16 at 8 AM (12Z), excluding absolute vorticity contours. The red dotted line indicates the position of the ridge in the upper airflow, while the blue dotted line represents a trough. The trough is more pronounced with closer isoheights, including one forming a circle in northern Ontario. This pattern typically indicates the position of an upper-level low-pressure system, represented by an "L," where locally cold temperatures are surrounded by warmer temperatures. As the trough is not perfectly aligned from south to north but is instead tilted from southwest to northeast, it is referred to as a positively tilted trough. This pattern is rarely associated with severe weather, though rainfall often occurs at the surface downstream of the trough. However, there is also a smaller-scale trough just west of the GTA corresponding to the vorticity maximum shown in Figure 4-5 which plays a more direct role in the extreme rainfall event.

Although upper-level charts do not directly identify the causes or triggers of the extreme rainfall event, they offer insights into the atmospheric patterns that led to the occurrence. These charts can also serve as early indicators for

potential future flooding events. Recognizing these atmospheric conditions may enhance vigilance and awareness when similar patterns emerge in the future.



Note: The blue lines indicate constant 500 hPa pressure heights. Red dotted lines represent a ridge in the upper-air flow, while blue dotted lines indicate a trough. A low-pressure system is marked by an "L" south of Hudson Bay.

Source: University of Wyoming, 2025

Figure 4-6: 500 hPa Height Contours Observational Chart (July 16, 2024, 12Z)

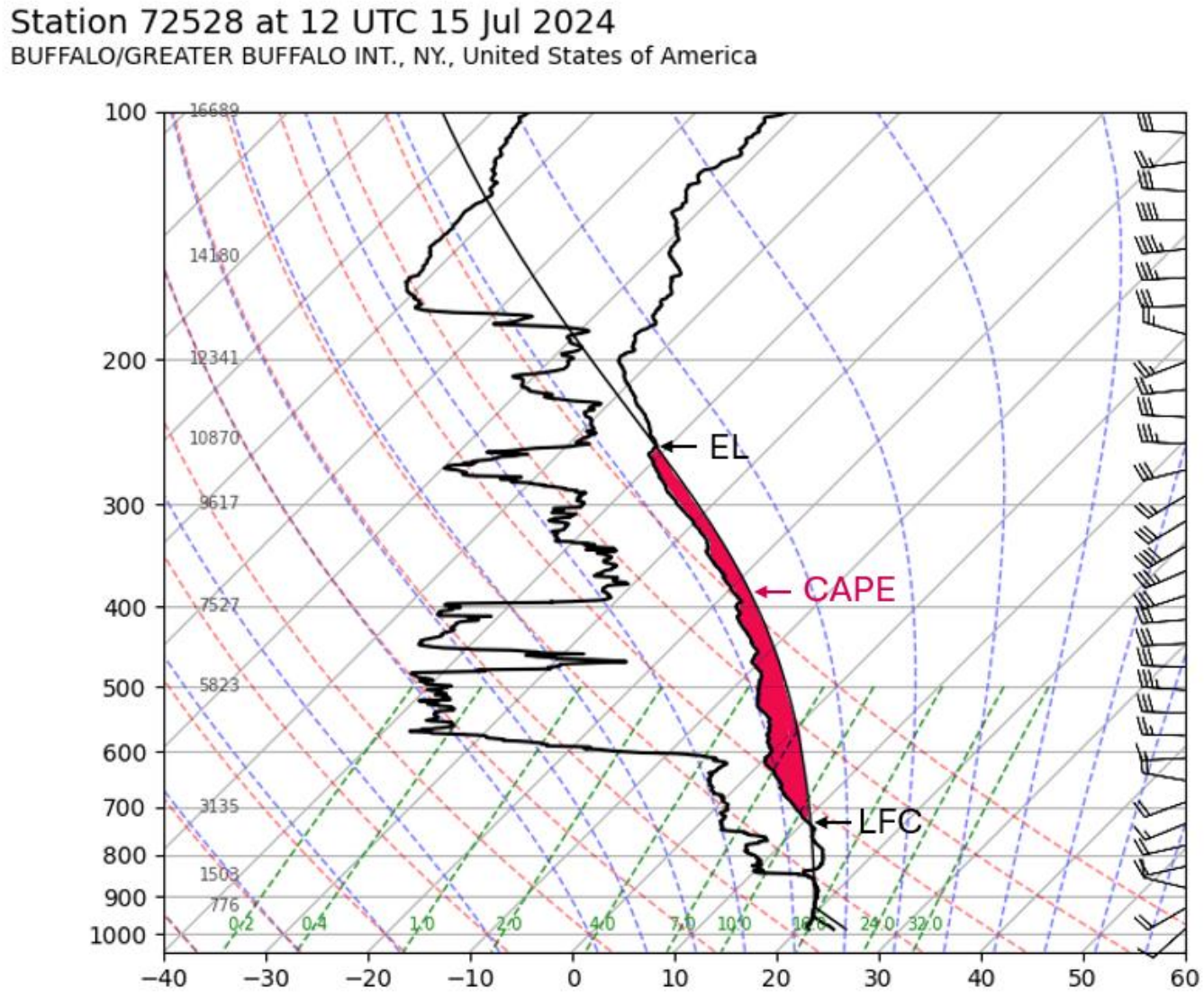
4.1.2.4 Tephigram Soundings

Tephigram soundings, also referred to as Skew-T diagrams, represent the thermodynamic parameters of an atmospheric column at a specific time and location. They display lines of constant pressure, temperature, saturation mixing ratio, dry adiabats, pseudo-saturated wet adiabats, and wind speed at various atmospheric levels. This meteorological tool is valuable for analyzing the temperature and humidity structure of the atmosphere, aiding the determination of precipitation types and assessing atmospheric stability. Furthermore, certain derived parameters are useful for operational purposes, including Convective Available Potential Energy (CAPE). CAPE quantifies the energy available for severe thunderstorms by measuring the convective energy accumulated within the atmosphere column.

The tephigram sounding valid on July 15 at 8 AM (12Z), 24 hours before the start of the extreme rainfall event, at the Buffalo weather station, the closest sounding to the GTA (Figure 4-7). The diagram highlights a moderate amount of CAPE, represented by the fuchsia-shaded area, as well as a very moist air mass in the low levels as depicted by the high dew points of just above 20 °C. The low-level moist air mass was also present in the sounding valid on July 15 at 8 PM (July 16 00Z). This atmospheric setup is conducive to thunderstorms and characterizes the air mass associated with the extreme rainfall event on July 16.

This assessment aligns with the high moisture content observed in the lower levels of the atmosphere on July 16 at 8 PM (July 16 at 00 UTC), where the dewpoint temperature closely follows the air temperature, indicating a minimal

difference between the two variables (Figure 4-7). It is important to note that as air temperature approaches the dewpoint temperature, relative humidity increases, approaching saturation. Thus, 12 hours prior to the onset of the July 16 event, the atmosphere exhibited high humidity levels and, consequently, elevated precipitable water content.



Note: The fuchsia area indicates the Convective Available Potential Energy (CAPE) with the identified Equilibrium Level (EL) and Level of Free Convection (LFC).

Source: University of Wyoming, 2025

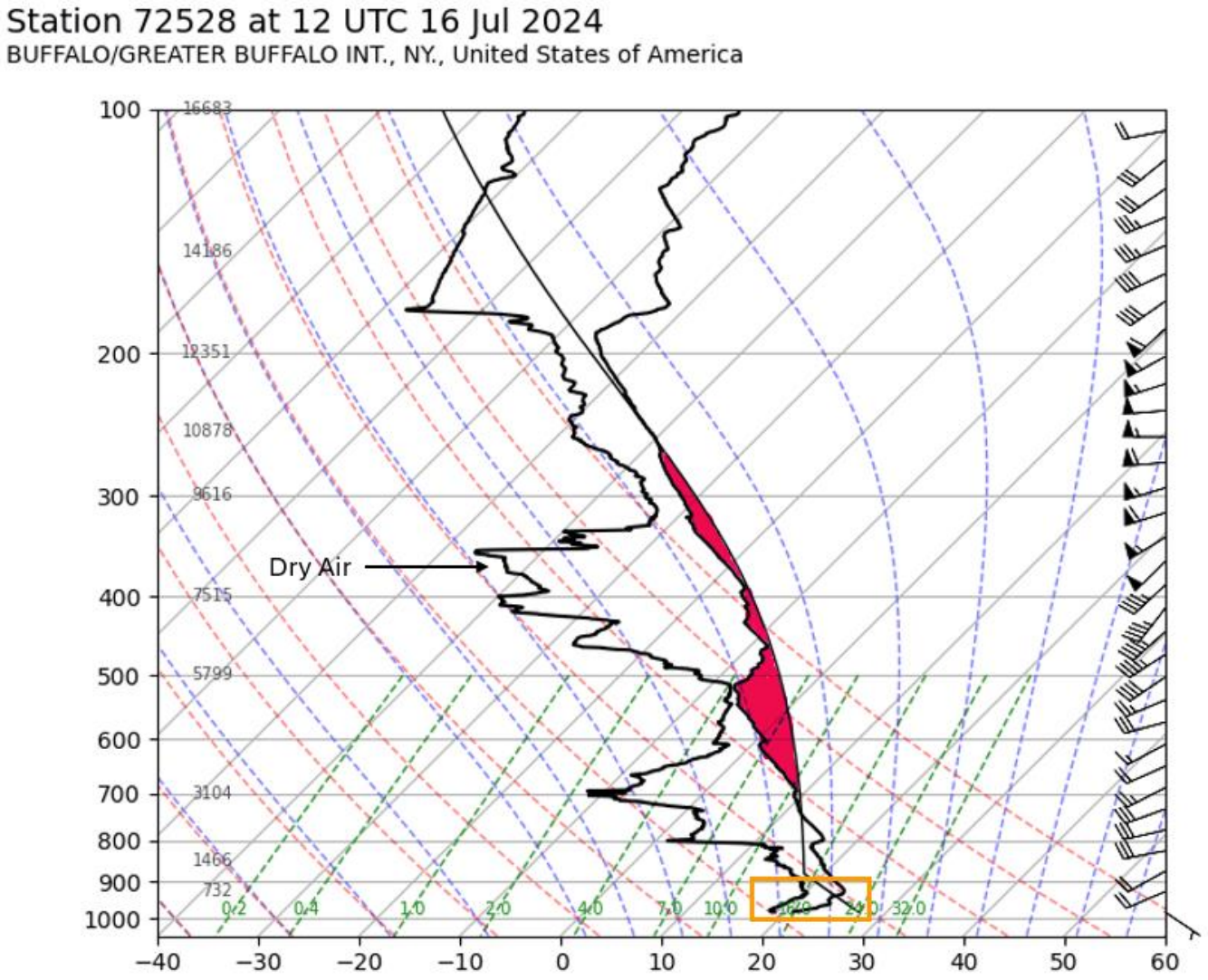
Figure 4-7: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (July 15, 2024, 12Z)

The most indicative tephigram sounding was produced on July 16 at 8 AM (12Z), less than an hour prior to the rainfall event. To accurately interpret this Skew-T diagram, it is essential to recognize that vertical atmospheric structures may not strictly adhere to theoretical patterns but can exhibit characteristics from multiple atmospheric phenomena. The tephigram sounding reveals instability in the vertical structure along with pronounced downdraft features, indicative of a hybrid pattern combining severe thunderstorm characteristics and wet microburst dynamics (Figure 4-8).

The fuchsia-shaded area represents a moderate amount of CAPE, gradually increasing with instability. This is typically associated with severe weather sounding types, which are indicative of severe thunderstorms capable of producing strong wind gusts, heavy rainfall, hail, and even tornadoes. There was a low-level temperature inversion, indicating temperatures rising with height, which is common in the early morning after a clear night during which infrared radiation escapes into outer space, cooling the surface relative to slightly higher in the atmosphere. The

absence of clouds will be further examined in Section 4.1.2.5 using satellite imagery. Although this inversion reduces instability and typically makes thunderstorms less likely in the early morning, on this day, there was still enough remaining instability from the sun heating the lower atmosphere the previous day. The approaching vorticity maximum shown in Figure 4-5 and the corresponding mesoscale convective vortex (MCV) that will be discussed in Section 4.1.3.1 triggered thunderstorm development.

On the day preceding the storm, much of southern Ontario was under a heat warning issued by MSC, as maximum and minimum temperatures exceeded 31 °C and 20 °C, respectively, for three consecutive days. This prolonged period of warmth affected multiple regions, including the areas of Windsor, Essex County, Chatham-Kent, Sarnia, and Lambton. This heat wave was situated to the west of the TRCA jurisdiction, directly along the storm's projected path. Consequently, the elevated temperatures contributed to an increase in CAPE as the storm approached the GTA, enhancing the potential for severe weather and free convection. This situation set the stage for heightened convective activity, increasing the likelihood of severe thunderstorm.



Note: The fuchsia-shaded area represents the Convective Available Potential Energy (CAPE), with the relative dry air portion of the vertical column also highlighted. The orange box shows the temperature inversion.

Source: University of Wyoming, 2025

Figure 4-8: Tephigram Sounding at the Buffalo/Greater Buffalo International Radiosonde Site (July 16, 2024, 12Z)

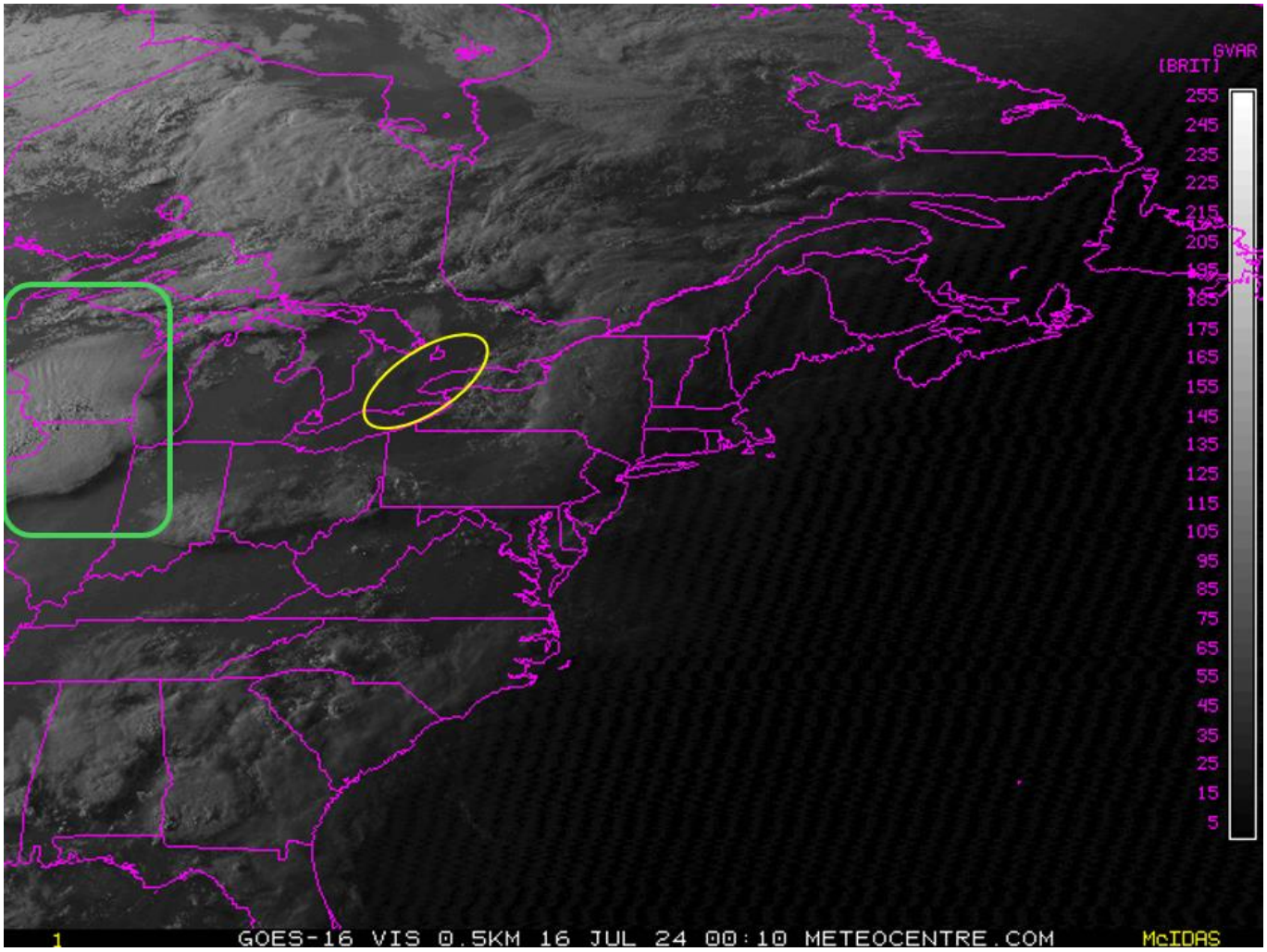
Figure 4-8 reveals a second atmospheric pattern indicative of wet microbursts. Microbursts are short-lived downdraft events embedded within larger severe thunderstorm systems that can persist for several hours. These phenomena are classified as dry, wet, or hybrid. Dry microbursts primarily result in severe wind gusts without significant precipitation, whereas wet microbursts are associated with substantial precipitation. Wet microbursts are characterized by the presence of dry air aloft, typically in the mid-levels of the atmosphere.

This dry air mass is entrained into the downdraft within the clouds, where the evaporation of falling raindrops leads to latent heat absorption and cooling. Cooler air masses, being denser than warmer air, enhance negative buoyancy, thereby intensifying the downdraft responsible for microbursts. When the cold downdrafts reach the surface, they spread out as outflow winds, which converge with winds in the warmer surrounding region. The warmer, lighter surrounding air is forced to rise along the convergence zone, triggering more thunderstorms and extending the lifespan of the thunderstorm cluster, and combined with the abundance of moisture in the warm air mass that is lifted, favors heavy rainfall amounts.

Figure 4-8 also shows winds generally in the 20-30 kt range from just above the surface up to 500 hPa, which means that even an individual storm cell with an extended life span would be in a particular area for only a relatively short time before moving away. However, on this day, the storm cells organized in a way that allowed for a succession of storms to deposit heavy rain over the same area for hours, as will be discussed in Section 4.1.3.1.

4.1.2.5 Satellite Imagery

Satellite imagery is a complimentary tool for a forecaster to assess certain atmospheric variables, such as cloud coverage, temperature and water vapour content. As they are provided nearly in real time and have a high temporal coverage, they allow to fill the gap of more conventional weather charts and observational data unavailable elsewhere except from forecasts. In this case, the satellite imagery was used to confirm previous statement regarding cloud coverage on the night of July 15 to July 16, 2024. Figure 4-9 presents the visible satellite image from July 15 at 8 PM (July 16 at 00Z), confirming that the evening was cloud-free prior to the extreme weather event of July 16. While not shown, the cloud cover increased overnight starting between 2 and 3 AM. In the visible imagery, the darker shades within the yellow oval indicate low brightness little or no reflection of sunlight back into outer space, signifying the absence of clouds or the presence of only thin clouds. The large area of lighter shades within the green rectangle represents highly reflective and therefore thick clouds associated with the mesoscale convective system (MCS) that would transition into the storm that affected the GTA, discussed in Section 4.1.3.1.



Note: The yellow oval highlights the GTA, while the green rectangle indicates the approaching weather system.
Source: Centre Météo (UQAM), 2025. All reproduction rights are reserved.

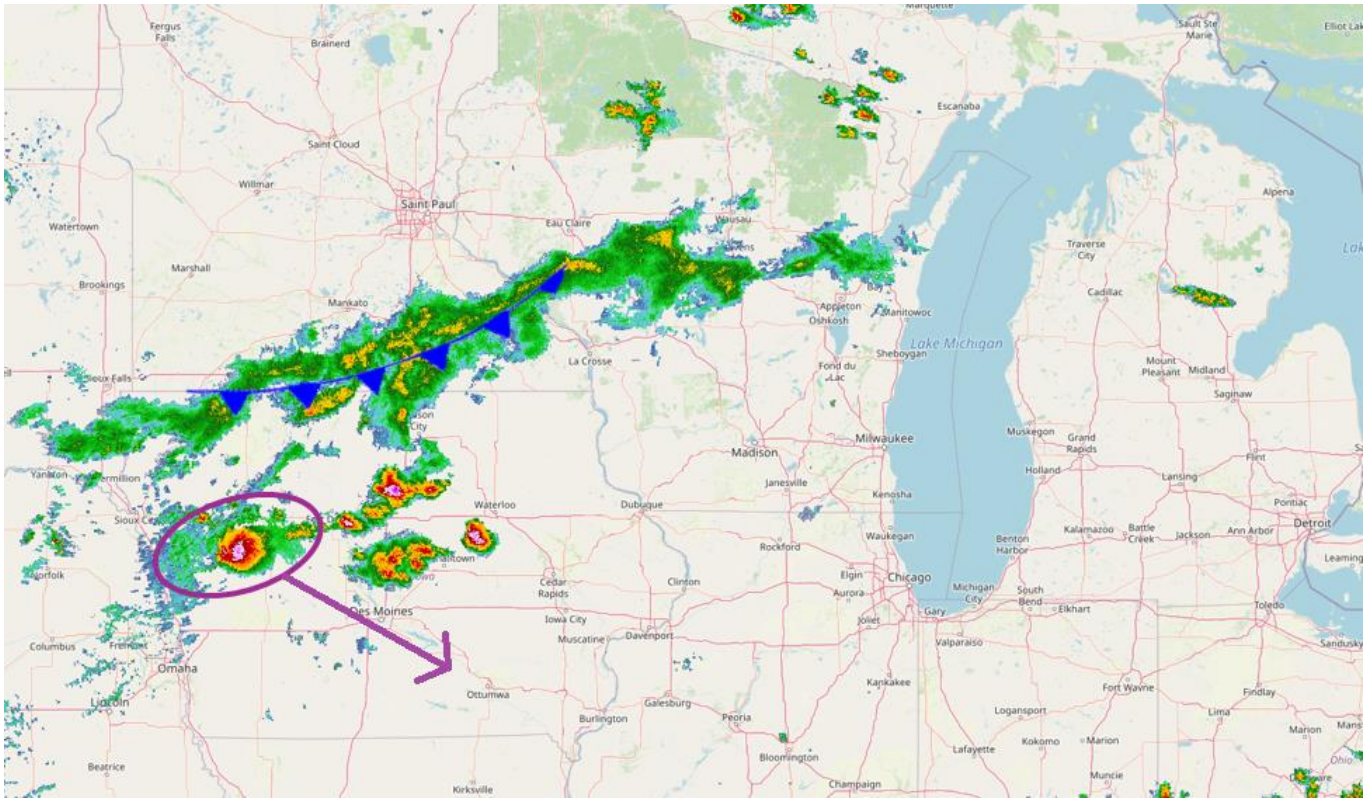
Figure 4-9: Visible Satellite Image Captured by GOES-16 (July 16, 2024, 00Z)

4.1.3 Severe Weather Event

Up to this point, components of the vertical structure and atmospheric upper-level parameters that could have intensified and prolonged the thunderstorm events of July 16 have been examined. However, the initial trigger remains unidentified. While the presence of high humidity levels, moderate CAPE, and strong vorticity suggest conditions conducive to thunderstorms and offer insights into the atmospheric context preceding the event, they do not fully explain the storm's development. Radar composite images and surface analysis charts are particularly useful in supporting the assessment of thunderstorm triggers.

4.1.3.1 Radar Images

On July 15, 2024, at 2030Z (3:30 PM local time), a supercell formed, initially as a single cell, associated with the passage of a cold front over Iowa (Figure 4-10). Approximately 2.5 hours later, this supercell evolved into a Mesoscale Convective System (MCS), a collection of thunderstorms that covered more than half of western Iowa. The MCS brought hail measuring 2.2 cm in diameter and wind gusts reaching up to 120 km/h. The system quickly intensified as it travelled over Wisconsin, where an EF1 tornado developed, causing structural damage at 6:14 PM local time.



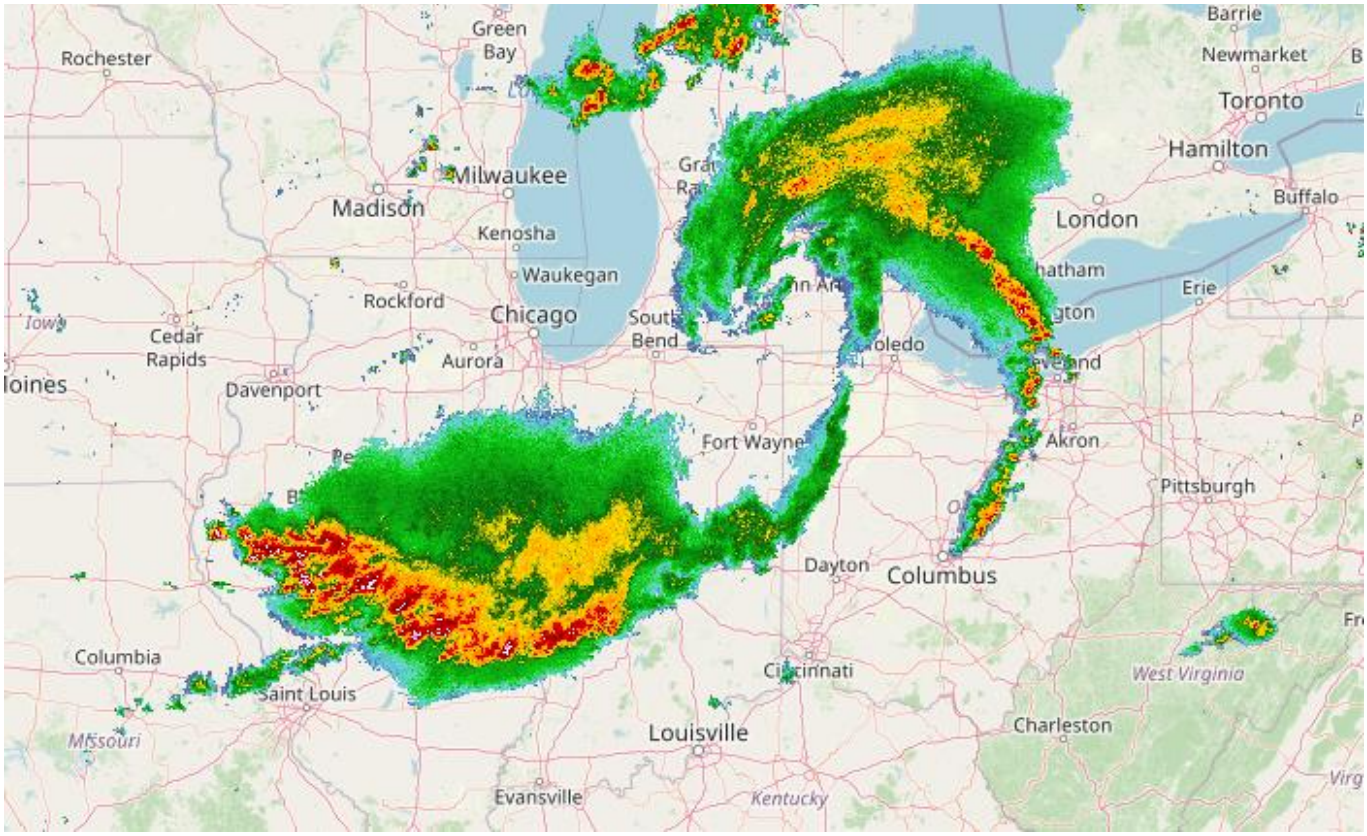
Note: *The purple oval indicates the supercell, the purple arrow indicates the supercell's direction of movement, and the blue line marks the cold front responsible for the precipitation line.*

Source: *Iowa State University, 2025a*

Figure 4-10: Radar Reflectivity Composite (July 15, 2024, 2030Z)

Over the next hours, the MCS intensified and developed into a line of thunderstorms extending over 360 km, resulting in ten tornadoes along its path. At this stage, the system generated widespread wind gusts exceeding 160 km/h, causing significant damage to trees and properties in Iowa, flash flooding, power outages, and roofs being blown off houses in Illinois during the evening. In Illinois and Indiana, this event was classified as a derecho, a long-lived, fast-moving windstorm characterized by unilateral winds over a continuous line of thunderstorms, distinct from tornadoes. In addition to wind damage, flood warnings were issued throughout the evening of July 15 across Iowa, Wisconsin, and Michigan due to extreme rainfall.

As the MCS progressed eastward, it also extended meridionally from southern Indiana to central Michigan on July 16 at approximately 3 AM local time (07Z). Less than an hour later, the system split into two halves: the southern portion moved southward toward Missouri and Kentucky, while the northern portion advanced towards Lake Ontario (Figure 4-11). The northern segment was responsible for the extreme rainfall event over the GTA.

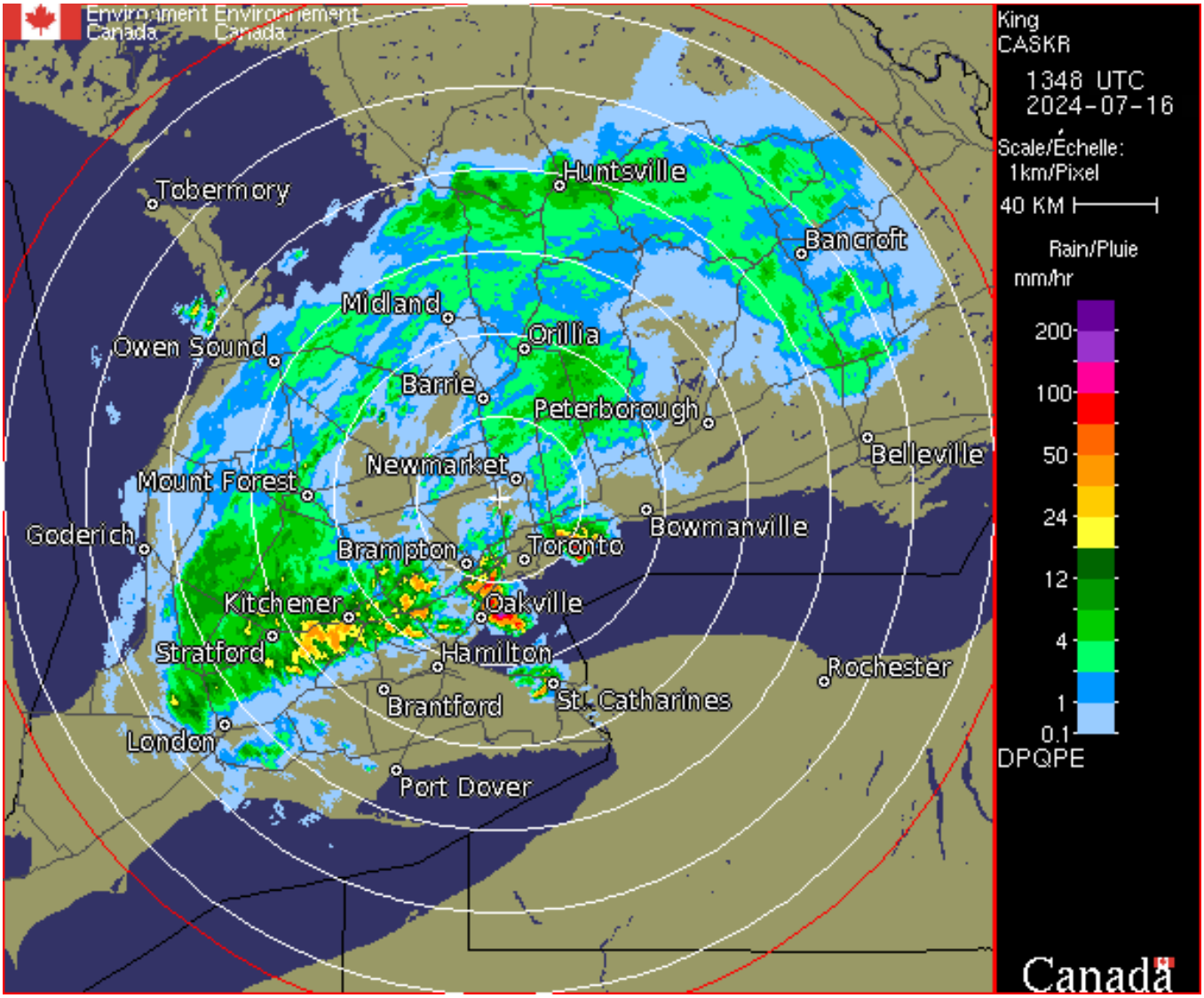


Source: Iowa State University, 2025a

Figure 4-11: Radar Reflectivity Composite (July 16, 2024, 0745Z)

After separating from the MCS, the system transitioned into a Mesoscale Convective Vortex (MCV), which corresponds to the vorticity maximum shown in Figure 4-5. This phenomenon involves a central low-pressure area with winds circulating in a counterclockwise pattern, persisting for hours and often bringing severe weather conditions. The system advanced and reached the western part of the TRCA jurisdiction at 8:42 AM local time on the morning of July 16, 2024. Two distinct high-intensity rainfall episodes were recorded. The first episode occurred from 8:42 AM to 9:48 AM (Figure 4-12), with peak rainfall intensities ranging between 75 and 100 mm/h. The second, more intense episode, lasted from 9:54 AM to 10:48 AM, with rainfall intensities ranging between 100 and 150 mm/h (Appendix Figure B 5).

Although individual storm cells moved east-northeastward at ~60 km/h, they organized in a line extending west-southwest to east-northeast, allowing for the line of storm cells to move over the same area (Appendix Figure B 3-Appendix Figure B 9). This is a phenomenon known as “training”, which prolongs the heavy rainfall and is often a key factor in flash floods (Doswell 1996). After 4 hours, the entire line finally moved off to the northeast (Appendix Figure B 10). The training of storm cells was crucial to obtaining the extreme rainfall in the narrow band over which the storm cells trained over, including parts of the TRCA. The TRCA’s communications with the Ontario Storm Prediction Centre (OSPC), the ECCC centre responsible for ECCC’s forecasts for Toronto, indicate that the meteorologists there did not anticipate such training of storms, assuming that the relatively fast motion of the storm cells would be enough to limit rainfall.

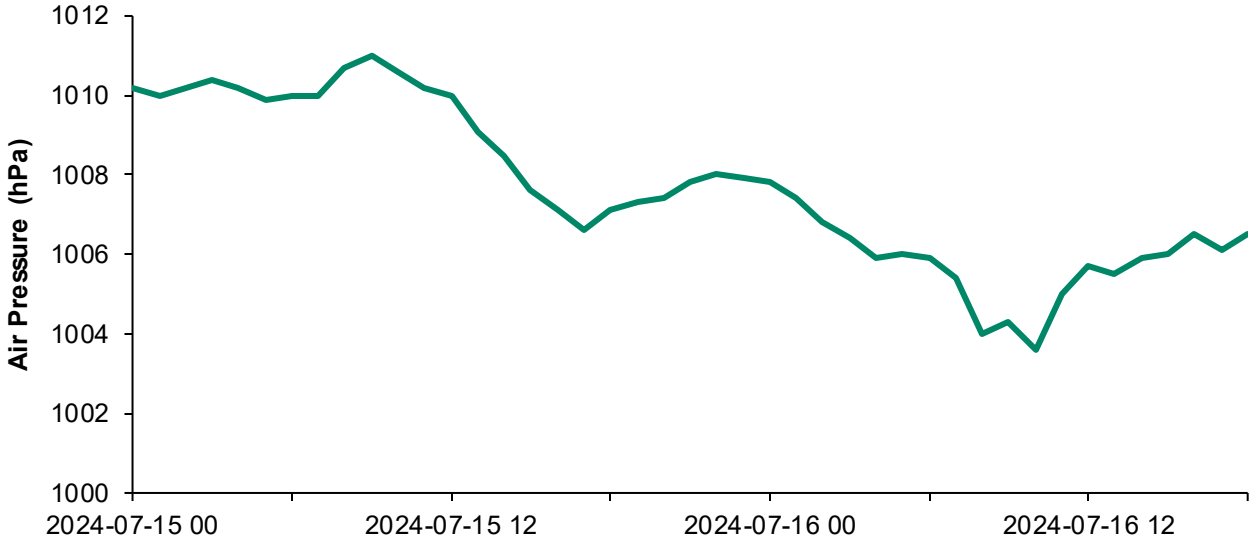


Source: ECCC, 2025c

Figure 4-12: Dual Polarization Quantitative Precipitation Estimation (DPQPE) King City Radar (July 16, 2024, 1348 UTC / 09:48 EDT)

4.1.3.2 Low-Level Data

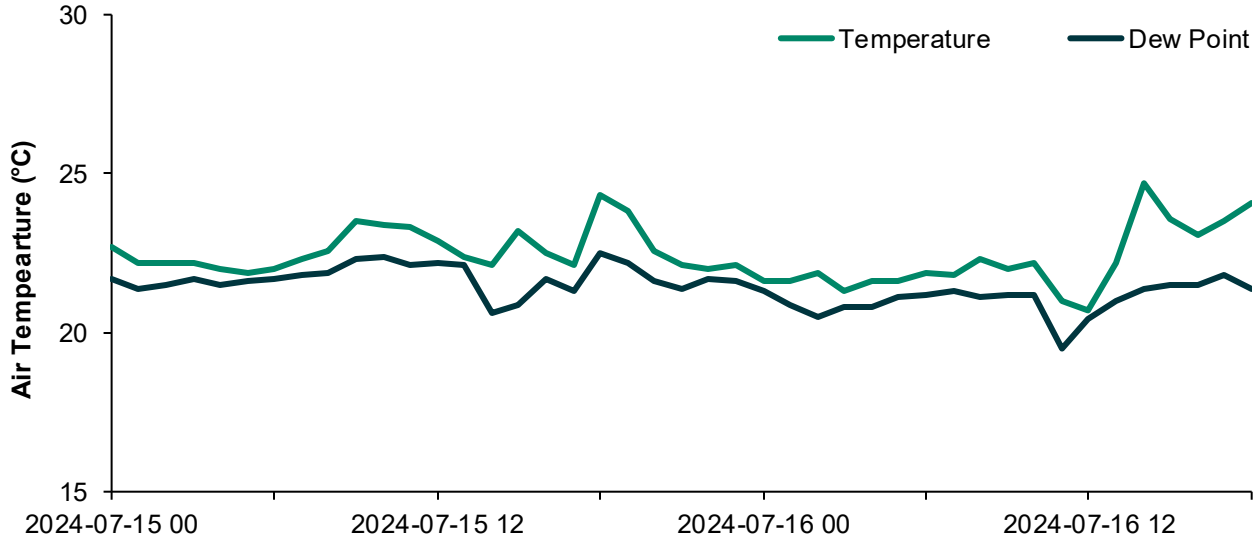
While radar imagery analysis is crucial for identifying timing and areal distribution of high rainfall intensity and tracking the movement of weather systems, surface observational data presented as meteograms offers complementary and valuable confirmations. For example, the surface air pressure meteogram at the Toronto City Centre weather station shows a rapid decrease in air pressure over 26 hours, dropping by 7.4 hPa (Figure 4-13). This significant pressure drop indicates the presence of a fast-developing low-pressure system, confirming that a MCV impacted the GTA, characterized by its low-pressure centre.



Source: Meteostat, 2025

Figure 4-13: Air Pressure Meteogram at Toronto City Centre (CYTZ; July 15-16, 2024)

Furthermore, the temperature and dew point meteogram illustrates the surface temperature and dew point during the event, highlighting the high dew points and associated elevated humidity levels near the surface that preceded the rainfall (Figure 4-14), favorable for heavy precipitation once convection intensified. Additionally, the stable surface air temperatures indicate the absence of a significant frontal system, which would typically be depicted on surface weather charts as a front and characterized by temperature variations.



Source: Meteostat, 2025

Figure 4-14: Temperature and Dew Point Meteogram at Toronto City Centre (CYTZ; July 15-16, 2024)

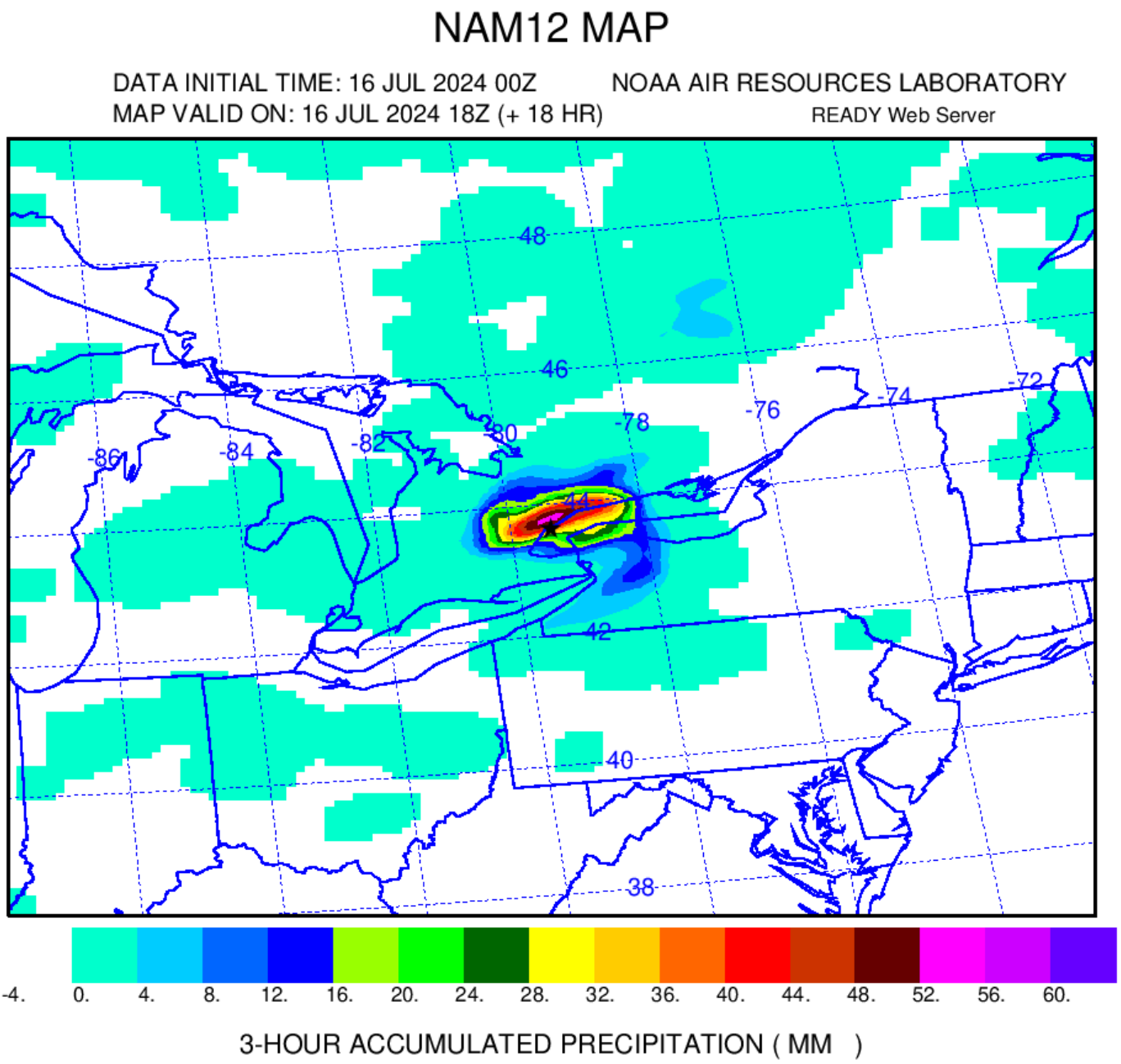
4.1.4 Numerical Forecasting

The objective of analyzing past numerical forecasts is to evaluate their accuracy and the lead time provided ahead of the extreme weather event. While storm systems themselves cannot be prevented, their impacts can be mitigated through the timely issuing of warning information to the public and the activation of pre-established emergency response measures. Local authorities depend on weather warnings issued with adequate lead time. The following section examines the accuracy of the weather forecasts provided by both MSC/ECCC and NOAA sources on July

16, 2024 and the effectiveness of these warnings, as well as several numerical model rainfall predictions used by the TRCA in its daily flood risk assessment.

Referencing the MSC/ECCC forecast bulletin, the first mention of a severe thunderstorm watch was issued at 8:22 AM on July 16 for the City of Toronto, Mississauga – Brampton, Caledon, and York – Durham regions. This was slightly less than thirty minutes before the onset of rainfall within the TRCA's jurisdiction (Table 4-1). Considering that the TRCA primarily relies on MSC forecasts to issue flood warnings, this limited timeframe provided minimal opportunity for the public and authorities to prepare for the impending extreme rainfall. Initially, at 8:53 AM, the MSC warned of 20 to 30 mm of rain over the City of Toronto. By 9:52 AM, this prediction was updated to 50 to 70 mm, and at 11 AM, it was further revised to forecast 80 to 110 mm of rain by mid-afternoon. Although the latest estimation was more accurate, the most intense rainfall had already occurred by that time. The MSC forecasts for other locations in the TRCA were similarly raised in the middle of the extreme rainfall event. It is also important to acknowledge that the MCS developed only 15 hours before reaching the GTA, originating in Iowa, over 1,100 km away. The rapid and short development of this storm further limited forecasters' ability to identify and communicate the associated risks effectively.

Among the numerical weather forecast systems available, the North American Mesoscale (NAM12) Forecast System is a non-hydrostatic multi-scale model with a 12 km spatial resolution over the North American domain and provides forecasts up to 84 hours ahead. Based on the forecast issued on July 15 at 8 PM (July 16, 00Z), NAM12 forecasted rainfall accumulation reach up to 56 mm for July 16, between 11 AM (15Z) and 2 PM (18Z) over the TRCA's jurisdiction (Figure 4-15). It hence significantly underestimated the total rainfall for the extreme rainfall event by half. While the timing of the NAM12 forecast was reasonably accurate with slightly later precipitation onset, the predicted rainfall quantity did not adequately reflect the intensity of the subsequent flooding event.

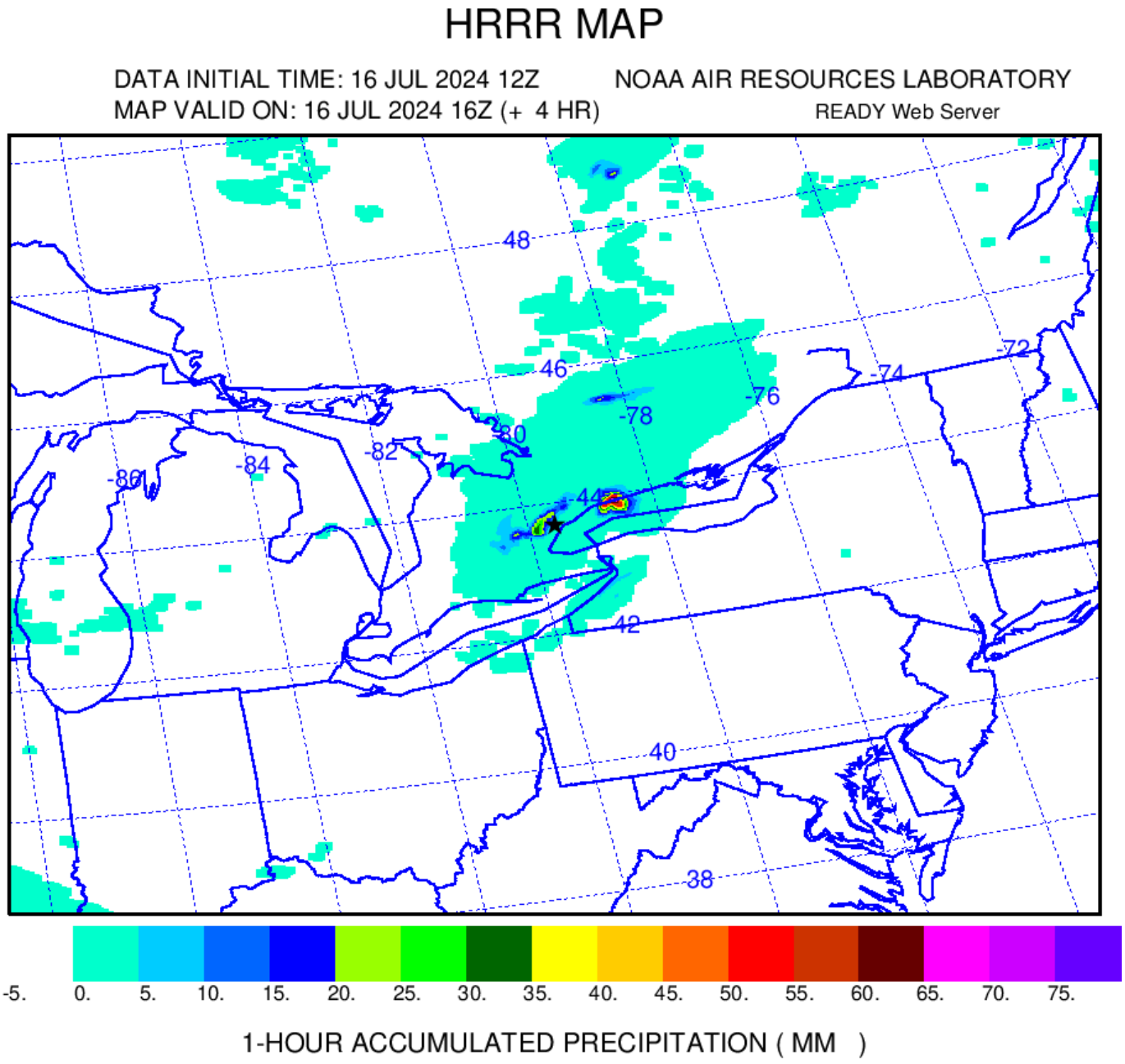


Note: Issued on July 16 on 00Z by the 12 km North American Model (NAM12).
Source: NOAA, 2025a

Figure 4-15: Forecasted Three-hour Accumulated Precipitation from 15Z to 18Z (July 16, 2024)

It is important to note that forecasters do not rely solely on a single numerical model to estimate rainfall amounts and storm timing. For instance, the High-Resolution Rapid Refresh (HRRR) model, developed by the National Centers for Environmental Prediction, offers real-time forecasts with a 3-km resolution and hourly updates. Based on the forecast issued on July 16 at 8 AM (12Z), the hourly accumulated rainfall between 11 AM (15Z) and 12 PM (16Z) is shown in Figure 4-16. The high-resolution and frequent updates provided by the HRRR model, compared to the NAM12 model, enhanced the accuracy of the forecasted rainfall amounts and improved the timing prediction of the storm. Due to the higher resolution, the HRRR model captured the two episodes of high rainfall with maximum hourly precipitation accumulation of 50-55 mm for the first and 40-45 mm for the second episode (Figure 4-16 and Appendix C.1.1). However, the area of highest intensity was forecasted toward the north and east of Toronto, and the total precipitation amount forecasted for the GTA between 9 AM and 2 PM was 35-60 mm. The performance of the HRRR model is an

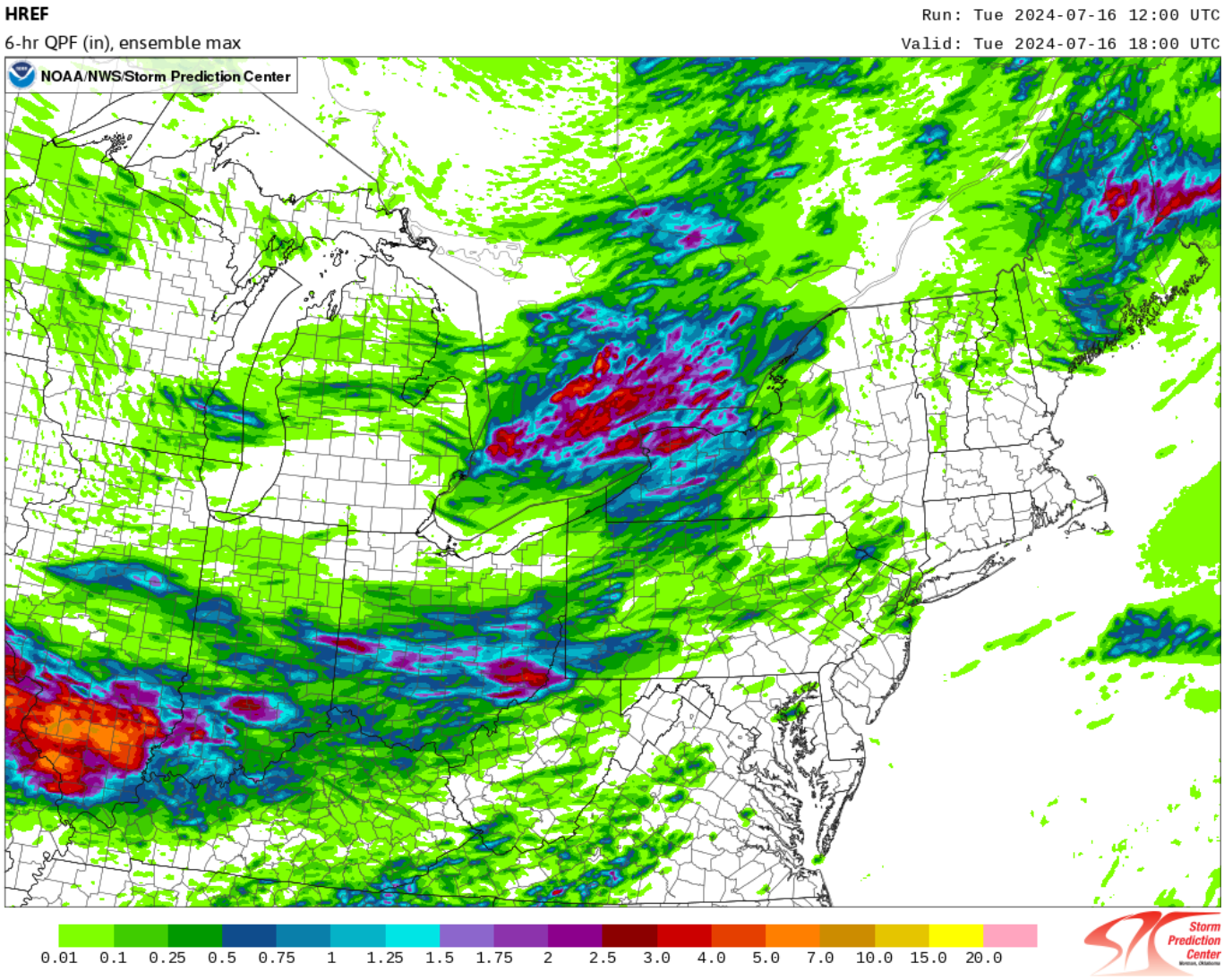
example of the difficulty of getting the exact location and time of thunderstorms and extreme precipitation correct even if simulated in high resolution models.



Note: *Issued on July 16 at 12Z by 3 km High-Resolution Rapid Refresh (HRRR).*
Source: *NOAA, 2025a*

Figure 4-16: Forecasted One-hour Accumulated Precipitation from 15Z to 16Z (July 16, 2024)

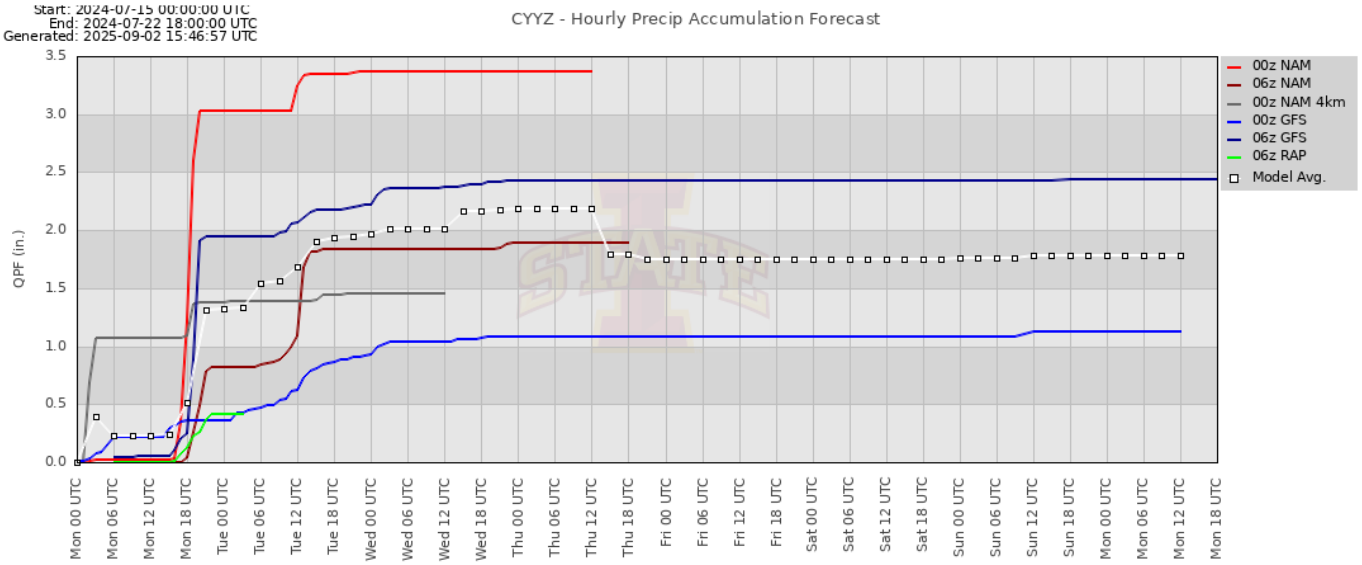
Forecaster can also use the High-Resolution Ensemble Forecast (HREF) model, a suite of 10 high-resolution models that includes the HRRR and can be used to estimate the probability of extreme rainfall occurring or the maximum possible rainfall for a storm. The HREF forecast issued on July 16 at 12Z indicated the potential for rainfall of 75-100 mm in the GTA in the following 6 hours in the worst-case scenario (Figure 4-17).



Source: SPC, 2025

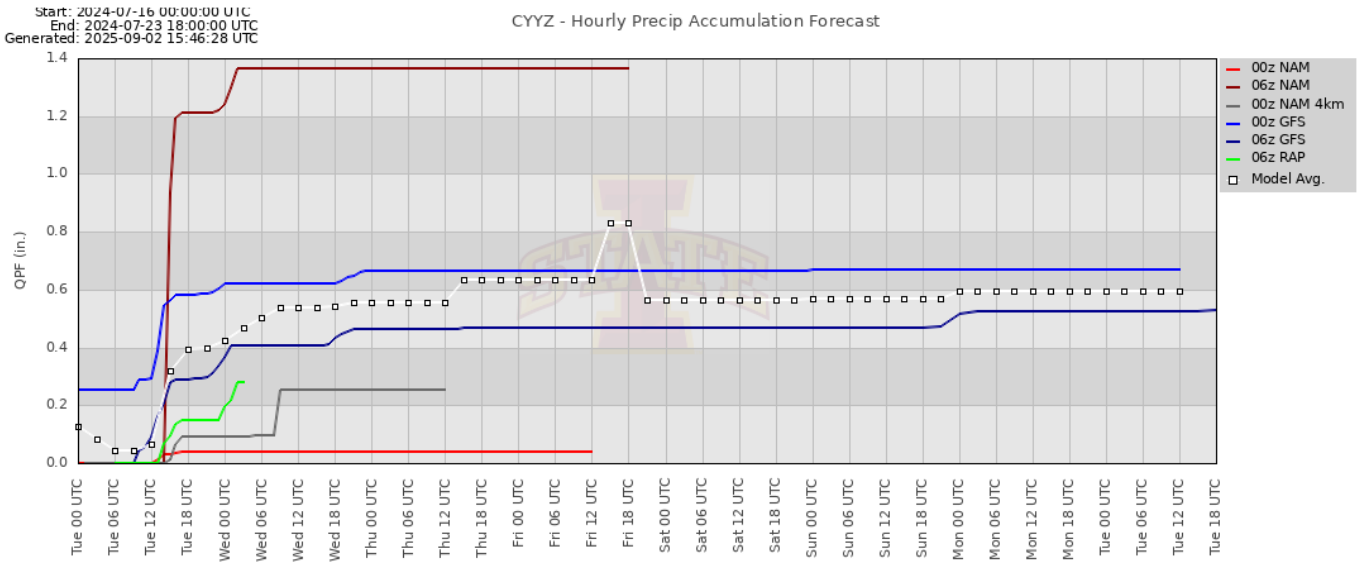
Figure 4-17: HREF 6-hour Ensemble Maximum Accumulated Precipitation from 12Z to 18Z (July 16, 2024)

The TRCA also used rainfall predictions from other numerical weather models to make its assessment. Meteograms showing the cumulative precipitation amount at Pearson International Airport predicted by models initialized on July 15 00Z and July 16 00Z are shown in Figure 4-18 and Figure 4-19, respectively. They indicated a wide range of possible rainfall amounts but all underestimated the rainfall in the area of rainfall maximum, though the July 15 00Z run of the NAM model was the closest, showing ~85 mm total.



Source: Iowa State University, 2025b

Figure 4-18: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport starting at July 15, 00Z



Source: Iowa State University, 2025b

Figure 4-19: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport starting at July 16, 00Z

Table 4-2 shows TRCA's assessment of the different model predictions on the morning of July 16.

Table 4-2: TRCA's Assessment of Predicted Rainfall and Runoff Amounts on the Morning of July 16

Model	Rainfall (mm)	Runoff (mm)
GDPS	30.57	27.31
GFS	16.62	13.59
HRDPS	75.41	71.97
HRRR	39.10	35.78
NAM	60.90	57.49
QPF	27.96	24.73
RDPS	38.32	35.00
Daily Maximum (HRDPS)	**75.41**	**71.97**

4.2 Rainfall Analysis

Rainfall data from the network of gauge stations (Section 3.1) was used to determine rainfall totals, rainfall duration and rainfall rate for each station during the July 16, 2024 event. In total, the dataset contains 123 gauges of which 99 are located within the TRCA jurisdiction. The remaining 24 gauges are located outside the jurisdiction, 14 are ECCC stations located in the wider region and the other 10 are City of Mississauga station outside the TRCA jurisdiction. These gauge stations provide spatial datasets of the different rainfall variables which were used to analyze precipitation patterns over the TRCA jurisdiction. The total rainfall amount, duration, and rainfall intensity for all stations are listed in Appendix D.

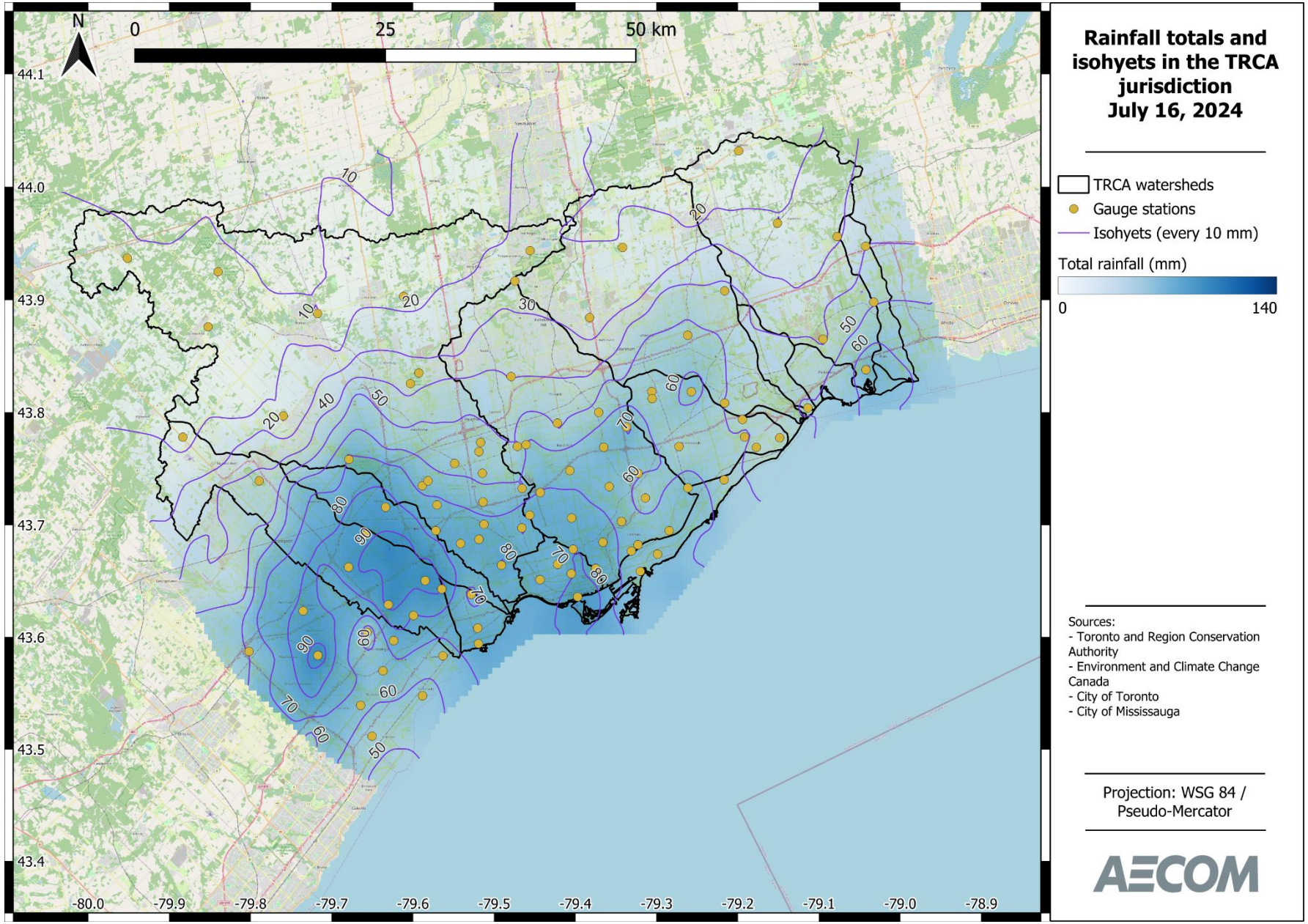
4.2.1 Total Precipitation and Isohyets

Total precipitation during the day of the July 16, 2024 storm was calculated for all the gauge stations presented in Figure 3-1. The quality control process for the July 16 event resulted in the rejection of 12 stations due to missing or incomplete data (Table 4-3). While the TRCA's and City of Mississauga's station data were complete, three (3) ECCC stations outside of the TRCA jurisdiction and nine (9) City of Toronto stations were discarded. As the gauge stations are distributed across the city, the impact on precipitation distribution calculation was deemed negligible.

Table 4-3: Number of Stations with Data on July 16, 2024

Provider	Number of Discarded Gauges	Number of Remaining Gauges
TRCA	0	40
ECCC	3	15
City of Toronto	9	43
City of Mississauga	0	13
Total	12	111

After discarding the stations with insufficient or missing data, the remaining stations provide a dataset of spatially distributed data points of total precipitation across the TRCA jurisdiction. Using the methodology presented in Section 2.2.1, these data points were used to create a gridded dataset of total precipitation. Isolines were then calculated (Section 2.2.2) from this dataset to define the isohyets (Figure 4-20).



Note: Total precipitation is shown by isohyets (purple lines) and precipitation gradient (white-to-blue).

Figure 4-20: Map of Total Precipitation across the TRCA Region (July 16, 2024)

The maximum precipitation within the TRCA jurisdiction was measured at the Rathwood station (101.5 mm) of the TRCA network in the Etobicoke watershed, though it was surpassed by precipitation measured at the Streetsville station (104.2 mm) of the City of Mississauga network, outside the TRCA jurisdiction. Precipitation during the July 16, 2024 storm was concentrated in the southwestern part of the TRCA jurisdiction, with the most intense rainfall (above 90 mm) happening in the Etobicoke and Mimico watersheds, and in parts of the City of Mississauga outside the TRCA jurisdiction. The significant variation in rainfall accumulation across the TRCA jurisdictions supports the analysis of the tephigram (Section 4.1.2.4) and the possibility of sub-mesoscale phenomena contributing to extreme rainfall amounts over localized areas. In the case of July 16, the mechanisms was likely a wet microbursts embedded in the thunderstorms.

The gridded dataset of total precipitation (interpolated through IDW, Section 2.2.1) was also used to determine the total precipitation within each watershed, following the methodology detailed in Section 2.2.3. For the storm on July 16, 2024, the total precipitation over the TRCA watersheds amounts to $103.5 \cdot 10^6$ m^3 of water ($103.5 \cdot 10^9$ litres, the equivalent to 41 400 Olympic-sized swimming pools, Table 4-4). Most of this amount fell over the Humber ($27.1 \cdot 10^6$ m^3), Don ($19.2 \cdot 10^6$ m^3), Etobicoke ($13.3 \cdot 10^6$ m^3), and Rouge ($11.3 \cdot 10^6$ m^3) watersheds. The Mimico watershed had on average the highest precipitation (77.9 mm), but due to its small size this watershed only received $6 \cdot 10^6$ m^3. The Humber watershed had on the other hand a much lower average precipitation (29.8 mm) but received the highest total amount of precipitation due to its larger size.

Table 4-4: Total Precipitation across the TRCA Watersheds (July 16, 2024)

Watershed	Area (km^2)	Precipitation (10^6 m^3)	Average precipitation (mm)
TRCA jurisdiction	2488	103.5	41.6
Highland	101	5.6	54.7
Petticoat	27	1.2	43.8
Frenchman's Bay	27	1.3	49.7
Mimico	77	6.0	77.9
Carruthers	38	1.8	48.5
Duffins	286	8.3	29.1
Rouge	332	11.3	34.0
Etobicoke	211	13.3	63.1
Don	358	19.2	53.6
Humber	909	27.1	29.8
Lakefront areas	121	8.4	68.9

4.2.2 Duration

Rainfall duration during the day of the July 16, 2024 was calculated for the high-resolution gauge stations provided by TRCA, City of Toronto, and City of Mississauga (Section 3.1). The coarse temporal resolution of the ECCC stations lead to an overestimation of the rainfall duration which required the exclusion of the ECCC stations from the rainfall duration calculation. As before, the stations with insufficient or missing data were discarded and the remaining stations provide a spatial dataset of total precipitation across the TRCA jurisdiction. Using the methodology presented in Section 2.2.1, these spatially distributed data points were used to create a gridded dataset of rainfall duration. Isolines were then calculated from this dataset to define duration isolines (Figure 4-21). The longest duration stations are located further west than the areas of highest total precipitation (Figure 4-20), which suggest an unequal rainfall intensity. A maximum duration of 290 minutes (4.83 hours) was registered at the RG_051 station (City of Toronto network). The rainfall duration is relatively homogeneous across the TRCA region, with the north and north-west having shorter rainfall and the areas along the shoreline having longer rainfall durations. As this does not reflect the pattern of total precipitation (Figure 4-20), it suggests an unequal rainfall intensity.

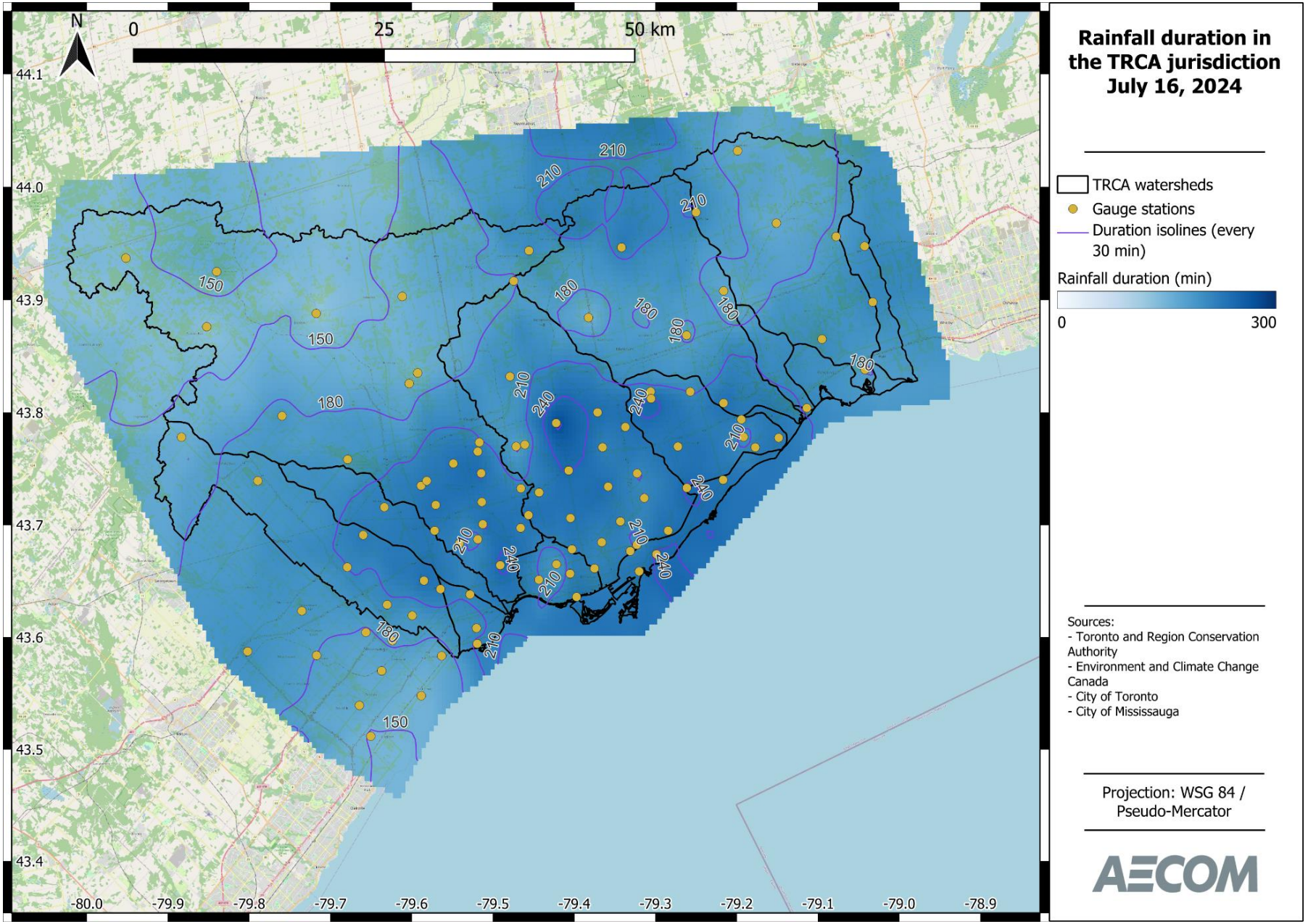


Figure 4-21: Map of Precipitation Duration across the TRCA Region (July 16, 2024)

4.2.3 Intensities

The average intensity or rainfall rate at each station was calculated by dividing the total precipitation during the day by the calculated duration. The spatial distribution of rainfall intensity shows a very intense rainfall in the south of the TRCA jurisdiction and Mississauga (Figure 4-22). The maximum intensity was 34.47 mm/h, recorded at the RG07 station (Streetsville station in the City of Mississauga network, 43.584° N, -79.717° E) outside the TRCA jurisdiction. Within the TRCA jurisdiction, the maximum hourly intensity was 29 mm/h recorded at the HY099 station (Rathwood station in the TRCA network, 43.629° N, -79.630° E).

The maximum 5-minutes intensity (Figure 4-23) during the July 16 event shows a similar spatial pattern to the average precipitation intensity. The highest value of 5-minutes precipitation was 16.0 mm in the HY099 station (TRCA network). The maximum 1-hour intensity (Figure 4-24) shows a maximum roughly located around the Toronto Pearson International Airport and smaller local maximums around Toronto City Centre and the municipalities of Markham and Ajax in the east. This is a similar pattern to that of the total rainfall during the event (Figure 4-20), with the same maximums although slightly displaced. The highest value of 1-hour precipitation was 58.6 mm measured at the HY067 station (West Humber at Hwy7 station in the TRCA network, 43.758° N, -79.679° E).

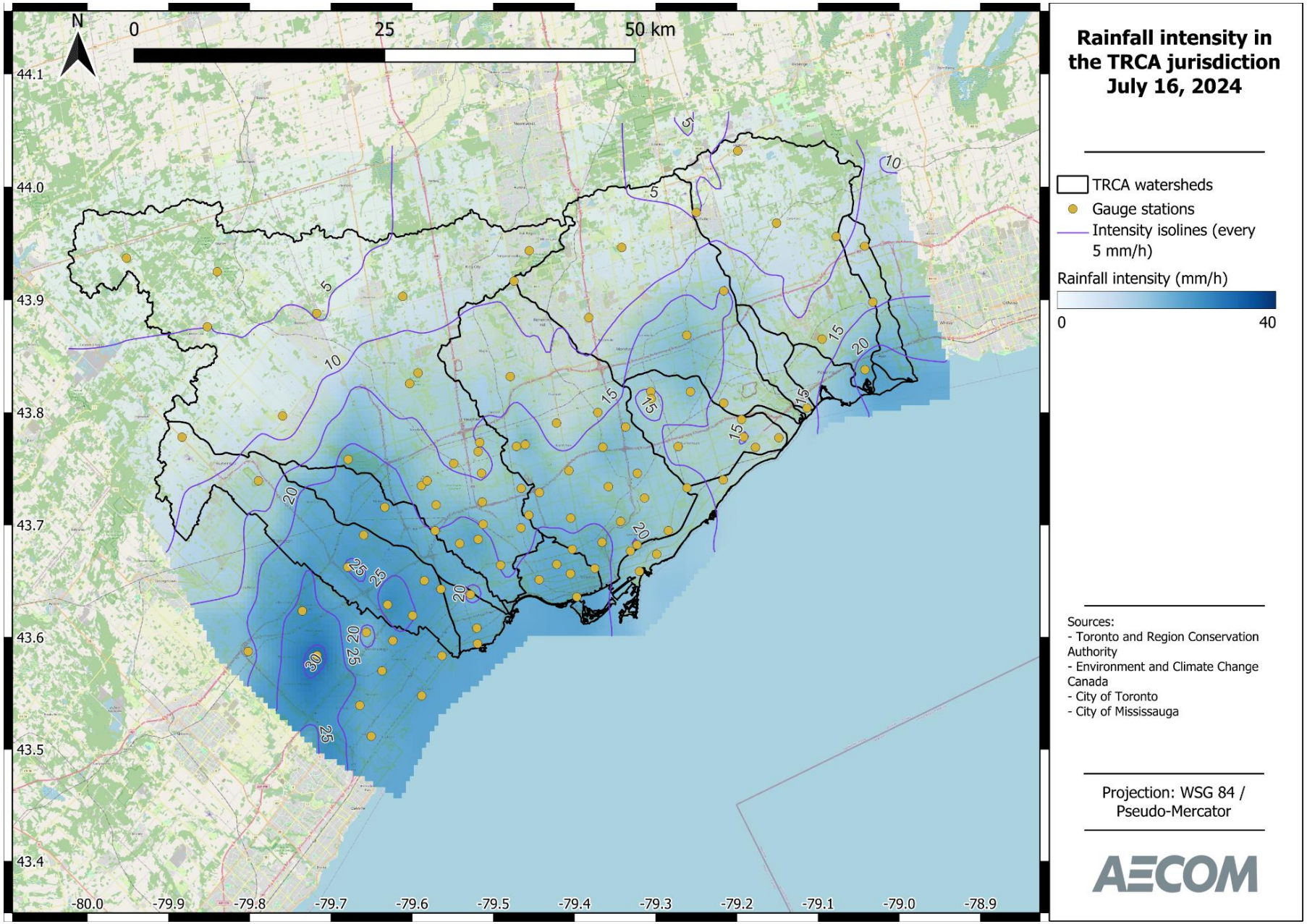


Figure 4-22: Map of Average Precipitation Intensity over the TRCA Region (July 16, 2024)

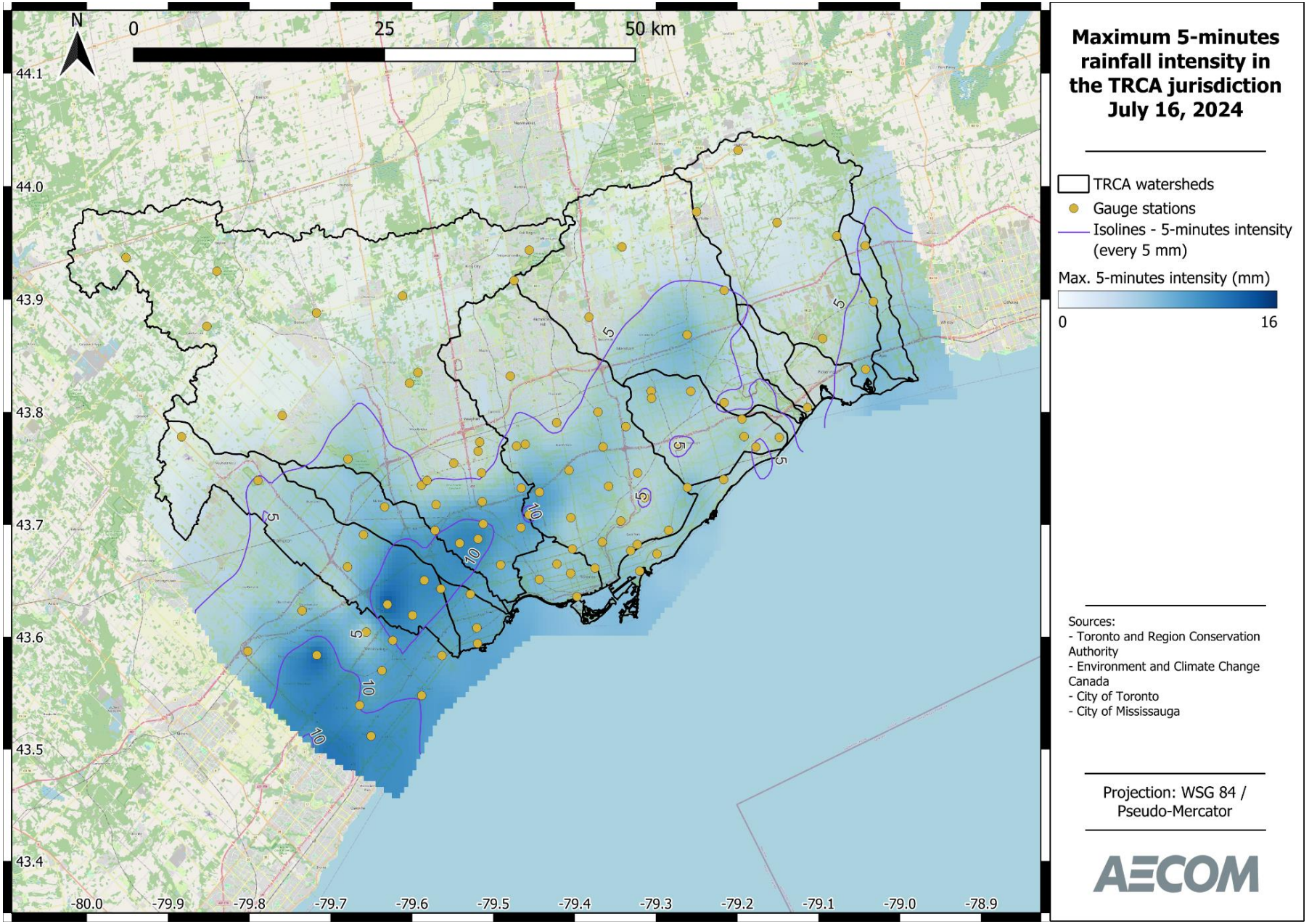


Figure 4-23: Map of Maximum 5-minutes Rainfall Intensity in the TRCA Jurisdiction (July 16, 2024)

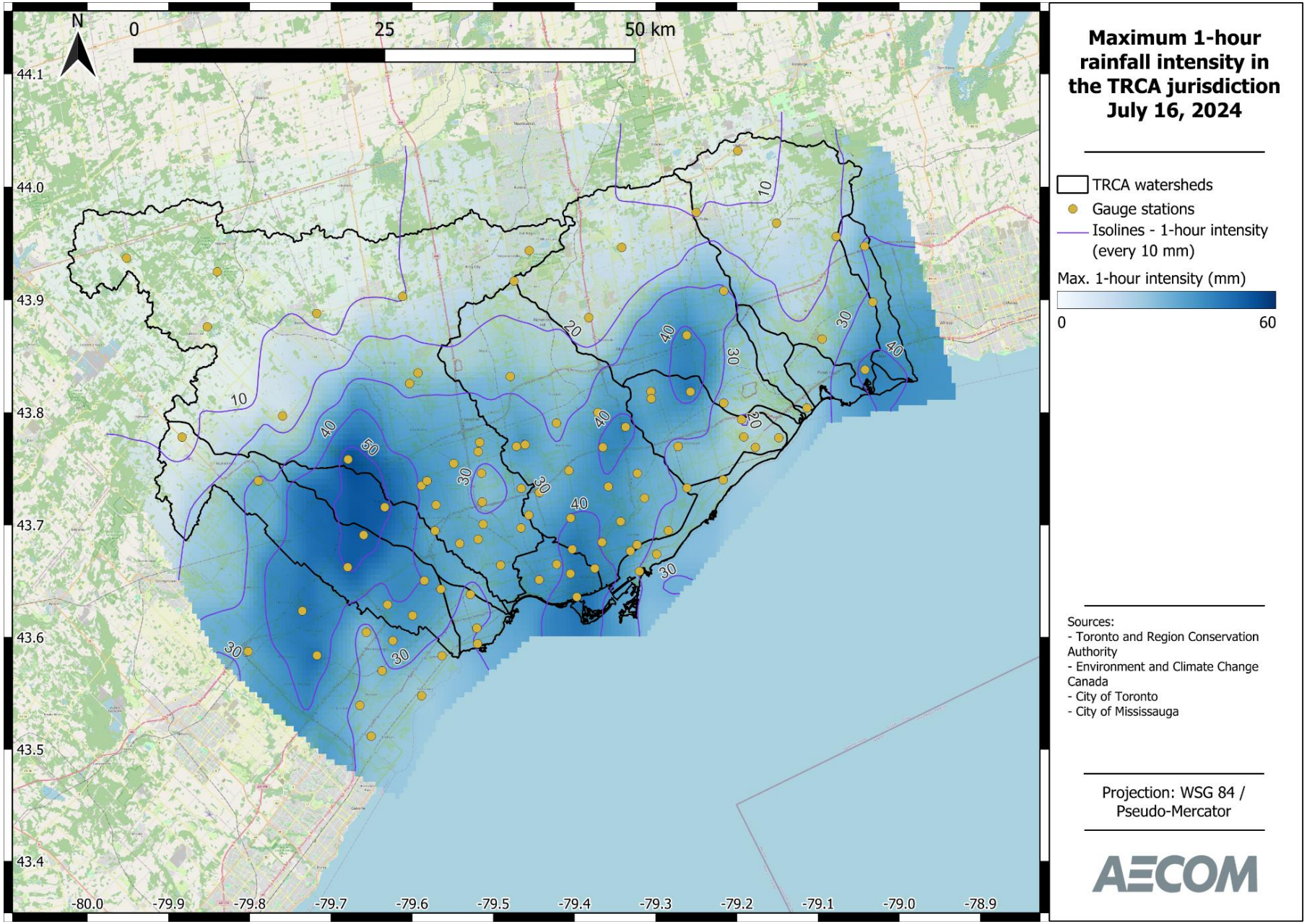


Figure 4-24: Map of Maximum 1-hour Rainfall Intensity in the TRCA Jurisdiction (July 16, 2024)

4.3 Plain-Language Summary

An extreme rainfall event affected a narrow band across southern Ontario, including the Greater Toronto Area (GTA) on the morning of July 16, 2024, with over 4 hours of successive thunderstorms passing over the same area depositing up to ~100 mm of rain locally. The most intense rainfall occurred between 9:48 AM and 10:36 AM in the TRCA jurisdiction.

The atmospheric instability was sufficient for thunderstorms to develop, and the large-scale meteorological setup was favorable for rising air and contained triggers for the thunderstorms. In addition, there was a very humid air mass in place due to the transport of Gulf of Mexico moisture into southeastern Canada, indicating the potential for intense rainfall rates with any thunderstorms. However, by itself, the large-scale setup could not indicate the potential for successive thunderstorms for multiple hours, nor could it indicate the exact locations of localized extreme rainfall deposited by the smaller-scale thunderstorms. The thunderstorms were triggered by a smaller-scale weather system resulting from a cluster of thunderstorms over the Midwest U.S. just 15 hours earlier.

Smaller-scale weather systems, such as the one that affected the GTA on July 16, have a shorter lead time for forecasting, and this particular extreme rainfall event was poorly forecasted. At 12:52 PM, just 20 hours before the onset of the extreme rainfall, ECCC indicated only a 40% chance of showers in Toronto during the event, with no indication of any potential for heavy rainfall. Based on the lack of heavy rainfall expected, at 11:25 AM, the TRCA issued a Watershed Conditions Statement – Water Safety, in relation to thunderstorm risk for that day (July 15), indicating that residents should avoid being near water due to higher water levels in streams, but that no immediate flooding was expected that day on July 15. At this time, water levels in most of TRCA watercourses were normal or slightly above normal. Weather models had shown a wide range of possible rainfall amounts for July 16, illustrating great uncertainty, though they all underestimated the rainfall in the area of heaviest rainfall.

When the storm was approaching the GTA just a few hours before the event, well after the small-scale weather system developed over the Midwest U.S., high-resolution weather models showed the potential for a period of heavy rain and thunderstorms for several hours that morning, though it was not clear that it would occur in the GTA. The first ECCC alert for the TRCA was a severe thunderstorm watch issued at 8:22 AM on July 16, less than 30 minutes before the onset of rainfall in the TRCA, providing minimal opportunity for the public and authorities to prepare for the impending extreme rainfall. As the storm got underway, ECCC's rainfall forecast was increased from 20-30 mm at 8:53 AM to 50-70 mm at 9:52 AM and then finally to 80-100 mm at 11 AM, after the most intense rainfall had already occurred. The TRCA responded by issuing a flood watch at 9:23 AM and then a flood warning at 11:52 AM.

While the rainfall duration was relatively homogeneous across the TRCA region, the rainfall intensity and total amount varied widely within the TRCA, typical of summer thunderstorms. The rainfall rates and total amounts were maximized within 25 km of the Lake Ontario shoreline, the region where successive thunderstorm cores trained, especially in the southwestern portions of the TRCA. Areas to the north and east received less than 30 mm, no more than a typical summer thunderstorm. Among the TRCA watersheds, the Mimico watershed had on average the highest intensity, but the much larger Humber watershed received the highest total amount of precipitation even with a lower intensity.

5. Extreme Rainfall of August 17, 2024

5.1 Storm Overview

In this section, preceding weather conditions and the formation and development of the storm that led to the extreme rainfall event on August 17, 2024, over the GTA within TRCA's jurisdiction are examined. First, to provide a comprehensive understanding, the meteorological context leading up to the storm was analyzed. This includes an analysis of the chronology of events using flood messages issued by the TRCA and severe weather forecasts from the MSC of ECCC. Subsequently, multiparameter weather maps, radar imagery, tephigram soundings, surface observations, and past forecasts are discussed. This analysis aims to provide a deeper understanding of the storm's development and the extreme weather conditions it caused, which were only briefly addressed in the public weather warnings and bulletins.

5.1.1 Chronology of the Event

5.1.1.1 METAR

The chronology of the event can be effectively reconstructed using METAR, which are provided by most airports. These observation reports include hourly codes and annotations that facilitate the sharing of weather data, particularly for the aviation industry to inform nearby pilots of prevailing weather conditions. Pearson International Airport (CYYZ) reported light showers on August 17, 2024 at 12:10 PM. Over the following 40 minutes, the rain showers transition into first light and then heavy thunderstorms. Until 4:35 PM, rain shower and thunderstorms were reported at Pearson International Airport (CYYZ). The Toronto City Centre Airport (CYTZ) first reported thunderstorms at 12:28 PM. Multiple reports of thunderstorms and thunderstorms in the vicinity were recorded until 3:13 PM. A second series of thunderstorms report were issued between 4:21 PM and 6:21 PM (Appendices B.2.1 and B.2.2).

5.1.1.1 Warnings and Bulletins

The chronology of the event can further be described by reviewing the publicly available information from the day leading up to and of the event. To provide this perspective, severe weather warnings and bulletins issued by the MSC, along with flood warnings by TRCA were utilized (Table 5-1). TRCA's Flood Forecasting and Warning Program, issues flood warnings to local agencies and the public, based on continuous monitoring of weather conditions and flood forecasts.

Table 5-1: Chronological List of Forecasts, Weather Warnings, Alerts, and Bulletins (August 17, 2024)

Date and Time	Type	Description
Friday, August 16, 2024, 2:46 PM	Special Weather Statement issued by Environment Canada for City of Toronto, Mississauga – Brampton, Pickering – Oshawa – Southern Durham Region, Vaughan – Richmond Hill – Markham	SIGNIFICANT RAINFALL IS EXPECTED THIS WEEKEND. HAZARDS: LOCAL RAINFALL AMOUNTS OF 30 TO 60 MM. RAINFALL RATES OF UP TO 40 MM IN AN HOUR. TIMING: BEGINNING THIS EVENING AND CONTINUING THROUGH SUNDAY. DISCUSSION: RAIN WILL BEGIN THIS EVENING AND CONTINUE INTO SUNDAY. THE HEAVIEST RAINFALL IS EXPECTED ON SATURDAY. LOCALLY HIGHER AMOUNTS ARE POSSIBLE SATURDAY AFTERNOON AND EVENING. THIS WEATHER PATTERN TYPICALLY BRINGS RAPIDLY CHANGING CONDITIONS BETWEEN SUNNY SKIES AND HEAVY

Date and Time	Type	Description
		DOWNPOURS. RAINFALL WARNINGS MAY BE REQUIRED AND ISSUED ON SHORT NOTICE TO REFLECT RAPIDLY CHANGING CONDITIONS. HEAVY DOWNPOURS CAN CAUSE FLASH FLOODS AND WATER POOLING ON ROADS. LOCALIZED FLOODING IN LOW-LYING AREAS IS POSSIBLE.
Friday, August 16, 2024, 2:49 PM	Special Weather Statement issued by Environment Canada for Caledon	SIGNIFICANT RAINFALL IS EXPECTED THIS WEEKEND. HAZARDS: LOCAL RAINFALL AMOUNTS OF 40 TO 80 MM. RAINFALL RATES OF UP TO 40 MM IN AN HOUR. TIMING: BEGINNING THIS EVENING AND CONTINUING THROUGH SUNDAY. DISCUSSION: RAIN WILL BEGIN THIS EVENING AND CONTINUE INTO SUNDAY. THE HEAVIEST RAINFALL IS EXPECTED ON SATURDAY. LOCALLY HIGHER AMOUNTS ARE POSSIBLE SATURDAY AFTERNOON AND EVENING. THIS WEATHER PATTERN TYPICALLY BRINGS RAPIDLY CHANGING CONDITIONS BETWEEN SUNNY SKIES AND HEAVY DOWNPOURS. RAINFALL WARNINGS MAY BE REQUIRED AND ISSUED ON SHORT NOTICE TO REFLECT RAPIDLY CHANGING CONDITIONS. HEAVY DOWNPOURS CAN CAUSE FLASH FLOODS AND WATER POOLING ON ROADS. LOCALIZED FLOODING IN LOW-LYING AREAS IS POSSIBLE.
Friday, August 16, 2024, 3:01 PM	TRCA Flood Message Issuance: Watershed Conditions Statement – Water Safety	Due to saturated soil conditions, heavy rainfall associated with thunderstorms Friday and Saturday will cause water levels to rise in watercourses. Total of 30-60mm of rainfall is expected over two days. People should be reminded to stay away from watercourses as they will be high and fast flowing, and the banks may be slippery.
Friday, August 16, 2024, 3:30 PM	Public Forecasts by Environment Canada	CITY OF TORONTO. SATURDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM IN THE MORNING AND AFTERNOON. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING EAST 20 KM/H LATE IN THE AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 5 OR MODERATE. SATURDAY NIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H. LOW 20. MISSISSAUGA - BRAMPTON. SATURDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM IN THE MORNING AND AFTERNOON. LOCAL AMOUNT 10 TO 20 MM. WIND SOUTHWEST 30 KM/H BECOMING LIGHT LATE IN THE MORNING. WIND BECOMING SOUTHWEST 20 IN THE AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 5 OR MODERATE.

Date and Time	Type	Description
		SATURDAY NIGHT..SHOWERS. RISK OF A THUNDERSTORM IN THE EVENING. LOCAL AMOUNT 5 TO 10 MM. LOW 20. CALEDON. SATURDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM IN THE MORNING AND AFTERNOON. LOCAL AMOUNT 20 TO 30 MM. WIND BECOMING SOUTHWEST 20 KM/H LATE IN THE MORNING. HIGH 24. HUMIDEX 32. UV INDEX 5 OR MODERATE. SATURDAY NIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. LOW 19. VAUGHAN - RICHMOND HILL - MARKHAM. SATURDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM IN THE MORNING AND AFTERNOON. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHEAST 30 KM/H LATE IN THE AFTERNOON. HIGH 25. HUMIDEX 33. UV INDEX 5 OR MODERATE. SATURDAY NIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 30 KM/H BECOMING LIGHT NEAR MIDNIGHT. LOW 20. PICKERING - OSHAWA - SOUTHERN DURHAM REGION. SATURDAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS IN THE MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM IN THE MORNING AND AFTERNOON. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHEAST 20 KM/H LATE IN THE AFTERNOON. HIGH 25. HUMIDEX 34. UV INDEX 5 OR MODERATE. SATURDAY NIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H BECOMING LIGHT NEAR MIDNIGHT. LOW 19.
Saturday, August 17, 2024, 4:58 AM	Special Weather Statement issued by Environment Canada for City of Toronto, Mississauga – Brampton, Pickering – Oshawa – Southern Durham Region, Vaughan – Richmond Hill – Markham	SIGNIFICANT RAINFALL IS EXPECTED THIS WEEKEND. HAZARDS: LOCAL RAINFALL AMOUNTS OF 30 TO 60 MM. RAINFALL RATES OF UP TO 40 MM IN AN HOUR. TIMING: CONTINUING THIS MORNING THROUGH SUNDAY. DISCUSSION: RAIN WILL CONTINUE INTO SUNDAY. LOCALLY HIGHER AMOUNTS IN THUNDERSTORMS ARE POSSIBLE THIS AFTERNOON AND EVENING. THIS WEATHER PATTERN TYPICALLY BRINGS RAPIDLY CHANGING CONDITIONS BETWEEN SUNNY SKIES AND HEAVY DOWNPOURS. RAINFALL WARNINGS MAY BE REQUIRED AND ISSUED ON SHORT NOTICE TO REFLECT RAPIDLY CHANGING CONDITIONS.

Date and Time	Type	Description
		HEAVY DOWNPOURS CAN CAUSE FLASH FLOODS AND WATER POOLING ON ROADS. LOCALIZED FLOODING IN LOW-LYING AREAS IS POSSIBLE.
Saturday, August 17, 2024, 5:00 AM	Public Forecasts by Environment Canada	CITY OF TORONTO. TODAY..CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS THIS MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING EAST 20 KM/H LATE THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. MISSISSAUGA - BRAMPTON. TODAY..CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS THIS MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHWEST 30 KM/H THIS MORNING. HIGH 27. HUMIDEX 35. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS. RISK OF A THUNDERSTORM THIS EVENING. LOCAL AMOUNT 5 TO 10 MM. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 15 MM. HIGH 25. HUMIDEX 32. UV INDEX 3 OR MODERATE. CALEDON. TODAY..CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS THIS MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND BECOMING SOUTHWEST 20 KM/H LATE THIS MORNING. HIGH 24. HUMIDEX 32. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. LOW 19. SUNDAY..SHOWERS. RISK OF A THUNDERSTORM IN THE MORNING. LOCAL AMOUNT 5 TO 10 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS THIS MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHEAST 30 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 33. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 30 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE. PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TODAY..CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS THIS MORNING. SHOWERS BEGINNING NEAR NOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHEAST 20 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 34. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 19.

Date and Time	Type	Description
		SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE.
Saturday, August 17, 2024, 5:02 AM	Special Weather Statement issued by Environment Canada for Caledon	SIGNIFICANT RAINFALL IS EXPECTED THIS WEEKEND. HAZARDS: LOCAL RAINFALL AMOUNTS OF 40 TO 80 MM. RAINFALL RATES OF UP TO 40 MM IN AN HOUR. TIMING: CONTINUING THROUGH SUNDAY. DISCUSSION: RAIN WILL CONTINUE THIS MORNING INTO SUNDAY. LOCALLY HIGHER AMOUNTS IN THUNDERSTORMS ARE POSSIBLE THIS AFTERNOON AND EVENING. THIS WEATHER PATTERN TYPICALLY BRINGS RAPIDLY CHANGING CONDITIONS BETWEEN SUNNY SKIES AND HEAVY DOWNPOURS. RAINFALL WARNINGS MAY BE REQUIRED AND ISSUED ON SHORT NOTICE TO REFLECT RAPIDLY CHANGING CONDITIONS. HEAVY DOWNPOURS CAN CAUSE FLASH FLOODS AND WATER POOLING ON ROADS. LOCALIZED FLOODING IN LOW-LYING AREAS IS POSSIBLE.
Saturday, August 17, 2024, 7:55 AM	Updated Public Forecasts by Environment Canada	PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TODAY..SHOWERS CHANGING TO 40 PERCENT CHANCE OF SHOWERS THEN CHANGING TO SHOWERS NEAR NOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHEAST 20 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 34. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 19. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE.
Saturday, August 17, 2024, 8:52 AM	Updated Public Forecasts by Environment Canada	CITY OF TORONTO. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND BECOMING EAST 20 KM/H LATE THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. MISSISSAUGA - BRAMPTON. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND SOUTHWEST 30 KM/H BECOMING LIGHT LATE THIS MORNING. WIND BECOMING SOUTHWEST 20 THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS. RISK OF A THUNDERSTORM THIS EVENING. LOCAL AMOUNT 5 TO 10 MM. LOW 20.

Date and Time	Type	Description
		SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 15 MM. HIGH 25. HUMIDEX 32. UV INDEX 3 OR MODERATE. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND BECOMING SOUTHEAST 30 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 30 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE.
Saturday, August 17, 2024, 10:58 AM	Severe Thunderstorm Watch issued by Environment Canada for City of Toronto	CONDITIONS ARE FAVOURABLE FOR THE DEVELOPMENT OF SEVERE THUNDERSTORMS THAT MAY BE CAPABLE OF PRODUCING STRONG WIND GUSTS, LARGE HAIL AND HEAVY RAIN. HAZARDS: 90 KM/H WIND GUSTS. TOONIE SIZE HAIL. HEAVY DOWNPOURS. THERE IS A RISK OF TORNADOES. TIMING: TODAY THROUGH THIS EVENING. DISCUSSION: THUNDERSTORMS HAVE DEVELOPED THAT MAY BE CAPABLE OF PRODUCING 90 KM/H WIND GUSTS AND TOONIE SIZE HAIL. RAINFALL RATES OF 40 MM ARE POSSIBLE WITH THESE THUNDERSTORMS. REFER TO THE SPECIAL WEATHER STATEMENT IN EFFECT FOR DETAILS ON RAINFALL TOTALS.
Saturday, August 17, 2024, 11:00 AM	Public Forecasts by Environment Canada	CITY OF TORONTO. TODAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS EARLY THIS AFTERNOON. SHOWERS BEGINNING THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING EAST 20 KM/H LATE THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 7 OR HIGH. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. MISSISSAUGA - BRAMPTON. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHWEST 20 KM/H THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS. RISK OF A THUNDERSTORM THIS EVENING. LOCAL AMOUNT 5 TO 10 MM. LOW 20.

Date and Time	Type	Description
		SUNDAY..SHOWERS. RISK OF A THUNDERSTORM IN THE AFTERNOON. LOCAL AMOUNT 10 TO 15 MM. HIGH 25. HUMIDEX 32. UV INDEX 3 OR MODERATE. CALEDON. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND SOUTHWEST 20 KM/H. HIGH 24. HUMIDEX 32. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. LOW 19. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 15 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS EARLY THIS AFTERNOON. SHOWERS BEGINNING THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHEAST 30 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 33. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 30 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE. PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TODAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS EARLY THIS AFTERNOON. SHOWERS BEGINNING THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING SOUTHEAST 20 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 34. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 19. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE.
Saturday, August 17, 2024, 11:31 AM	Tornado Watch issued by Environment Canada for Caledon	CONDITIONS ARE FAVOURABLE FOR THE DEVELOPMENT OF SEVERE THUNDERSTORMS WHICH MAY PRODUCE TORNADOES. STRONG WINDS, LARGE HAIL AND HEAVY RAIN ARE ALSO POSSIBLE. HAZARDS: TORNADOES. 90 KM/H WIND GUSTS. TOONIE SIZE HAIL. HEAVY DOWNPOURS. TIMING: TODAY THROUGH THIS EVENING. DISCUSSION: THUNDERSTORMS HAVE DEVELOPED THAT MAY BE CAPABLE OF PRODUCING TORNADOES ALONG WITH 90 KM/H WIND GUSTS AND TOONIE SIZE HAIL. RAINFALL RATES OF 40 MM PER HOUR ARE POSSIBLE WITH THESE THUNDERSTORMS. REFER TO THE SPECIAL WEATHER STATEMENT IN EFFECT FOR DETAILS ON RAINFALL TOTALS.

Date and Time	Type	Description
		THESE STORMS WILL DISSIPATE THIS EVENING AS DAYTIME HEATING COMES TO AN END.
Saturday, August 17, 2024, 12:23 PM	Updated Public Forecasts by Environment Canada	CITY OF TORONTO. TODAY..MAINLY CLOUDY. 40 PERCENT CHANCE OF SHOWERS EARLY THIS AFTERNOON. SHOWERS BEGINNING THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND BECOMING EAST 20 KM/H LATE THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 7 OR HIGH. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. MISSISSAUGA - BRAMPTON. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 30 TO 40 MM. WIND BECOMING SOUTHWEST 20 KM/H THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS. RISK OF A THUNDERSTORM THIS EVENING. LOCAL AMOUNT 5 TO 10 MM. LOW 20. SUNDAY..SHOWERS. RISK OF A THUNDERSTORM IN THE AFTERNOON. LOCAL AMOUNT 10 TO 15 MM. HIGH 25. HUMIDEX 32. UV INDEX 3 OR MODERATE. CALEDON. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND SOUTHWEST 20 KM/H. HIGH 24. HUMIDEX 32. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. LOW 19. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 15 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..CLOUDY. 40 PERCENT CHANCE OF SHOWERS EARLY THIS AFTERNOON. SHOWERS BEGINNING THIS AFTERNOON. RISK OF A THUNDERSTORM. LOCAL AMOUNT 20 TO 30 MM. WIND BECOMING SOUTHEAST 30 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 33. UV INDEX 5 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 30 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE.
Saturday, August 17, 2024, 1:44 PM	Rainfall Warning issued by Environment Canada for City of Toronto, Mississauga – Brampton, Caledon, Vaughan – Richmond Hill – Markham	HEAVY RAIN CONTINUES. HAZARDS: LOCAL RAINFALL AMOUNTS OF 50 TO 100 MM. RAINFALL RATES OF UP TO 40 MM IN AN HOUR. TIMING: CONTINUING THIS AFTERNOON THROUGH SUNDAY.

Date and Time	Type	Description
		DISCUSSION: RAIN WILL CONTINUE THIS AFTERNOON THROUGH SUNDAY. LOCALLY HIGHER AMOUNTS IN THUNDERSTORMS ARE POSSIBLE THIS AFTERNOON AND EVENING.
Saturday, August 17, 2024, 2:00 PM	TRCA Flood Message Issuance: Flood Watch	TRCA has upgraded its previous Watershed Conditions Statement – Water Safety and replacing it with a Flood Watch. TRCA advises that ECCC has issued severe thunderstorm warnings with the potential to bring up to 50mm per hour for most of the TRCA jurisdiction. The Southwest portion of TRCA's jurisdiction has already received 81 mm within one hour.
Saturday, August 17, 2024, 2:12 PM	Special Weather Statement end issued by Environment Canada for Caledon	
Saturday, August 17, 2024, 2:13 PM	Special Weather Statement end issued by Environment Canada for City of Toronto, Mississauga – Brampton, Vaughan – Richmond Hill - Markham	
Saturday, August 17, 2024, 2:26 PM	Updated Public Forecasts by Environment Canada	CITY OF TORONTO. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 40 TO 50 MM. WIND BECOMING EAST 20 KM/H LATE THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 2 OR LOW. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. MISSISSAUGA - BRAMPTON. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 40 TO 50 MM. WIND SOUTHWEST 20 KM/H. HIGH 27. HUMIDEX 35. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS. RISK OF A THUNDERSTORM THIS EVENING. LOCAL AMOUNT 5 TO 10 MM. LOW 20. SUNDAY..SHOWERS. RISK OF A THUNDERSTORM IN THE AFTERNOON. LOCAL AMOUNT 10 TO 15 MM. HIGH 25. HUMIDEX 32. UV INDEX 3 OR MODERATE. CALEDON. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 40 TO 50 MM. WIND SOUTHWEST 20 KM/H. HIGH 24. HUMIDEX 32. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. LOW 19. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 15 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 40 TO 50 MM. WIND BECOMING SOUTHEAST 30 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 30 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 20.

Date and Time	Type	Description
		SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE.
Saturday, August 17, 2024, 2:44 PM	Rainfall Warning update issued by Environment Canada for Pickering – Oshawa – Southern Durham Region, City of Toronto, Mississauga – Brampton, Caledon, Vaughan – Richmond Hill – Markham	HEAVY RAIN CONTINUES. HAZARDS: LOCAL RAINFALL AMOUNTS OF 50 TO 100 MM. RAINFALL RATES OF UP TO 40 MM IN AN HOUR. TIMING: CONTINUING THIS AFTERNOON THROUGH SUNDAY. DISCUSSION: RAIN WILL CONTINUE THIS AFTERNOON THROUGH SUNDAY. LOCALLY HIGHER AMOUNTS IN THUNDERSTORMS ARE POSSIBLE THIS AFTERNOON AND EVENING.
Saturday, August 17, 2024, 2:59 PM	Updated Public Forecasts by Environment Canada	CITY OF TORONTO. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 50 TO 70 MM. WIND BECOMING EAST 20 KM/H LATE THIS AFTERNOON. HIGH 27. HUMIDEX 35. UV INDEX 2 OR LOW. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 20 KM/H. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. MISSISSAUGA - BRAMPTON. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 50 TO 70 MM. WIND SOUTHWEST 20 KM/H. HIGH 27. HUMIDEX 35. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS. RISK OF A THUNDERSTORM THIS EVENING. LOCAL AMOUNT 5 TO 10 MM. LOW 20. SUNDAY..SHOWERS. RISK OF A THUNDERSTORM IN THE AFTERNOON. LOCAL AMOUNT 10 TO 15 MM. HIGH 25. HUMIDEX 32. UV INDEX 3 OR MODERATE. VAUGHAN - RICHMOND HILL - MARKHAM. TODAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 40 TO 50 MM. WIND BECOMING SOUTHEAST 30 KM/H LATE THIS AFTERNOON. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. TONIGHT..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 5 TO 10 MM. WIND SOUTHEAST 30 KM/H BECOMING LIGHT LATE THIS EVENING. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 23. HUMIDEX 31. UV INDEX 3 OR MODERATE.
Saturday, August 17, 2024, 3:08 PM	Rainfall Warning update issued by Environment Canada for City of Toronto, Mississauga - Brampton	EXTREMELY HEAVY RAIN CONTINUES. HAZARDS: LOCAL RAINFALL AMOUNTS OF 100 TO 200 MM. RAINFALL RATES OF UP TO 50 MM IN AN HOUR. TIMING: CONTINUING THIS AFTERNOON THROUGH SUNDAY.

Date and Time	Type	Description
		DISCUSSION: RAIN WILL CONTINUE THIS AFTERNOON THROUGH SUNDAY. HEAVY RAIN THIS AFTERNOON HAS BROUGHT NEAR 100 MM OVER SOME LOCATIONS WITH MORE ON THE WAY. THE HEAVIEST RAIN HAS BEEN REPORTED IN THE MISSISSAUGA AND ETOBICOKE AREAS. THIS IS AN EXTREMELY DANGEROUS SITUATION AND TRAVEL IS NOT RECOMMENDED.
Saturday, August 17, 2024, 3:20 PM	Severe Thunderstorm Watch update issued by Environment Canada for City of Toronto, Mississauga – Brampton, Vaughan – Richmond Hill – Markham, Pickering – Oshawa – Southern Durham Region	CONDITIONS ARE FAVOURABLE FOR THE DEVELOPMENT OF SEVERE THUNDERSTORMS THAT MAY BE CAPABLE OF PRODUCING STRONG WIND GUSTS, LARGE HAIL AND HEAVY RAIN. HAZARDS: 90 KM/H WIND GUSTS. NICKEL SIZE HAIL. HEAVY DOWNPOURS. THERE IS A RISK OF TORNADOES. TIMING: TODAY THROUGH THIS EVENING. DISCUSSION: THE PRIMARY THREAT WITH THESE THUNDERSTORMS IS HEAVY RAIN. RAINFALL RATES OF 50 MM PER HOUR ARE POSSIBLE WITH THESE THUNDERSTORMS. REFER TO THE RAINFALL WARNINGS AND SPECIAL WEATHER STATEMENTS IN EFFECT FOR DETAILS ON RAINFALL TOTALS.
Saturday, August 17, 2024, 3:30 PM	Public Forecasts by Environment Canada	CITY OF TORONTO. TONIGHT..SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 60 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS EVENING AND OVERNIGHT. LOCAL AMOUNT 40 TO 50 MM. WIND EAST 20 KM/H BECOMING SOUTH 20 GUSTING TO 40 LATE THIS EVENING THEN LIGHT AFTER MIDNIGHT. LOW 21. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING NORTHWEST 20 KM/H LATE IN THE AFTERNOON. HIGH 26. HUMIDEX 33. UV INDEX 3 OR MODERATE. SUNDAY NIGHT..A FEW SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE EVENING. LOCAL AMOUNT 5 TO 10 MM. WIND NORTHWEST 30 KM/H GUSTING TO 50. LOW 16. MISSISSAUGA - BRAMPTON. TONIGHT..SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 60 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS EVENING AND OVERNIGHT. LOCAL AMOUNT 30 TO 40 MM. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 15 MM. WIND BECOMING NORTH 20 KM/H IN THE AFTERNOON. HIGH 26. HUMIDEX 34. UV INDEX 3 OR MODERATE. SUNDAY NIGHT..SHOWERS ENDING IN THE EVENING THEN CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE EVENING AND AFTER MIDNIGHT. WIND NORTH 30 KM/H GUSTING TO 50. LOW 15.

Date and Time	Type	Description
		CALEDON. TONIGHT..SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 60 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS EVENING AND OVERNIGHT. LOCAL AMOUNT 30 TO 40 MM. LOW 18. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 15 MM. WIND BECOMING NORTHWEST 20 KM/H GUSTING TO 40 LATE IN THE AFTERNOON. HIGH 22 WITH TEMPERATURE FALLING TO 19 IN THE AFTERNOON. HUMIDEX 30. UV INDEX 3 OR MODERATE. SUNDAY NIGHT..SHOWERS ENDING IN THE EVENING THEN CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM EARLY IN THE EVENING. WIND NORTH 30 KM/H GUSTING TO 50. LOW 14. VAUGHAN - RICHMOND HILL - MARKHAM. TONIGHT..SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 60 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS EVENING AND OVERNIGHT. LOCAL AMOUNT 30 TO 40 MM. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING NORTHWEST 20 KM/H IN THE AFTERNOON. HIGH 25. HUMIDEX 33. UV INDEX 3 OR MODERATE. SUNDAY NIGHT..A FEW SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE EVENING. LOCAL AMOUNT 5 TO 10 MM. WIND BECOMING NORTHWEST 20 KM/H GUSTING TO 40 IN THE EVENING. LOW 17. PICKERING - OSHAWA - SOUTHERN DURHAM REGION. TONIGHT..SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 60 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS EVENING AND OVERNIGHT. LOCAL AMOUNT 20 TO 30 MM. WIND SOUTHEAST 20 KM/H BECOMING LIGHT AFTER MIDNIGHT. LOW 20. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. HIGH 24. HUMIDEX 32. UV INDEX 3 OR MODERATE. SUNDAY NIGHT..A FEW SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 40 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM IN THE EVENING. LOCAL AMOUNT 5 TO 10 MM. WIND BECOMING NORTH 20 KM/H GUSTING TO 40 NEAR MIDNIGHT. LOW 17.
Saturday, August 17, 2024, 5:19 PM	Rainfall Warning update issued by Environment Canada for City of Toronto, Mississauga – Brampton, Caledon, York – Durham	RAIN, AT TIMES HEAVY, IS EXPECTED. THE GROUND, ALREADY NEAR SATURATION, HAS LITTLE ABILITY TO ABSORB FURTHER RAINFALL. HAZARDS: ADDITIONAL RAINFALL AMOUNTS OF 30 TO 60 MM. RAINFALL RATES OF UP TO 50 MM IN AN HOUR. TIMING: CONTINUING TONIGHT THROUGH SUNDAY.

Date and Time	Type	Description
		DISCUSSION: SHOWERS AND THUNDERSTORMS ARE EXPECTED TO CONTINUE TONIGHT THROUGH SUNDAY. EXTREMELY HEAVY RAIN FELL THIS AFTERNOON, SURPASSING 100 MM OVER A FEW LOCATIONS. ADDITIONAL RAINFALL IS EXPECTED TO RESULT IN FURTHER IMPACTS TONIGHT AND SUNDAY. A SLIGHT LULL IN SHOWERS AND THUNDERSTORMS IS EXPECTED OVERNIGHT BEFORE STRENGTHENING SUNDAY WITH DAYTIME HEATING INTENSIFYING THUNDERSTORMS. THIS WEATHER PATTERN TYPICALLY BRINGS RAPIDLY CHANGING CONDITIONS BETWEEN SUNNY SKIES AND HEAVY DOWNPOURS. SHOWERS AND THUNDERSTORMS ARE EXPECTED TO TAPER TO ISOLATED SHOWERS MONDAY MORNING.
Saturday, August 17, 2024, 5:40 PM	Special Weather Statement end issued by Environment Canada for Pickering – Oshawa – Southern Durham Region	
Saturday, August 17, 2024, 6:01 PM	Updated Public Forecasts by Environment Canada	ORANGEVILLE - GRAND VALLEY - SOUTHERN DUFFERIN COUNTY. TONIGHT..SHOWERS ENDING NEAR MIDNIGHT THEN CLOUDY WITH 60 PERCENT CHANCE OF SHOWERS. RISK OF A THUNDERSTORM THIS EVENING AND OVERNIGHT. LOCAL AMOUNT 10 TO 20 MM. LOW 18. SUNDAY..SHOWERS WITH RISK OF A THUNDERSTORM. LOCAL AMOUNT 10 TO 20 MM. WIND BECOMING NORTHWEST 20 KM/H GUSTING TO 40 IN THE AFTERNOON. HIGH 22 WITH TEMPERATURE FALLING TO 19 IN THE AFTERNOON. HUMIDEX 29. UV INDEX 3 OR MODERATE.
Saturday, August 17, 2024, 6:47 PM	Severe Thunderstorm Watch update issued by Environment Canada for Caledon, City of Toronto, Mississauga – Brampton, Vaughan – Richmond Hill – Markham, Pickering – Oshawa – Southern Durham Region Severe Thunderstorm Watch replaces Tornado Watch issued by Environment Canada for Caledon	CONDITIONS ARE FAVOURABLE FOR THE DEVELOPMENT OF SEVERE THUNDERSTORMS THAT MAY BE CAPABLE OF PRODUCING STRONG WIND GUSTS, LARGE HAIL AND HEAVY RAIN. HAZARDS: 90 KM/H WIND GUSTS. NICKEL SIZE HAIL. HEAVY DOWNPOURS. THERE IS A RISK OF TORNADOES. TIMING: CONTINUING THIS EVENING. DISCUSSION: THE PRIMARY THREAT WITH THESE THUNDERSTORMS IS HEAVY RAIN. RAINFALL RATES OF 50 MM PER HOUR ARE POSSIBLE WITH THESE THUNDERSTORMS. REFER TO THE RAINFALL WARNINGS AND SPECIAL WEATHER STATEMENTS IN EFFECT FOR DETAILS ON RAINFALL TOTALS. THESE THUNDERSTORM MAY ALSO BE CAPABLE OF PRODUCING 90 KM/H WIND GUSTS AND NICKEL SIZE HAIL. THESE THUNDERSTORMS WILL DISSIPATE THIS EVENING AS DAYTIME HEATING COMES TO AN END.

Date and Time	Type	Description
Sunday, August 18, 2024, 11:55 AM	Rainfall Warning update issued by Environment Canada	RAIN, AT TIMES HEAVY, IS EXPECTED. THE GROUND, ALREADY NEAR SATURATION, HAS LITTLE ABILITY TO ABSORB FURTHER RAINFALL. HAZARDS: ADDITIONAL RAINFALL AMOUNTS OF 20 MM. RAINFALL RATES OF UP TO 20 MM IN AN HOUR. TIMING: CONTINUING THROUGH TONIGHT.
Sunday, August 18, 2024, 7:00 PM	TRCA Flood Message Issuance: Update and Continuation of Flood Watch	TRCA is continuing the Flood Watch. TRCA has received 15 to 90 mm of rainfall within its jurisdiction, and up to 171mm locally in the southwest end of Mississauga over the last 48 hours. Environment Canada advises an additional 20mm is possible overnight. Flooding in TRCA watersheds is possible due to rainfall amounts received and saturated ground conditions.
Monday, August 19, 2024, 11:30 AM	TRCA Flood Message Issuance: Cancellation of Flood Watch	TRCA has cancelled its Flood Watch issued on Saturday, August 17 at 2:00 PM and is returning back to Normal Conditions. Flooding is no longer expected and river conditions are back to normal.

Source: TRCA, 2025b; ECCC, 2025b

5.1.1.2 Meteograms

For August 17, 2024, the meteograms provide a detailed temporal depiction of weather conditions before, during, and after the storm. The high-resolution precipitation accumulation is particularly significant in identifying the timing of the most intense precipitation rates. At ECCC weather stations across Toronto, the meteograms show light to medium precipitation on August 16, leading to elevated soil moisture before the onset of the heavy precipitation event on August 17. The meteogram for the Rathwood station, which measured the highest precipitation on August 17, shows an onset of precipitation around 12:50 PM. The most intense precipitation fell around 1:40 PM before the rainfall lessened and stopped at 3:20 PM (Figure 5-1). A small precipitation event occurred between 7:35 and 7:45 AM. A third event, shorter and less intense than the main event, lasted from 3:45 to 4:30 PM.

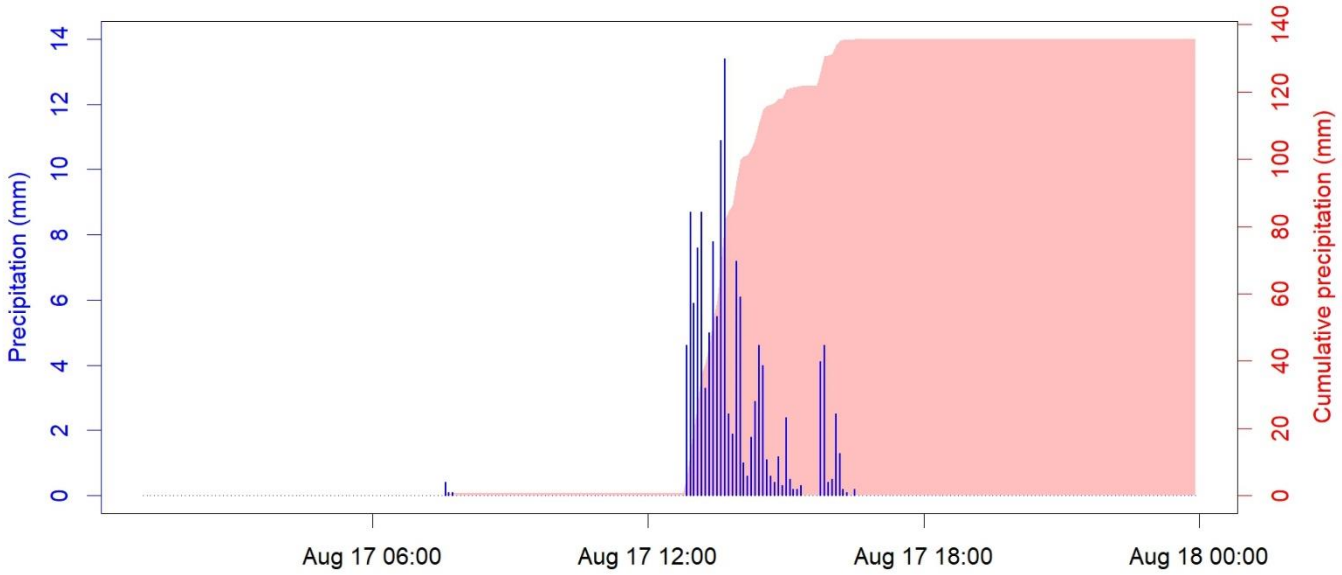


Figure 5-1: Total Precipitation Meteogram at Rathwood station (August 17, 2024)

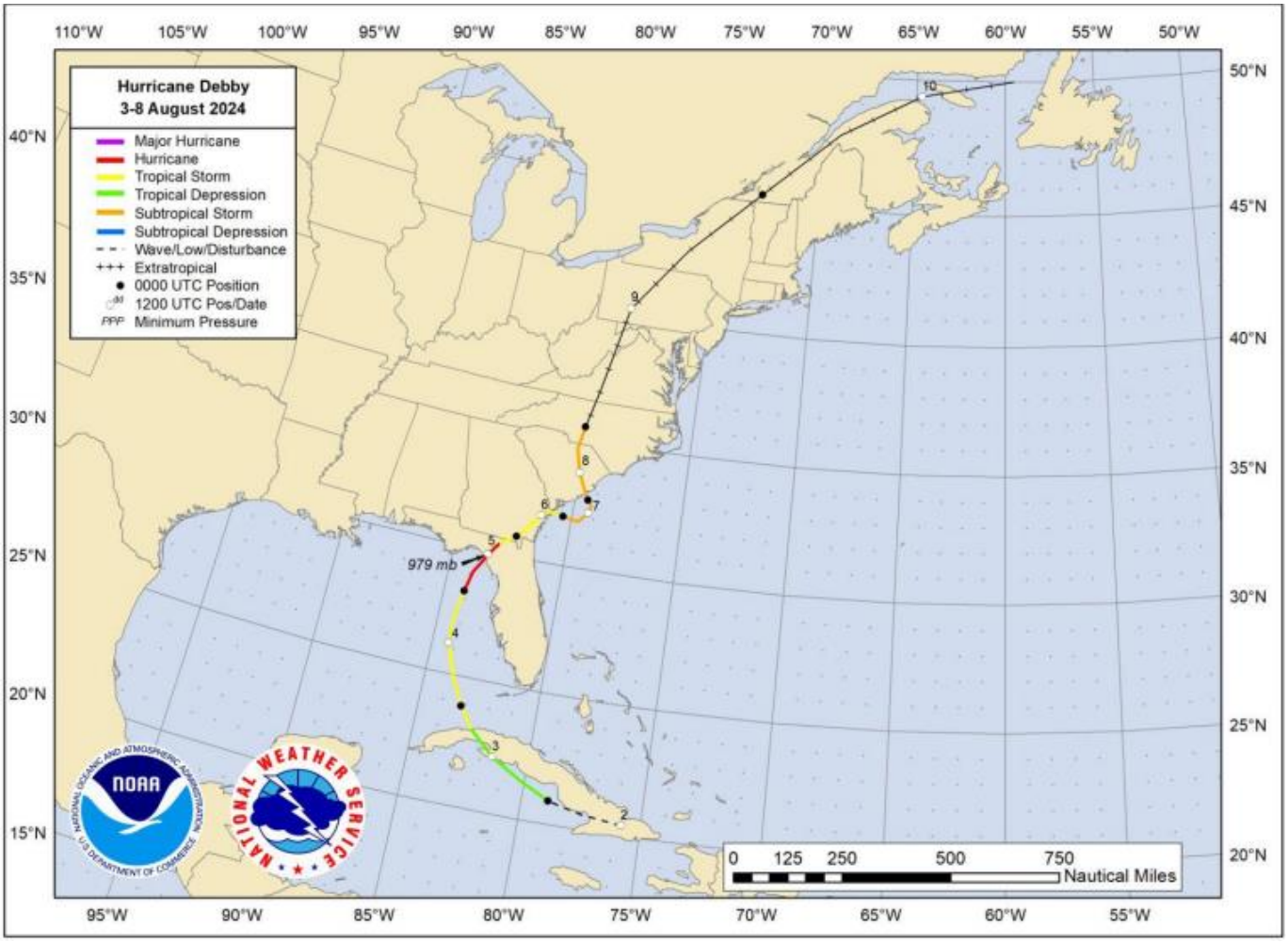
5.1.2 Atmospheric Context

5.1.2.1 Hurricane Debby

Similar to the July 16 event, the August 17 event was preconditioned by the passage of the remnants of a hurricane over New York State and Southern Quebec even though it did not track directly across the GTA. Hurricane Debby and the general moisture transport from the Gulf of Mexico brought substantial atmospheric moisture across northeastern North America that contributed at least partially to the intensity of the rainfall on August 17. The high moisture content of the ground due to previous precipitation contributed to the flooding.

Hurricane Debby initially formed as a tropical wave near the west coast of Africa on July 25-26. After a quick westward passage across the eastern and central Atlantic Ocean, its activity slowed down on July 30 due the presence of dry environmental air. On July 31, it moved over the Lesser Antilles where it brought showers and thunderstorms without having gained much organization. Over the next two days, the tropical wave showed increased organization, and the closed surface circulation developed during the passage over eastern Cuba on August 2 (Figure 5-2). Passing along Cuba southern coast, the tropical wave transitioned into a tropical depression on August 3 (Reinhart et al., 2025). After crossing northwestern Cuba, the tropical depression entered the Gulf of Mexico, where it strengthened further and became Hurricane Debby at 18 UTC that day. Extremely high sea-surface temperatures of the eastern Gulf of Mexico and weak wind shear led to a rapid intensification of Hurricane Debby before it made landfall on August 5 in the Big Bend area of Florida as a Category 1 hurricane on the Saffir-Simpson Hurricane Wind Scale. During its passage over Florida and southeastern Georgia, Hurricane Debby lost some of its strength and organization and was reclassified as a subtropical storm. A subtropical storm has characteristics of both tropical storms, which are fueled by convection and in areas of near-uniform temperatures, and extratropical cyclones, which are fueled by temperature contrasts. On August 8, Debby made a second landfall, this time as subtropical storm in South Carolina. Following the landfall, Debby moved northward, merged with a front over central North Carolina, and transitioned into an extratropical cyclone on August 9. The extratropical storm continued northeastward crossing over New York State and into southern Quebec on August 9-10 (Reinhart et al., 2025).

In southern Quebec, the remnants of Hurricane Debby brought extremely high precipitation with the Montreal International Airport recording 150.2 mm on August 9 (ECCC, 2025a). Its passage south and southwest of Lake Ontario meant that the GTA was only affected by the outer rainband. Hence, the ECCC station at Toronto City Airport measured 7.4 mm on August 9 (ECCC, 2025a). However, the most important aspect of Hurricane Debby is the atmospheric moisture that it brought to the greater region, part of which remained in the atmosphere.



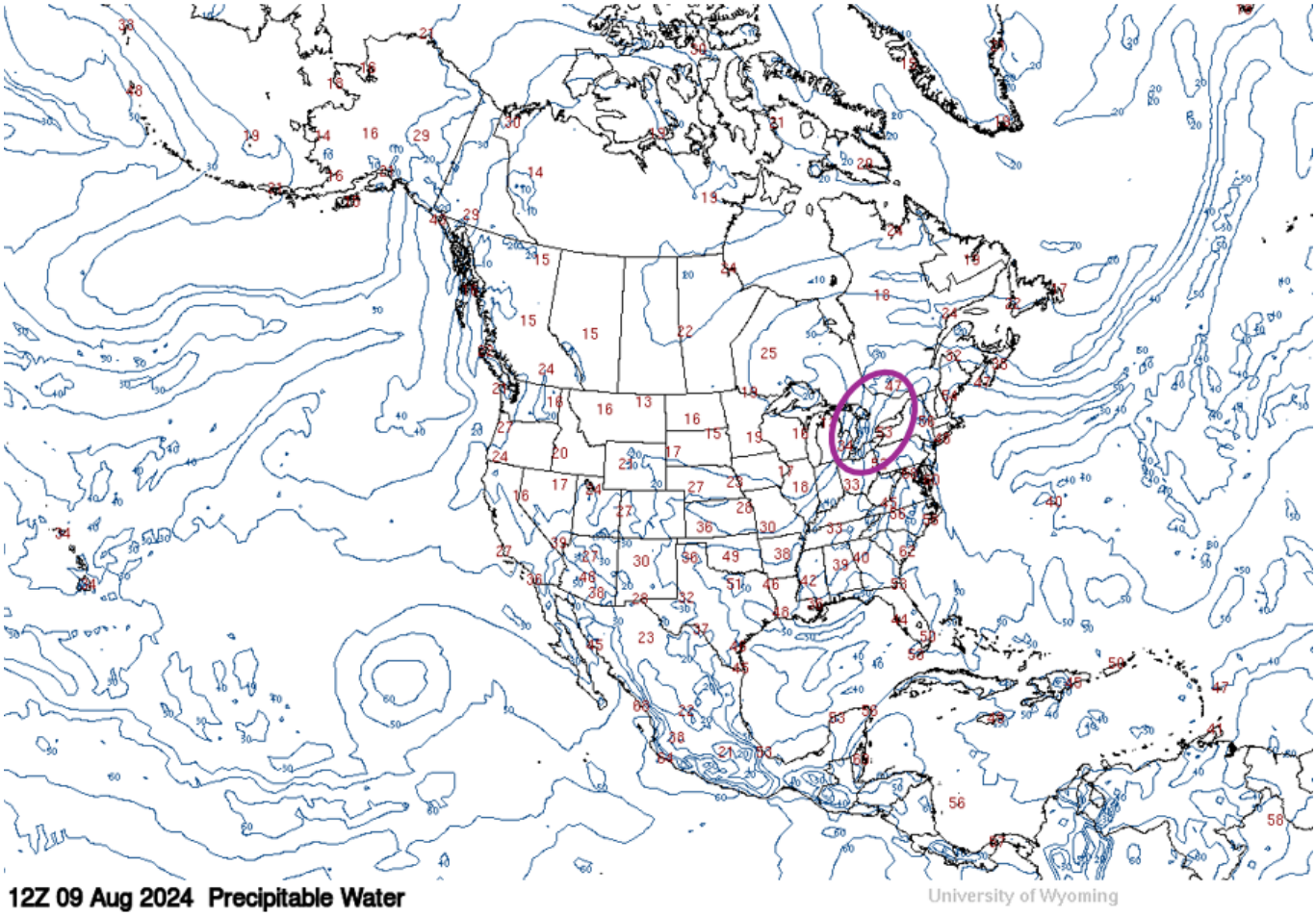
Note: Tracks over the United States and during the extratropical stage are partially based on analyses from the NOAA Weather Prediction Center and the NOAA Prediction Center.

Source: Reinhart et al., 2025

Figure 5-2: Hurricane Debby Track, 3-8 August 2024

5.1.2.1 Precipitable Water

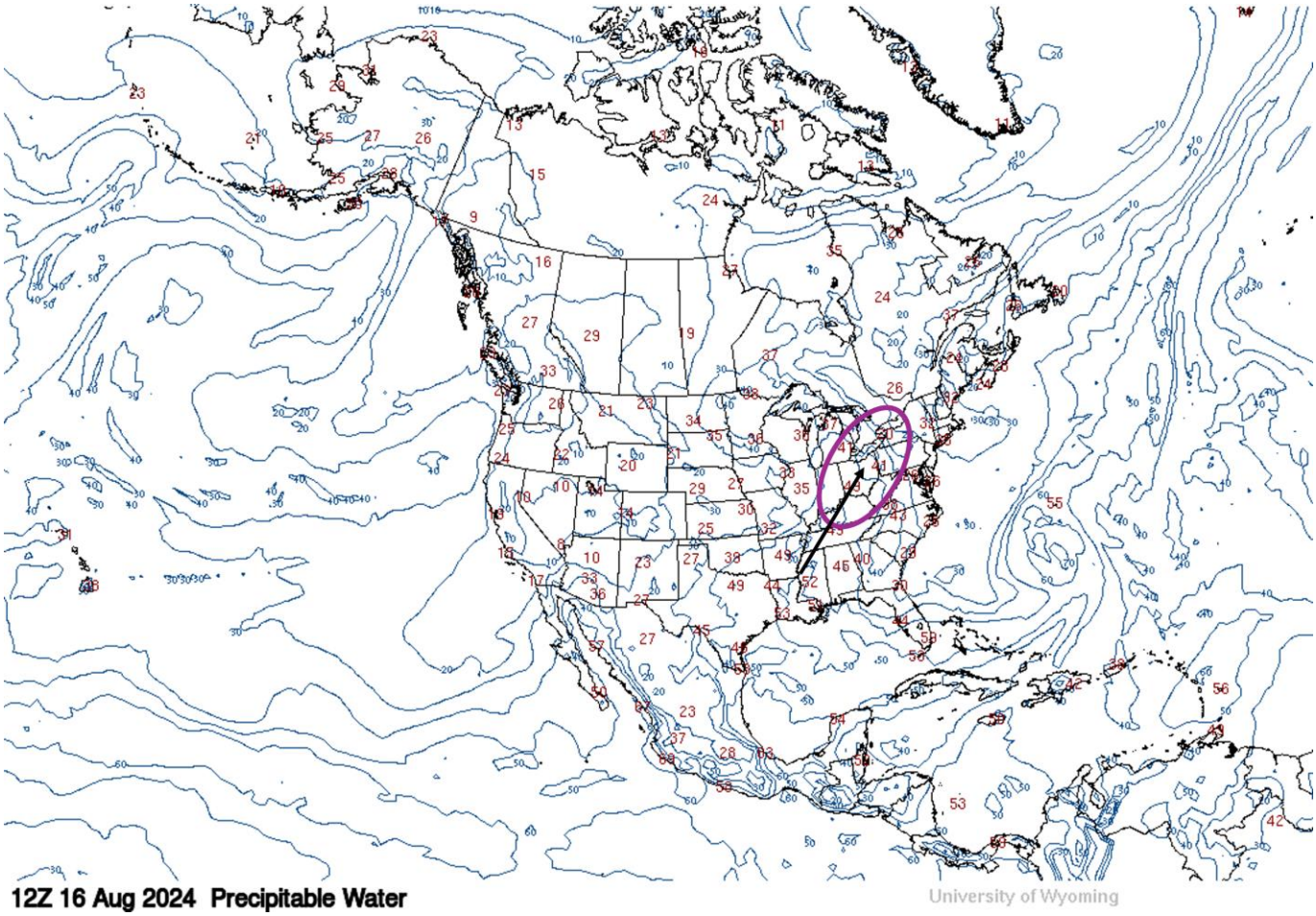
Around the time of the passage of the remnants of Debby, the Buffalo International Airport radiosonde site, situated ~100 km southeast of Toronto, recorded a precipitable water of 53 mm on August 9 at 8 AM (12Z; Figure 5-3). Following the conclusion of the precipitation events associated with the Debby over northeastern U.S., southeastern Ontario, and southern Quebec, a substantial reduction in atmospheric moisture content was observed due to the precipitation. The weather station in Buffalo recorded precipitable water of 22 mm one day after the passage of Debby. Although the atmospheric moisture was reduced by the precipitation, it was not entirely depleted, and a substantial amount remained in the atmosphere. Over the following days, the atmospheric moisture remained relatively stable. About 36 hours before the August 17 event additional moisture was advected into the greater region of northeastern U.S. and southern Ontario (Figure 5-4). This additional moisture supplemented the already existing precipitable water over the GTA that remained from Hurricane Debby.



Note: Blues lines denote constant precipitable water values, red numbers indicate radiosonde observations (in mm), and the purple oval emphasizes regions of elevated precipitable water.

Source: University of Wyoming, 2025

Figure 5-3: Precipitable Water Observational Chart (August 9, 2024, 12Z)



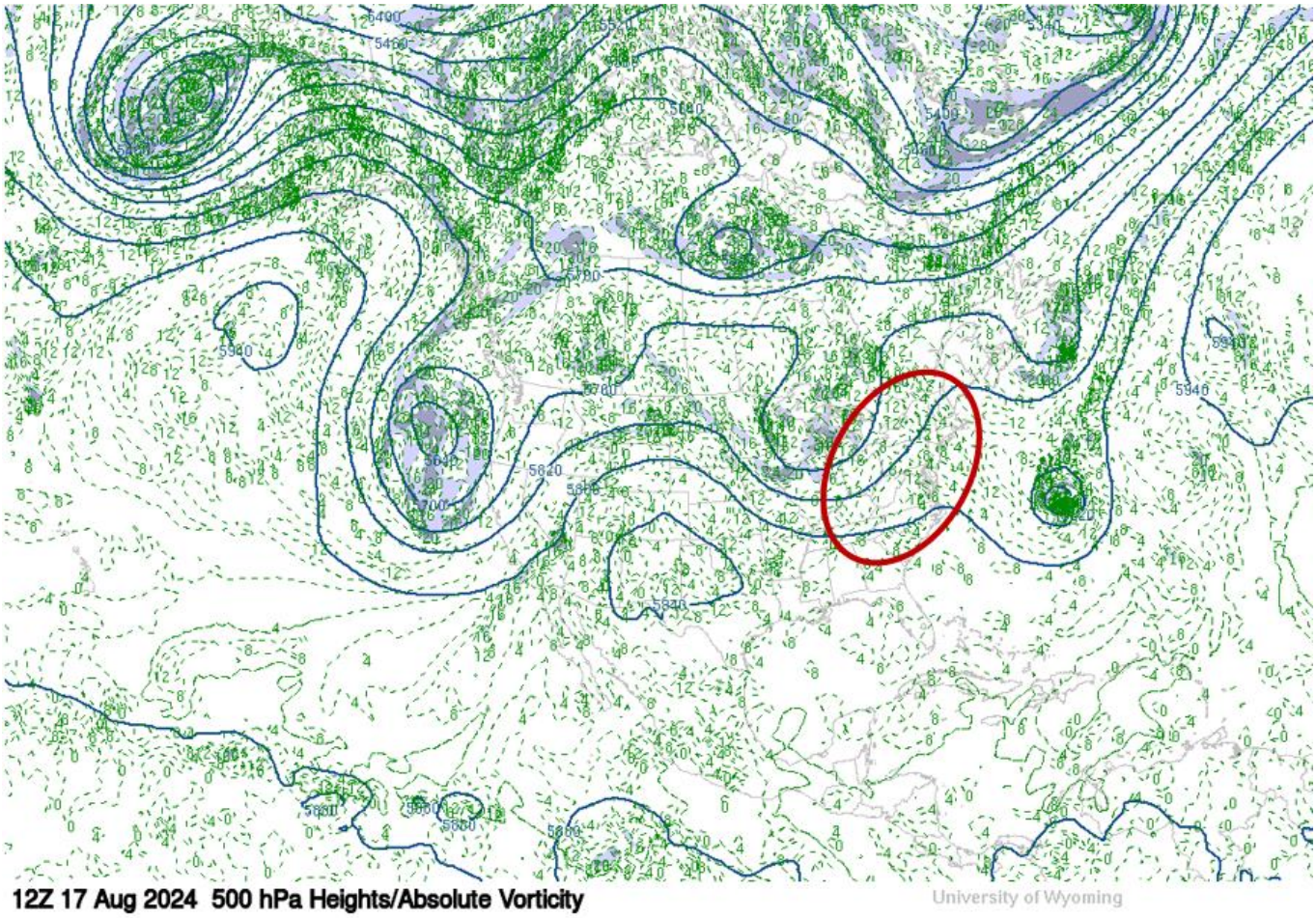
Note: Blues lines denote constant precipitable water values, red numbers indicate weather station observations, the purple oval emphasizes regions of elevated precipitable water, and the black arrow indicates the direction of advection of additional atmospheric moisture.

Source: University of Wyoming, 2025

Figure 5-4: Precipitable Water Observational Chart (August 16, 2024, 12Z)

5.1.2.2 Upper-Level Charts

The analysis of the vorticity at 500 hPa reveals moderate absolute vorticity downstream of the trough on August 17 at 8 AM local time (12Z) as evidenced by the relatively large distance between the dotted green lines within the red circle (Figure 5-5). Nonetheless, there was still positive shear vorticity just upstream of the GTA leading to divergence aloft which necessitates compensation by a corresponding convergence at the surface level leading to rising air and the potential for rain in the subsequent hours. This moderate absolute vorticity was by itself not strong enough to produce sufficient uplift and cloud formation for the extreme event of August 17. Additional parameters for forced convection are required.

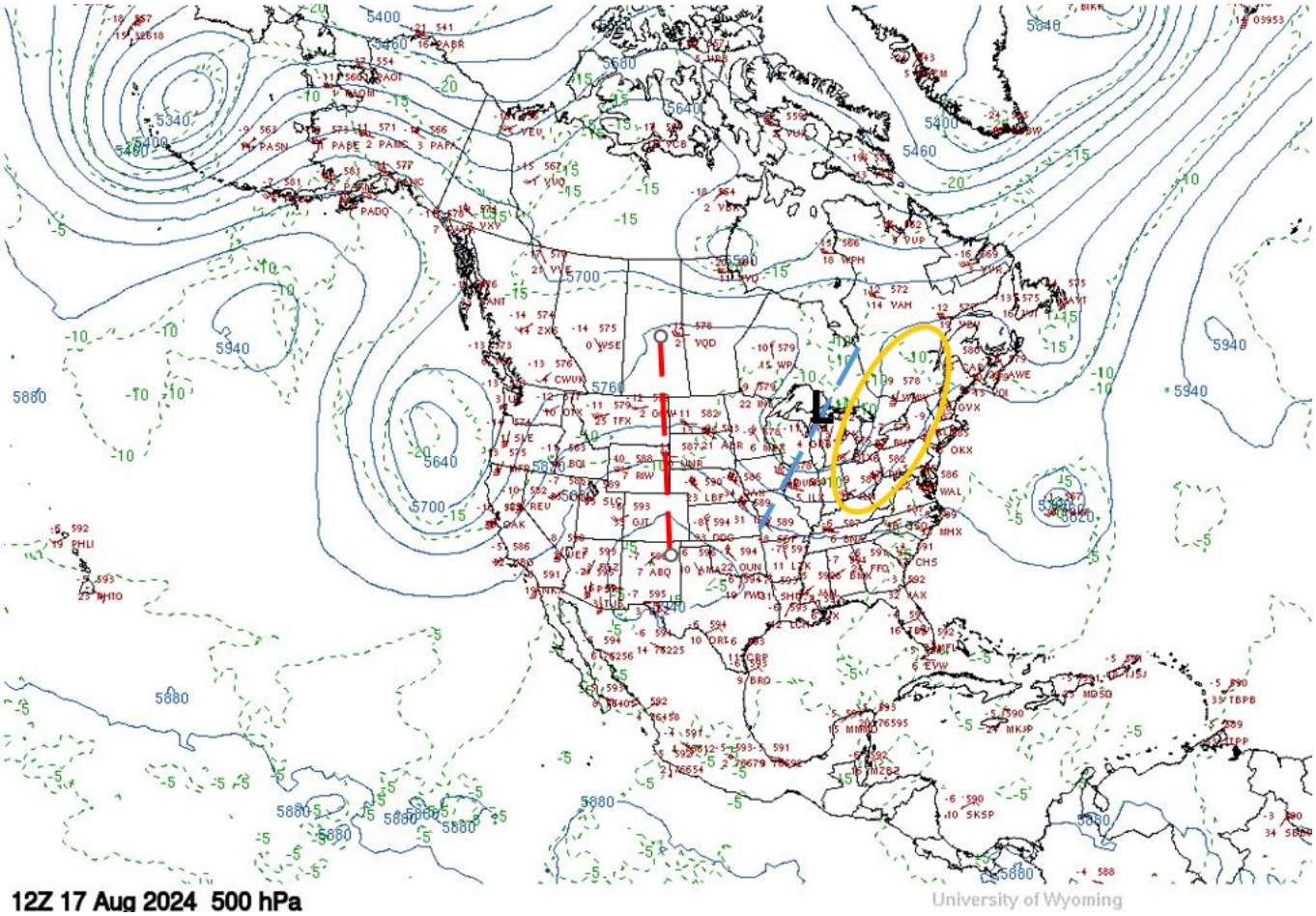


Note: Blue lines depict constant 500 hPa pressure heights, while green dotted lines represent absolute vorticity values. The red circle highlights the region of positive shear vorticity.

Source: University of Wyoming, 2025

Figure 5-5: 500 hPa Height and Absolute Vorticity Observational Chart (August 17, 2024, 12Z)

For clarity, Figure 5-6 shows the 500 hPa level contours on August 17 at 8 AM (12Z), excluding absolute vorticity contours. The red dotted line indicates the position of the ridge in the upper airflow, while the blue dotted line represents a trough. Neither the ridge nor the trough was very pronounced and the 500 hPa geopotential height isolines were mostly zonal over North America, which is indicative of small temperature gradients from south to north. The ridge was particularly weak over central USA and Canada while the trough was more pronounced with closer isoheights. As the trough is not perfectly aligned from south to north but is instead tilted from southwest to northeast, it is referred to as a positively tilted trough. This pattern is rarely associated with severe weather, though rainfall often occurs at the surface downstream of the trough. Despite the relatively moderate strength of the trough, it was strong enough to generate positive shear vorticity and create a zone of possible rainfall in the area indicated by the yellow circle. Also, in summer, large-scale upper-level forcing is often weak and even subtle and/or relatively weak features can trigger convection and heavy rainfall given enough moisture and atmospheric instability.

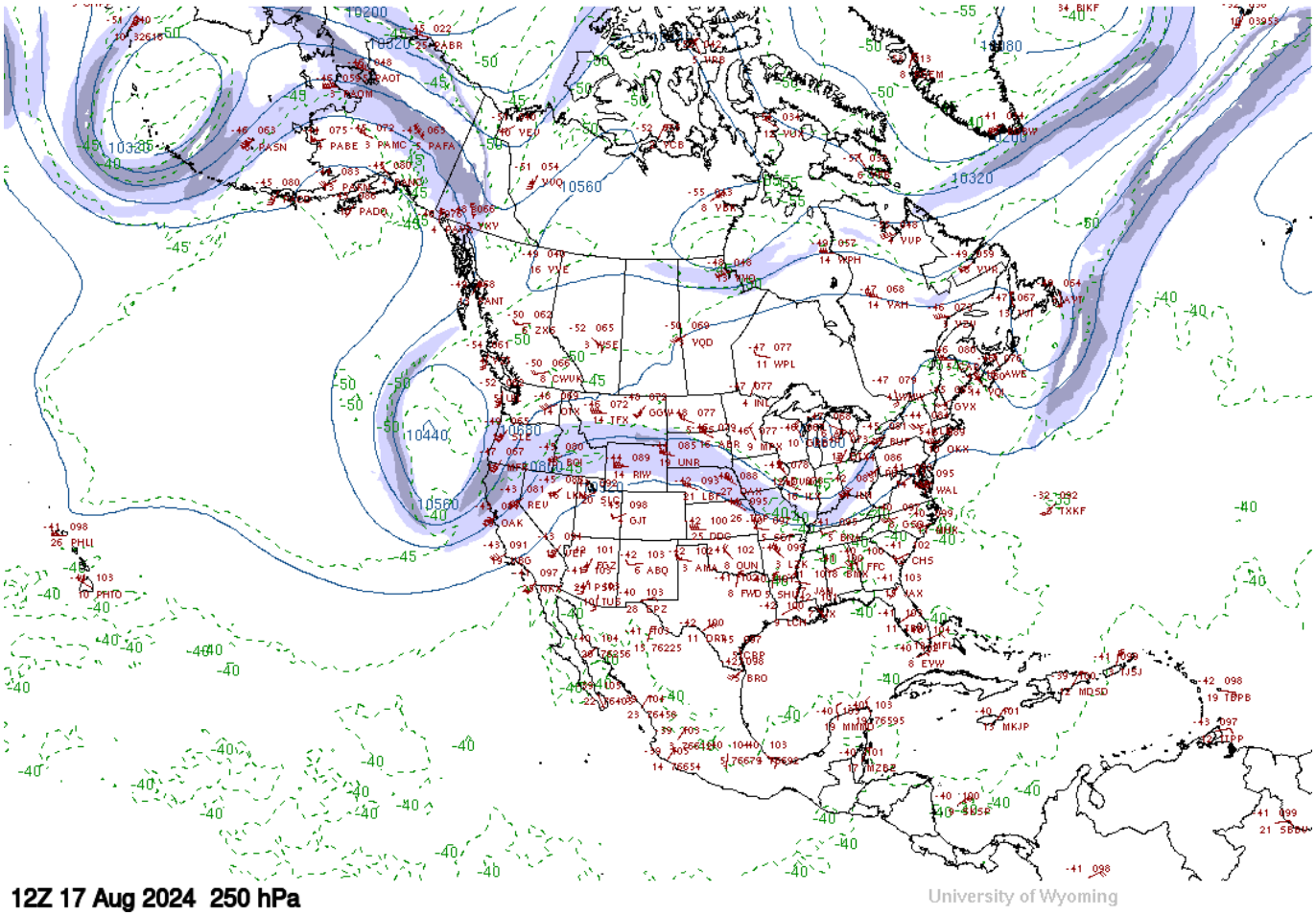


Note: The blue lines indicate constant 500 hPa pressure heights. Red dotted lines represent a ridge in the upper-air flow, while blue dotted lines indicate a trough. A low-pressure system is marked by an "L" over the western Great Lakes. Yellow circle indicates the area of most probable rainfall.

Source: University of Wyoming, 2025

Figure 5-6: 500 hPa Height Contours Observational Chart (August 17, 2024, 12Z)

Higher in the atmosphere at the 250 hPa level, the trough and low-pressure system over the western Great Lakes region were more pronounced (Figure 5-7). On August 17 at 8 AM (12Z), the GTA remained on the downstream side of the system in the area of divergence. This divergence aloft necessitated compensation by a corresponding convergence at the surface level and created some upward motions. The favorable conditions supported the development of showers and thunderstorms during the event. There was even an EF2 tornado that touched down at 10:40 AM in Ayr, Ontario, ~100 km southwest of Toronto.



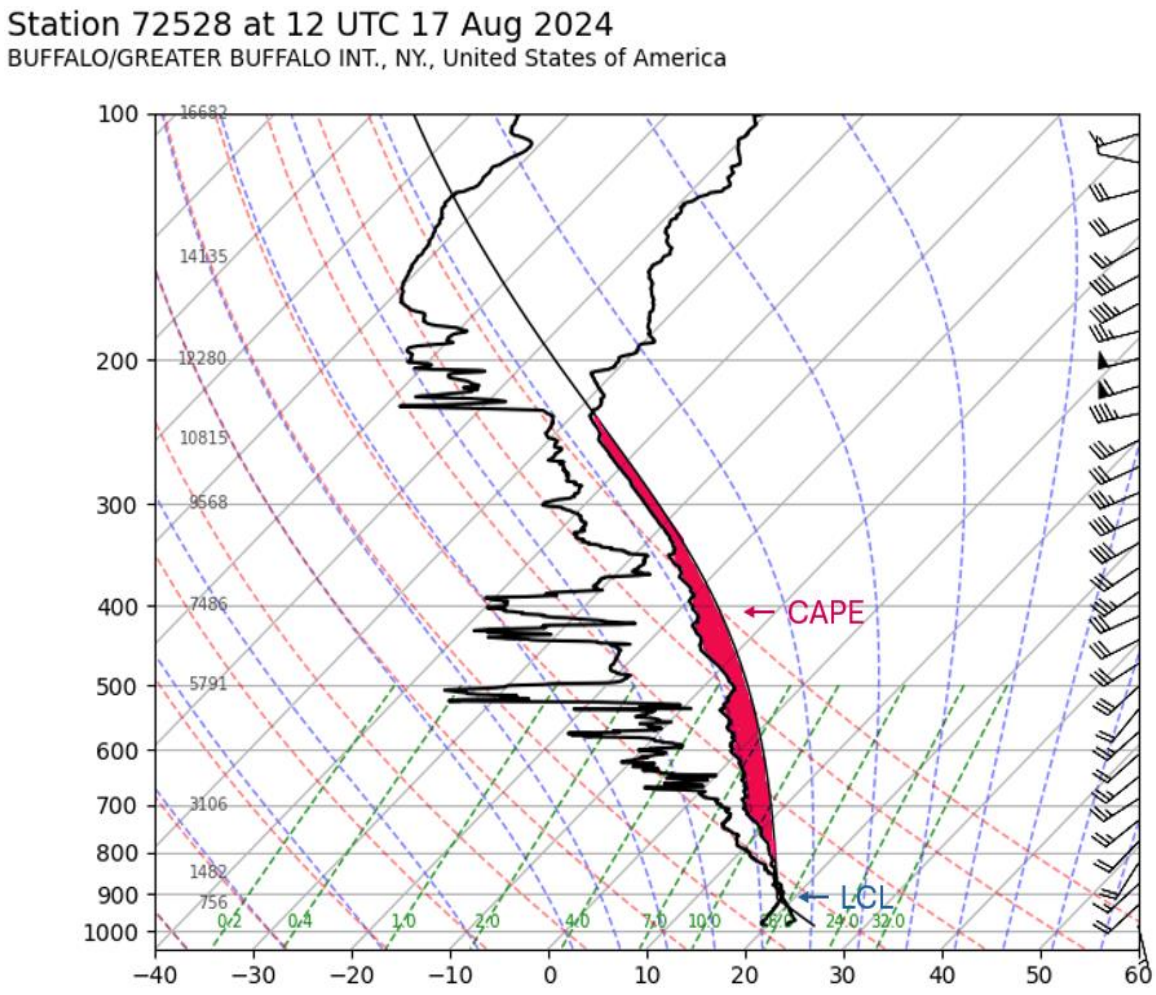
Note: The blue lines indicate constant 250 hPa pressure heights and blue-purples shades indicate wind speed.
Source: University of Wyoming, 2025

Figure 5-7: 250 hPa Height Contours Observational Chart (August 17, 2024, 12Z)

5.1.2.3 Tephigram Soundings

The tephigram sounding hours prior to the start of the event on August 17 at 8 AM (12Z) at the Buffalo International Airport radiosonde site, the closest radiosonde site to the GTA, shows a moderate amount of CAPE sufficient to produce thunderstorms (Figure 5-8). The type of CAPE recorded in the tephigram is sometimes characterized as tall instability due to its great vertical extent and is often associated with heavy precipitation and flash flooding. But it doesn't necessarily lead to substantial damages due to high wind speeds or tornadoes. Furthermore, the tephigram soundings shows the presence of dry air at mid-level of the atmosphere. As explained in Section 4.1.2.4, the mid-level dry air indicates the potential development of a wet microburst and can also trigger more thunderstorms, extending the lifespan of the thunderstorm cluster.

Figure 5-8 also shows winds generally in the 20-25 kt range from just above the surface up to 500 hPa, which means that even an individual storm cell with an extended life span would be in a particular area for only a relatively short time before moving away. However, on this day, like during the July 16 event, the storm cells repeatedly developed upstream and organized in a way that allowed for a succession of storms to deposit heavy rain over the same area for hours, as will be discussed in Section 5.1.3.



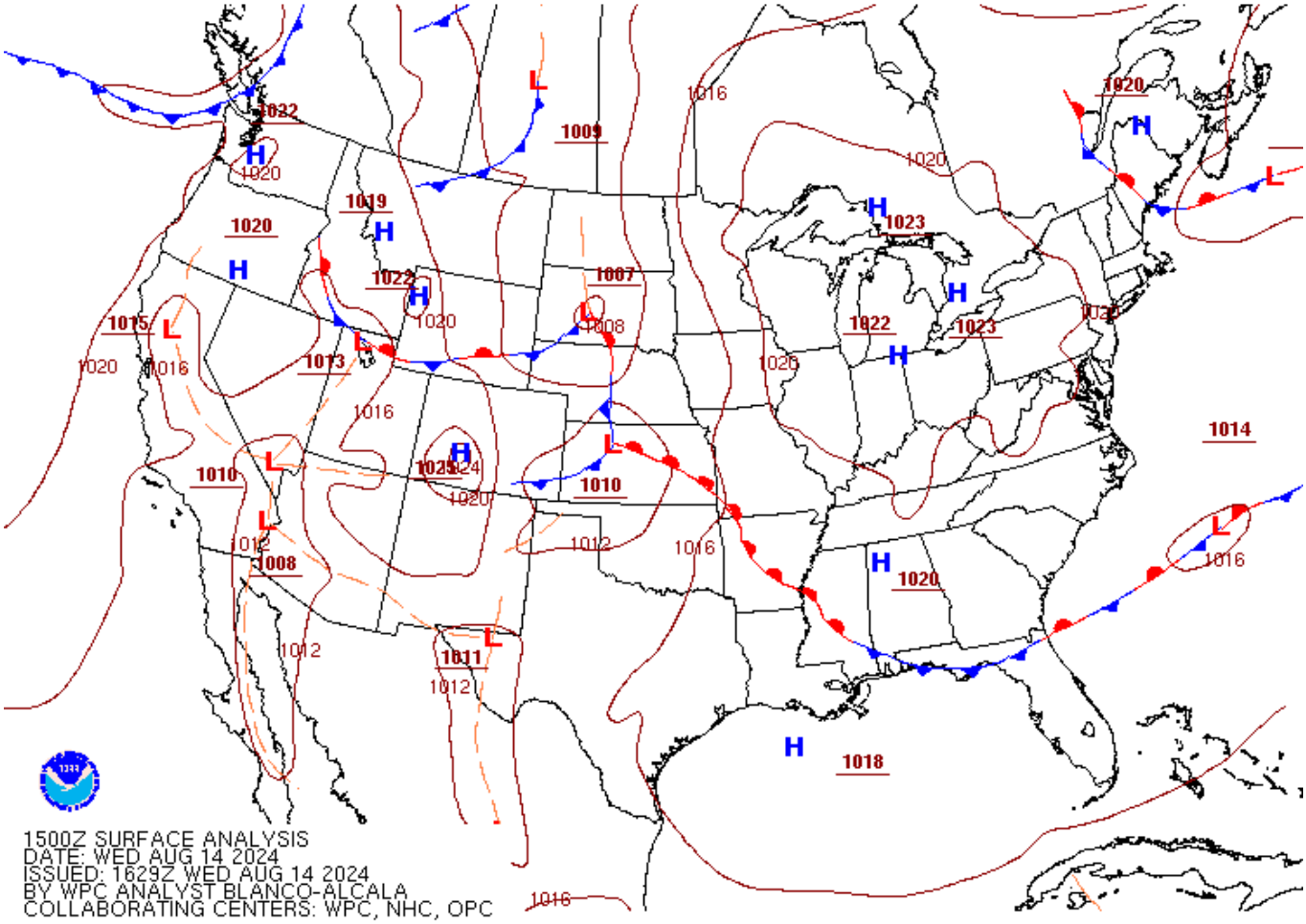
Note: The fuchsia area indicates the Convective Available Potential Energy (CAPE) and LCL stands for Lifting Condensation Level.
Source: University of Wyoming, 2025

Figure 5-8: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 17, 2024, 12Z)

5.1.3 Severe Weather Event

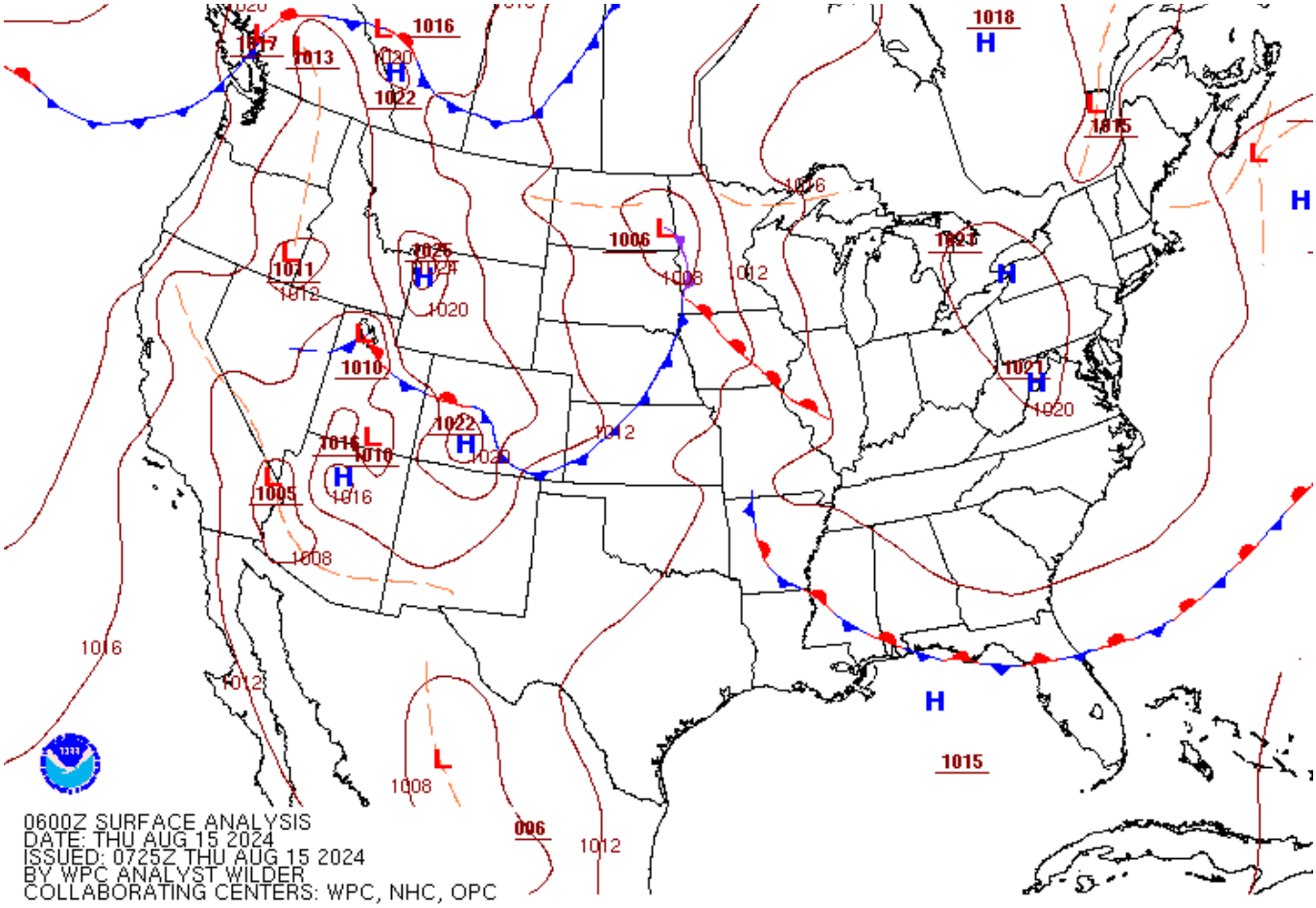
In Section 5.1.2, components of the vertical structure and atmospheric upper-level parameters that could have intensified and prolonged the thunderstorm events of August 17 have been examined. However, the initial trigger such as the lifting mechanism remains unidentified. While the presence of high humidity levels, moderate CAPE, and moderate vorticity suggest conditions conducive to thunderstorms and offer insights into the atmospheric context preceding the event, they do not fully explain the storm's development. Radar composite images and surface analysis charts are particularly useful in supporting the assessment of thunderstorm triggers.

Identifying the exact moment and location a low-pressure and frontal system is formed initially can be complicated as low-pressure systems can merge and divide multiple times throughout their lifetimes. Nonetheless, the low-pressure systems that contributed to the extreme rainfall event on August 17 can be retraced to two systems over South Dakota and Kansas on August 14, 2024, at 15Z (Figure 5-9). The two systems are linked by a stationary front and merged on August 15 over North Dakota. An extensive frontal system developed with a stationary occluded front from which a warm and cold front extended (Figure 5-10).



Note: *The dark red lines indicate isobars, the red lines indicate warm front, and the blue lines indicate cold front.*
Source: *Weather Prediction Center, 2022*

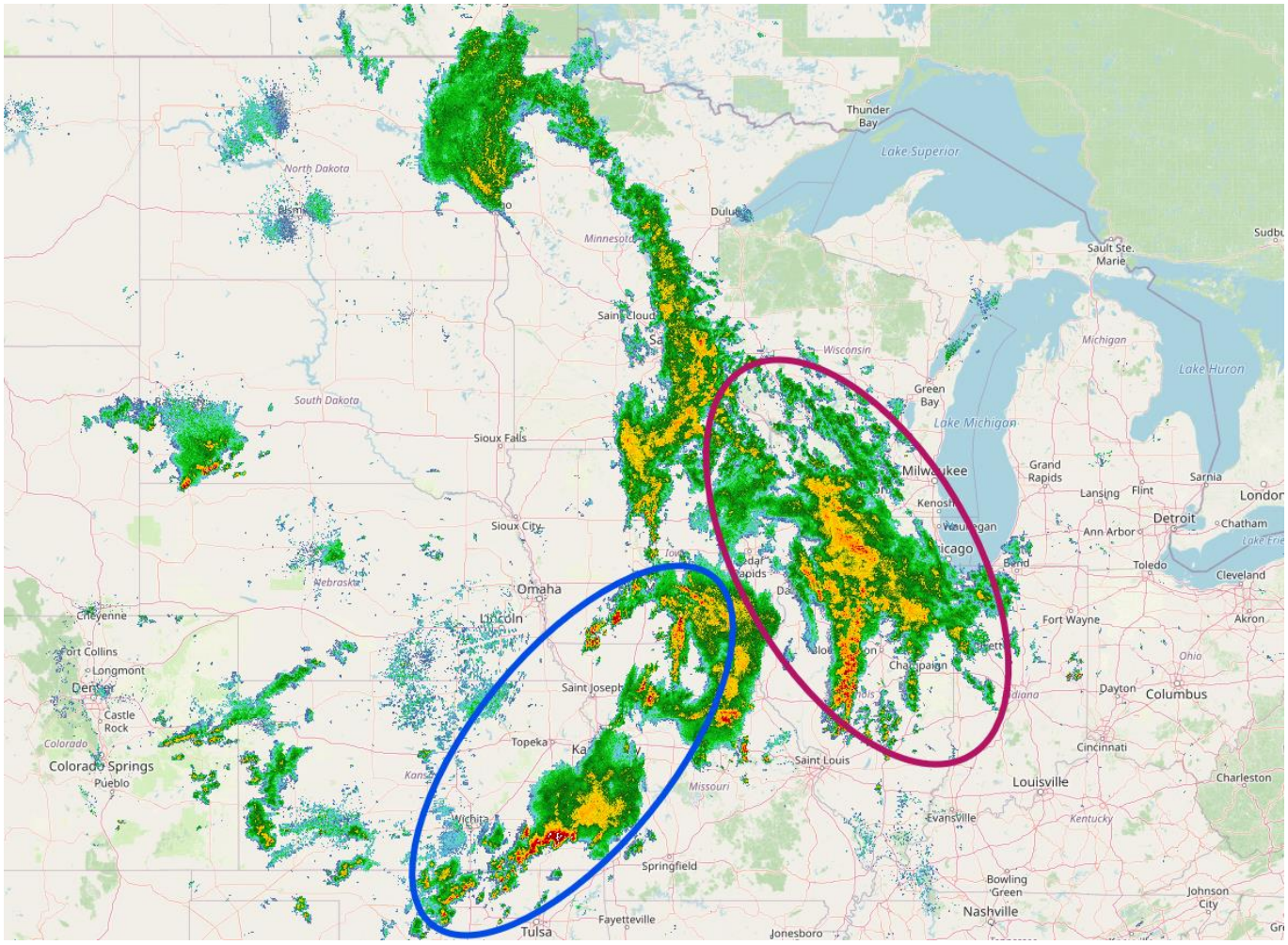
Figure 5-9: Surface Frontal Analysis (August 14, 2024, 15Z)



Note: The dark red lines indicate isobars, the red lines indicate warm front, and the blue lines indicate cold front.
Source: Weather Prediction Center, 2022

Figure 5-10: Surface Frontal Analysis (August 15, 2024, 6Z)

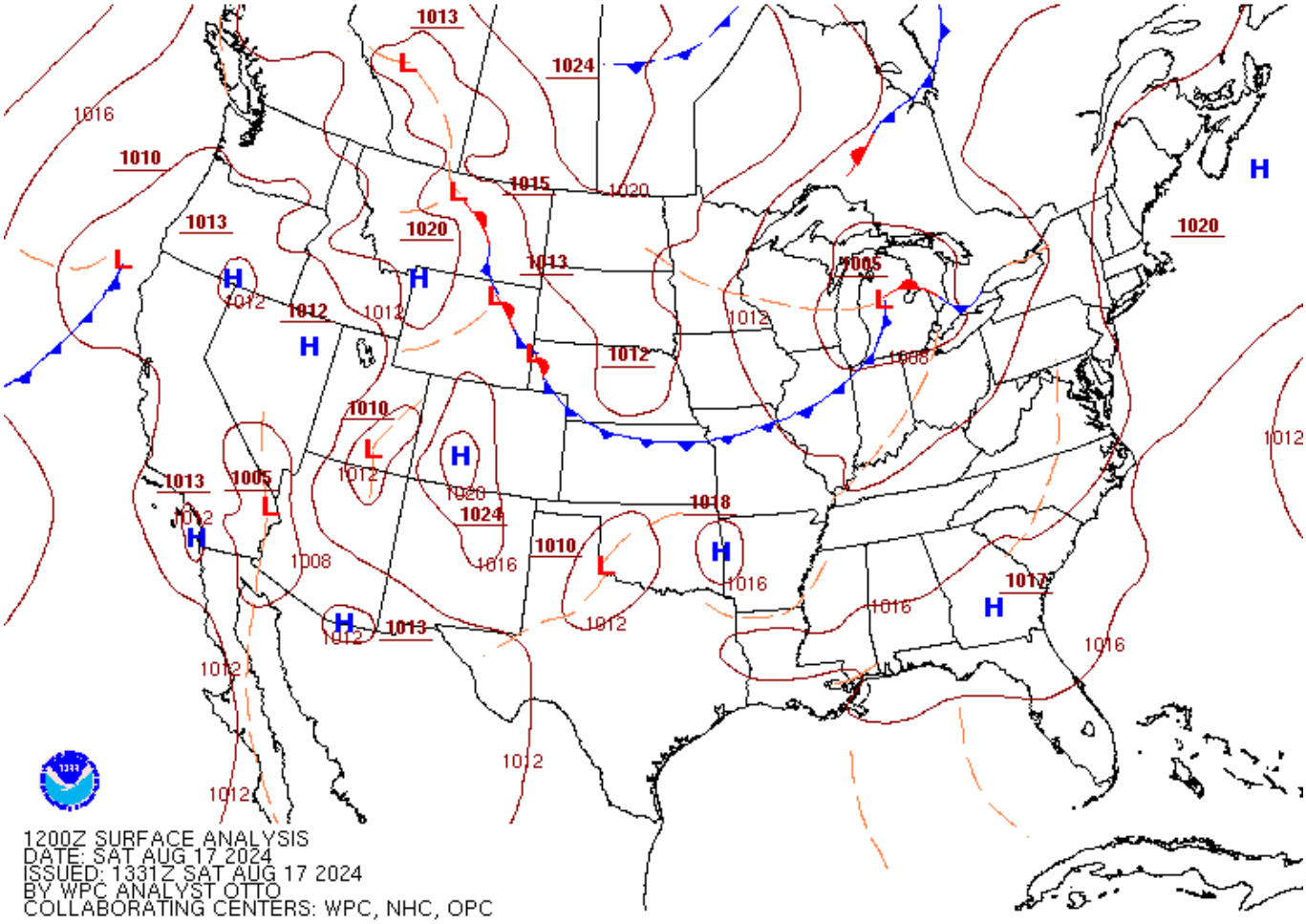
On August 15, once the low-pressure systems had evolved, substantial precipitation was observed along the frontal system over the Midwest (Figure 5-11). Over the following two days, the frontal system moved eastward while the precipitation intensity lessened along the fronts and became more intermittent. However, the atmospheric moisture content remained high (Section 5.1.2.1).



Note: The fuchsia oval indicates the precipitation along the warm front and the blue oval indicates the precipitation along the cold front.
Source: Iowa State University, 2025a

Figure 5-11: Radar Reflectivity Composite (August 15, 2024, 06Z)

To determine the precise trigger and lifting mechanism for the extreme rainfall event of August 17, the surface analysis charts, radar images and low-level data were reviewed holistically in their temporal sequence. The analysis of individual maps or data points can be misleading in particular when it comes to the precise location of frontal systems as the surface analysis charts provide only approximate locations of pressure systems and fronts due to overall coarse data coverage. For example, Figure 5-12 shows a stationary front extending from a low-pressure system over Michigan to Lake Erie on August 17 at 8 AM (12Z). However, this front has likely passed over the GTA a one point during night from August 16 to 17 after it brought some light to moderate precipitation in the evening of August 16. The humidity near the surface remained high despite the precipitation (Figure 5-8). This stationary front created the uplift and instability seen on the tephigram. Also attached to the low-pressure system, a cold front extended southward from Michigan into Indiana and Illinois (Figure 5-12). The extreme rainfall event on August 17 occurred in the warm, humid air mass without a nearby front or other obvious trigger to spawn thunderstorms, which likely contributed to the lack of predictability that will bed discussed in Section 5.1.4. There might have been a mesoscale low-level trough or convergence zone influenced by a weak lake breeze off Lake Ontario, but it is hard to verify such a subtle feature with the available information. While most of the precipitation fell on August 17, the slow-moving cold front resulted in showers and downpours also on August 18 when it eventually passed over the GTA in the afternoon (red circles in Figure 5-13 and Figure 5-14).



Note: *The dark red lines indicate isobars, the red lines indicate warm front, and the blue lines indicate cold front. Stationary front was located north of Lake Erie, approaching the GTA.*

Source: *Weather Prediction Center, 2022*

Figure 5-12: Surface Frontal Analysis (August 17, 2024, 12Z)

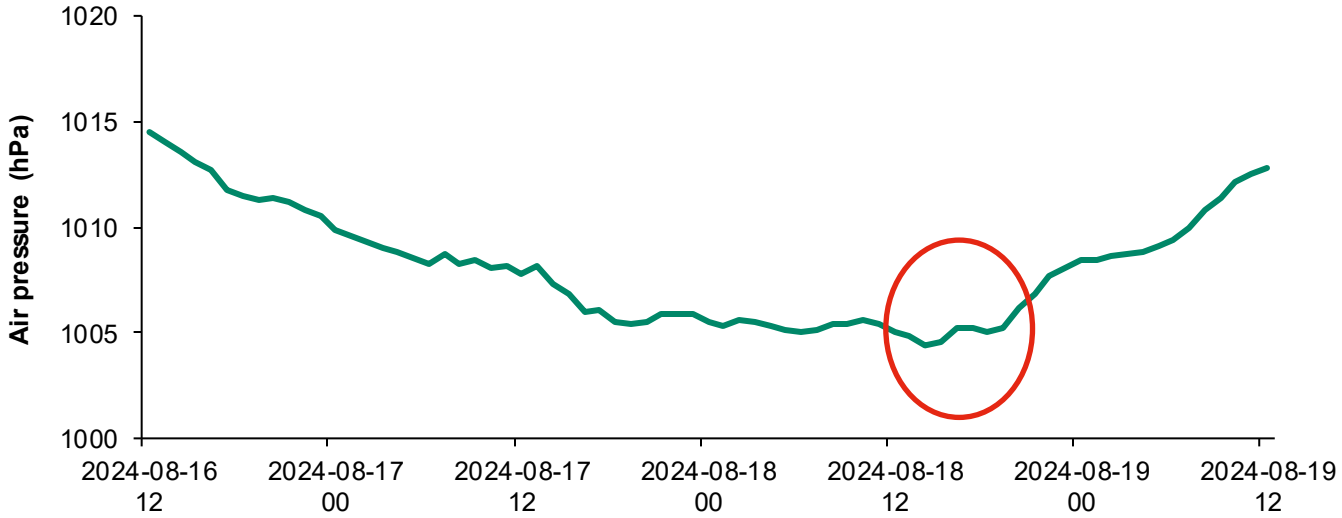


Figure 5-13: Air Pressure Meteogram at Toronto International Airport (CYYZ; August 16-19, 2024)

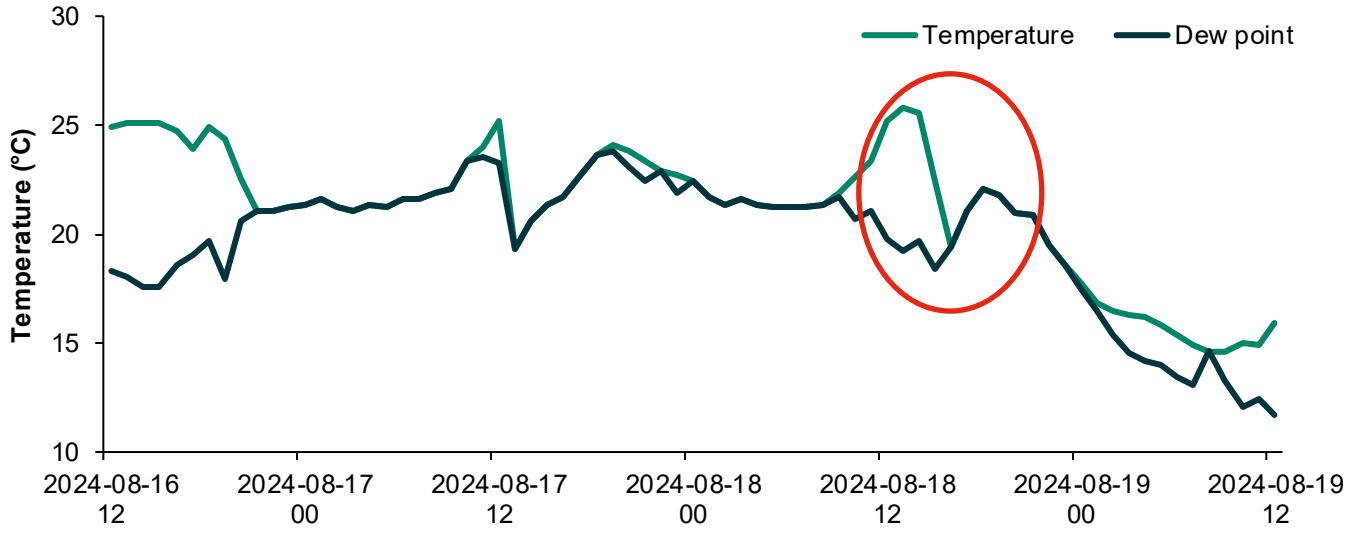
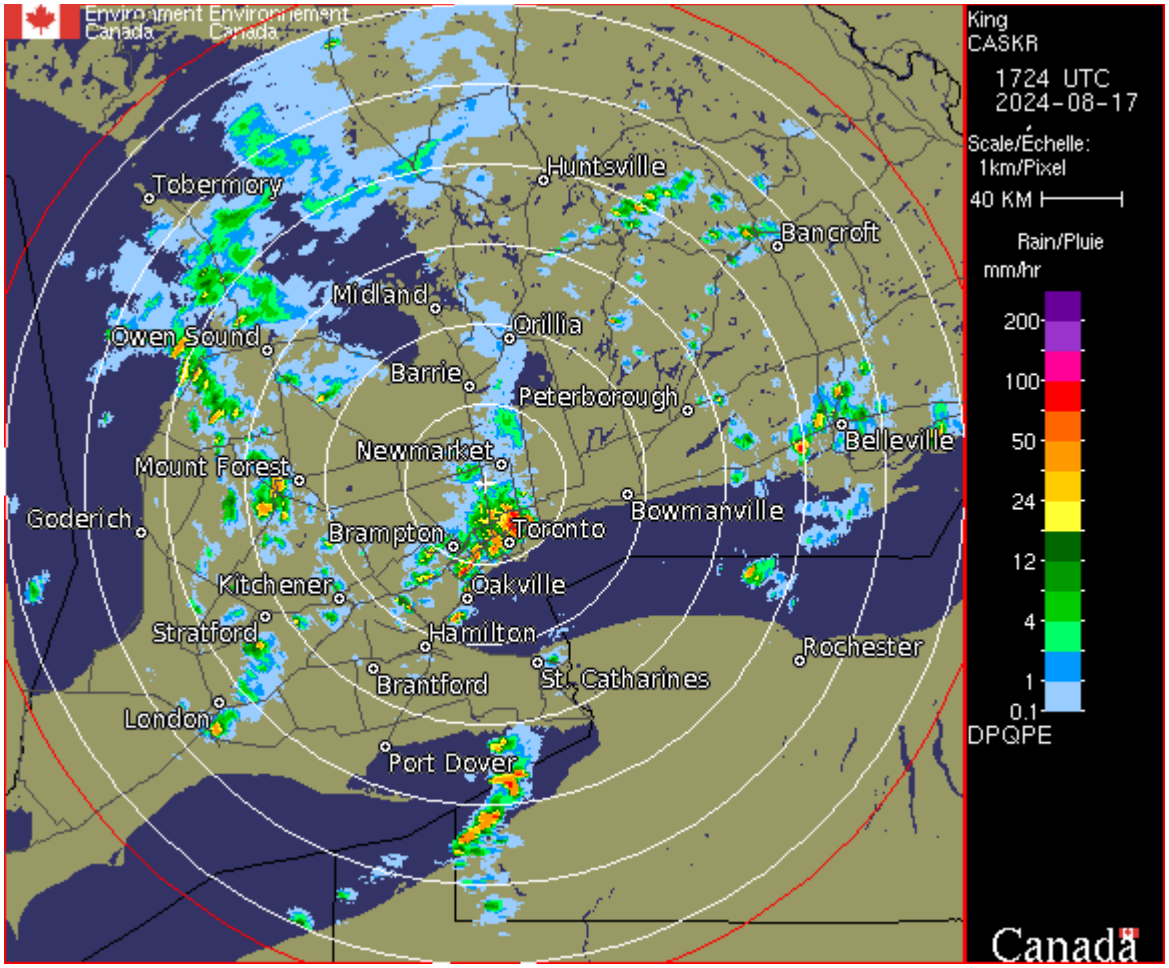


Figure 5-14: Temperature and Dew Point Meteogram at Toronto International Airport (CYYZ; August 16-19, 2024)

The high dew point indicates very high moisture content near the surface at the Toronto International Airport weather station (Figure 5-14), illustrating the moisture that could fall as rain when thunderstorms are triggered. The first rainfall episode which brought the highest rainfall intensity started on August 17 at 1:06 PM and lasted until 1:48 PM local time. During this episode, the rainfall intensity reached between 75 to 100 mm/h over the GTA (Figure 5-15), after which the rain intensity decreased to an average of 30 mm/h and lasted until 8:00 PM. While most of the rain fell on August 17, residual precipitation was recorded on August 18 before the passage of the cold front concluded the event.

Similar to the July 16 event, training of storm cells was also critical during the August 17 event to producing the very localized narrow band of extreme rainfall in the TRCA. Individual storm cells moved northeastward at ~50 km/h along the narrow southwest to northeast oriented line of storm cells. In addition, the storm cells continuously reformed to the southwest, or upstream, at the back end of the storms, a phenomenon known as “backbuilding”. The combination of training and backbuilding storms led to 5 hours of moderate to heavy rain in the narrow zone of extreme rainfall (Appendix Figure B 11-Appendix Figure B 21) before the backbuilding finally ceased with the storms moving to the northeast and weakening by 6 PM (Appendix Figure B 22). Unlike for the July 16 event, for the August 17 event, the TRCA’s communications with the OSPC indicated the potential of up to 80 mm due to the training of storms.



Source: ECCC, 2025c

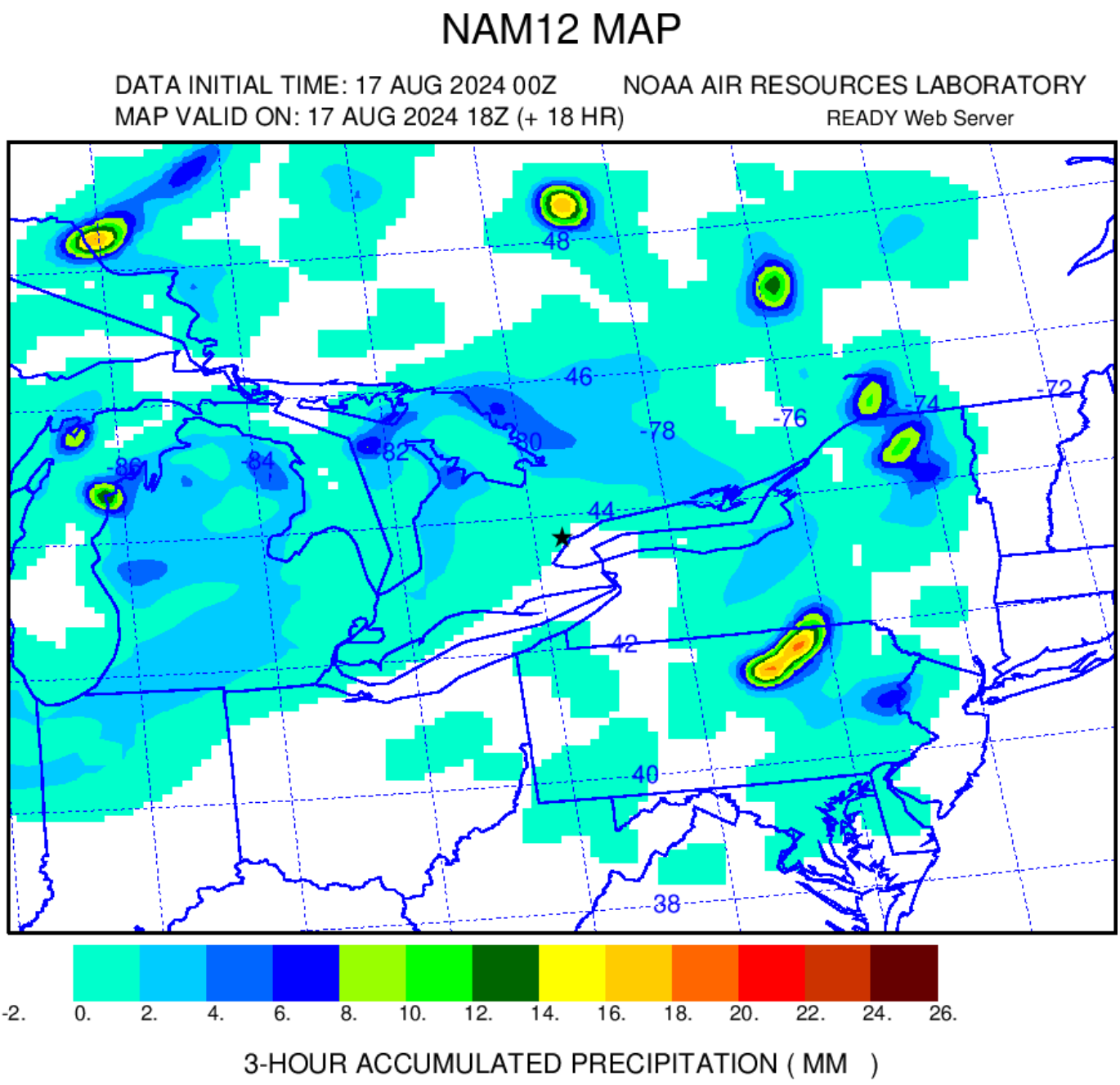
Figure 5-15: Dual Polarization Quantitative Precipitation Estimation (DPQPE) King City Radar (August 17, 2024, 1324 UTC / 0924 EDT)

5.1.4 Numerical Forecasting

ECCC issued a special weather statement on August 16 at 2:46 PM warning that significant rainfall was expected throughout the weekend. They indicated that intermittent rainfall would occur from Friday evening through Sunday with total rainfall amounts of up to 60 mm. The warning included that the heaviest showers with rainfall rates of up to 40 mm/h were expected for Saturday (Table 5-1). The regular forecast issued at 3:30 PM on August 16, mentioned a risk of thunderstorms for the evening of August 16 and throughout the day of August 17. The forecasted rainfall amounts were given as locally 10-15 mm or 10-20 mm for August 16 and locally 10-20 mm or 20-30 mm for August 17, depending on the exact location in the TRCA jurisdiction. Similar to the forecast issued by ECCC, the NAM12 Forecast System forecasted light to moderate rainfall (up to 6 mm) associated with the warm front for the evening of August 16 (Appendix C.2.1), the day before the extreme rainfall event. Both systems captured the passage of the warm front and the associated rainfall amount reasonably well, with recorded rainfall ranging between 3.7 and 7.6 mm across the GTA (Meteostat, 2025).

The forecasts had more difficulties capturing the thunderstorms and especially the training of storms over parts of the GTA on August 17. ECCC issued another regular bulletin on August 17 at 5 AM, forecasting locally 10-20 mm of rainfall throughout the day and noting a risk of thunderstorms. The NAM12 model showed even less precipitation in its forecast from August 16 at 8 PM (August 17 at 00Z) for 11 AM to 2 PM with 0-2 mm of accumulated precipitation (Figure 5-16). One explanation is that the coarse model resolution of 12 km which was insufficient to resolve the atmospheric instability and high moisture content present in the environment locally in the GTA. An additional

explanation could be that the position of the cold front was not accurately captured in the model. Without the trigger mechanism, the energy was not released in the model, and no thunderstorms were forecasted.

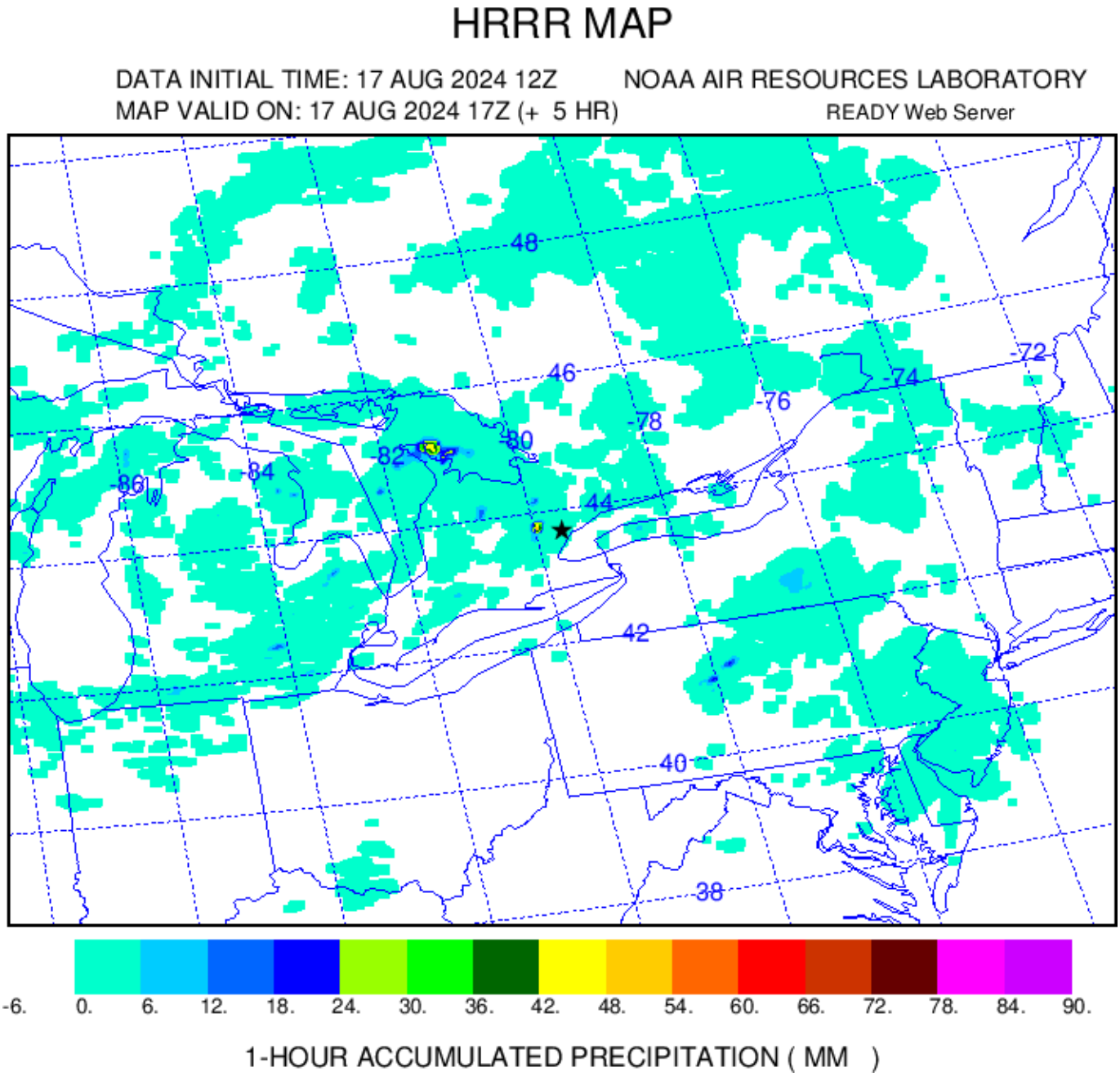


Note: Issued on July 16 on 00Z by the 12 km North American Model (NAM12).
Source: NOAA, 2025a

Figure 5-16: Forecasted Three-hour Accumulated Precipitation from 15Z to 18Z (August 17, 2024)

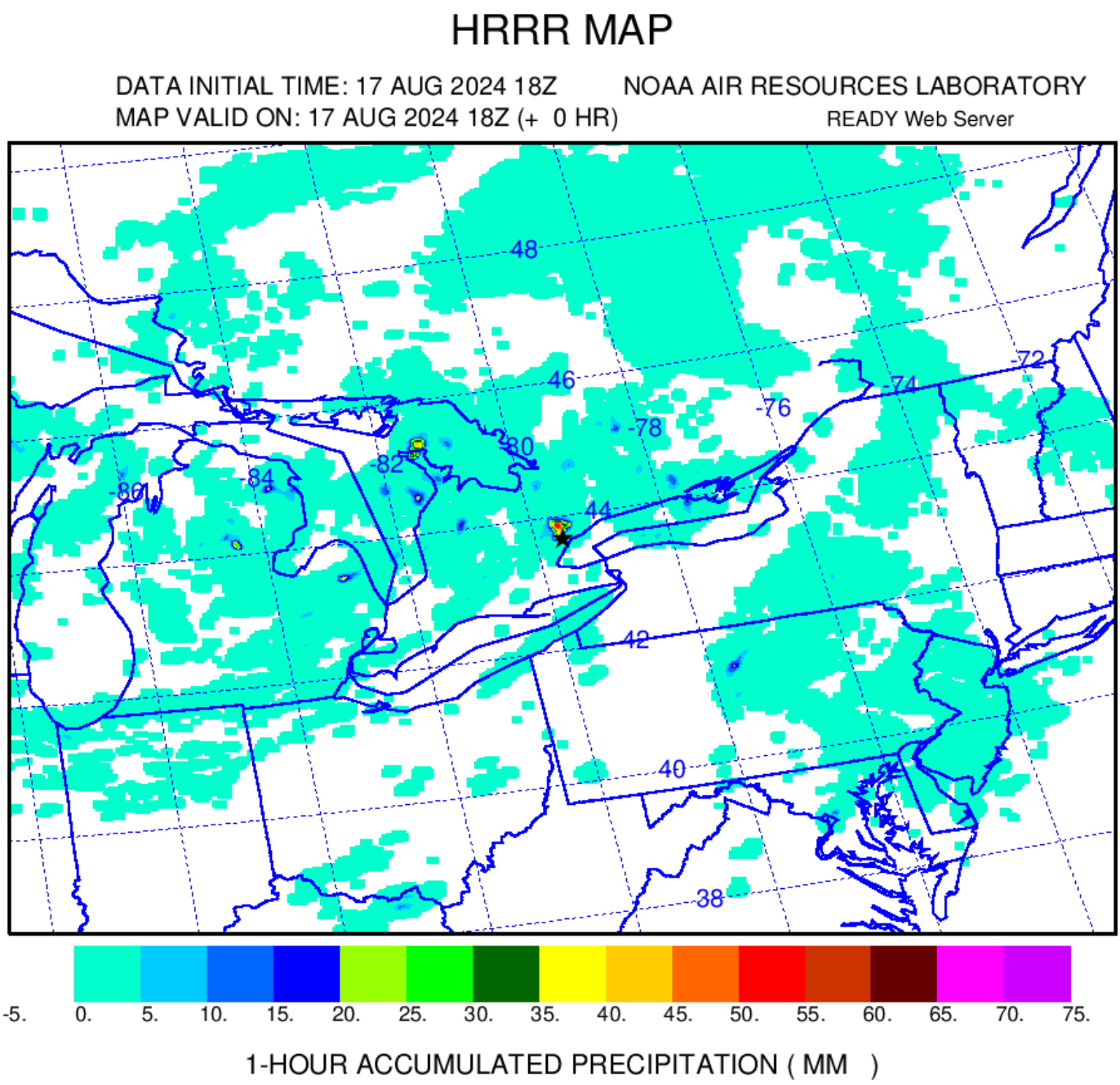
These speculations are supported by the forecasts of the higher resolution HRRR model. The higher spatial and temporal resolution allowed the model to capture the intensity of a very localized rainfall event significantly better than the NAM12 model. Based on the forecast issued on August 17 at 8 AM (12Z), the one-hour accumulated precipitation between 12 and 1 pm would reach up to 60 mm (Figure 5-17). However, the location of the maximum precipitation was forecasted to be to the northwest of the GTA. While this forecast would have provided the region some lead time for warnings and mitigation action, the focus of the effort would have likely been misplaced due to the incorrect location of the maximum precipitation. Even the following forecast issued at 2 PM (18Z), which benefited from updated

observations showed a maximum one-hour accumulated precipitation of up to 55 mm for 1-2 PM placed to the north of Toronto (Figure 5-18). This forecast would have provided the TRCA and the GTA no lead time as the extreme rainfall event was well under way at this time. In addition, even the ensemble maximum rainfall indicated by the HREF forecast issued on August 17 at 12Z did not indicate any reasonable likelihood of >50 mm in the GTA (Figure 5-19). Unless storms are known to systematically train over this area in this meteorological setup, it would be nearly impossible to forecast the extreme rainfall with more lead time, similar to the July 16 event.



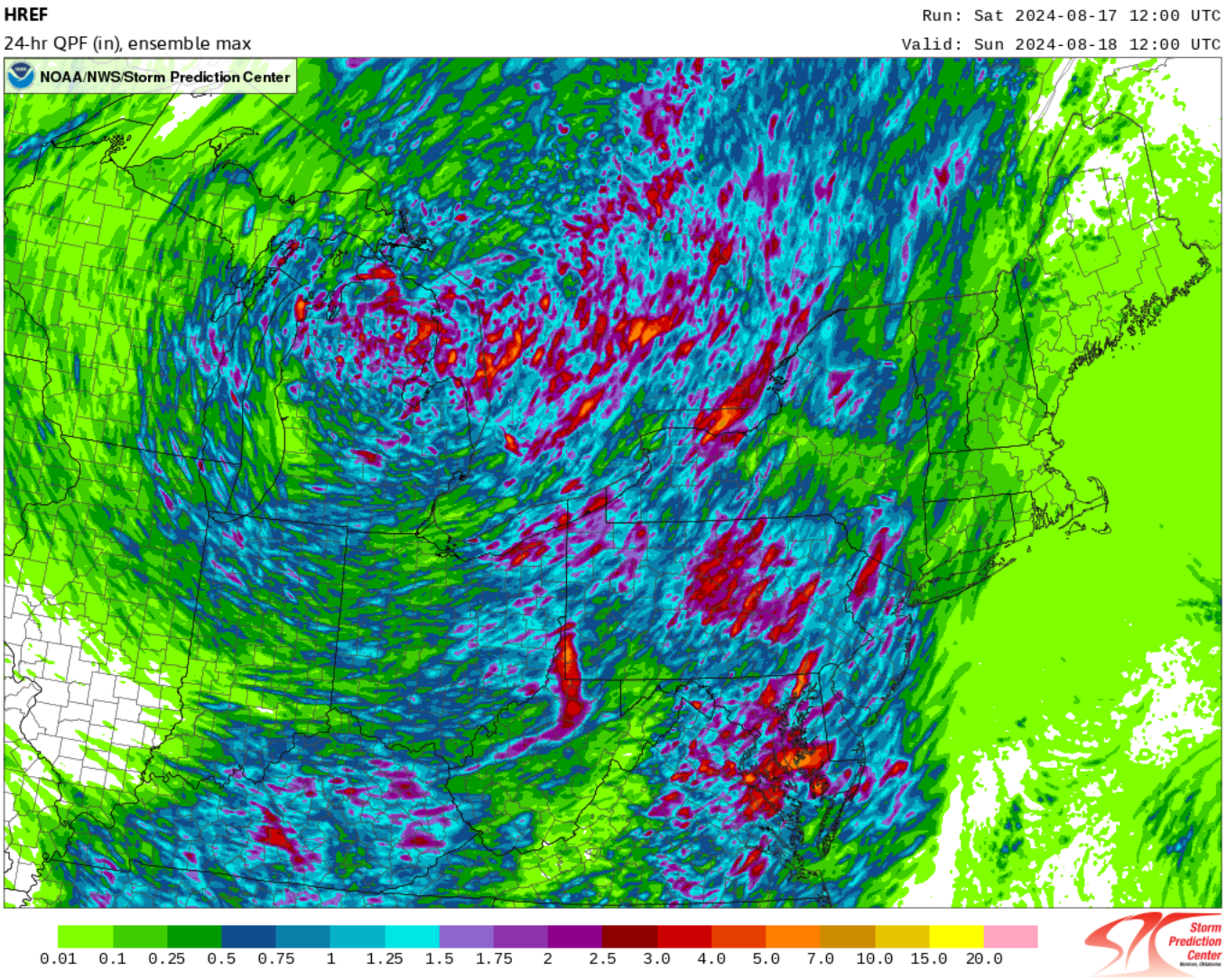
Note: Issued on August 17 at 12Z by 3 km High-Resolution Rapid Refresh (HRRR).
Source: NOAA, 2025a

Figure 5-17: Forecasted One-hour Accumulated Precipitation from 16Z to 17Z (August 17, 2024)



Note: *Issued on August 17 at 18Z by 3 km High-Resolution Rapid Refresh (HRRR).*
Source: *NOAA, 2025a*

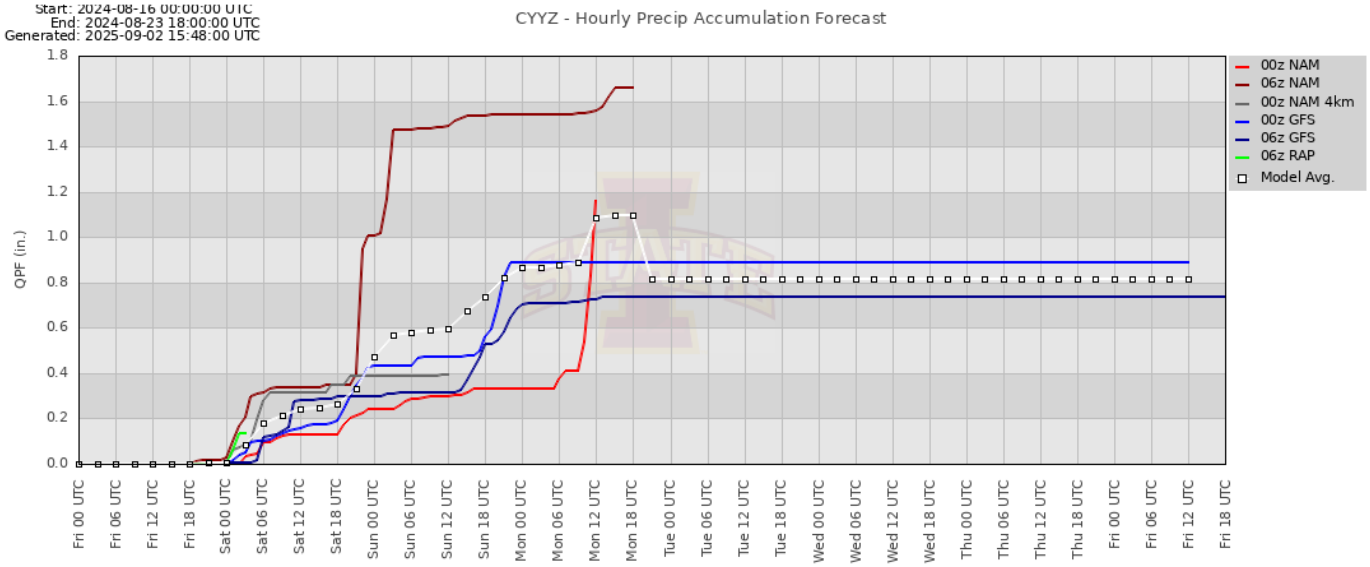
Figure 5-18: Forecasted One-hour Accumulated Precipitation from 17Z to 18Z (August 17, 2024)



Source: SPC, 2025

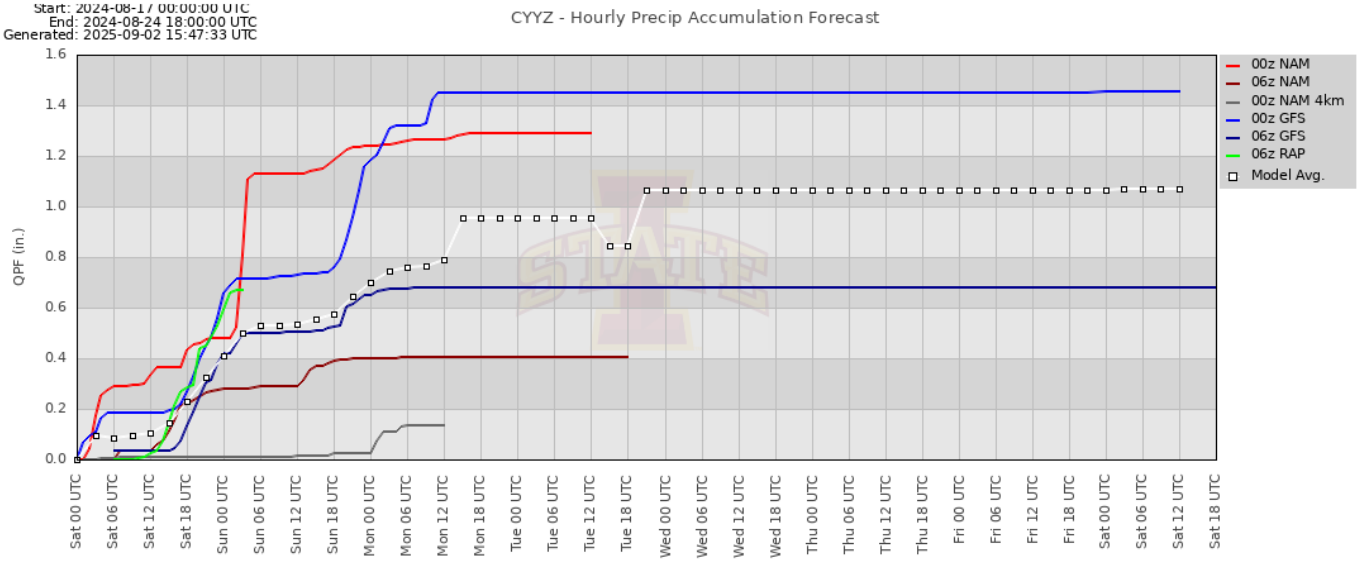
Figure 5-19: HREF 24-hour ensemble maximum accumulated precipitation from 12Z to 12Z (August 17-18, 2024)

The TRCA also used rainfall predictions from other numerical weather models to make its assessment. Meteograms showing the cumulative precipitation amount at Pearson International Airport predicted by models initialized on August 16 00Z and August 17 00Z are shown in Figure 5-20 and Figure 5-21, respectively. While they showed more agreement than with the July 16 event, they all greatly underestimated the rainfall in the narrow area of rainfall maximum.



Source: Iowa State University, 2025b

Figure 5-20: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport Starting at August 16, 00Z



Source: Iowa State University, 2025b

Figure 5-21: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport Starting at August 17, 00Z

Table 5-2 shows TRCA's assessment of the different model predictions on the morning of July 16, which showed that the HRDPS did indicate the potential for heavy rainfall in the GTA, but it was noted that the HRDPS also often overestimates total rainfall values.

Table 5-2: TRCA's Assessment of Predicted Rainfall and Runoff Amounts on the Morning of August 17

Model	Rainfall (mm)	Runoff (mm)
GDPS	52.59	45.09
GFS	11.01	5.83
HRDPS	85.05	77.20
HRRR	18.68	12.51
NAM	11.04	5.86
QPF	26.64	19.92
RDPS	51.66	44.18
Daily Maximum (HRDPS)	**85.05**	**77.20**

5.2 Rainfall Analysis

Rainfall data from the network of gauge stations (Section 3.1) was used to determine rainfall totals, rainfall duration and rainfall rate for each station during the August 17, 2024 event. As discussed in Section 4.2, the dataset contains 123 gauges of which 99 are located within the TRCA jurisdiction. Combined, these gauge stations provide spatial datasets of the different rainfall variables which were used to analyze precipitation patterns over the TRCA jurisdiction. The total rainfall amount, duration, and rainfall intensity for all stations are listed in Appendix D.2.

5.2.1 Total Precipitation and Isohyets

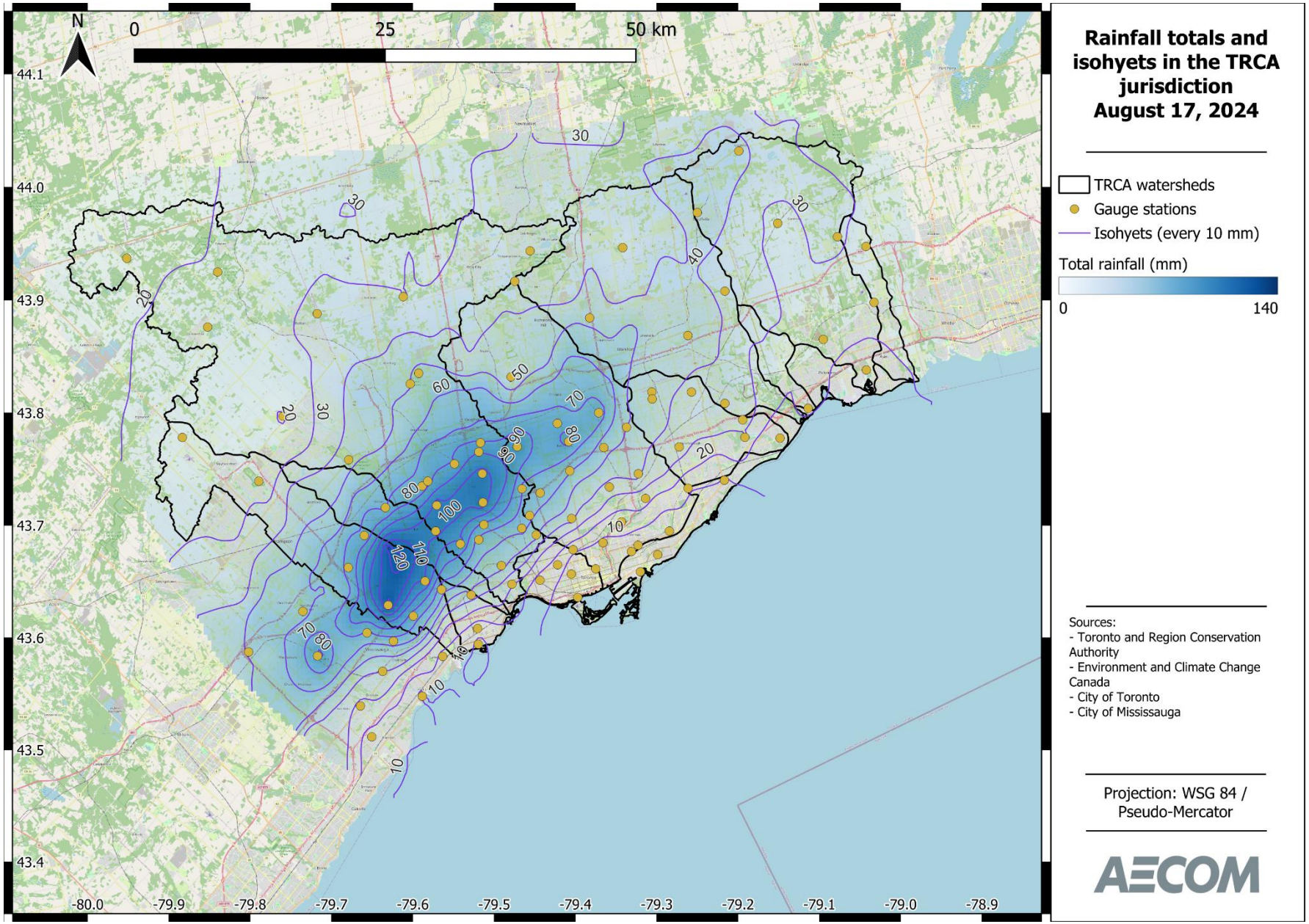
Total precipitation during the day of the August 17, 2024 storm was calculated for all the gauge stations presented in Figure 3-1. The quality control process for the August 17 event resulted in the rejection of eight (8) stations due to missing or incomplete data (Table 5-3). While the City of Mississauga's station data were complete, one (1) TRCA station, three (3) ECCC stations outside of the TRCA jurisdiction, and four (4) City of Toronto stations were discarded. As the gauge stations are distributed across the TRCA, the impact on precipitation distribution calculation was deemed negligible.

Table 5-3: Number of Station with Data on August 17, 2024

Provider	Number of Discarded Gauges	Number of Remaining Gauges
TRCA	1	39
ECCC	3	15
City of Toronto	4	48
City of Mississauga	0	13
Total	8	115

One lakeshore station, RG_041 in the City of Toronto network, registered continuous measurements of very small amounts of precipitation (~0.001 mm in 5-minute intervals) that are likely the result of an interference in the instruments. Comparison with nearby stations show no indication that the measurements of the main rainfall event are inaccurate, and thus the station was kept for the spatial analysis of total precipitation. However, the small amounts of precipitation disturb the calculation of rainfall duration, that totals 810 minutes compared to 90-180 minutes in nearby stations, and therefore this station was discarded for the analysis of rainfall duration and intensity.

After discarding the stations with insufficient or empty data, the remaining stations provide a dataset of spatially distributed data points of total precipitation across the TRCA jurisdiction. Using the methodology presented in Section 2.2.1, these data points were used to create a gridded dataset of total precipitation. Subsequently, isolines were calculated from this dataset to define the isohyets (Figure 5-22).



Note: Total precipitation intensity is shown by isohyets (purple lines) and precipitation gradient (white-to-blue).

Figure 5-22: Map of Total Precipitation across the TRCA Region (August 17, 2024)

The maximum precipitation within the TRCA jurisdiction was measured in the Rathwood station (135.7 mm) of the TRCA network in the Etobicoke watershed. Precipitation during the August 17, 2024 storm was concentrated in the south-western part of the TRCA jurisdiction, with the most intense rainfall (above 120 mm) occurring in the Etobicoke watershed. Precipitation was much more concentrated than during the July 16, 2024 storm, with a narrow (~10 km) band of very intense precipitation (> 100 mm) between 12-15 km parallel to the shoreline over the Etobicoke, Mimico and Humber watersheds. Precipitation decreased rapidly towards the shoreline, with much of it receiving less than 20 mm. In some parts along Lake Ontario, the total precipitation amount was as little as 10 mm.

The gridded dataset of total precipitation (interpolated through IDW, Section 2.2.1) was then used to determine the total precipitation within each watershed, following the methodology detailed in Section 2.2.3. For the August 17, 2024 storm, the total precipitation across the TRCA watersheds amounts to $98.1 \cdot 10^6$ m^3 of water ($98.1 \cdot 10^9$ litres, the equivalent to 39 240 Olympic-sized swimming pools, Table 5-4). Most of this amount fell over the Humber ($35.1 \cdot 10^6$ m^3), Don ($16.8 \cdot 10^6$ m^3), Rouge ($13.2 \cdot 10^6$ m^3), and Etobicoke ($11.6 \cdot 10^6$ m^3) watersheds. The Mimico watershed had on average the highest precipitation (68.5 mm), but due to its small size this watershed only received $5.3 \cdot 10^6$ m^3. The Humber watershed had on the other hand a much lower average precipitation (38.6 mm) but received the highest total amount of precipitation due to its larger size.

Table 5-4: Total Precipitation across the TRCA Watersheds (August 17, 2024)

Watershed	Area (km^2)	Precipitation (10^6 m^3)	Average intensity (mm)
Whole TRCA region	2488	98.1	39.4
Highland	101	3.2	31.9
Petticoat	27	0.7	26.4
Frenchman's Bay	27	0.6	20.4
Mimico	77	5.3	68.5
Carruthers	38	0.9	22.9
Duffins	286	8.9	31.0
Rouge	332	13.2	39.7
Etobicoke	211	11.6	54.9
Don	358	16.8	47.1
Humber	909	35.1	38.6
Lakefront areas	121	1.8	15.0

5.2.2 Duration

Rainfall duration during the day of the August 17, 2024 was calculated for the high-resolution gauge stations provided by TRCA, City of Toronto, and City of Mississauga (Section 3.1). The coarse temporal resolution of the ECCC stations lead to an overestimation of the rainfall duration which required the exclusion of the ECCC stations from the rainfall duration calculation. As before, the stations with insufficient or missing data were discarded and the remaining stations provide a spatial dataset of total precipitation across the TRCA jurisdiction. Using the methodology presented in Section 2.2.1, these spatially distributed data points were used to create a gridded dataset of rainfall duration. Isolines were then calculated from this dataset to define the duration isolines (Figure 5-23). The rainfall duration is significantly higher at the centre TRCA region, with the RG_028 station (City of Toronto network) receiving precipitation for 520 minutes (8.66 hours). The longest duration stations are located further west than the areas of highest total precipitation (Figure 5-22), which suggest an unequal rainfall intensity.

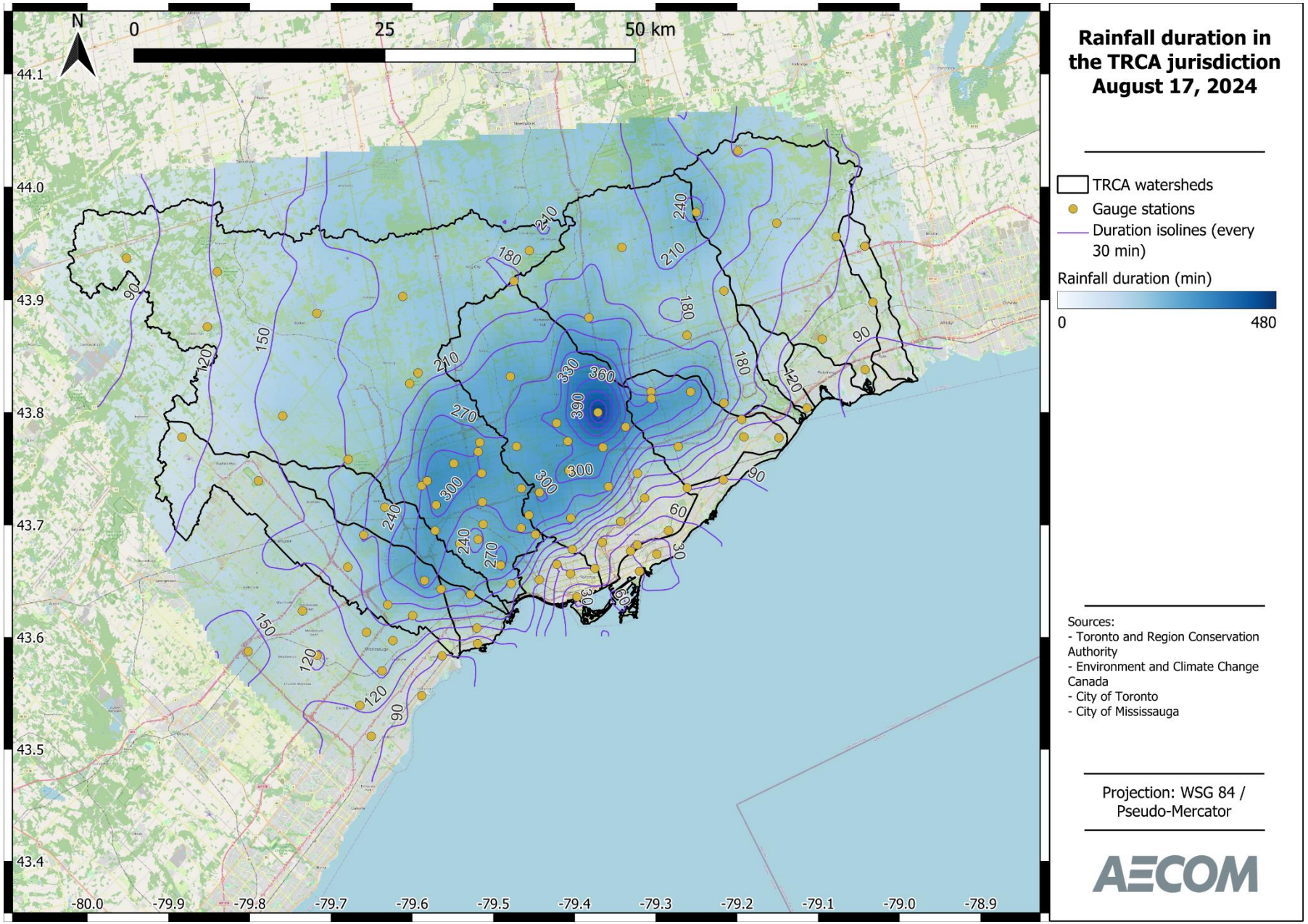


Figure 5-23: Map of Precipitation Duration over the TRCA Region (August 17, 2024)

5.2.3 Intensities

The average rainfall intensity or average rainfall rate at each station was calculated by dividing the total precipitation during the day by the calculated duration. The spatial distribution of average rainfall intensity shows a very intense rainfall in the south of the TRCA jurisdiction and Mississauga (Figure 5-24). The highest average intensity was 49.09 mm/h, recorded at the RG07 station (Streetsville station in the City of Mississauga network, 43.584° N, -79.717° E)) outside the TRCA jurisdiction. Within the TRCA jurisdiction, the highest average intensity was 37.87 mm/h recorded at the HY099 station (Rathwood station in the TRCA network, 43.629° N, -79.630° E).

The maximum 5-minutes intensity (Figure 5-25) during the August 17 event shows a similar but not identical spatial pattern to the average precipitation intensity. The highest value of 5-minutes precipitation was 14.65 mm in the RG_024 station (City of Toronto network). While average intensity was extremely large in Mississauga (RG07 station) and decreasing rapidly in the surrounding area, the maximum 5-minutes intensity shows much smoother gradients. The maximum 1-hour intensity (Figure 5-26) during the event shows a similar pattern to that of the event's total precipitation (Figure 5-22). The highest measurement of 1-hour intensity was 83.9 mm at the HY099 station (Rathwood station in the TRCA network, 43.629° N, -79.630° E).

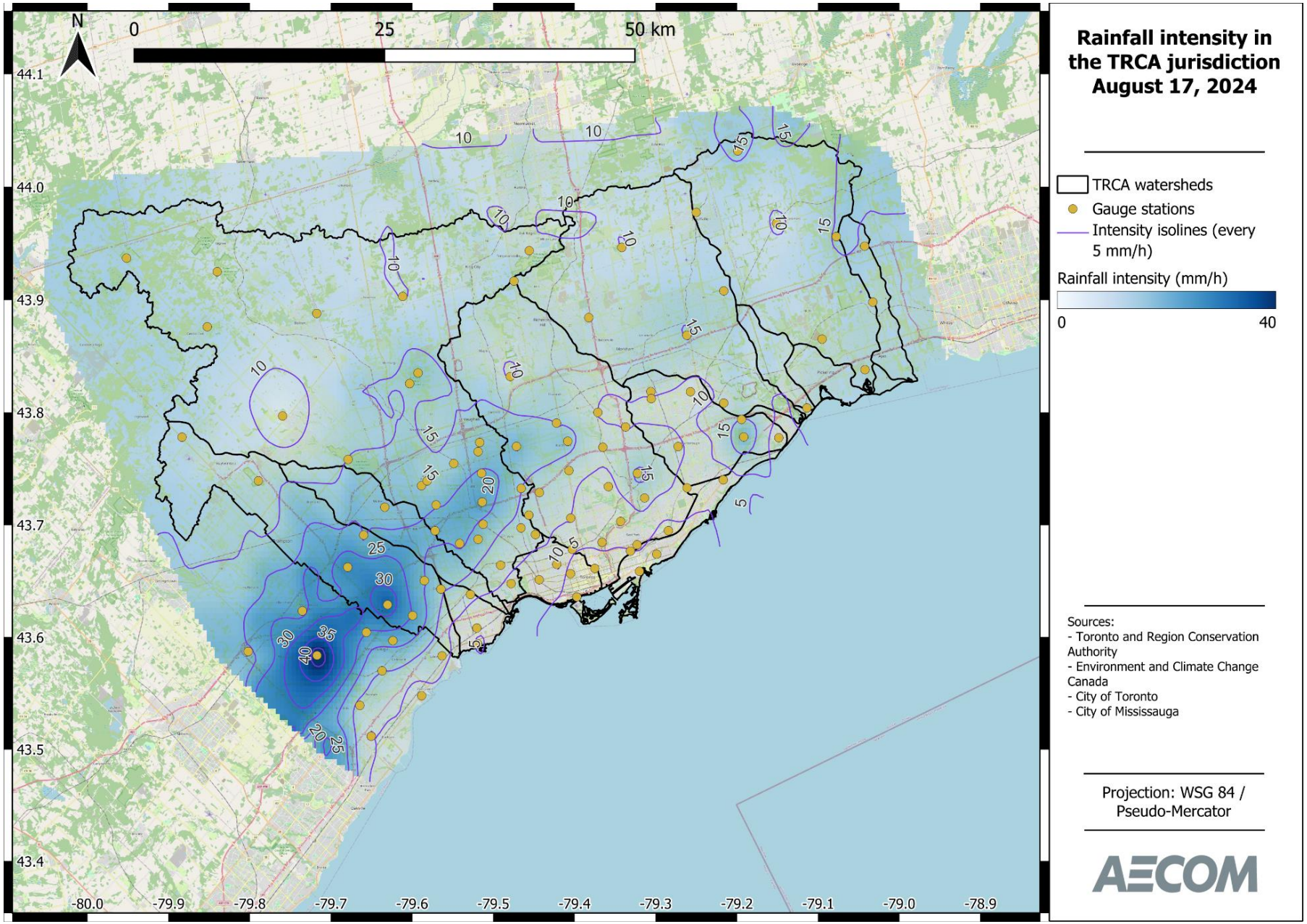


Figure 5-24: Map of Precipitation Intensity over the TRCA Region (August 17, 2024)

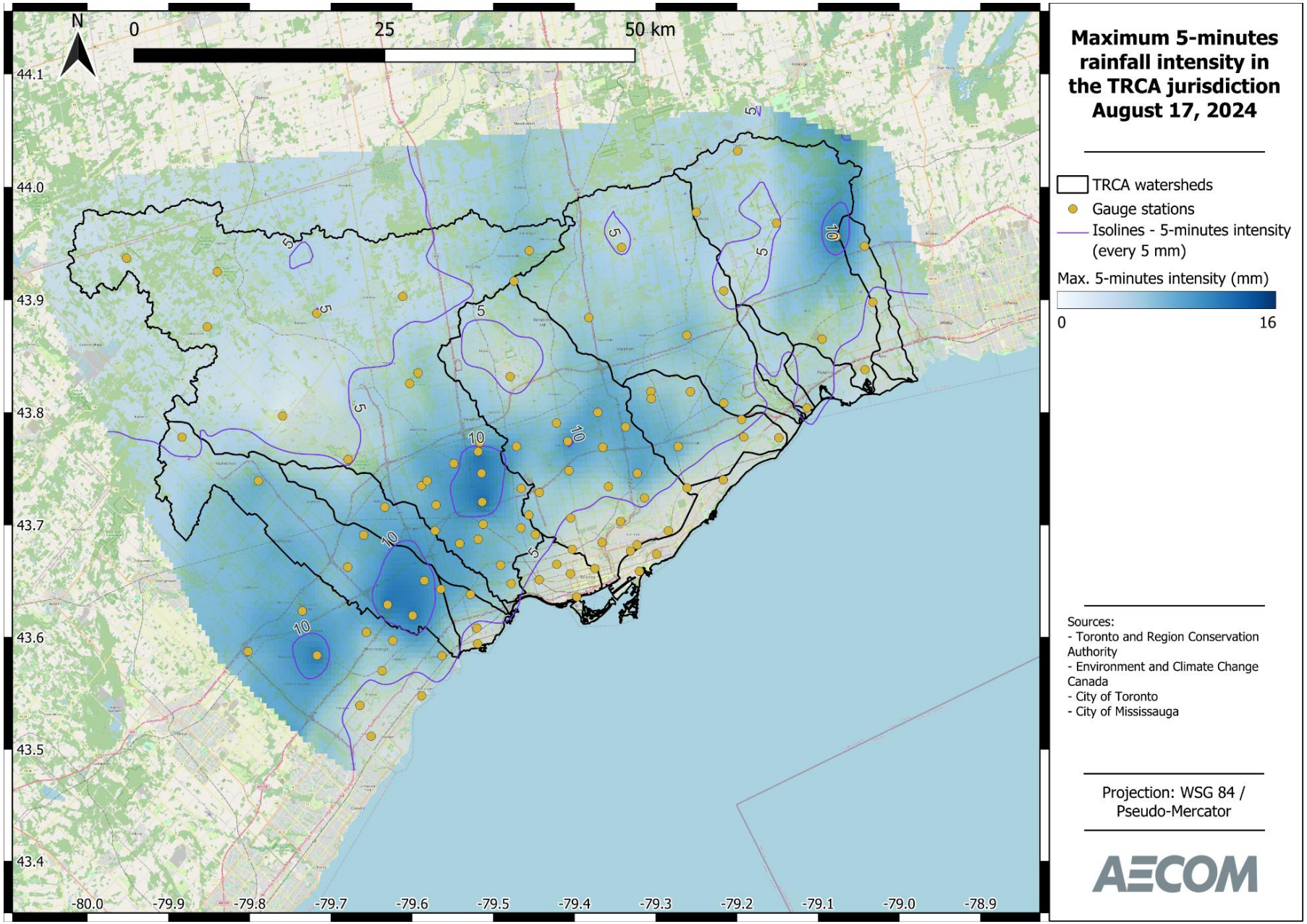


Figure 5-25: Map of Maximum 5-minutes Rainfall Intensity in the TRCA Jurisdiction (August 17, 2024)

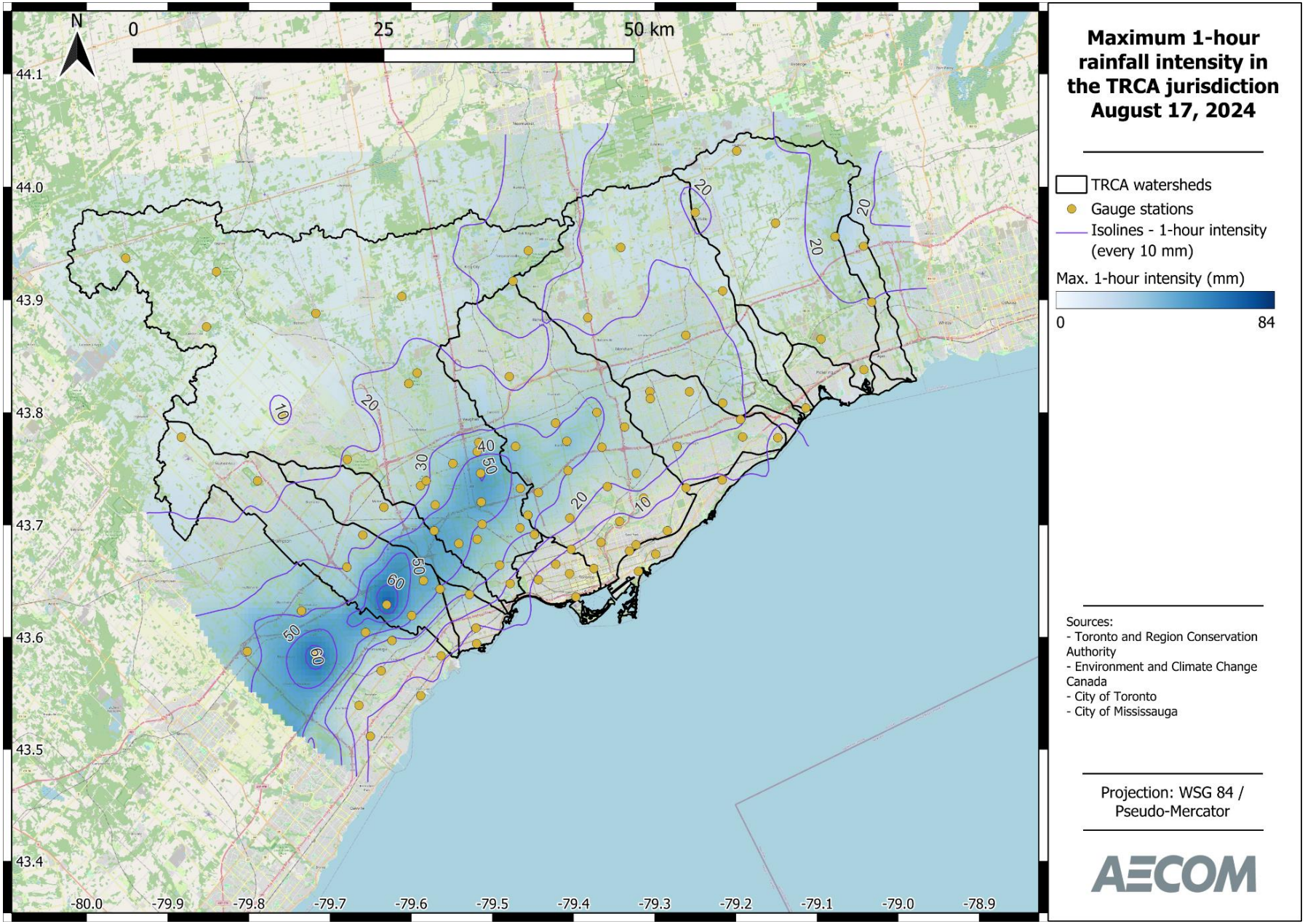


Figure 5-26: Map of Maximum 1-hour Rainfall Intensity in the TRCA Jurisdiction (August 17, 2024)

5.3 Plain-language Summary

A highly localized extreme rainfall event occurred in parts of the Greater Toronto Area (GTA) on August 17, 2024, with rainfall amounts being concentrated in a small part of the TRCA jurisdiction and very small amounts being observed in the other parts. Similar to the July 16 event, the large-scale atmospheric setup for the August 17 event favored rising air in a very humid air mass due to southwesterly flow bringing in Gulf of Mexico moisture with sufficient atmospheric instability and energy for thunderstorms to develop. A weak weather disturbance triggered thunderstorm development producing locally heavy rainfall rates on the afternoon of August 17. However, unlike outside the GTA, successive thunderstorms moved over the same portion of the GTA between 12:30 PM and 5 PM, with prolonged period of heavy rainfall leading to locally ≥100 mm of rain.

ECCC warned on August 16 at 2:46 PM of significant rainfall of 30-60 mm and rainfall rates of up to 40 mm possible over the weekend of August 17-18, providing a lead time of ~1 day for the public and authorities to prepare. Given the already saturated soil conditions, on August 16 at 3:01 PM, the TRCA issued a Watershed Conditions Statement – Water Safety, stating watercourses would be high and fast flowing and that the banks might be slippery, though no immediate flooding was expected. Still, the magnitude of rainfall locally in the GTA was substantially underestimated. ECCC issued a severe thunderstorm watch on August 17 at 10:58 AM, approximately 2 hours before the onset of thunderstorms in the TRCA. As the training of successive thunderstorms occurred, ECCC increased its rainfall prediction to locally 50-100 mm at 1:44 PM, and then for the area of maximum rainfall, to locally 100-200 mm at 3:08 PM. The TRCA responded by issued a Flood Watch at 2 PM.

Although weather models showed the possibility of localized extreme rainfall rates, such extreme rains would only occur in isolated areas. All the models underestimated the rainfall in the narrow band of heaviest rainfall. This makes forecasting the extremity of the event with any useful lead time almost impossible. Like the July 16 event, the August 17 event illustrates the challenge of predicting both the occurrence and location of extreme rainfall driven by localized training of warm-season thunderstorms and the importance of forecasters to have situational awareness of the quickly evolving weather using radar, satellite, and station observations when the atmospheric conditions favor thunderstorms.

Unlike for the July 16 event, for the August 17 event, the rainfall duration was highly variable within the TRCA and was maximized in the centre of the TRCA. The average rainfall totals were also highly variable within the TRCA but was maximized to the southwest, in Mississauga. Both of these areas correspond to the areas affected by the training of successive thunderstorms, contributing to a narrow (~10 km) band of very intense precipitation (>100 mm) 12-15 km from the shoreline and parallel to the shoreline over the Etobicoke, Mimico and Humber watersheds. Precipitation decreased rapidly to <30 mm away from the band, and some locations along the Lake Ontario shoreline received only 10 mm. Like for the July 16 event, for the August 17 event, the Mimico watershed had on average the highest precipitation, but the much larger Humber watershed had the highest total amount of precipitation among the TRCA watersheds.

6. IDF Update

The IDF stations chosen for the IDF curves update, Toronto City (TORONTO CITY) and Toronto Pearson International Airport (TORONTO INTL A), correspond to ECCC meteorological stations that only record precipitation at a daily resolution. To obtain the precipitation amounts for the different sub-daily durations used in IDF curves, nearby stations were identified where high-resolution records (5-minutes) of precipitation are available (Table 6-1). It was assumed that the temporal distribution of precipitation throughout the days of the storms of the nearby station was similar to the distribution at the IDF stations. This assumption introduces potential biases in the results. However, these biases were inevitable given the lack of high-resolution sub-daily precipitation records at the IDF stations. Temporal disaggregation techniques, such as scaling relationships or stochastic disaggregation, require calibration with known sub-daily precipitation distributions that have to be assumed similar to that of the event, for instance known distributions for other events in the same location (like existing IDF curves) or for the same event at nearby locations. The latter case corresponds to the approach used in this analysis, where nearby stations with high-resolution records are assumed to have a similar distribution to the targeted IDF stations.

Table 6-1: Precipitation at the IDF Stations during Both Events and Nearest High-resolution Stations

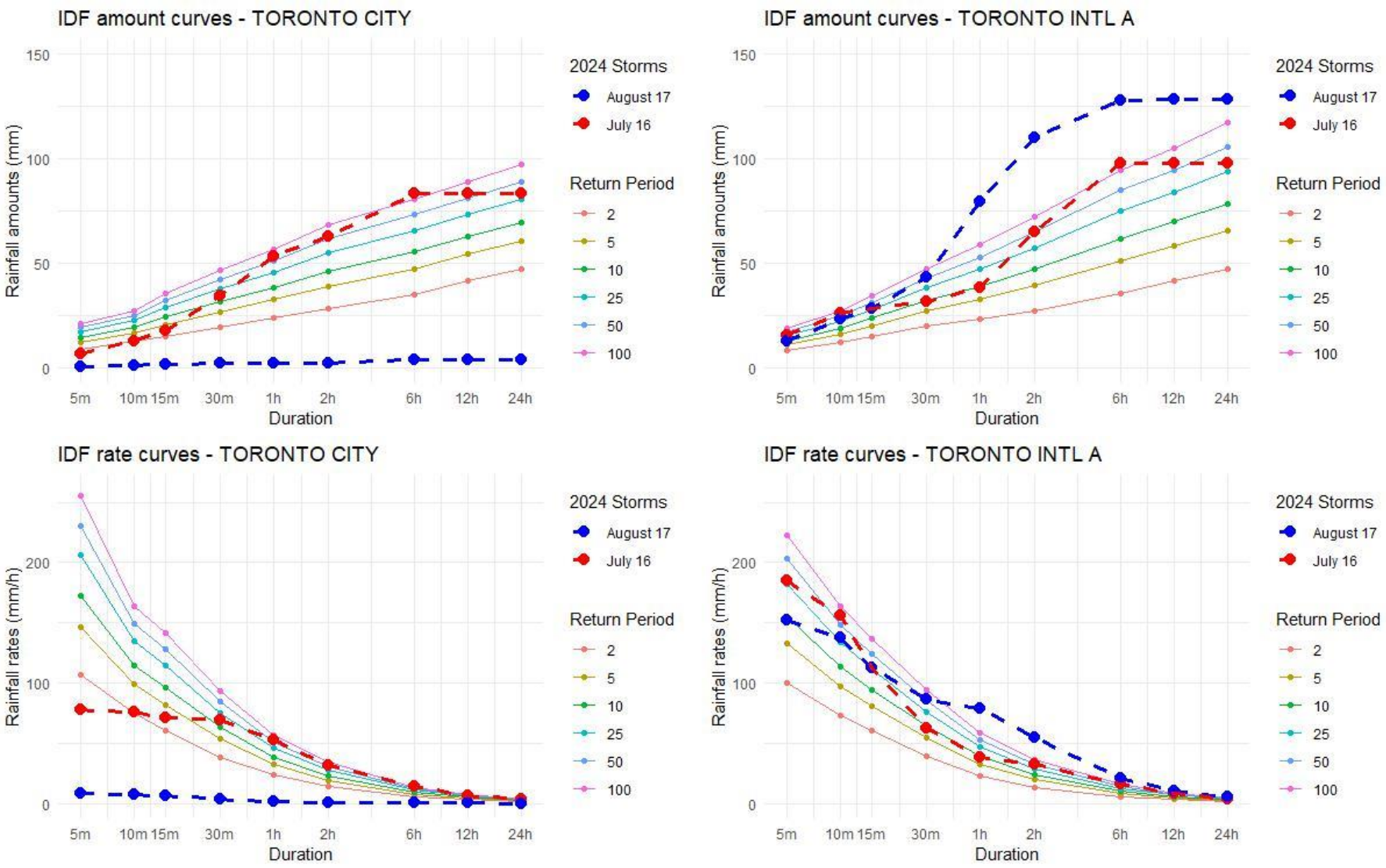
IDF station	Precipitation		Nearby station	
	July 16, 2024	August 17, 2024	ID / Name (network)	Distance to IDF station
TORONTO CITY	83.6 mm	3.5 mm	RG_004 / 7680 (City of Toronto)	960 m
TORONTO INTL A	97.8 mm	128.3 mm	HY099 / Rathwood (TRCA)	5 680 m

Hence, the maximum precipitation of the two events was selected, and rainfall amounts for sub-daily durations were calculated following the temporal precipitation distribution of the nearby stations. The precipitation amounts corresponding to the different durations can be found in Appendix E.

The existing IDF curves were then compared to the IDF curves of the July 16, 2024 and August 17, 2024 storms (Figure 6-1). The July 16 storm was spread-out, depositing high amounts of precipitation at the location of both IDF stations. Toronto City surpassed the 50-year return level for the 1h, 2h and 12h durations, and the 100-year level for the 6h duration. Similarly, the Toronto Pearson International Airport surpassed 50-year return level for the 2h and 12h durations and the 100-year return level for the 6h duration.

The August 17 storm deposited a similar amount of precipitation as the July 16 storm, but it was concentrated over a relatively narrow band parallel to the shoreline, bypassing the Toronto City station and concentrating over Toronto Pearson International Airport. While Toronto City registered insignificant levels of precipitation, rainfall over Toronto Pearson International Airport surpassed the 100-year return level for the 1h, 2h, 6h, 12h and 24h by a wide margin. The 100-year return level for the 2h duration (72.5 mm) was surpassed by more than 50%, indicative of an extremely rare event.

Incorporating the 2024 data into the historical dataset of annual maximums for rainfall durations, the IDF curves were updated (Figure 6-2). The updated curves show an increase in the rainfall amount for rainfall durations longer than 30 minutes, particularly for Toronto Pearson International Airport. At this location, for the durations between 1h and 12h, the new rainfall amounts for the 50-year and 25-year return periods correspond to what used to be 100-year and 50-year return periods, respectively. This indicates a doubling in frequency of high-rainfall events at these durations.



Note: Data from the July 16, 2024 and August 17, 2024 storms in comparison to existing IDF curves for the TORONTO CITY and TORONTO INTL A stations.

Figure 6-1: Rainfall to IDF Comparison 2024

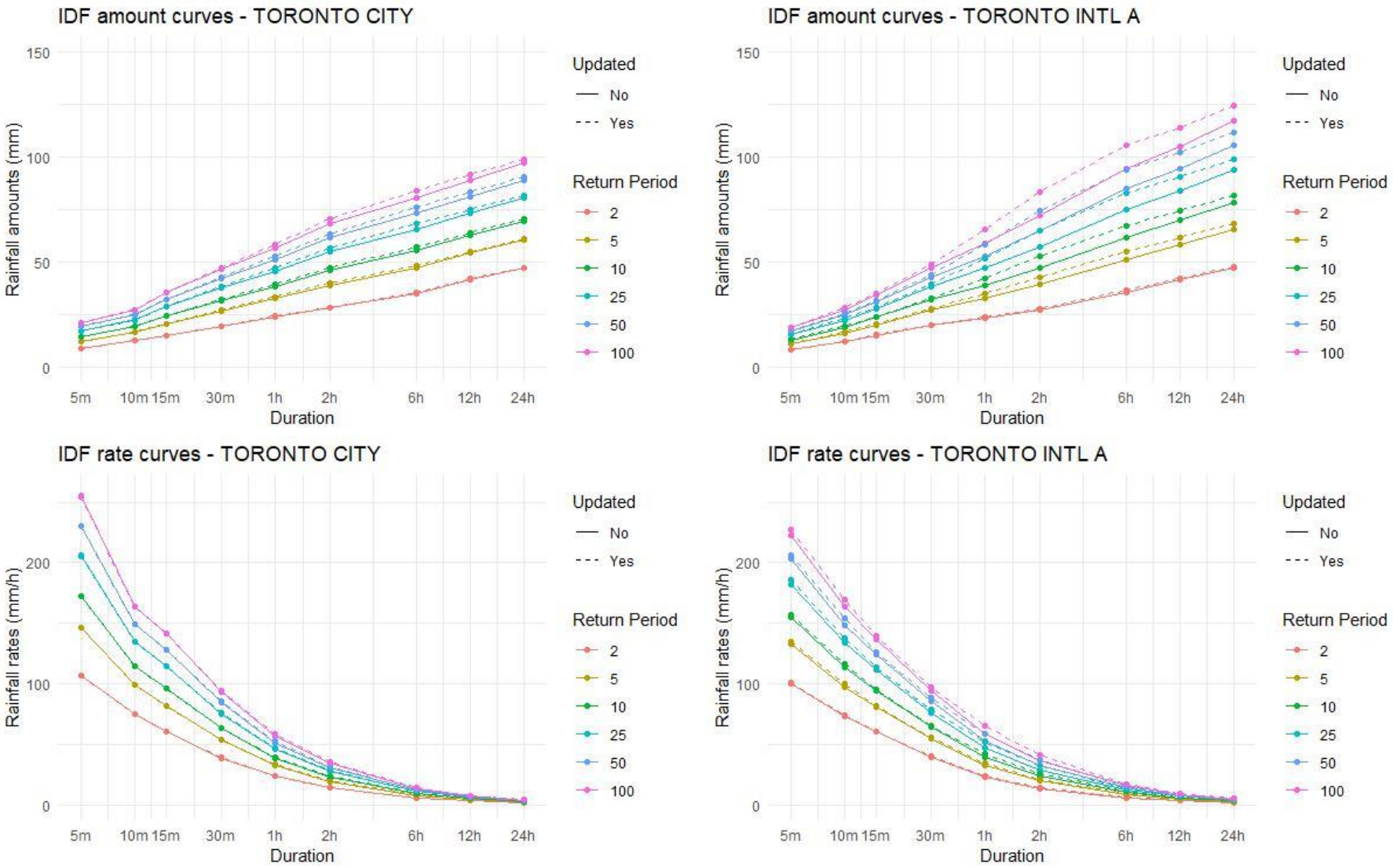


Figure 6-2: Existing and Updated IDF Curves for the TORONTO CITY and TORONTO INTL A Stations

7. Topographical Analysis

7.1 Heat Island Effect

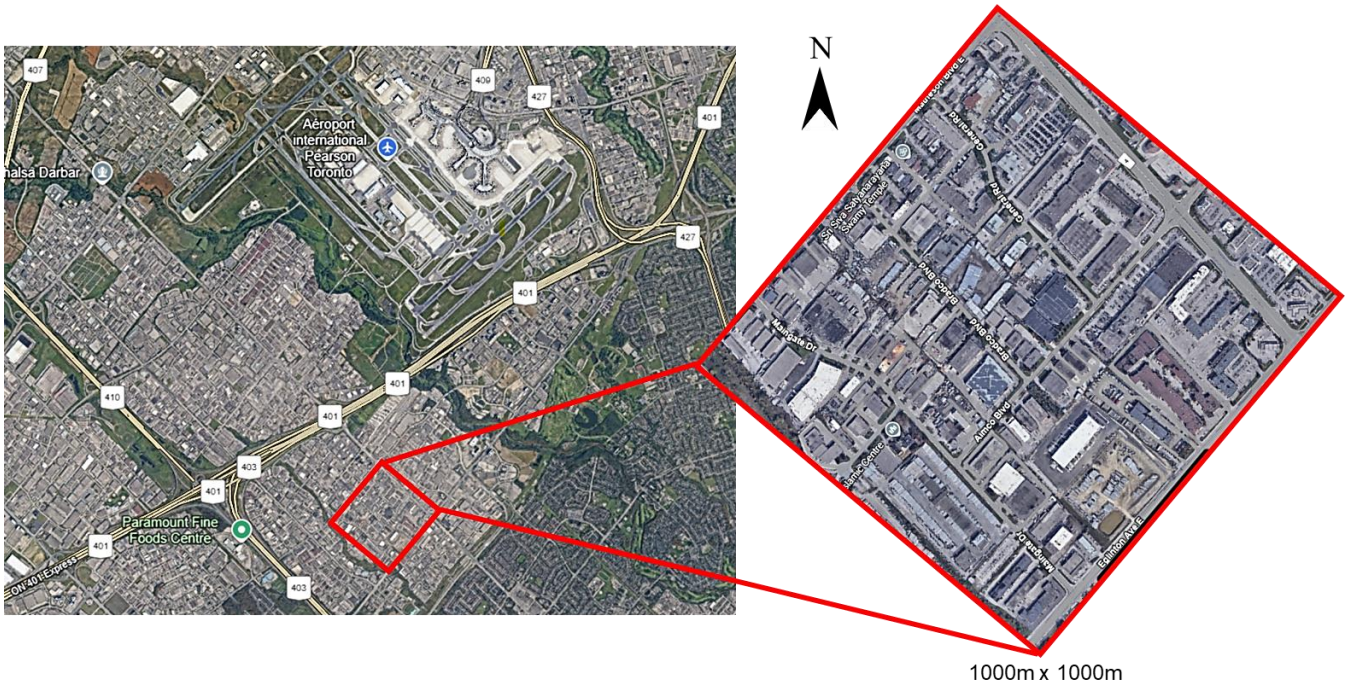
The role of Urban Heat Island (UHI) and heat buildup in the lower atmosphere in increasing atmospheric instability, and potentially contributing to storm development and intensification, has been explored in scientific literature (Twohey and Naylor, 2019; Baik et al., 2001). These studies have shown that the additional heat input from UHI into the lower atmosphere can trigger isolated convection and can initiate rainfall. With increasing heat island intensity, the time until clouds and rainfall form decreases. At least in isolated convection without larger atmospheric trigger, the convection and precipitation maxima are located downwind of the maximum UHI. A secondary effect of the cityscape is the surface convergence caused by channeling effects around the urban infrastructure elements. This effect is most noticeable upwind of the UHI. In this section the thermodynamic aspects of the UHI were analysed using microclimate modeling and comparing thermal performance between:

- Vegetated rural area in Mississauga in about 1958,
- Transition period of 1976, and
- Built-up industrial area as it is today.

The objective of this assessment is to quantify the intensity of the UHI effect within the study area during the two extreme rainfall events of July and August 2024.

7.1.1 Study Area and Scenarios

The study area in Mississauga was selected based on a review of precipitation records across the GTA during the July and August 2024 heavy rainfall events. The Rathwood station recorded the highest precipitation amount and was identified as a reference point for the detailed urban microclimate modeling. Within the surrounding area, a representative industrial zone that is characterized by large amounts of paved surfaces, including parking lots, warehouses, and flat-roof buildings (Figure 7-1) was chosen.



Source: Imagery © Google, Airbus, NOAA, 2025. Map date range: 09/05/2004 – 15/06/2025.

Figure 7-1: Map of Study Area for UHI Modeling

Three different simulation domains were developed within a **1000 m x 1000 m** area:

- **Urban 2025 domain:** Located west of Toronto Pearson International Airport, this zone is characterized by:
  - Flat-roofed industrial buildings.
  - Extensive impervious surfaces, including asphalt parking lots, roadway, and loading zones.
  - Large, open surface areas exposed to direct solar radiation.
  - Absence of vegetation or shaded areas.
  - Estimated coverage: ~95% built-up and impervious surfaces, less than ~5% pervious surfaces.

- **Urban 1976 domain:** Represents the transitional land-use conditions of the mid-1970s. This model includes:
  - More moderate building density
  - Fewer impervious surfaces than the present day.
  - It captures the intermediate stage of development between the largely vegetated landscape and the heavily build-up industrial environment of 2025 (Figure 7-2).
  - Estimated coverage: ~60% built-up and impervious surfaces, ~40% vegetation, open and pervious surfaces



Source: Obtained from the TRCA aerial photograph archive (TRCA Aerial Photograph Archive, Northway Gestalt Co., Roll RMTRCA-1, Line L6, Exposure 80)

Note: The red outline indicates the modelled domain.

Figure 7-2: Historical Aerial Photograph of the Study Area in 1976

- **Rural domain:** Constructed as a reference scenario, this model includes:
  - Approximately 75% vegetation coverage, consisting of distributed trees and open grassy areas.
  - Pervious ground surfaces.
  - Minimal build form, with a few low-density structures to simulate typical rural land use.
  - Estimated coverage: ~25% built-up and impervious surfaces, ~75% vegetation, open and pervious surfaces

The geometry layout for the three domains was manually created in Rhino 3D based on real urban configuration from high-resolution satellite imagery (Google Earth, 2025; TRCA Aerial Photograph Archive, , 1976; Figure 7-3).

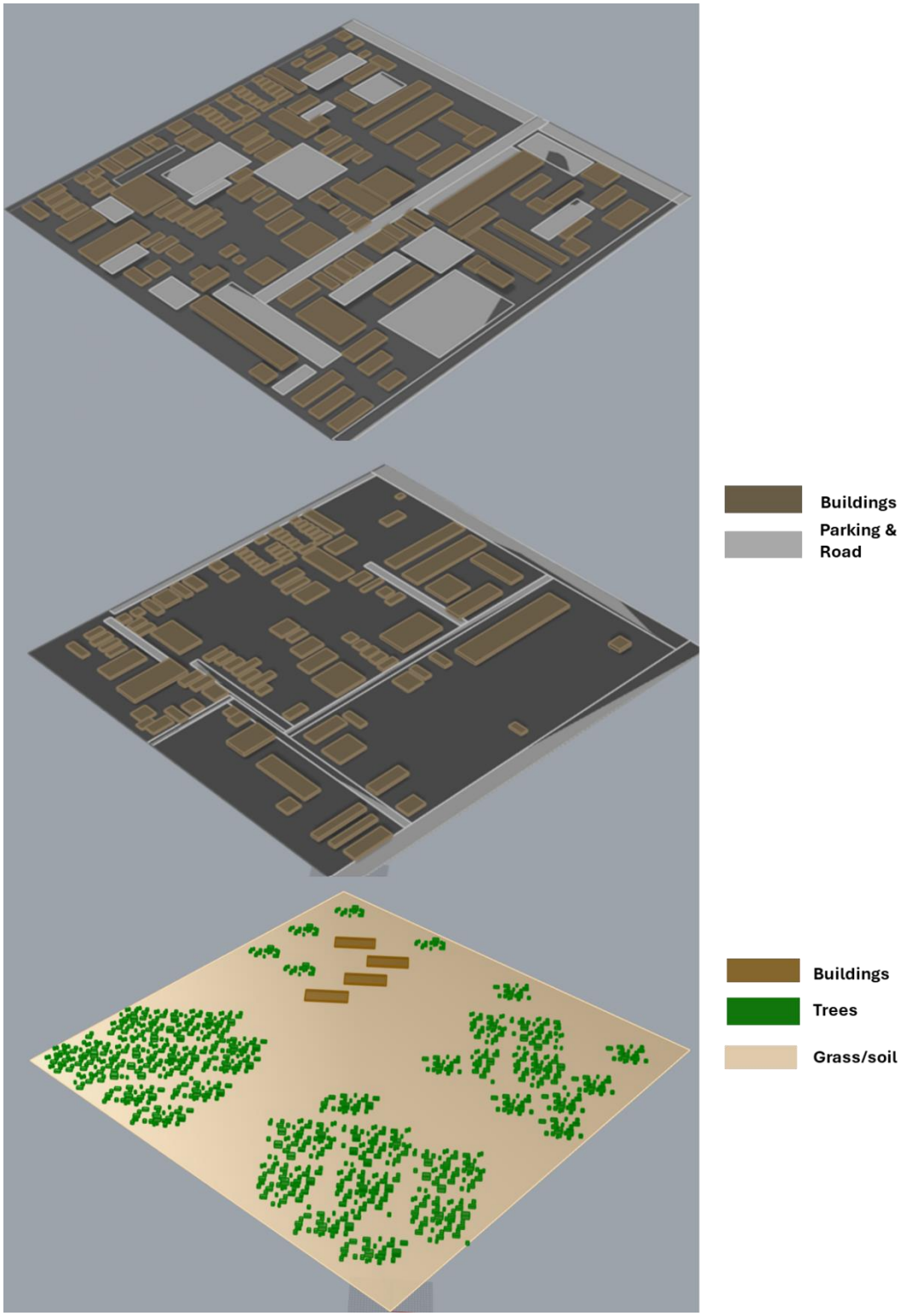


Figure 7-3: Urban 2025 Model (Top), Urban 1976 Model (Middle), and Rural Model (Bottom) (Simulation)

7.1.2 Simulation

The simulations were driven by hourly meteorological input data from the ECCC station at the Pearson International Airport in Toronto. This dataset includes dry bulb temperatures, wind speed and direction, and relative humidity, and serves as the baseline input for Ladybug Tools simulations.

To identify and quantify the presence and intensity of the urban heat island, this assessment simulated thermal conditions across three different land use domains (Urban 2025, Urban 1976, and Rural), under identical weather conditions for two five-day periods (July 13-17 and August 14-18, 2024). The results provide a basis for understanding localized thermal behavior and may serve as a reference for exploring the potential influence of UHI on storm development.

7.1.3 Results

7.1.3.1 July 16, 2024

During the simulation period for the July 16 event, the three models present a consistent diurnal temperature pattern characterized by a rapid rise in temperature between 6:00 and 11:00 AM, driven by increasing solar radiation and surface heating (Figure 7-4). Temperatures reach their peak between 12:00 and 16:00 PM, which corresponds with the time of maximum solar altitude. With the setting sun, the temperature declines in both simulations to reach a daily minimum in early morning hours.

While all simulations show very similar patterns, some crucial differences are obvious. For all days, the daily maximum temperature is highest in the Urban 2025 simulation, lowest in the Rural case, with the Urban 1976 simulation falling between. After sunset, both Urban 2025 and Urban 1976 remain warmer than the Rural simulation, but the heat retention is strongest in Urban 2025. The higher peak temperatures and the slower cooling rate in urban areas is the result of higher heat capacity of surfaces such as asphalt and concrete which retain heat and release it gradually over time. The persistence of this thermal offset between the three domains reflects the UHI diurnal profile, in which urban environments absorb and store heat during the day and release it more gradually overnight, resulting in consistently warmer nighttime conditions.

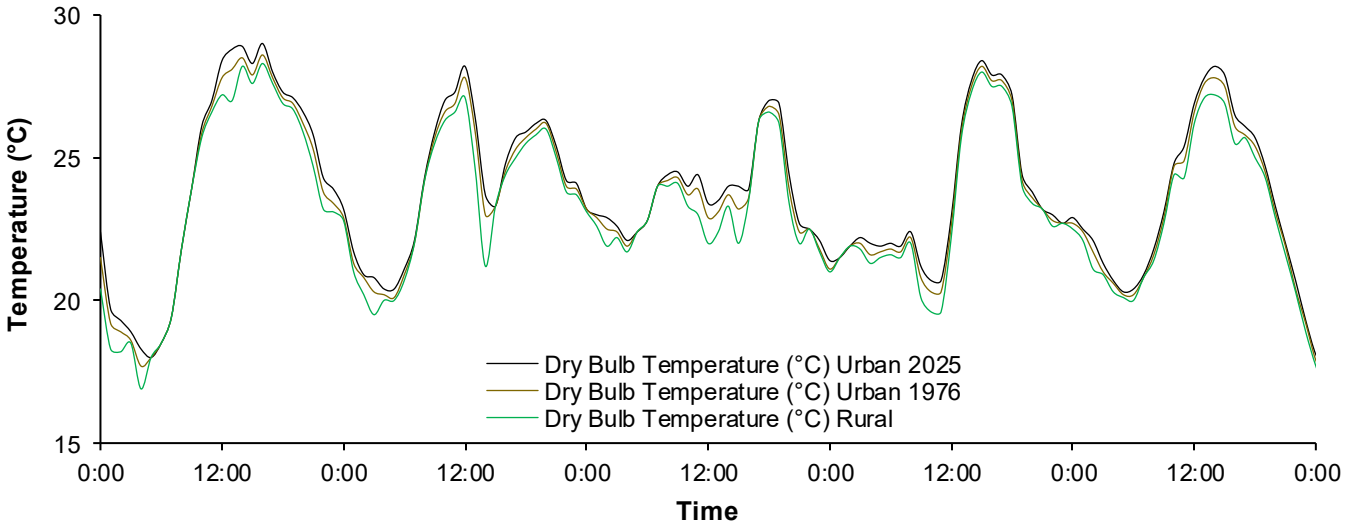


Figure 7-4: Simulated Hourly Air Temperature for Urban 2025, Urban 1976, and Rural Models (July 13 to 17, 2024)

Focusing on the days leading up to and of the July 16 event, the simple diurnal cycle was disrupted due to the presence of clouds and rainfall. For example, on July 14, a secondary temperature minimum is observed in the early afternoon when full cloud cover and 2.1 mm of precipitation were observed at the Pearson International Airport station (Meteostat, 2025, Figure 7-5). It is important to note that precipitation effects on temperature are not explicitly

simulated in Ladybug, and the cooling is driven by the input data. Hence, the focus must lie on the comparison of the three simulations.

The different behaviour of the simulations is obvious during the peak in temperature around 12 PM but even more so during the subsequent cooling. The lingering heat is most pronounced in Urban 2025, while Urban 1976 shows a smaller but still visible offset compared to Rural (Figure 7-5). On July 14 at 2 PM, the difference between Urban 2025 and Rural reached 2.5 °C, the highest value during this period, while the Urban 1976 case showed an intermediate difference of about 1–1.8 °C. In the morning of July 15, the urban and rural temperatures are very similar, highlighting the more immediate warming of the rural environment whereas the darker surfaces in the urban setting absorb more of the solar energy and therefore delaying the warming of the atmosphere to some extent. Once the surfaces were heated, the urban temperature remained elevated for longer even when the cloud cover increased and precipitation began in the late morning and early afternoon. After the rain showers had passed, the clear-sky conditions returned (Figure 4-9) and with it the differential heat of the rural and urban environments. Overnight, the temperatures in the simulations remained relatively stable due to the increasing cloud cover as the MCV approached the GTA. Surfaces and, in particular, the dark surfaces in urban simulations cooled less as the clouds reflect emitting heat back, trapping the energy. The temperature remained elevated in the urban simulation before and during the event on July 16, with a maximum difference between the two simulations of 1.1 °C at 12 PM.

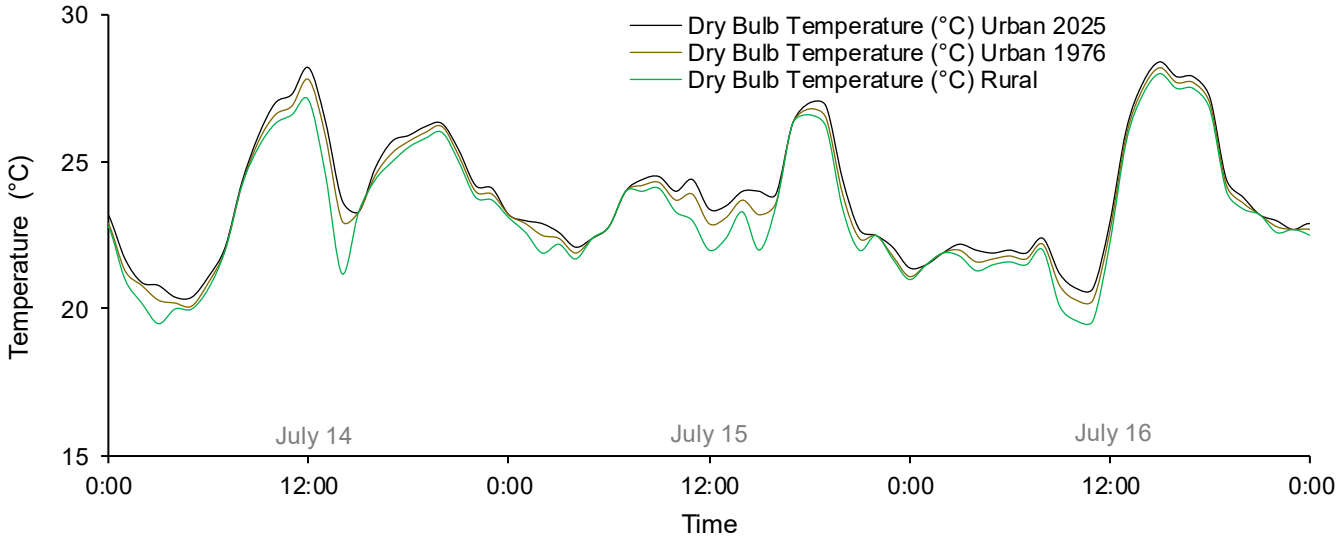


Figure 7-5: Simulated Hourly Air Temperature for Urban 2025, Urban 1976, and Rural Models (July 14 to 16, 2024)

7.1.3.2 August 17, 2024

During the simulation period of August 14-18, the three domains show parallel diurnal cycles (Figure 7-6). The daily temperature rise starts around 6:00 AM and continues through the afternoon, peaking between 12:00 and 16:00 PM. The Rural case cools most rapidly with the setting sun, Urban 1976 cools more slowly, and Urban 2025 remains warmest well into the night, especially after multiple hot days. Both urban simulations consistently show slower nighttime cooling, reinforcing the pattern of retained heat in built-up areas.

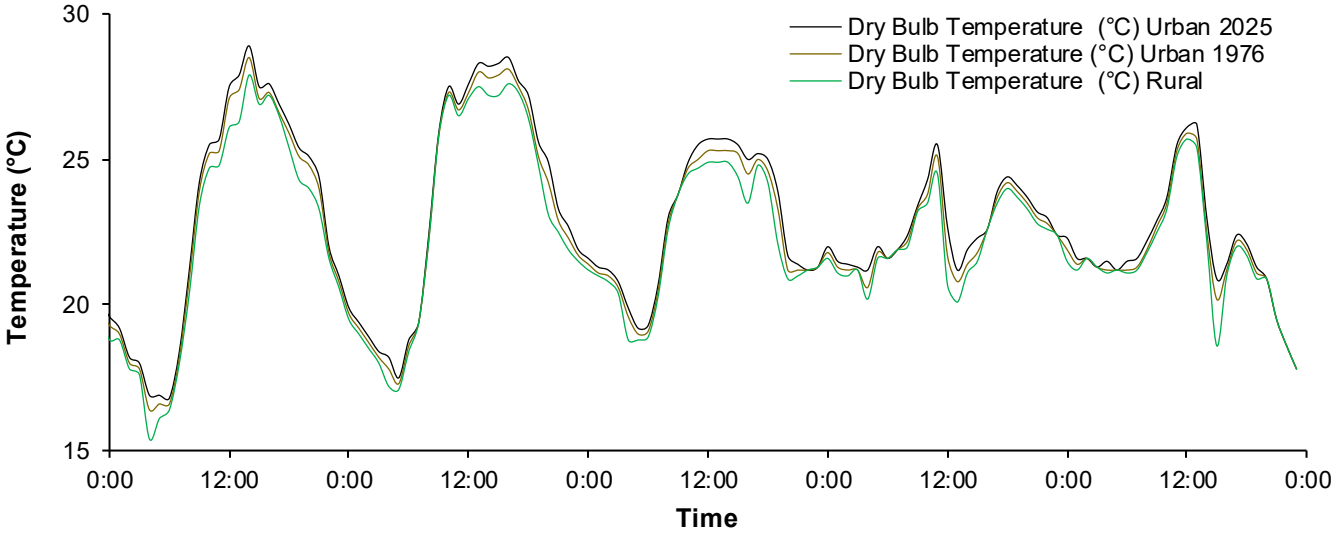


Figure 7-6: Simulated Hourly Air Temperature for Urban 2025, Urban 1976, and Rural Environments (August 14 to 18, 2024)

Reviewing the hours leading up to the August 17 event, the temperature in both urban simulations on August 16 were systematically higher than the rural temperatures, with Urban 2025 showing the largest offset (Figure 7-7). The difference was the largest at night and in the early morning hours and over mid-day and into the evening when the heat capacity differential had the greatest impact. Urban surfaces with their darker colour and higher heat capacity absorb more of the solar radiation in the morning after sunrise and delay the warming of the surrounding air. During the night from August 16 to 17, the Urban 2025 temperatures remained highest, Urban 1976 temperatures stayed slightly above Rural, while Rural cooled fastest. Similar to the day before, the warming in the urban simulations was slightly delayed in the morning of August 17 before the temperature difference increased.

With the onset of the precipitation, the temperature dropped in the simulations due to the temperature decrease in the input file. The Ladybug simulation itself does not account for cloud cover and precipitation directly and reflects only the temperature decrease in the observational dataset used to drive the simulations. Nonetheless, the simulations capture how the rural and urban environments influence the local temperature profile during the episode of rapid temperature decrease and humidity increase. The urban–rural temperature difference reached 2.0 °C on August 17 at 12 PM, during the storm event. Throughout the storm event, the urban temperature remained elevated compared to the rural setting, providing additional energy to the environment.

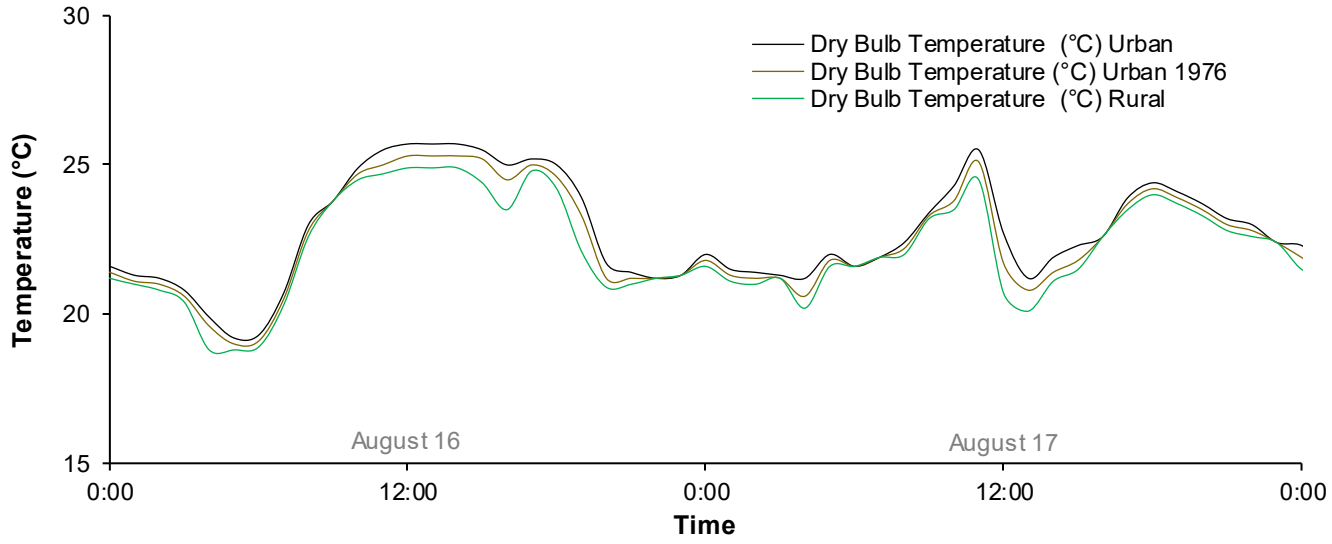


Figure 7-7: Simulated Hourly Air Temperature for Urban 2025, Urban 1976, and Rural Environments (August 16 to 17, 2024)

7.1.4 Influence Factors on Urban Heat Island

An increase of 35% in built-up area may correspond to a measurable rise in surface and air temperatures, reflecting the role of impervious surfaces in absorbing and re-radiating heat. However, the urban heat dynamics extend beyond built-up density, reflecting the combined influence of multiple environmental and design variables. It is influenced by a complex interaction of factors such as building orientation, the thermal properties of construction materials, the presence and age of green spaces, and the type, density, and spatial location of trees or vegetation. These variables affect the heat absorption and reflection in urban settings, making each neighbo urhood's response unique even under similar levels of built-up growth.

7.1.5 Effect on Storm Development and Intensity

The UHI simulation results point toward a buildup of heat in the urban simulation and may have contributed to pre-storm atmospheric instability. In the lead-up to the July 16 storm, urban surfaces retained heat overnight from July 15 to 16, resulting in elevated temperatures during the morning of July 16. This stored energy may have been contributed to the atmospheric instability already present in the atmosphere. Similarly, before the August 17 storm, a measurable UHI was present. The additional heat from the urban environment might have contributed to storm intensification over Toronto. In both cases, the additional heat from the UHI might have played a supporting role and further enhance the larger-scale factors such as the MCV and the frontal system. The attribution of why the storms occurred over Mississauga and the isolation of the UHI's influence on the storm intensities cannot be answered without a detailed investigation of mesoscale dynamics and localized surface characteristics. A focused heat-island modeling study, integrating both high-resolution climate and atmospheric modeling with local land use and surface characteristics, would be needed to explain the localized differences. Nonetheless, high-level mitigation recommendations are included in Section 10.2.

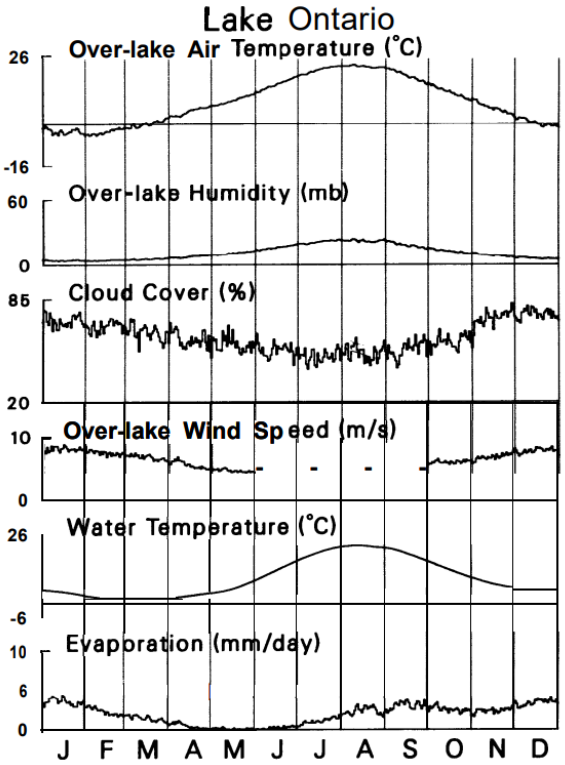
7.2 Lake Ontario

The presence of a large water body like Lake Ontario next to the TRCA jurisdiction has the potential to significantly impact the frequency and intensity of storms. This influence manifests in three ways:

- Providing moisture to the atmosphere,
- Regulating the temperature of the lower atmosphere, and
- Development of lake breeze.

7.2.1 Moisture Source

The main sources of humidity for the Great Lakes region are the Great Plains (contributing 35% of moisture in the Spring and Summer) and the Great Lakes themselves (contributing 40% of moisture in the Autumn and Winter), while other sources such as the Canada-Alaska region and the eastern Mid-Pacific making significant contributions (Yang et al., 2023). Despite not being the main source of humidity in the summer, evaporation from Lake Ontario contributes a substantial amount of moisture to the atmosphere over surrounding region (Croley, 1989). The main drivers of evaporation are wind speed, air and water temperature, and air humidity. Between April and June, the evaporation from Lake Ontario is minimal, and it peaks during September and January (Figure 7-8). In Spring and early Summer, evaporation is low due to a combination of low wind speed and low water and air temperature, despite relatively low air humidity. In late summer, evaporation rate rises due to the high water and air temperature, while in winter evaporation is high due to low humidity and high wind speeds.



Source: Croley, 1989

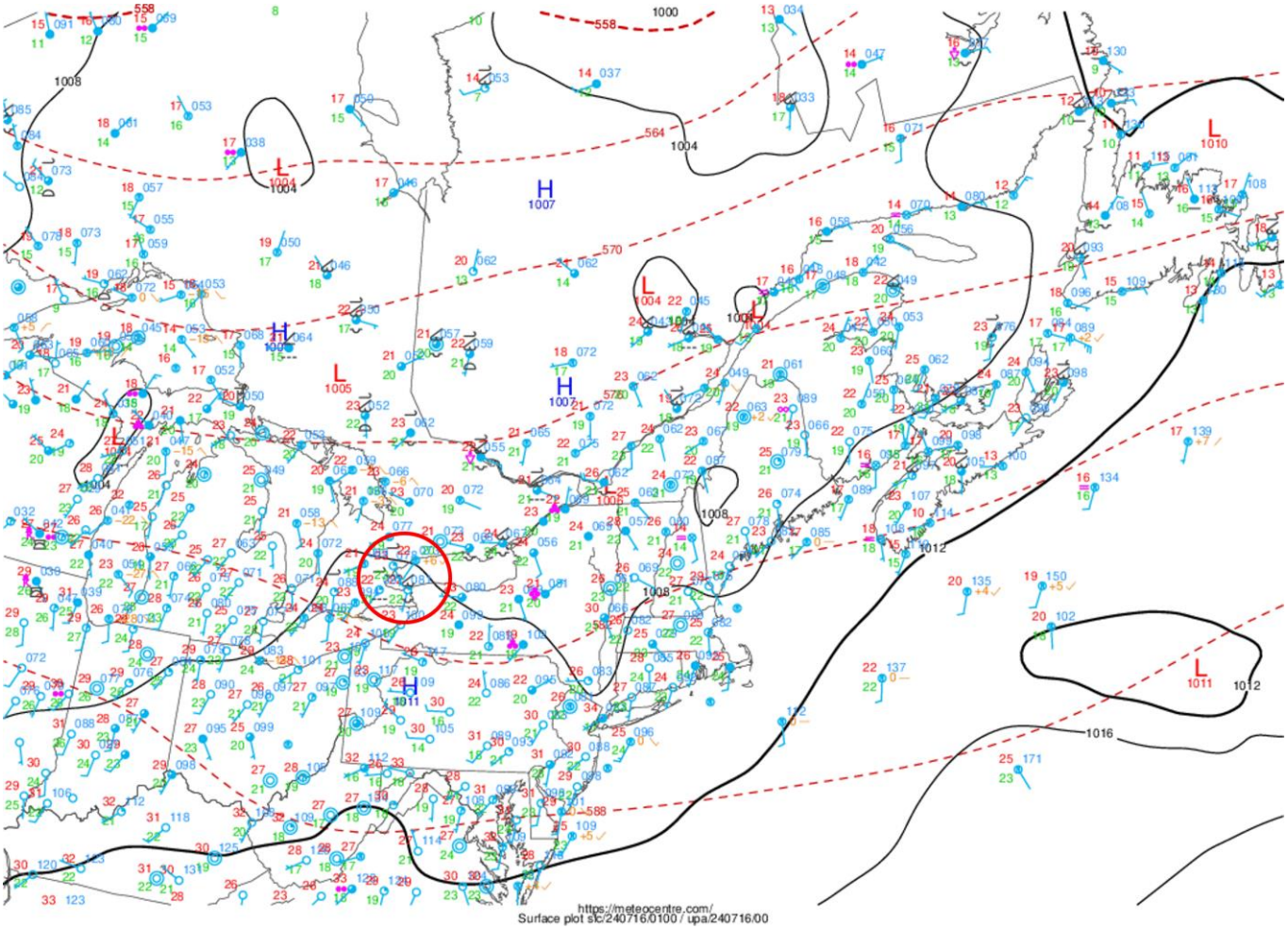
Figure 7-8: Annual Cycles of Average Lake Ontario Meteorology and Evaporation

This evaporation humidifies the atmospheric layer immediately above the lake, which can then be transported inland by winds coming from the direction of the lake. This additional humidity in the environment can, when encountered by storms that form or move over the GTA such as the July and August 2024 storms, intensify their effects. For example, the meteorological station at the Toronto Pearson International Airport indicated temperature of 26.3 °C and relative humidity of 65% at 7 PM on July 15 (Table 7-1). One hour later, the same station measured an air temperature of 22.7 °C and a relative humidity of 100%. This relatively sharp decrease in temperature and increase in humidity points towards the advection of cooler and more humidity air. With the approaching MCV, the wind direction had shifted to southerly wind in the GTA. Although the wind speeds were low, humid air from Lake Ontario was brought into the city (Figure 7-9). These humid conditions persisted until the storm arrived at around 9 AM on July 16, potentially contributing the favorable conditions in the GTA.

Table 7-1: Temperature and Humidity Measurements at TORONTO INTL A Station (Late Hours of July 15 and Early Hours of July 16, 2024)

Date	T (°C)	T_d (°C)	RH (%)
2024-07-15 17:00	26.3	21.4	74
2024-07-15 18:00	26.7	19.4	64
2024-07-15 19:00	26.3	19.2	65
2024-07-15 20:00	22.7	22.7	100
2024-07-15 21:00	22.1	22.1	100
2024-07-15 22:00	22.5	20.7	89
2024-07-15 23:00	21.8	21.0	95
2024-07-16 0:00	21.1	21.1	100
2024-07-16 1:00	21.5	20.9	97
2024-07-16 2:00	21.9	21.1	95
2024-07-16 3:00	21.9	21.0	95
2024-07-16 4:00	21.4	21.4	100
2024-07-16 5:00	21.6	21.4	99
2024-07-16 6:00	21.7	21.7	100
2024-07-16 7:00	21.6	21.6	100
2024-07-16 8:00	22.1	22.1	100
2024-07-16 9:00	20.4	20.4	100
2024-07-16 10:00	19.9	19.9	100
2024-07-16 11:00	19.9	19.9	100
2024-07-16 12:00	22.3	22.3	100

Note: T indicates air temperature, T_d denotes dew point temperature, and RH stands for relative humidity.
Source: ECCC, 2025a



Note: Red circle marks the wind arrows for the GTA.
Source: Centre Météo (UQAM), 2025. All reproduction rights are reserved.

Figure 7-9: Surface Wind Conditions (16-July-2024, 01 UTC)

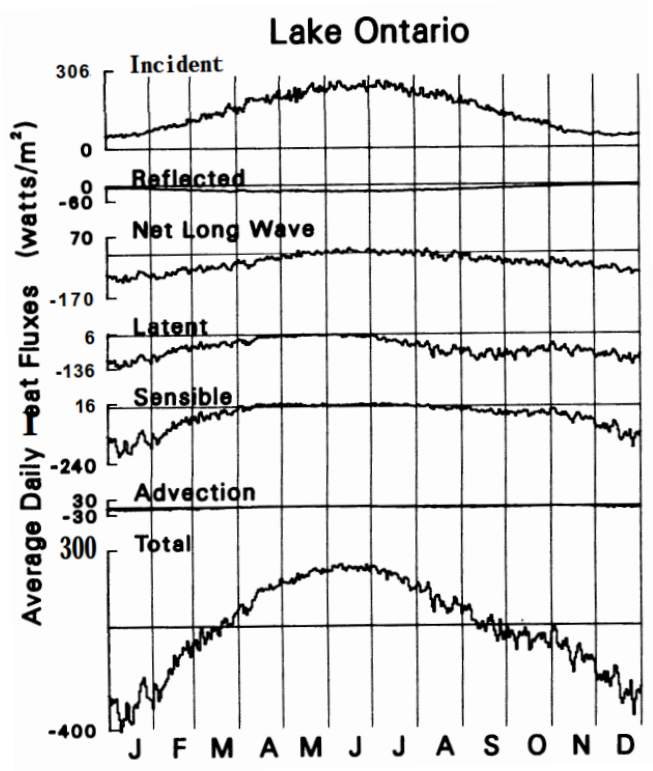
7.2.2 Temperature Modulation

Water bodies act as large heat reservoirs that absorb heat during summer and release it during winter due to the high thermal capacity of water and the vertical convection in the water column. This high thermal capacity results in water bodies following the annual temperature cycle with a time delay, allowing them to be warmer than their balance temperature (the temperature at which they would be in energetic balance with the overlaying atmosphere) during winter and colder during summer. This imbalance results in a net exchange of heat with the atmosphere, warming the overlying air during winter and cooling it during summer. This exchange of heat takes the form of sensible heat, latent heat, and longwave radiation. While sensible and latent heat concentrate this exchange of heat within the lowest layer of the atmosphere that is in contact with the water body, longwave radiation tends to release heat higher throughout the troposphere.

In the case of Lake Ontario, the heat fluxes add up to a positive energy balance during summer and a negative during winter, averaging to an annual net-zero energy for 1950-1985 (Croley, 1989; Figure 7-10). Since the mid-1990s, the heat fluxes are no longer be balanced, and water temperature has been increasing at an annual rate of 0.03 °C to 0.05 °C (Gronewold, 2013). However, the results of Croley (1989) are still considered to be representative of the relative magnitude of the heat fluxes across the water-air interface of Lake Ontario.

During winter, Lake Ontario releases large amounts of heat in the form of longwave radiation, sensible heat due to the relatively higher water temperature compared to the air temperature, and of latent heat due to the high levels of evaporation that result from the low air humidity during this season. Negative values in Figure 7-10 indicate heat loss for Lake Ontario. During a short period in late spring and early summer, these fluxes become positive as Lake Ontario

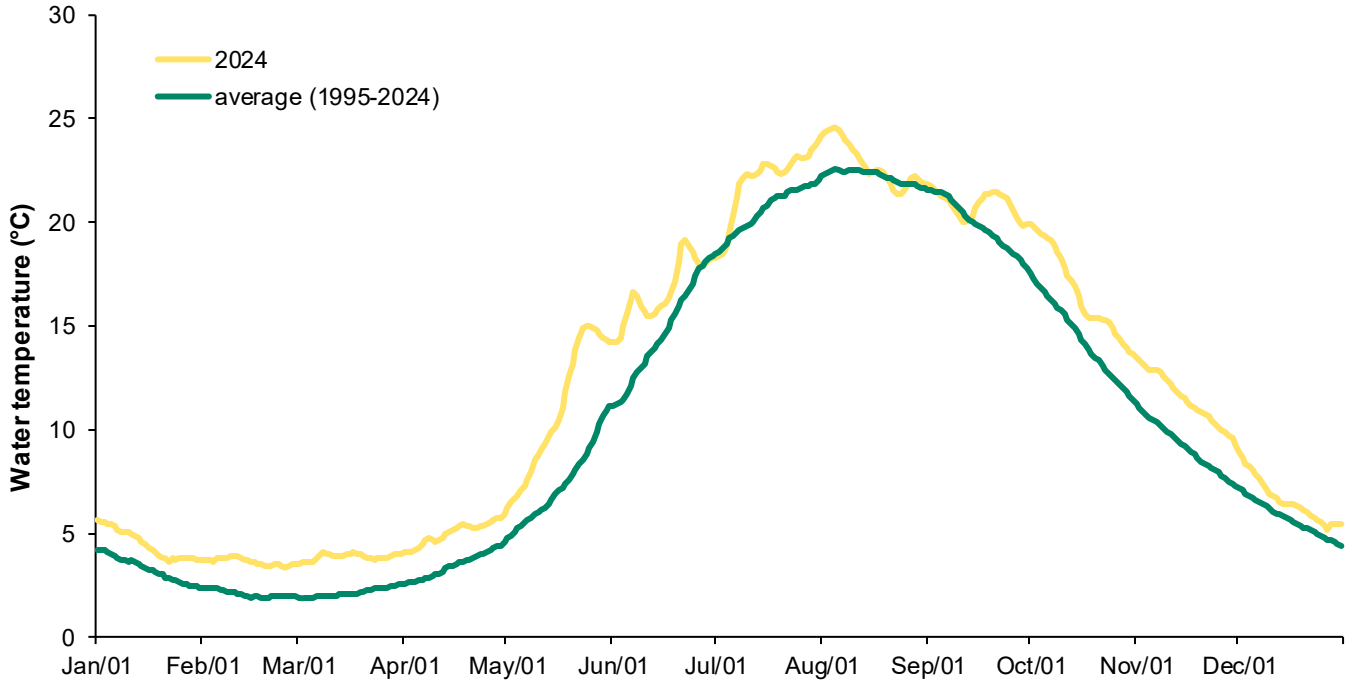
absorbs a small amount of heat from the atmosphere, before the heat fluxes become negative again in July and August, increasing to instead of limiting the high air temperatures. The heat uptake by Lake Ontario in spring and early summer likely contributes to a slight delay in the peak summer temperature towards later in July, from the peak of solar radiation in late June.



Source: Croley, 1989

Figure 7-10: Annual Cycles of Average Lake Ontario Heat Fluxes

In the summer of 2024, the average water temperature of Lake Ontario was higher than the long-term average from 1995 to 2024 with July 16 recording 22.8 °C, which constitutes water temperatures 2.0 °C higher than the average (Figure 7-11). The warm spell in terms of water temperatures lessened in early August and water temperature was 0.1 °C above by August 17. Assuming that the average lake temperatures are representative for the northwestern part of Lake Ontario, the difference between the nighttime air temperature and the lake temperature indicates positive sensible heat fluxes during the night leading up to both events. This points towards a positive contribution of Lake Ontario to the storm intensity by further destabilizing the atmosphere through the injection of additional heat in the lower layer.



Source: NOAA, 2025b

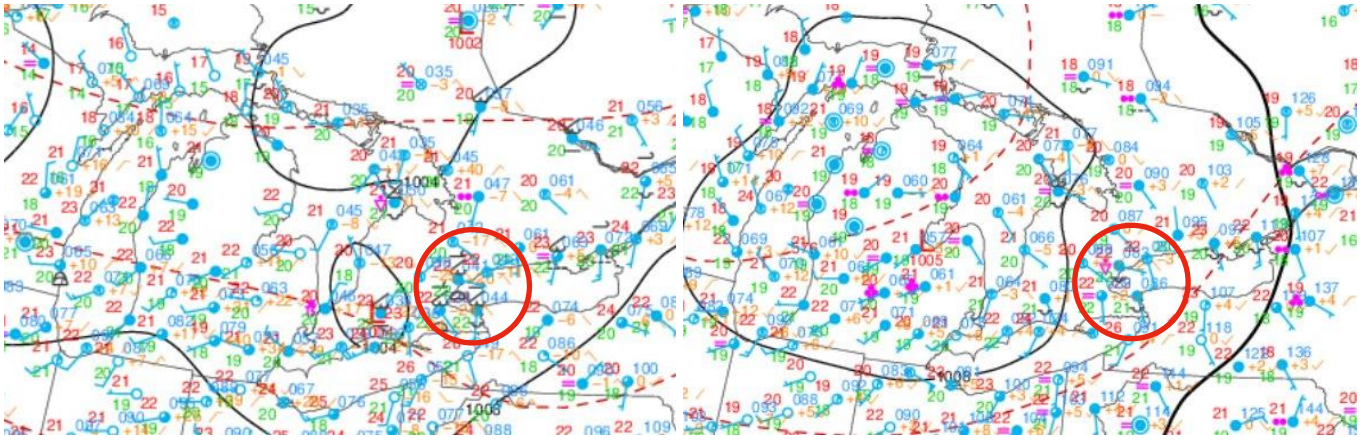
Figure 7-11: Water Temperature Lake Ontario

7.2.3 Lake Breeze

Lake breezes are a type of local, mesoscale wind that forms near large bodies of water like the Great Lakes, due to differences in temperature between the land and the water. During daytime, the high thermal capacity of the water body results in it warming slower than the coast. Over land, the warmer air rises due to its reduced density and higher buoyancy. It is immediately replaced by cooler air from the Lake, creating an onshore flow. Typically, a lake breeze develops several hours after sunrise when sufficient differential heating of the land mass and the body of water has occurred. The opposite phenomenon occurs at night because the land cools down faster than the water, resulting in an air flow directed outland, the land breeze.

Lake breezes produce masses of cold air advancing over the shoreline and replacing the warmer air over land, thus creating a Lake Breeze Front (LBF). The LBF replaces the warmer near-surface air over the land by advancing cooler air and forces additional ascent and convection. In the long term, the cold air moved inland by the LBF mixes in the air column and increases atmospheric stability, decreasing the chance of storms developing. However, in the short term, the forced ascent of warm inland air destabilizes the atmosphere and can lead to the development or intensification of storms systems. The LBF carries humidity from the lake, which is lifted in the convection, potentially further increasing precipitation.

While surface winds during both the storms of July 16, 2024 and August 17, 2024 were onshore along the northwestern shoreline of Lake Ontario (Figure 7-12), it is unlikely that these winds constituted a LBF in part due to the timing of the storms in the morning and early afternoon hours. The winds along the southeastern shoreline of Lake Ontario follow the same direction as the northwestern shoreline (Figure 7-12), which indicates that the lake-breeze winds were overridden by more powerful winds in synoptic scales, likely associated to the storm events themselves. The more likely explanation can be found in the larger scale environment with the MCV on July 16 and the frontal system on August 17. Nonetheless, these winds advected cold and humid air in the lowest layer of the atmosphere over the GTA, which had the potential to enhance the storms by destabilizing the atmosphere and injecting additional humidity.



Source: Centre Météo (UQAM), 2025. All reproduction rights are reserved.

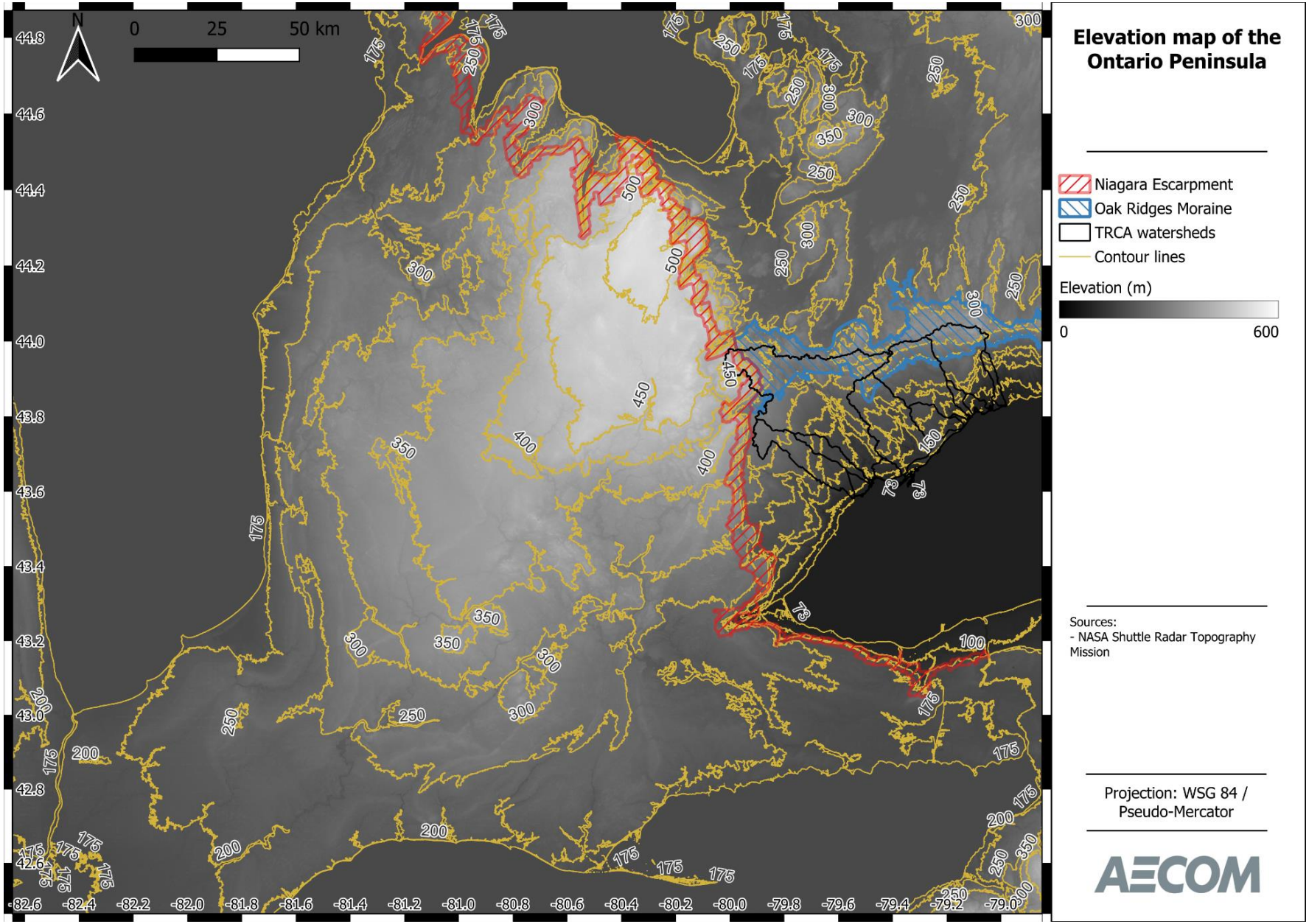
Figure 7-12: Surface Conditions at 12Z for July 16, 2024 (Left) and August 17, 2024 (Right)

7.3 Niagara Escarpment and Oak Ridges Moraine

The weather and climate in the GTA are affected by the topography of the surrounding region (Figure 7-13). This includes the uplands of the Ontario peninsula that rise softly from Lake Huron in the West, the Niagara Escarpment that marks the sharp end of the uplands on their eastern side, and Oak Ridges Moraine marking the northern boundary to the TRCA jurisdiction. The Niagara Escarpment is an arc-shaped geological formation running north to south, just west of Toronto. It marks a sharp drop in elevation (~ 100 m) from the centre of the Ontario peninsula towards the Ontario Lake basin. The centre of the Ontario peninsula sits at a height of 400- 450 m (with a maximum above 500 m) above sea level, rising from Lake Huron in the West (~175 m) and descending to Lake Ontario in the East (~75 m). The Oak Ridges Moraine is a line-shaped geological formation running north of Toronto. It marks the northern boundary of the Ontario Lake basin (including several of the biggest watersheds of the TRCA jurisdiction), rising to 300- 350 m above sea level and constituting an orographic barrier of about 100 m compared to the flatter terrain north and south of it.

Orographic barriers such as these are an obstacle to the circulation of surface winds, which are deviated around or above the obstacle. This can affect meteorology in several ways including:

- Wind channeling,
- Orographic lift, and
- Lee waves.



Note: Contour lines for small topographical features have been removed for improved legibility.

Figure 7-13: Elevation Map for the Ontario Peninsula

7.3.1 Wind Channeling

When faced with an obstacle, wind is diverted either horizontally or vertically to bypass the obstacle. Following the path of least resistance, it tends to flow around the obstacle rather than over it as it requires less energy. Surmounting an obstacle requires the kinetic energy of the wind to be able to surpass the gravitational potential energy associated with the height of the obstacle. Atmospheric conditions such as absolute or neutral stability can further restrict the air's ability to be lifted over an obstacle. Hence, a horizontal deflection of the wind is often observed, especially for isolated obstacles or barriers with limited horizontal extent.

When an obstacle faces the wind perpendicular to its longest axis, the wind is deflected by the obstacle and flows alongside its axis, rather than surmounting it. This effect is the greatest close to the surface where the wind comes in direct contact with the obstacle. The surface drag, which slows down and redirects the wind, also impacts the layers above by itself producing drag on those layers. The channeling effect of orography propagates decreasingly upwards through the boundary layer of the atmosphere and dissipates at higher levels. The extent to which the upper layers are influence by the wind channeling effect depends on the height of the obstacles.

The wind channeling effect associated to the Niagara Escarpment and the Oak Ridges Moraine is difficult to detect, given the low altitude of these obstacles. Furthermore, the location and layout of both orographic elements do not point towards any impact on the storm paths or intensities. The long northwest to southeast extent of the Niagara Escarpment and its perpendicular axis to the storm path makes horizontal deflections on a large scale unlikely. On the other hand, horizontal deflections along the Oak Ridges Moraine are possible but they would affect the area downstream of the GTA towards the eastern part of the Lake Ontario basin. It is therefore highly unlikely that the storms of July 16, 2024 and August 17, 2024 were impacted by potential wind channeling along the Niagara Escarpment and the Oak Ridges Moraine.

7.3.2 Orographic Lift

In addition to the horizontal deflection of the wind by an obstacle, wind is also diverted vertically. This implies working against the gravitational field and sometimes against the atmospheric stability, hence requiring sufficient kinetic energy. It can happen when an obstacle with a long axis faces the wind at an almost perpendicular angle or when the slope of the obstacle is sufficiently small for the wind to easily flow upwards (such as the wind approaching the uplands of the Ontario Peninsula from the west). This forced ascension of the air due to the presence of an orographic obstacle is known as orographic lift and can be contrasted with thermodynamic lift where the air becomes buoyant and rises.

Following the laws of thermodynamics and fluid dynamics, air pressure decreases as it ascends, and when this happens its temperature decreases adiabatically and its capacity to hold water vapour also decreases. If the air is lifted high enough, the RH will reach 100% and condensation will occur. The height at which this occurs is called LCL (Lifting Condensation Level). If the obstacle is higher than the LCL, condensation will occur on its windward side, forming clouds. Once condensation has began, the temperature decreases at a rate known as pseudo-adiabatic lapse rate. This rate is smaller than the dry adiabatic lapse rate with which the air cooled during the ascent before reaching the LCL as the air receives heat from the condensation process.

After reaching the summit of the obstacle, the air starts to descend on the leeward side, the pressure increases, the temperature increases adiabatically, and the water-holding capacity of the air increases. When reaching the height of the LCL on the windward side of the obstacle, the air is warmer and has, therefore, a lower RH than the air had at the same height before the ascent. This is known as the orographic effect, and its magnitude depends on the height of the obstacle and on the initial RH of the air (which decreases the LCL) before initiating the ascent. The LCL can be calculated with an approximate formula (Epsy, 1836) that uses the difference between temperature (T) and dew point temperature (T_d), divided by the difference of the lapse rates for dry adiabatic lifting (Γ_d) and for moist adiabatic lifting or dew point (Γ_{dew}):

$$LCL = \frac{T - T_d}{\Gamma_d - \Gamma_{dew}} = 125\ (T - T_d) \qquad \textbf{Equation 7-1}$$

The difference between the dry and moist adiabatic lapse rates was approximate by Epsy (1936) to be 8 K/km, or 1/125 m/K.

The elevation differences across the Ontario Peninsula are relatively small. Lake Huron has an elevation of 175 m and the most parts at centre of the peninsula rise between 300 and 350 m above mean sea level (MSL). The highest elevation reaches 500 m while the surface of Lake Ontario lies at 75 m above MSL. For example, an eastbound air mass passing from the surface level from Lake Huron over the centre of the Ontario Peninsula would only experience the orographic effect if the T-T_d difference was in the order of 1-1.4 °C.

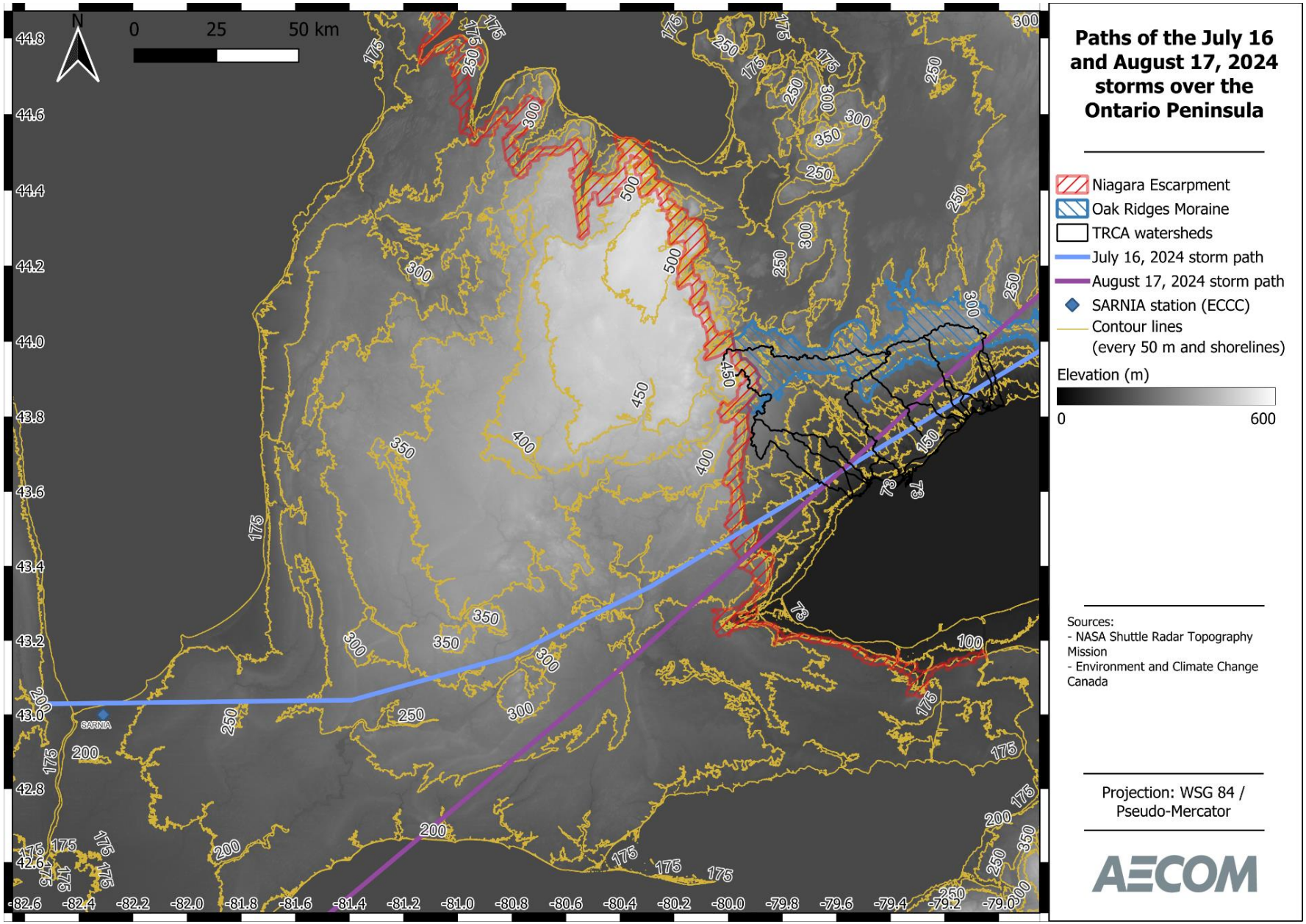
While the trajectory from Lake Huron to Lake Ontario passes over the greatest elevation differences, the paths of both the July 16 and August 17 storms was similar even though they had a more southernly component (Figure 7-14). Along the path on July 16, the storm passes over the City of Sarnia in the southwest of the Ontario Peninsula at an elevation of 180 m. The highest elevation along the storm path was roughly 325 m. From Equation 7-1, it follows that the T-T_d difference less than 1.2 °C would have been sufficient for the orographic effect. Records from the SARNIA station (Climate ID 6127510) of the ECCC network (ECCC, 2025a) show that during the four hours prior to and during the passing of the storm through Sarnia, the T-T_d difference was indeed less than 1.2 °C, with an average of 0.7 °C and a minimum of 0.5 °C (Table 7-2). It is therefore very likely that the orographic lift was sufficient for the air to reach the LCL and contribute to the cloud and potentially rainfall development in the path of the July 16, 2024 storm through the Ontario Peninsula towards the TRCA area.

Table 7-2: Temperature, Dew Temperature and Precipitation at SARNIA Station (July 16, 2024)

Date	T (°C)	T_d (°C)	T-T_d (°C)	Precipitation (mm)
2024-07-16 0:00	23.3	21.8	1.5	0.0
2024-07-16 1:00	23.1	21.4	1.7	0.0
2024-07-16 2:00	23.4	22.1	1.3	0.0
2024-07-16 3:00	23.3	22.3	1.0	0.0
2024-07-16 4:00	23.2	22.7	1.5	0.8
2024-07-16 5:00	23.0	22.5	0.5	0.5
2024-07-16 6:00	22.0	21.3	0.7	4.3
2024-07-16 7:00	20.2	19.7	0.5	44.2
2024-07-16 8:00	20.8	19.8	1.0	3.2

Note: T indicates air temperature and T_d denotes dew point temperature.
Source: ECCC, 2025a

In the case of the August 17, the storm approached the GTA from the southwest, having passed over Lake Erie before entering the Ontario Peninsula. However, it did not pass over any meteorological station along the shoreline of Lake Erie that would allow a similar assessment. From the shore of Lake Erie at 175 m, the storm passed through the south of the Ontario Peninsula at a much lower elevation than the centre. However, the surface air had to be lifted to at least 300 m at the Niagara Escarpment towards the east of the Peninsula before descending to the Ontario Lake basin. This indicates that the orographic lift is comparable to that of the July 16 storm. Without meteorological surface data upstream of the TRCA jurisdiction, it is not possible to assess the orographic effect.



Note: Contour lines for small topographical features have been removed for improved legibility.

Figure 7-14: Approximate Storm Path for July 16 and August 17, 2024

7.3.3 Lee Waves

An additional effect of the orographic lift is the formation of Lee waves, an atmospheric gravity wave that forms on the leeward side of the obstacle when the air flows over it. When the air coming from the windward side is stably stratified, the air on the leeward side will descend. But due to its momentum and the restoring force of gravity, it overshoots its equilibrium level, causing it to ascend again, creating a wave-like oscillation. As lee waves form in stable and stratified flows, their interactions with storms are limited. However, when lee waves break, localized instability and turbulent mixing can occur.

The horizontal extension and the vertical amplitude of the Lee waves depend on several factors like wind speed and the height of the obstacle (Durran, 1990). For an obstacle in the order of 100 m such as the Niagara Escarpment or the Oak Ridges Moraine, Lee waves typical would be expected to extend in the order of 5-10 km downwind and have an amplitude of around 10 m at the source. Given the distance from the edges of the Niagara Escarpment or the Oak Ridges Moraine to the TRCA jurisdiction (about 26 km to the Rathwood station where the maximum precipitation in the TRCA jurisdiction was measured for both the July 16 and the August 17 storms) and the formation during stable atmospheric conditions makes it very unlikely that lee waves have played a significant role in the storms developments.

8. Major Storm Comparison

A literature review has been performed on prior extreme rainfall and flooding events in the GTA and TRCA, including events on

- August 4, 2014,
- July 8, 2013,
- August 4, 2009,
- August 19, 2005, and
- August 27-28, 1976.

An exceptionally extreme event on July 19-20, 1989, in Harrow on the northwestern shore of Lake Erie (Ontario), outside the GTA and TRCA, that produced a maximum rainfall amount of more than twice that of any of the reviewed TRCA events, has also been studied. The Harrow storm review by M. M. Dillon Limited (1990) indicates that a similar storm occurring over the western half of the Lake Ontario, including across the GTA and TRCA, is, although less likely, still probable.

For each event, additional meteorological data and maps were analyzed where insufficient meteorological information was found in the literature review. Archived model forecasts are not readily available before 2005, so forecast performance was not analyzed for the July 19-20, 1989 and August 27-28, 1976 storms. Furthermore, the HRRR model that was analyzed for the 2024 storms was not yet available for any of the previous events. Antecedent Moisture Conditions (AMC), which describes the overall ground moisture levels prior to the onset of the storms, are evaluated based on total 5-day antecedent rainfall:

- AMC I (dry): <36 mm
- AMC II (normal): >36 mm and <53 mm
- AMC III (wet): >53 mm

AMC were not mentioned in the literature review for the August 4, 2014; August 4, 2009; and August 19, 2005 events. For these 3 events, AMC were inferred based on the prior 5-day rainfall measured at the ECCC weather stations at Pearson Airport, Toronto Island Airport, Buttonville Airport, and Toronto City, a sampling of weather stations in the TRCA that have reliable data (Figure 8-1). All stations recorded AMC I conditions prior to each of the 3 events.

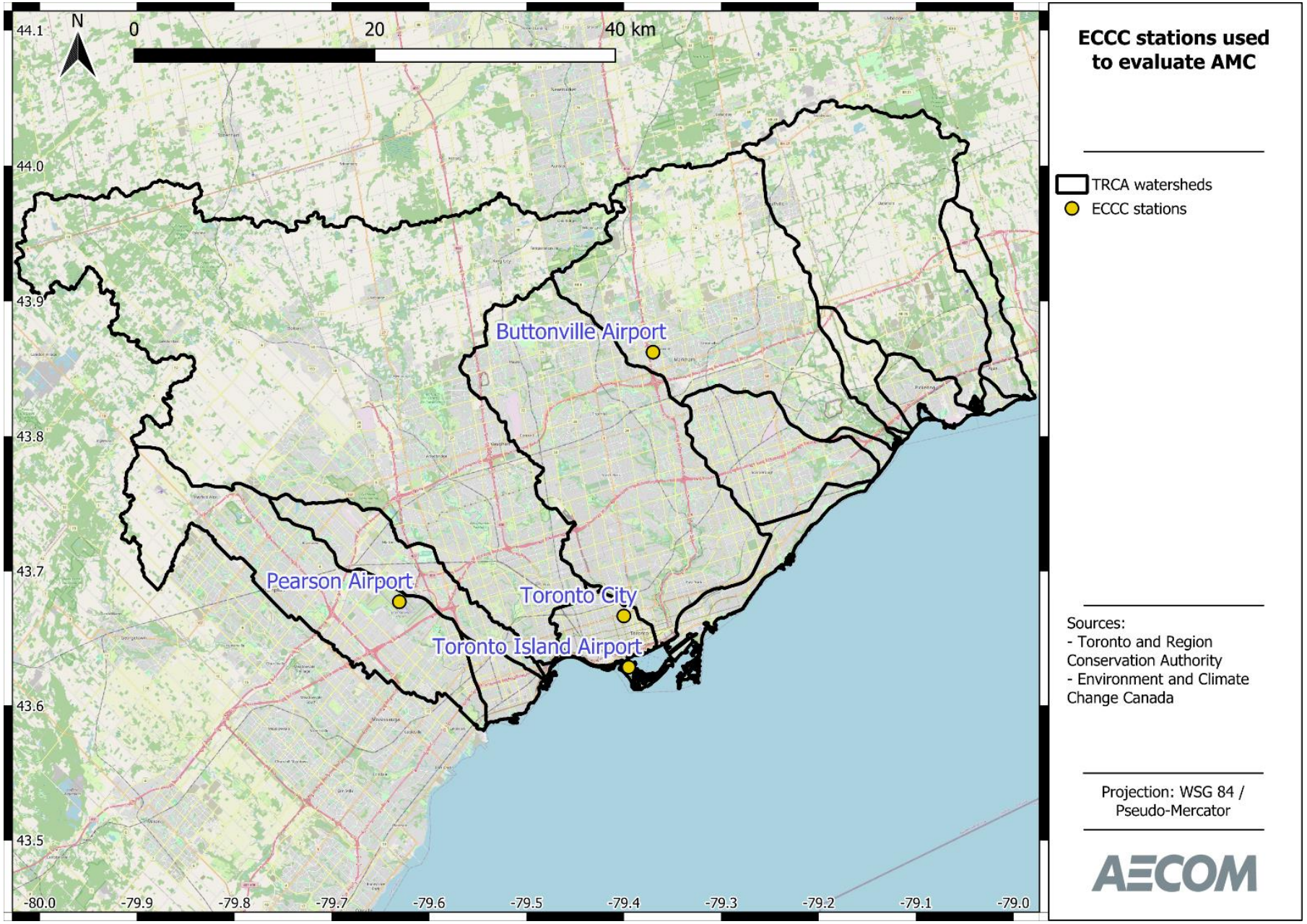
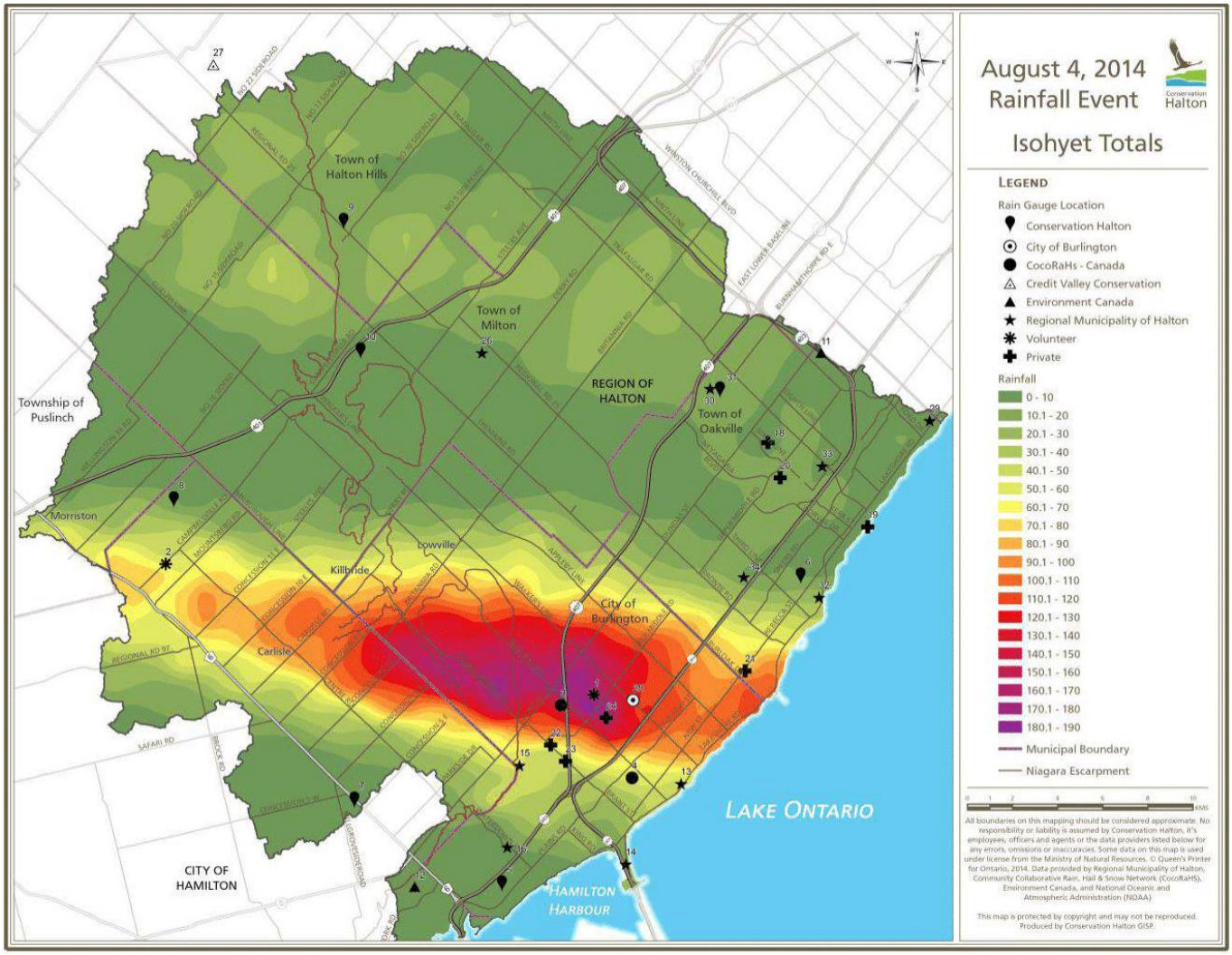


Figure 8-1: Map of ECCC Stations for the AMC Calculations

8.1 August 4, 2014

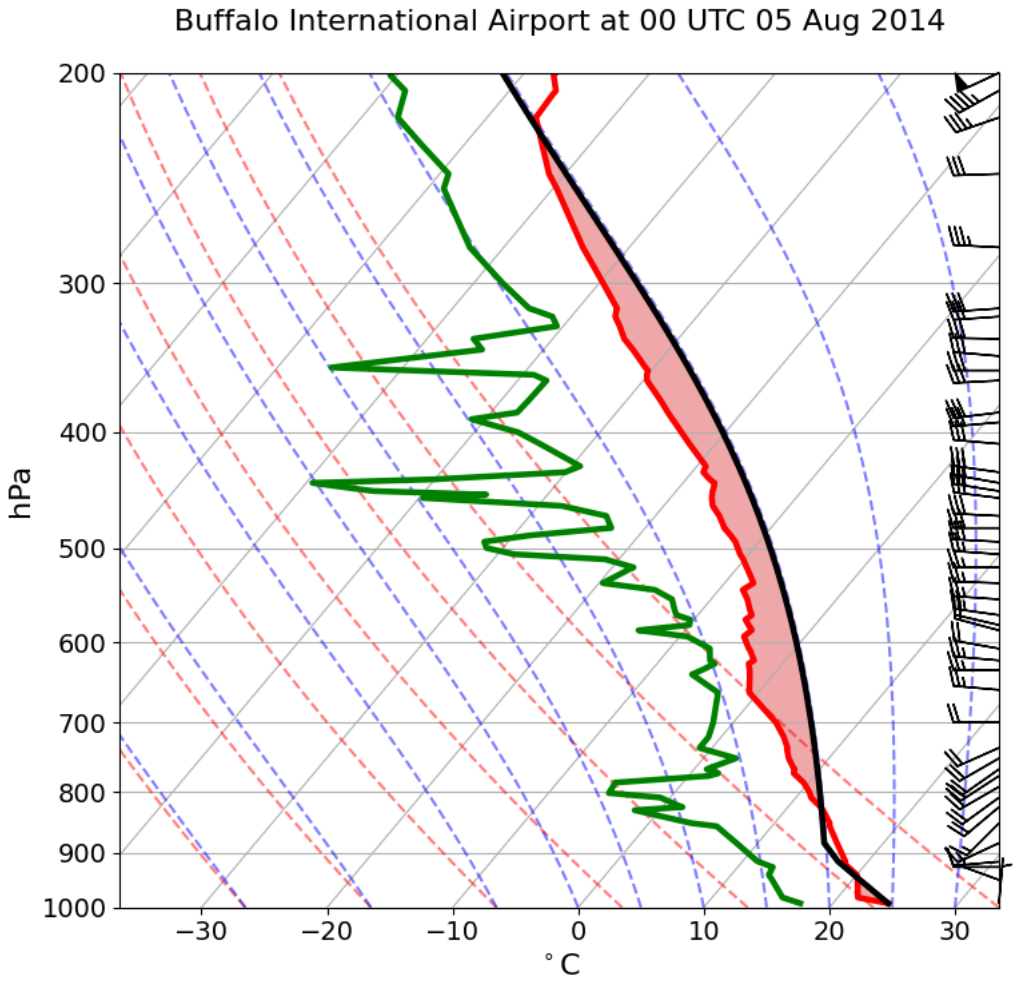
In the afternoon and evening of August 4, 2014, heavy rain fell in Burlington, Ontario, just southwest of the TRCA but still in the GTA, caused by a narrow band of thunderstorms that redeveloped, trained, and intensified over the same area. The area of maximum rainfall of up to 192 mm was aligned in a west-northwest to east-southeast direction with a length, width, and area of only approximately 25 km, 9 km, and 200 km^2, respectively (Figure 8-2). The maximum 1-hour rainfall recorded was 69.6 mm. The storm was centred over middle and upper portions of Roseland Creek and Tuck Creek, just east of Ontario Highway 407, generating flash flooding that flooded homes, businesses, parks, and motor vehicles as well as overtopped watercourse crossings and closed roads (EWRG, 2015).



Source: EWRG, 2015

Figure 8-2: Total Rainfall Accumulation across the Conservation Halton Area (August 4, 2014)

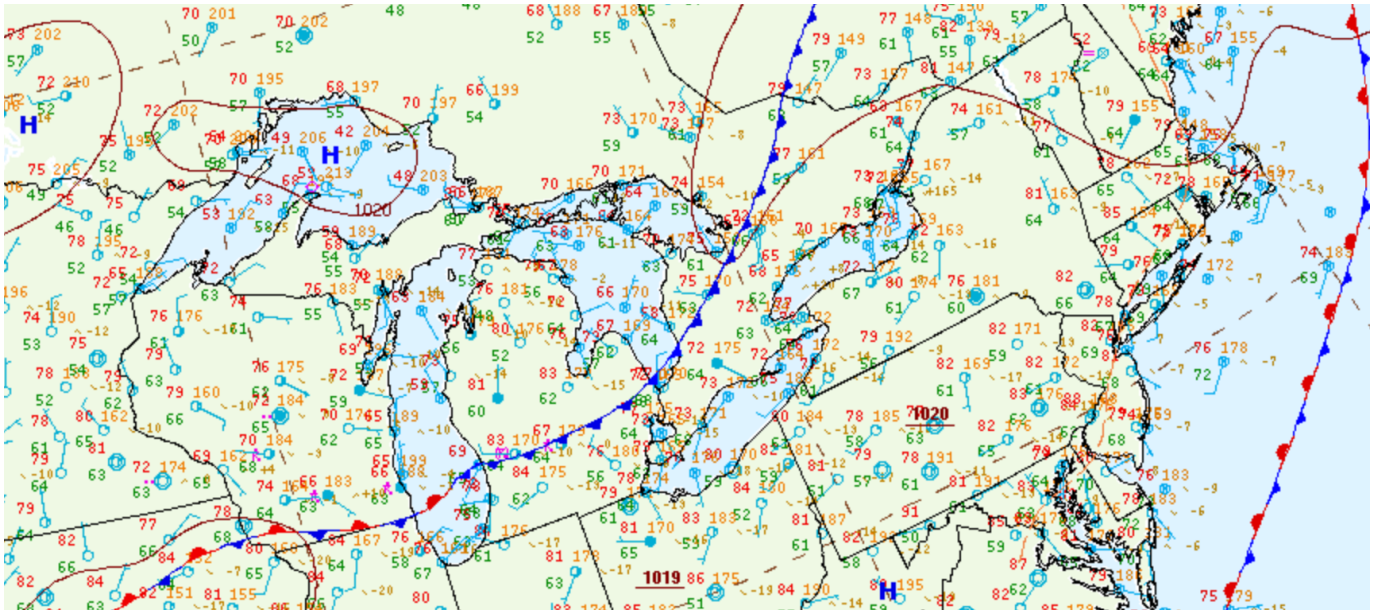
The August 4 at 8 PM (00Z) sounding at the Buffalo International Airport radiosonde site, representative of the environment in which the thunderstorms developed, showed modest instability for thunderstorms (Figure 8-3). The precipitable water amounted to 29 mm, around the climatological average for early August and lower than during the other extreme rainfall events reviewed in this report. However, the relatively weak west-southwesterly winds of 15-20 kt means that any thunderstorms that did form would move relatively slowly. At the same time, a broad upper-level trough to the west and approaching cold front from the northwest created dynamic forcing and a trigger for scattered thunderstorms with sufficient instability (Figure 8-4; Appendix Figure F 1).



Note: *The green and red lines show the dewpoint and air temperature measurements and red area indicates the Convective Available Potential Energy (CAPE).*

Source: *University of Wyoming, 2025*

Figure 8-3: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 5, 2014, 00Z)

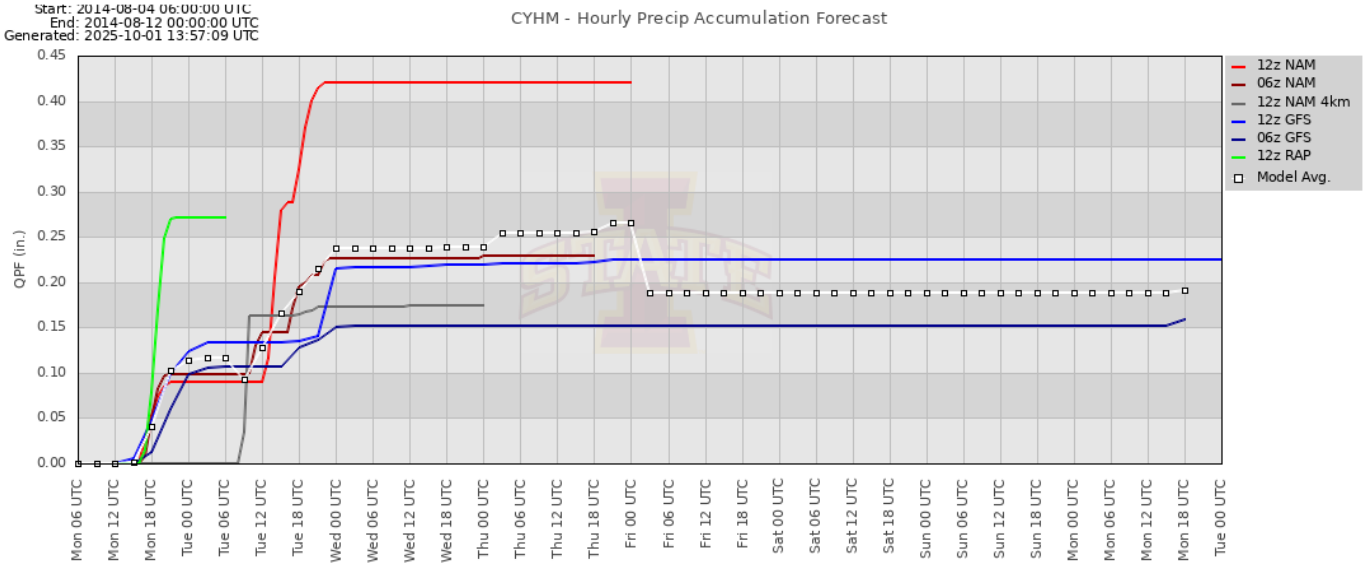


Note: The dark red lines indicate isobars, the red lines indicate warm front, and the blue lines indicate cold front.
Source: Weather Prediction Center, 2022

Figure 8-4: Surface Map (August 4, 2014, 21Z)

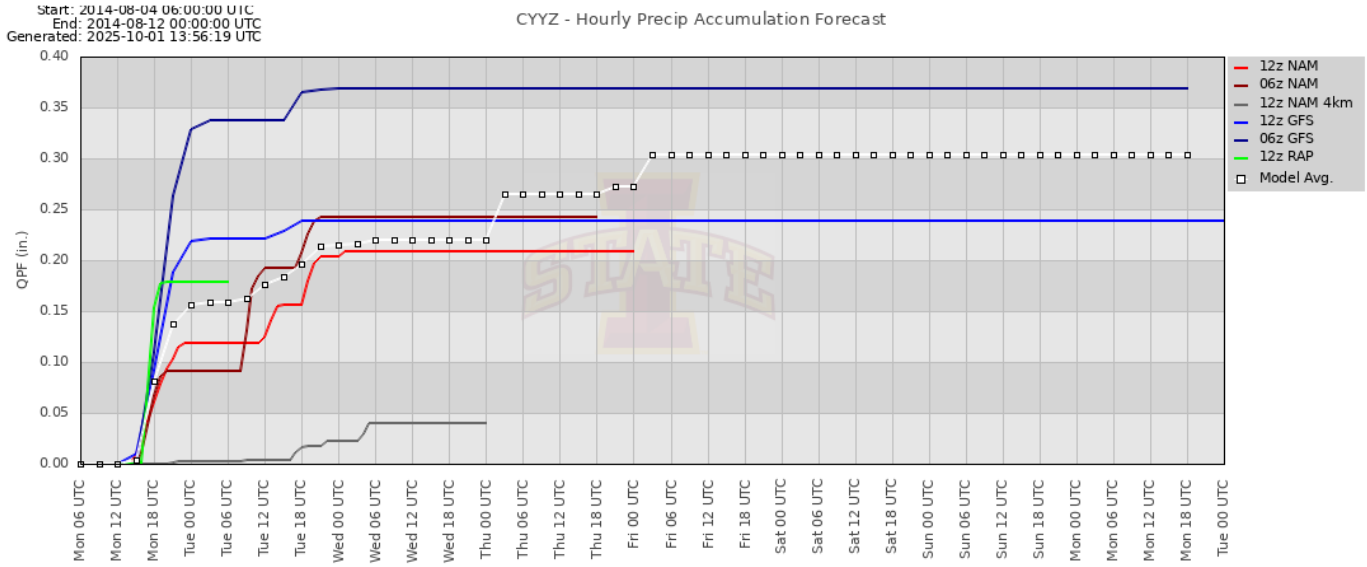
Scattered thunderstorms formed ahead of the weak cold front north and west of the TRCA around 1-2 PM (17-18 UTC) (Appendix Figure F 2). These storms moved southeastward into Burlington but initially did not train over a particular area, limiting total rainfall. However, additional thunderstorms formed around Burlington just before 4 PM (20Z) and oriented themselves in a line from west to east, parallel to the low to mid-level wind, leading to training of storms (Appendix Figure F 3-Appendix Figure F 8). The light winds meant that a lake breeze circulation from Lake Ontario could form, and combined with outflow winds from other nearby storms, caused thunderstorms to be focused and redevelop along that line, leading to a very narrow area of persistent thunderstorms that moved out and dissipated at around 9 PM (1Z) (Appendix Figure F 9). This persistence offset the relative lack of tropical moisture, resulting in a maximum rainfall of ~192 mm (EWRG, 2015; Figure 8-2), resulting in flash flooding even thought little or no rain fell in the previous 5 days (AMC I).

Like with the storms in July and August 2024, the extreme rainfall of August 4, 2014 was not well-predicted by numerical weather models, which was to be expected given that models had insufficient spatial resolution to resolve narrow areas of heavy rain, especially at that time, when the HRRR model was not yet available. All models showed <11 mm at both Hamilton Airport (CYHM, 20-25 km south-southeast of heaviest rainfall, Figure 8-5) and Pearson Airport (CYYZ, 35-40 km northeast of heaviest rainfall, Figure 8-6). Neither the GFS nor the NAM models showed anywhere in southern Ontario receiving >20 mm of rain (Appendix Figure F 10-Appendix Figure F 11).



Source: Iowa State University, 2025b

Figure 8-5: Model Forecasts of Cumulative Precipitation at Hamilton Munro International Airport Starting at August 4, 2014, 12Z

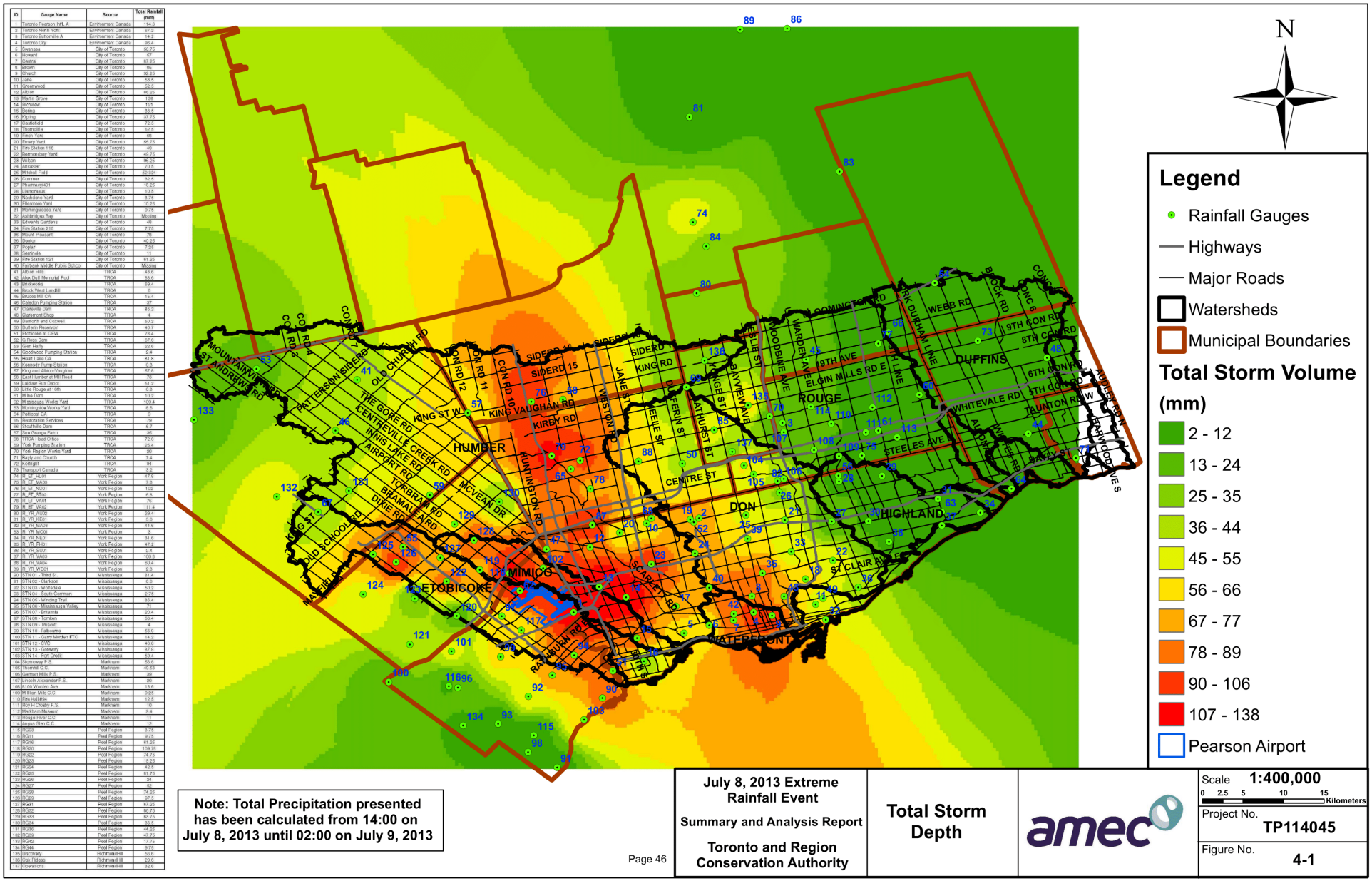


Source: Iowa State University, 2025b

Figure 8-6: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport Starting at August 4, 2014, 12Z

8.2 July 8, 2013

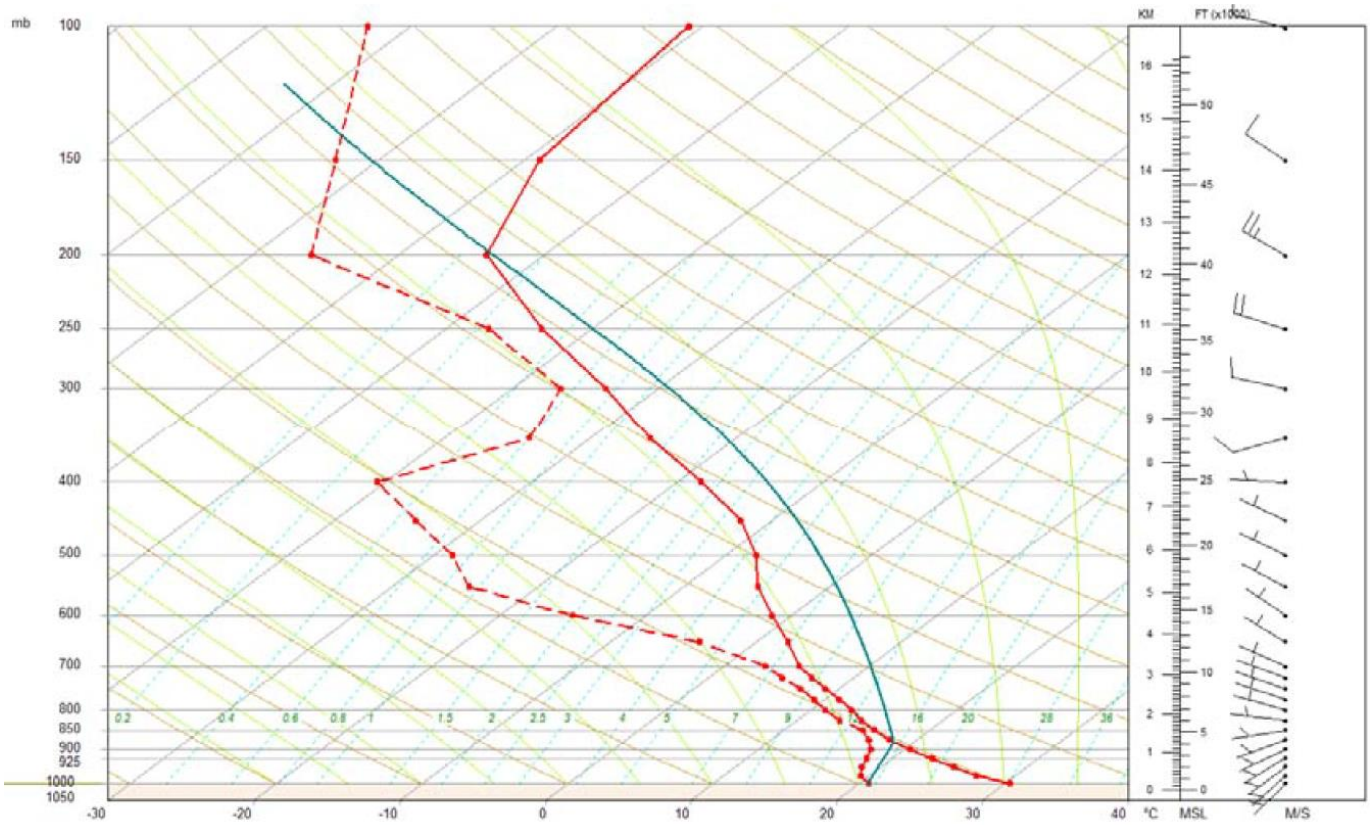
On the afternoon and evening of July 8, 2013, an extreme rainfall event occurred in parts of the GTA, causing widespread power outages and flooding roads, disrupting evening rush hour traffic. Though rainfall was widespread, the western and central part of TRCA received the heaviest rainfall, with a maximum total rainfall of 138 mm (Figure 8-7) and 1-hour rainfall of 78.8 mm. It is Ontario's most expensive natural disaster on record, with the Insurance Bureau of Canada estimating $850 million in insured property damage, beating the previous record of $671 million set by the August 19, 2005 Toronto flood (Section 8.4; ECCC, 2009; AMEC, 2014).



Source: AMEC, 2014

Figure 8-7: Total Rainfall Accumulation over the TRCA Jurisdiction (July 8, 2013)

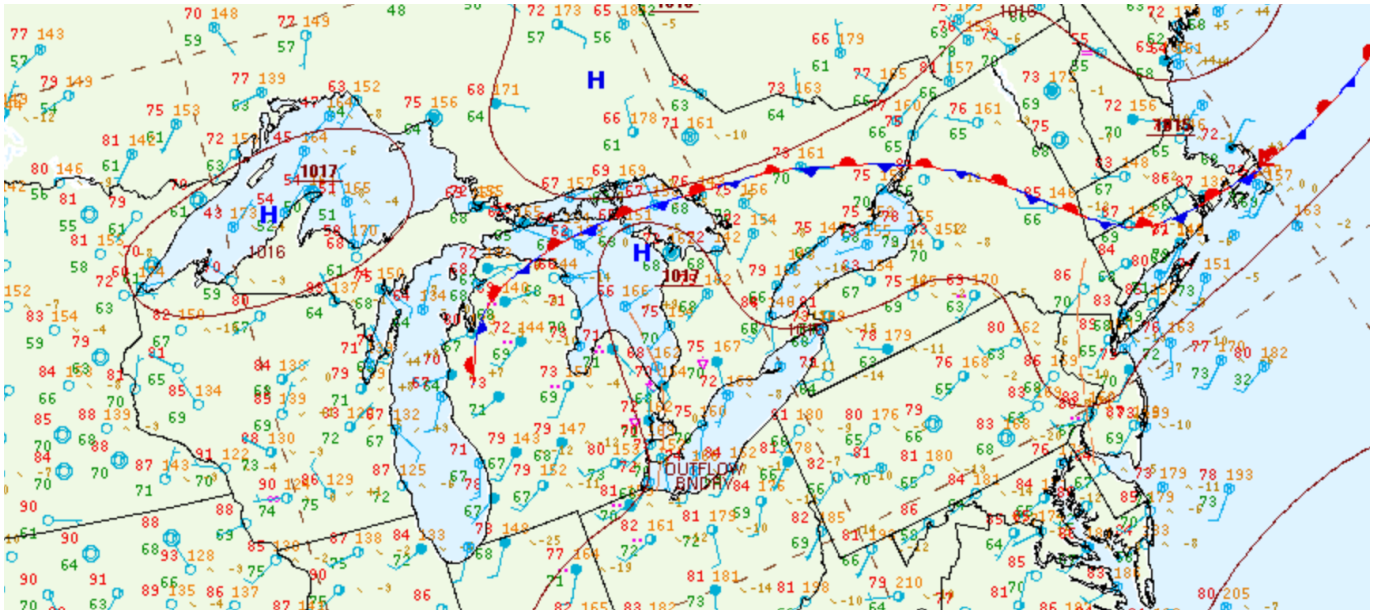
A very humid air mass from Gulf of Mexico was brought into the region over the preceding days via a clockwise flow around a broad high-pressure system over the western Atlantic (AMEC, 2014). The 8 AM (12Z) sounding at the Buffalo International Airport radiosonde site recorded a precipitable water of 43 mm and CAPE of ~900 J/kg, despite it being the early morning just after sunrise, when instability is usually the lowest (Appendix Figure F 15). The sounding also shows very weak winds of <15 kt, mostly from the west or northwest, from the surface up to 500 hPa. This is favorable for slow-moving, heavy rain-producing thunderstorms, provided the existence of a trigger for thunderstorms. CAPE increased throughout the day due to daytime heating (AMEC, 2014; Figure 8-8).



Source: AMEC, 2014

Figure 8-8: 21-hour NAM Model Forecast Sounding over Toronto valid at July 8, 2013, 21Z with the NAM Initialized July 8, 2013, 00Z

However, the synoptic-scale setup did not show clear triggers for thunderstorms in the GTA. At 8 AM (12Z), a weak, rather ill-defined low-pressure centre was located over Wisconsin, with a quasi-stationary warm front extending eastward into central and eastern Ontario north of the GTA (Appendix Figure F 12). The main upper-level trough had just passed the GTA and was already moving off to the east (Appendix Figure F 13). Meanwhile, there was a weak cold front and very weak vorticity maximum approaching from the west, but it was still over Michigan at the time of the extreme rainfall event (Appendix Figure F 14; Figure 8-9). Throughout the day, the GTA was located in the warm, moist sector without any clear front or convergence zone to trigger thunderstorms in the vicinity (Figure 8-9). However, given the unstable air mass and lack of convective inhibition, scattered “random” thunderstorms would still be possible.



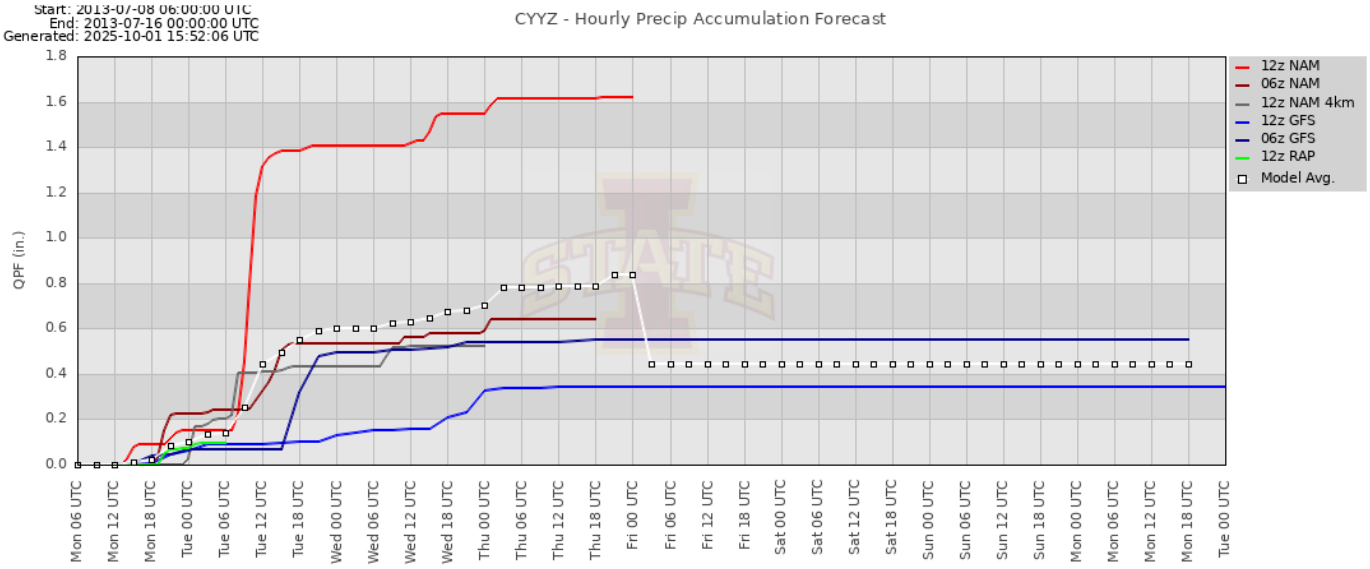
Note: The dark red lines indicate isobars, and the red-blue line indicates quasi-stationary warm front.
Source: Weather Prediction Center, 2022

Figure 8-9: Surface Map (July 8, 2013, 21Z)

Once thunderstorms did form just northwest of the GTA at around 3 PM (19Z) (Appendix Figure F 16), the moist and unstable environment led to the production of very heavy rainfall rates. The storms intensified and expanded as they moved southeastward, propagated by a meso-scale, thunderstorm outflow boundary, which is a boundary separating thunderstorm-cooled air from the surrounding warmer air. The storms likely interacted with a lake-breeze convergence line from Lake Ontario in the GTA, a common phenomenon in this area. Such meso-scale interactions are notoriously difficult to predict. The storms entered the TRCA at ~4:50 PM (2050Z) and trained over the same areas, eventually joining another larger line of storms associated with the weak vorticity maximum, with rain not ending until ~11 PM in the TRCA (Appendix Figure F 17-Appendix Figure F 24). The heaviest rain fell in the first hour, with the Toronto Pearson International Airport recording 67 mm in one hour (5-6 PM or 21-22Z) (AMEC, 2014).

Furthermore, the spring and early summer of 2013 was wetter than average, with the GTA receiving up to 82 mm of rainfall in the previous 7 days and nearly half of the Mimico and Etobicoke Creek watersheds experiencing AMC III conditions. The antecedent rainfall contributed to saturated soil conditions and higher rates of runoff (AMEC, 2014).

Despite no clear trigger for thunderstorms before the storms developed, numerical weather models and meteorologists had predicted possible thunderstorms that day. However, none accurately predicted the timing, exact location, or extreme nature of the rainfall event (AMEC, 2014; Figure 8-10; Appendix Figure F 25-Appendix Figure F 26). The NAM model showed the most rain with widespread moderate to heavy rain across southern Ontario but did not have sufficient resolution to resolve the localized extreme rain over the GTA. As is often the case with summertime flash floods, the heavy rain was convective in nature and associated with some training of thunderstorms moving over the same locations, both of which are extremely challenging to forecast (AMEC, 2014).

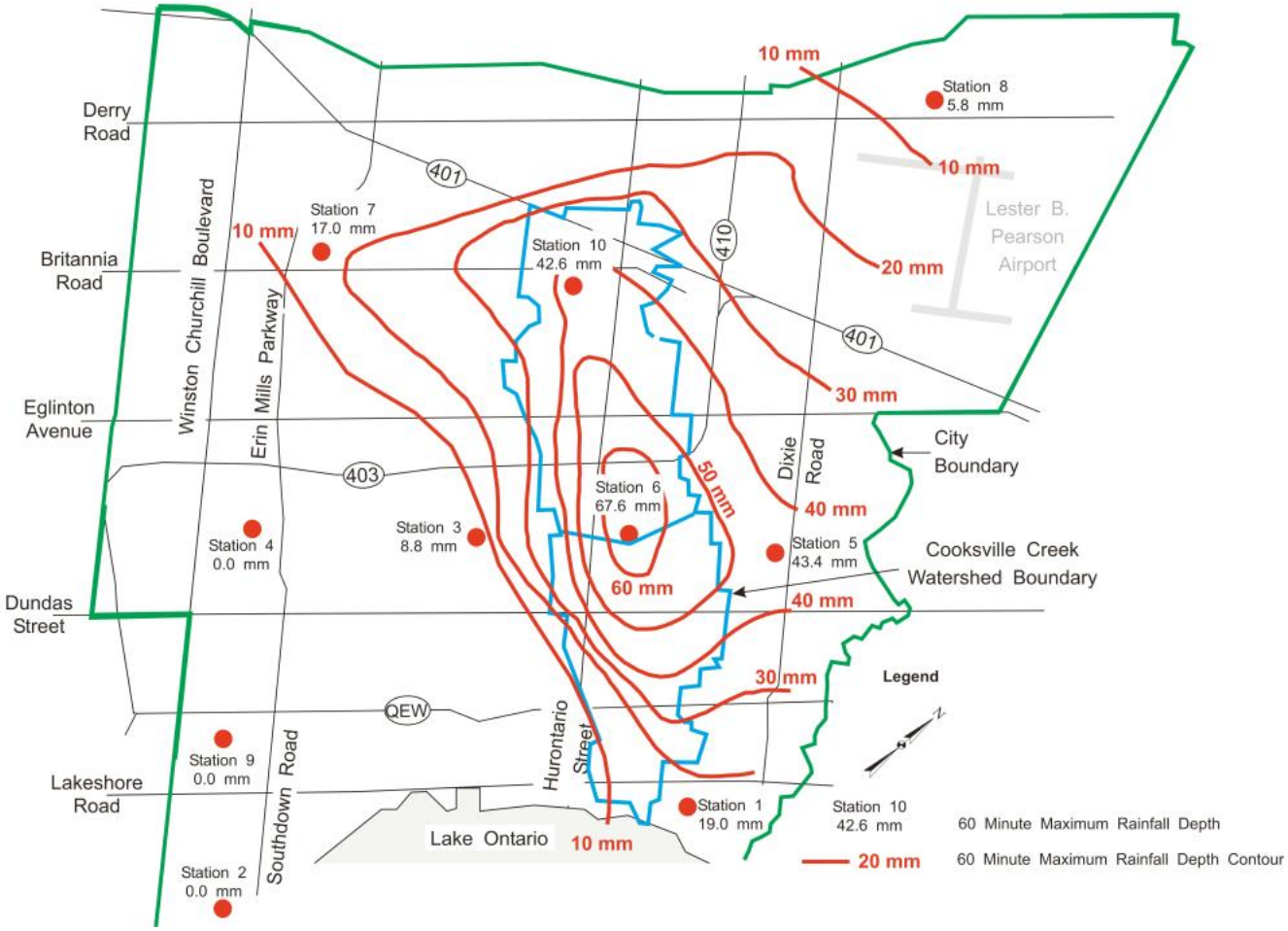


Source: Iowa State University, 2025b

Figure 8-10: Model Forecasts of Cumulative Precipitation at Toronto Pearson International Airport Starting at July 8, 2013, 12Z

8.3 August 4, 2009

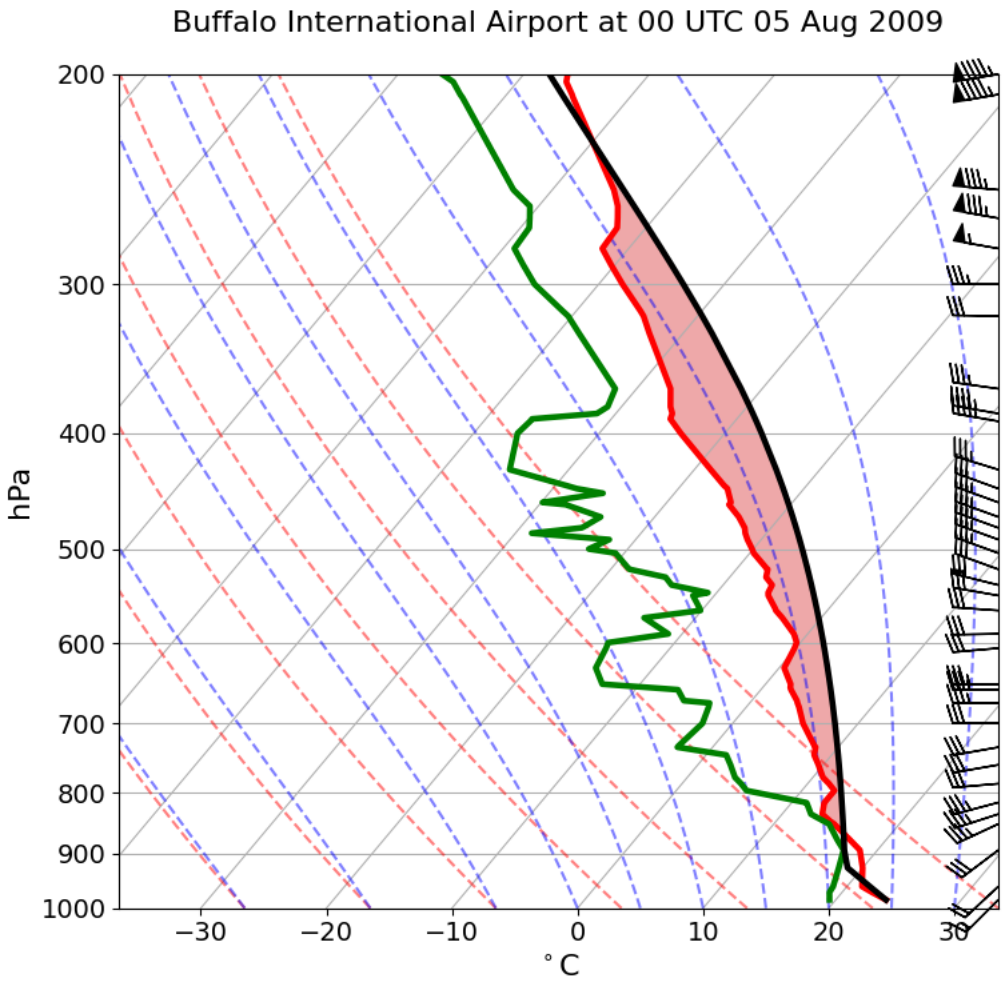
On the afternoon and evening of August 4, 2009, a localized high-intensity thunderstorm occurred over the Cooksville Creek watershed. Although the storm lasted only approximately one hour, the City of Mississauga's rainfall gauge recorded 67.6 mm of rain, causing flash flooding (EWRG, 2010; Figure 8-11), despite little to no rain having fallen in the previous 5 days (corresponding to AMC I).



Source: EWRG, 2010

Figure 8-11: Total Rainfall Accumulation over Cooksville, Ontario (August 4, 2009)

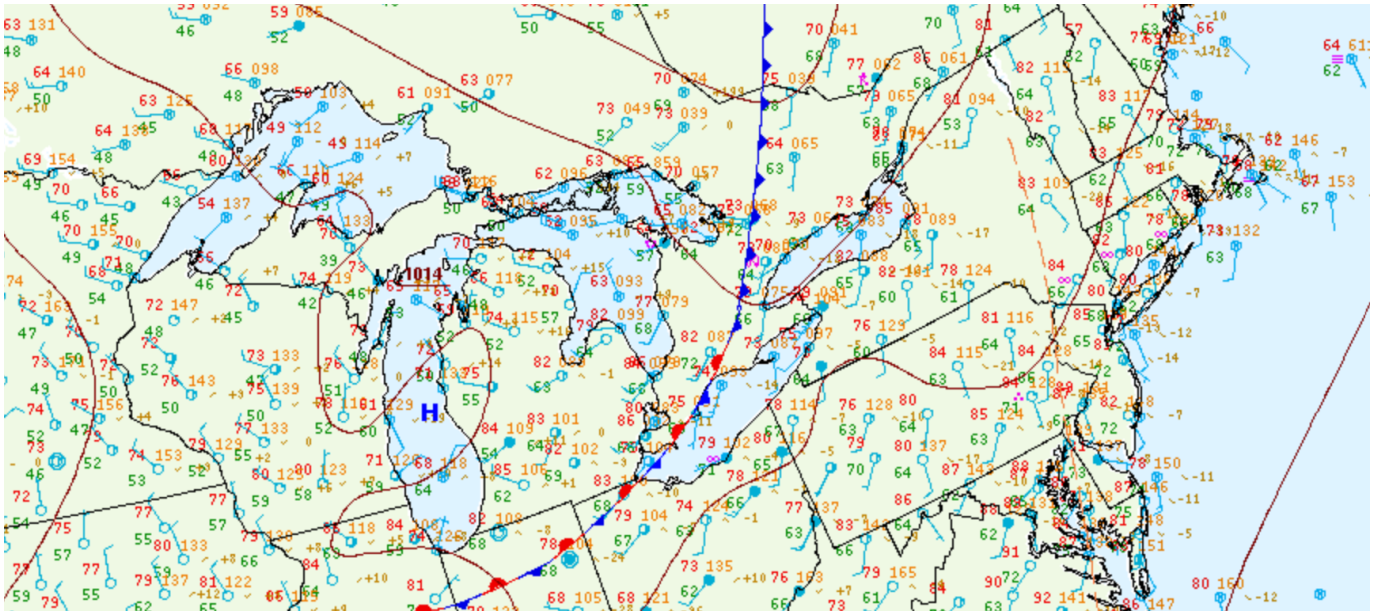
The August 4 at 8 PM (00Z) sounding at the Buffalo International Airport radiosonde site, representative of the environment in which the thunderstorms developed, showed a moderate ~1200 J/kg of CAPE, a precipitable water of 37 mm, and an almost uniform 30-35 kt west-southwest wind from just above the surface up to 600 hPa. The wind was fast for any individual storm to persist over an area for long (Figure 8-12). Throughout the day, a surface low-pressure was located over northeastern Ontario with a cold front extending from the low-pressure centre southwestward into the Great Lakes (Figure 8-13). This strong cold front acted as a trigger for the development of thunderstorms. There was also an unseasonably strong upper-level low over far northern Ontario with an upper-level trough axis extending south into Michigan (Appendix Figure F 27). The upper-level trough might have enhanced dynamics for ascent needed to initiate thunderstorms and enhanced instability through cooling the air in the mid to upper troposphere, though it could have been a bit too far north for it to have a large impact in the GTA.



Note: *The green and red lines show the dewpoint and air temperature measurements, and the red area indicates the Convective Available Potential Energy (CAPE).*

Source: *University of Wyoming, 2025*

Figure 8-12: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 5, 2009, 00Z)

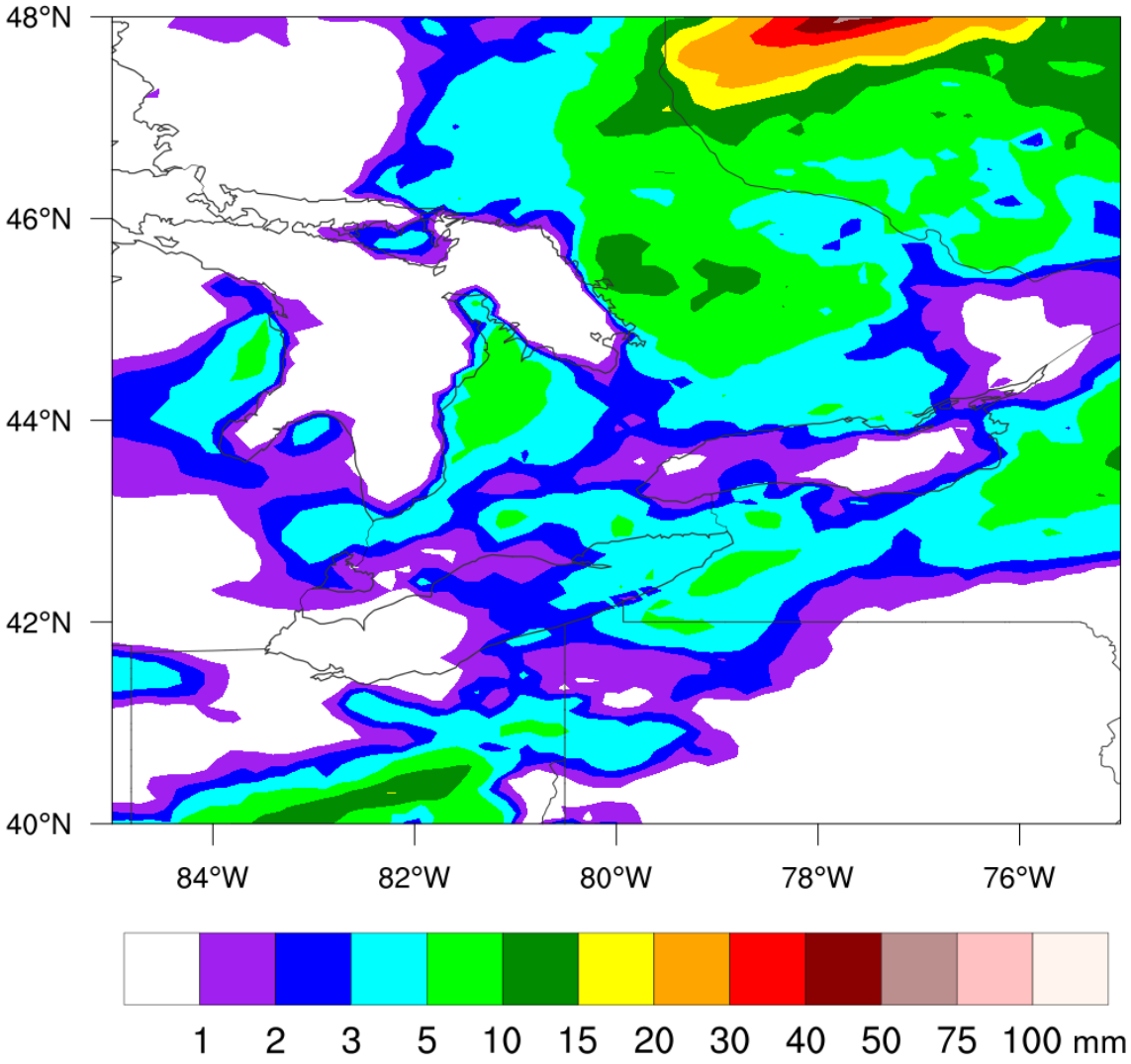


Note: The dark red lines indicate isobars, the red lines indicate warm front, and the blue lines indicate cold front.
Source: Weather Prediction Center, 2022

Figure 8-13: Surface Map (August 4, 2009, 21Z)

A broken line of thunderstorms developed well northwest of the GTA in the late morning and moved southeastward through the afternoon. With the fast southeastward storm motion at an angle to the broken small lines of thunderstorms, there was no notable training of thunderstorms, with each storm lasting less than an hour at a particular location, unlike with the other extreme rainfall events. Thunderstorms affected the GTA at 2 PM (18Z) and 4 PM (20Z) (Appendix Figure F 28-Appendix Figure F 34). Flooding resulted from the sheer extreme rainfall rates with localized >60 mm falling in just one hour, though the total rainfall maximum of 67.6 mm was the lowest among the storms compared in this report.

The heavy rainfall was poorly forecasted by weather models, with both the NAM and GFS showing <15 mm of rain in all of southern Ontario (Figure 8-14 and Appendix Figure F 35) despite the cold front acting as a clear trigger for thunderstorms, perhaps due to the brief and scattered nature of the storms. Also, although the models did show the frontal passage, they could not resolve the true magnitude of narrow areas given their coarse resolution of the models at that time did not allow for the proper representation of narrow areas of strong convection and heavy rain (Appendix Figure F 35).

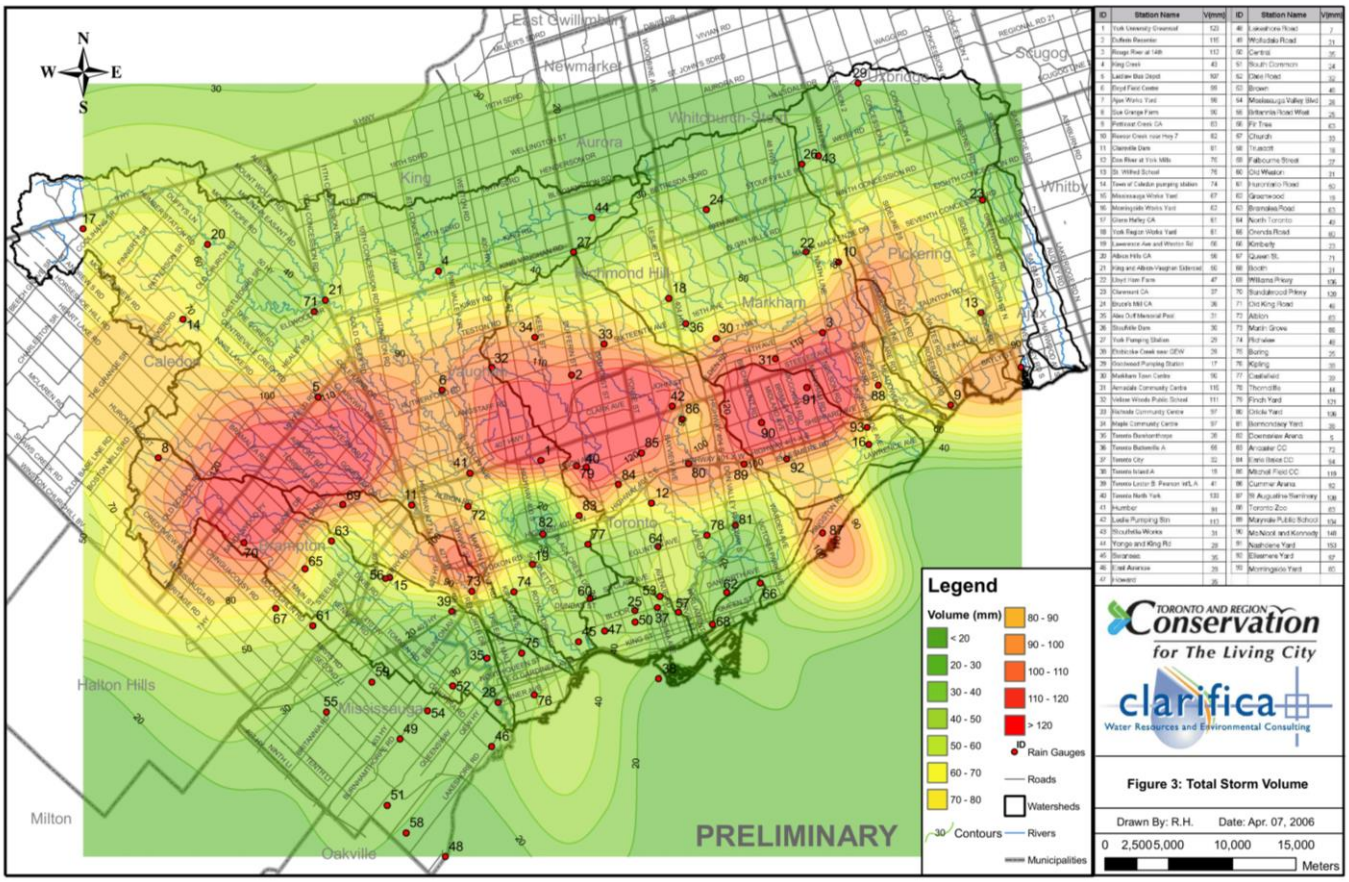


Source: NOAA, 2025e

Figure 8-14: 24-hour Precipitation Forecast from August 4, 2009, 12Z to August 5, 2009, 12Z by the NAM Model Initialized August 4, 2009, 12Z

8.4 August 19, 2005

Severe thunderstorms on August 19, 2005 brought torrential rains of up to 153.4 mm (Figure 8-15), quarter to golf-ball size hail, strong straight-line winds, and flash flooding to the GTA, with flooding causing the greatest impact (ECCC, 2009). The maximum 1-hour rainfall of 116.6 mm was the highest of the storms compared in this study and well above the 100-year value of just under 60 mm (Clarifica Water Resources and Environmental Consulting, 2006; Figure 8-15). Three tornadoes were confirmed in southern Ontario outside the GTA, with an unconfirmed tornado also reported in Toronto (The Weather Network, 2021). The Insurance Bureau of Canada's estimate of $ 671 million insured loss across southern Ontario made the storm the most expensive natural disaster in Ontario history until the July 8, 2013 Toronto flood (Section 8.2; ECCC, 2009; AMEC, 2014).

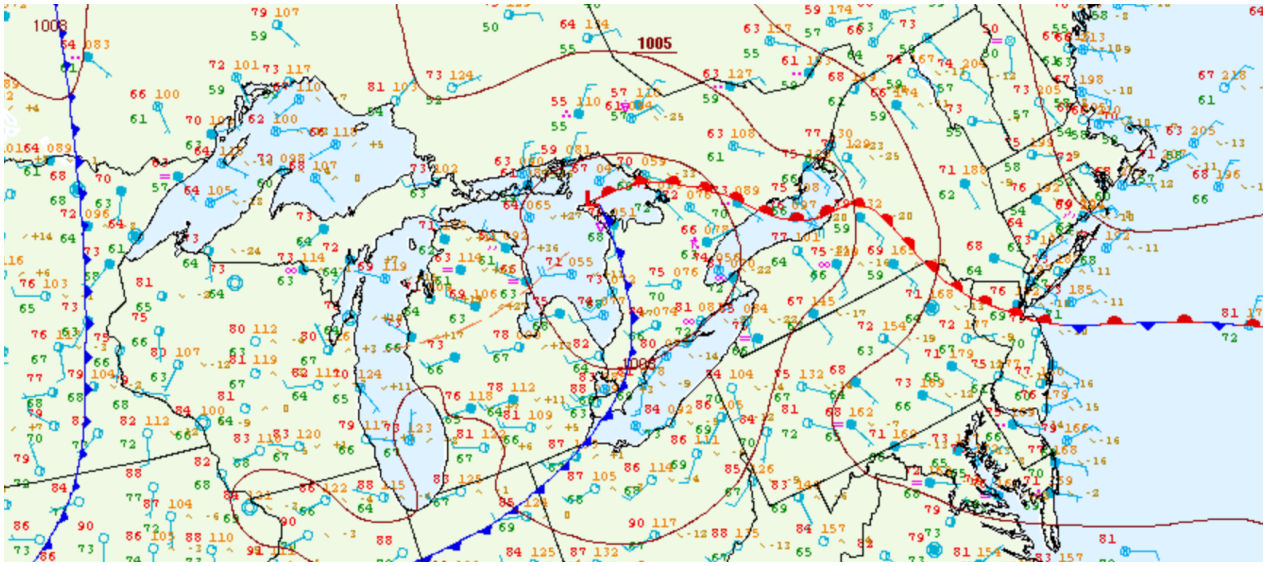


Source: Clarifica Water Resources and Environmental Consulting, 2006

Figure 8-15: Total Rainfall Accumulation (August 19, 2005)

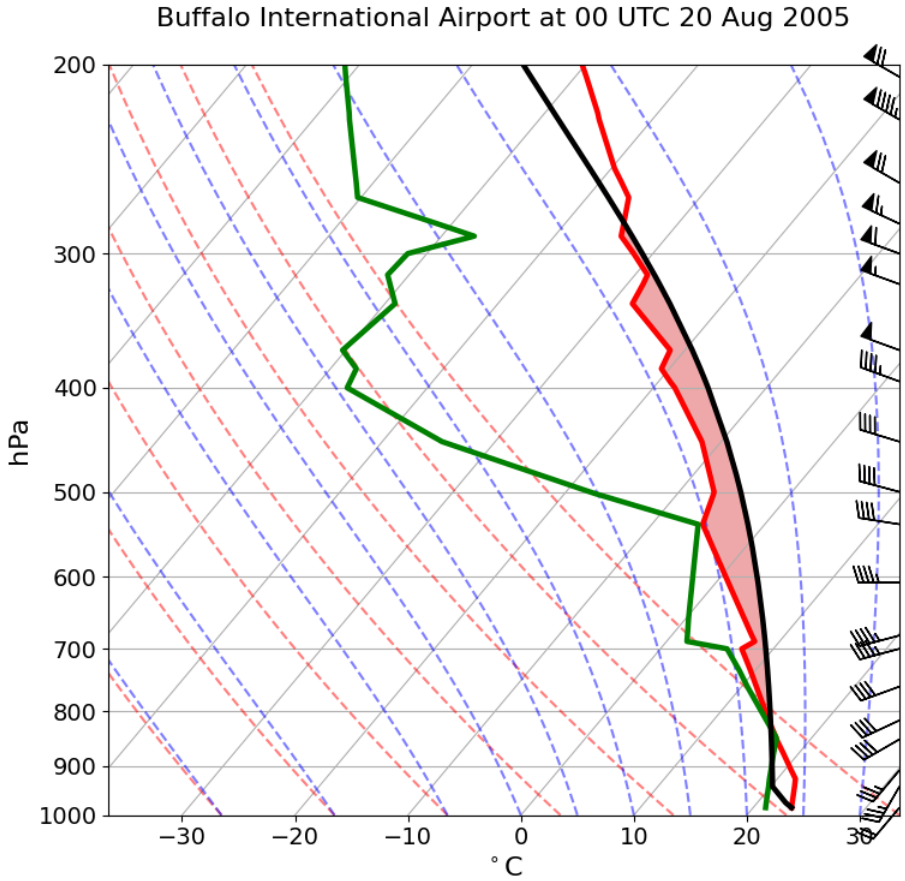
A synoptic-scale surface low-pressure system co-located with a weak upper-level trough was located over northern Michigan on August 19 at 8 AM (12Z) with a warm front extending to the east through the GTA and a cold front extending to the southwest over Michigan (Appendix Figure F 36-Appendix Figure F 37). The GTA, located to the east of the upper-level trough axis, experienced synoptic forcing for ascent throughout the day. Though little to no rain had fallen in the prior 5 days (corresponding to AMC I), the warm frontal passage led to several hours of light to moderate rain in the GTA in the early morning, saturating the ground and making the ground less capable of absorbing the rain that was to fall in the afternoon (Appendix Figure F 38-Appendix Figure F 39).

Following the warm front pushed to the north of the GTA, the GTA entered the warm sector, but with the cold front already approaching (Figure 8-16). The August 20, 2005 at 8 PM (00Z) sounding at Buffalo International Airport, in the warm sector and representative of the environment that the storms formed in, showed a CAPE of ~700 J/kg of CAPE, strong 40-50 kt winds from just above the surface to 600 hPa, turning from southwesterly to westerly. The winds brought deep Gulf of Mexico moisture corresponding to a precipitable water of ~50 mm, the highest of the storms compared in this study and among the highest values ever recorded at Buffalo (Figure 8-17). With the instability and very humid air, two lines of heavy rain-producing thunderstorms developed west of the GTA in the afternoon ahead of the cold front. These lines passed the GTA at 3 PM and 5 PM (19Z and 21Z) (Appendix Figure F 40-Appendix Figure F 44). The changing in wind direction with height was also favourable for the formation of the supercell thunderstorms with strong winds, large hail, and tornadoes that were observed in southern Ontario.



Note: *The dark red lines indicate isobars, the red lines indicate warm front, and the blue lines indicate cold front.*
Source: *Weather Prediction Center, 2022*

Figure 8-16: Surface Map (August 19, 2005, 21Z)

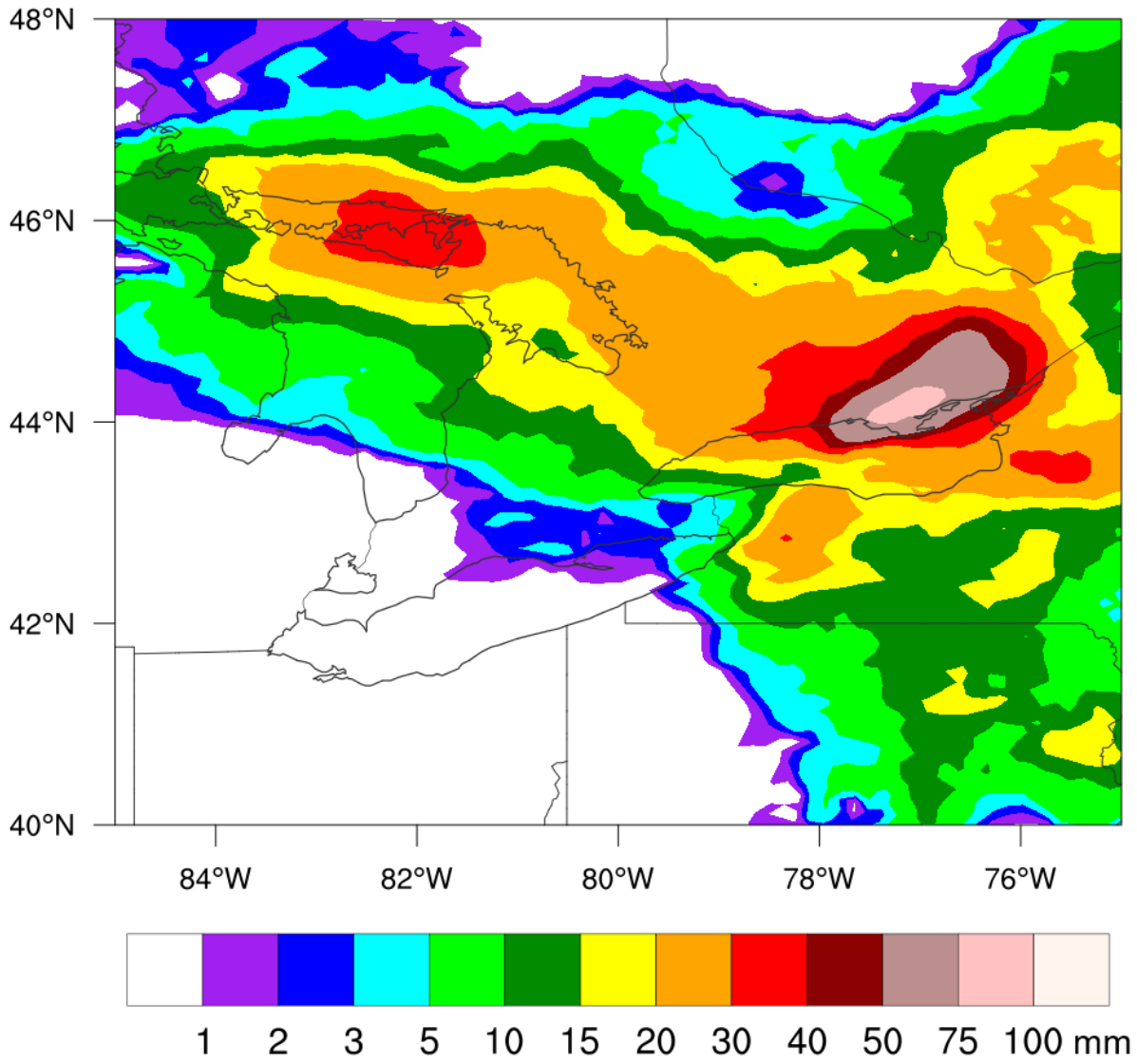


Note: *The green and red lines show the dewpoint and air temperature measurements, and the red area indicates the Convective Available Potential Energy (CAPE).*
Source: *University of Wyoming, 2025*

Figure 8-17: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 20, 2005, 00Z)

The rather strong winds precluded individual storms from persisting over an area, and the moderately fast eastward movement of the lines prevented training of thunderstorms over the same area. Nonetheless, the extreme rainfall rates fueled by the exceptionally moist air still led to extreme rainfall totals and flash flooding exacerbated by the saturated ground due to the morning rainfall. Although the thunderstorms produced widespread substantial rainfall in southern Ontario, the heaviest rainfall totals of >100 mm occurred over a relatively narrow west-southwest to east-northeast zone from Brampton to Markham, across major TRCA watersheds and near the northern boundary of City of Toronto.

With the synoptic-scale triggers for rainfall being more prominent than in most of the other events, both the GFS and NAM showed substantial rainfall across the GTA, but only up to 30 mm, with the heaviest rain missing to the north and northeast (Figure 8-18 and Appendix Figure F 45). The coarse model resolutions at that time made it impossible for models to accurately simulate the smaller-scale features that likely caused the heaviest rain to fall over the GTA instead.

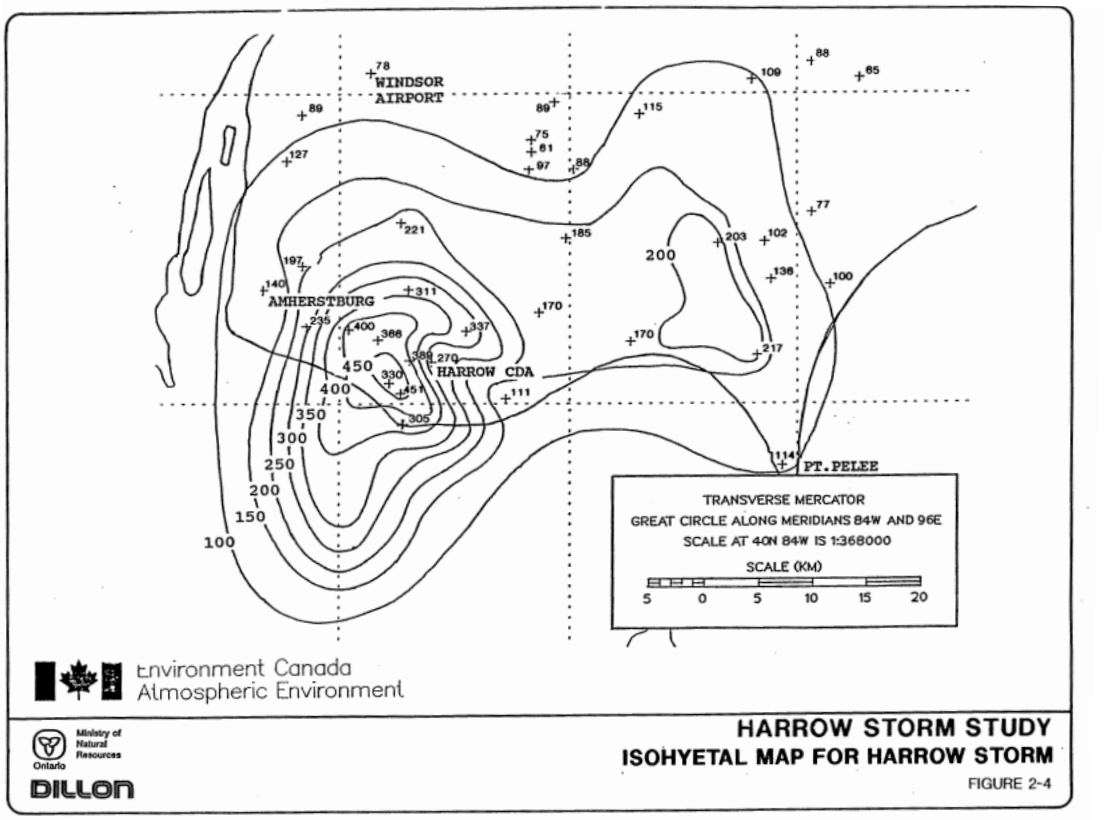


Source: NOAA, 2025e

Figure 8-18: 24-hour Precipitation Forecast from August 19, 2005, 12Z to August 20, 2005, 12Z by the NAM Model Initialized August 19, 2005, 12Z

8.5 July 19-20, 1989 (Harrow, Ontario)

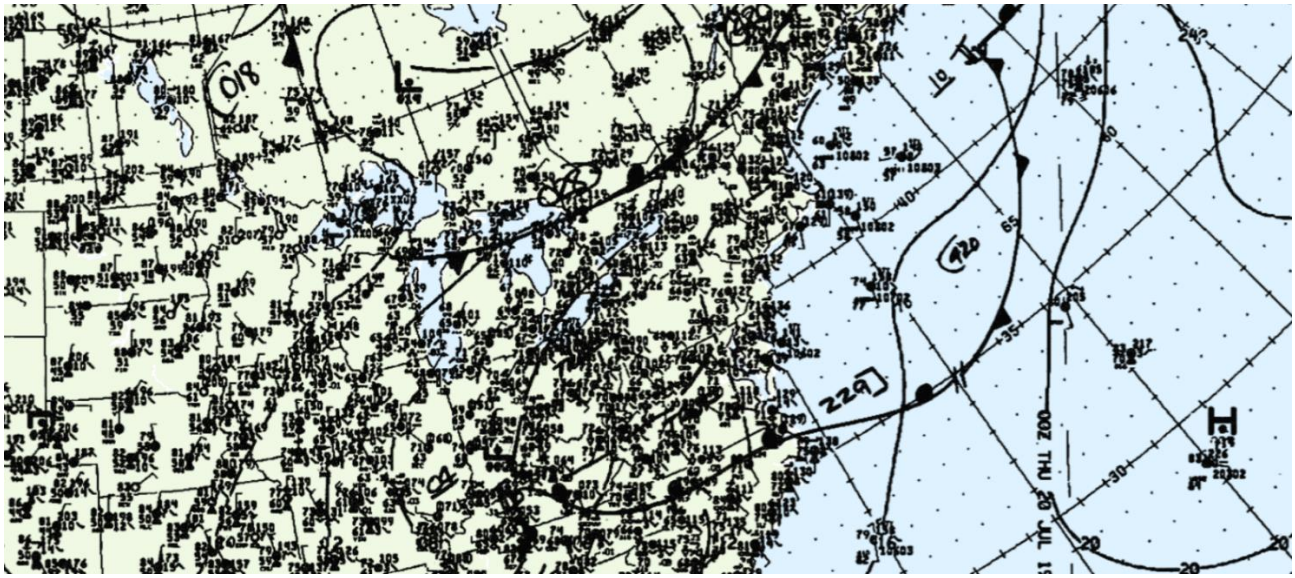
From the evening of July 19, 1989, through the afternoon of the following day, a series of thunderstorms occurred over Essex County, Ontario, centred near the community of Harrow, leading to localized flooding. Over an area of only 10 km^2, 450 mm of rain fell in 30 hours (Figure 8-19), far exceeding the 48-hour Ontario record of 285 mm set by the much larger Hurricane Hazel in 1954. The maximum 1-hour rainfall recorded was a relatively modest 50 mm, though there were no measurements in the small area of heaviest total rainfall. However, the long duration meant that even modest rainfall intensities yielded extreme rainfall totals. The rain fell in two parts: the first part on July 19 lasted ~9 hours, while the second part on July 20 lasted ~5 hours, both much exceeding the corresponding 100-year intensities. Despite the extreme rainfall, the absence of flow records near the centre of the localized storm and the extremely dry antecedent rainfall conditions, with only 0.6 mm of rain recorded in the previous 3 weeks (corresponding to AMC I), means that there were few measurements of severe runoff (M. M. Dillon Limited, 1990).



Source: Kilborn Limited, 1977

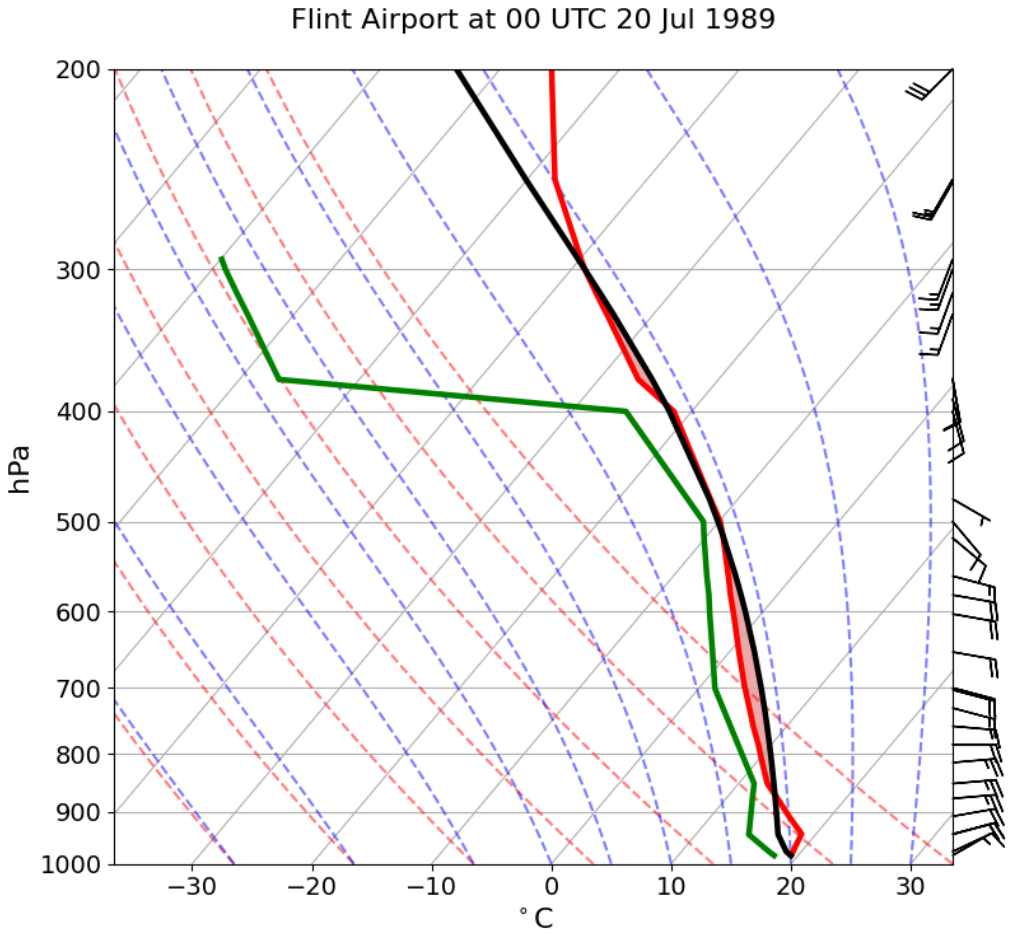
Figure 8-19: Rainfall Accumulation (Harrow, Ontario Storm of July 19-20, 1989)

On the synoptic scale, a slow-moving occluded low-pressure system was centred over Illinois (Appendix Figure F 46-Appendix Figure F 51). An upper-level trough across southwestern Ontario brought instability and deep moisture from the east and/or south to the region and triggered persistent showers and thunderstorms (M. M. Dillon Limited, 1990). Unlike the other extreme rainfall events, the synoptic-scale low-pressure system was almost stationary over Indiana from July 19 at 8 AM (12Z) to July 20 at 8 AM (12Z) and was south of the heaviest rainfall area (Figure 8-20). There was also a quasi-stationary cold front extending from the northern Great Lakes into southern Quebec. Harrow was south of the cold front and was in a warm and humid air mass despite being northeast of the surface low-pressure system with easterly to northeasterly winds. The July 19 at 8 PM (00Z) sounding at the Flint, Michigan radiosonde site, 87 km northwest of Harrow, had a precipitable water of 39 mm and almost no CAPE, with 15-25 kt easterly winds from the surface up to 550 hPa, in contrast to the southwesterly to westerly winds in the other events (Figure 8-21). Given the very slow movement of synoptic-scale features, the winds and moisture stayed relatively constant through July 20. Despite the lack of CAPE at Flint, Harrow's location to the southeast could infer a warmer, more unstable airmass at Harrow than at Flint.



Source: Weather Prediction Center, 2022

Figure 8-20: Surface Map (July 20, 1989, 00Z)



Note: The green and red lines show the dewpoint and air temperature measurements, and the red area indicates the Convective Available Potential Energy (CAPE).

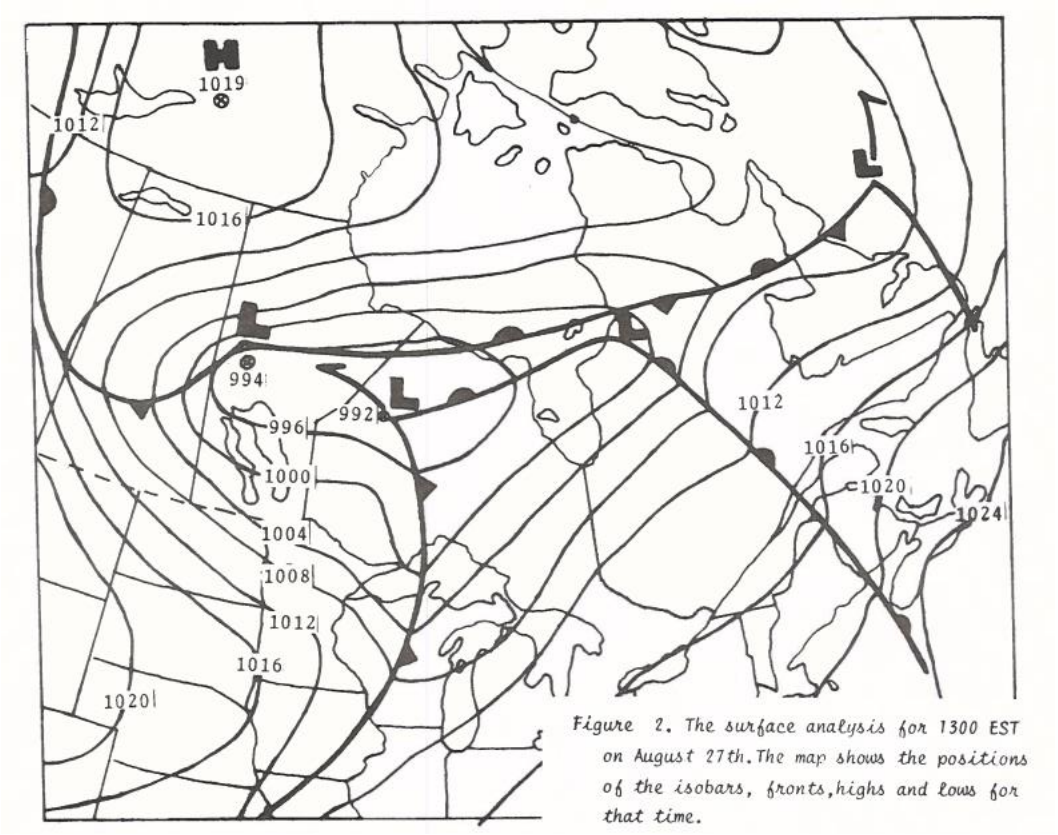
Source: University of Wyoming, 2025

Figure 8-21: Tephigram Sounding at the Flint Airport Radiosonde Site (July 20, 1989, 00Z)

The synoptic-scale northeasterly winds were funneled along the long axis of Lake Erie and combined with increased friction over the land to produce greatly enhanced small-scale low-level convergence in the Harrow area. A lake breeze front may have contributed to local generation of storms on July 20. Both the slow-moving synoptic-scale features and the mesoscale features fixed to the local topography led to extremely long periods of showers and thunderstorms over the same area and resulting extreme rainfall over a small area. A transposition study showed that a similar storm is less likely but still probable in the GTA, given that the GTA's location on the northwestern shore of Lake Ontario being analogous to Harrow's location on the northwestern shore of Lake Erie (M. M. Dillon Limited, 1990).

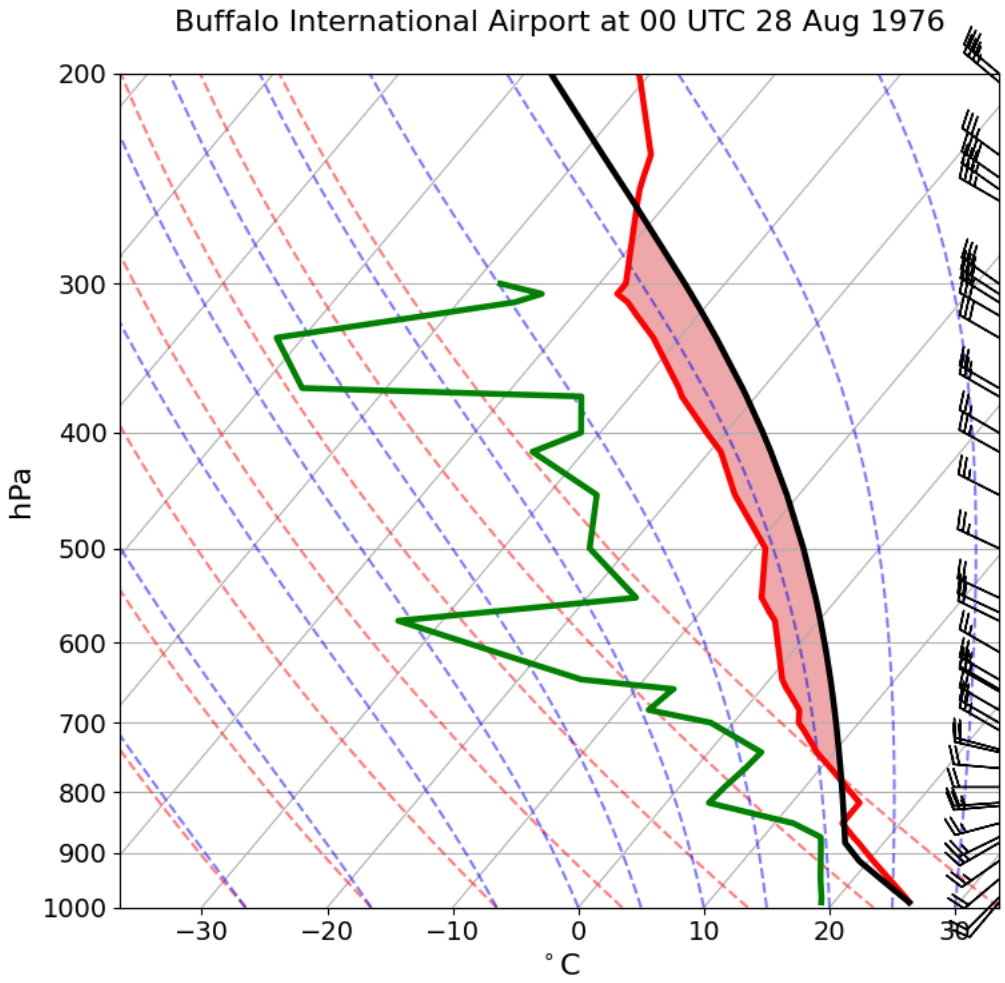
8.6 August 27-28, 1976

The intense thunderstorms of August 27-28, 1976 caused severe flooding over the Highland Creek basin in Scarborough, with parts of Scarborough receiving a total of >140 mm, with a maximum 1-hour rainfall recorded of ~70 mm. On August 27, a surface low-pressure system and associated upper-level low was moving eastward from Manitoba (Figure 8-22). The southwest winds ahead of the system brought warm, humid air into southern Ontario. The 8 AM (12Z) sounding at the Buffalo International Airport radiosonde site recorded 15-20 kt of westerly wind from just above the surface up to 600 hPa, along with a precipitable water of 30 mm, with the wind and precipitable water slowly increasing through August 28 as Gulf of Mexico moisture was brought into the region (Figure 8-23; Appendix Figure F 52-Appendix Figure F 54). The GTA was in the warm sector of the system, but also in an area of upper-level divergence favoring ascent due to a 300-hPa jet stream just south of the lower Great Lakes (Kilborn Limited, 1977).



Source: Kilborn Limited, 1977

Figure 8-22: Surface Map (August 27, 1976, 18Z)

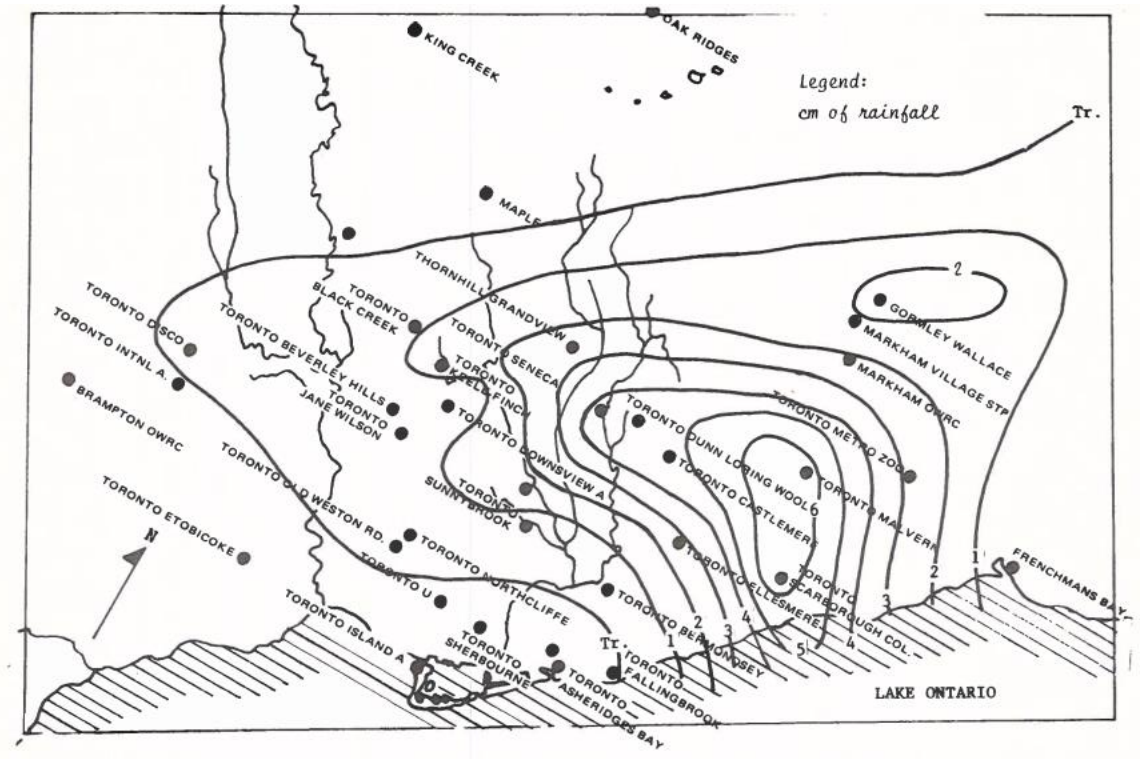


Note: *The green and red lines show the dewpoint and air temperature measurements, and the red area indicates the Convective Available Potential Energy (CAPE).*

Source: *University of Wyoming, 2025*

Figure 8-23: Tephigram Sounding at the Buffalo/Greater Buffalo International Airport Radiosonde Site (August 28, 1976, 00Z)

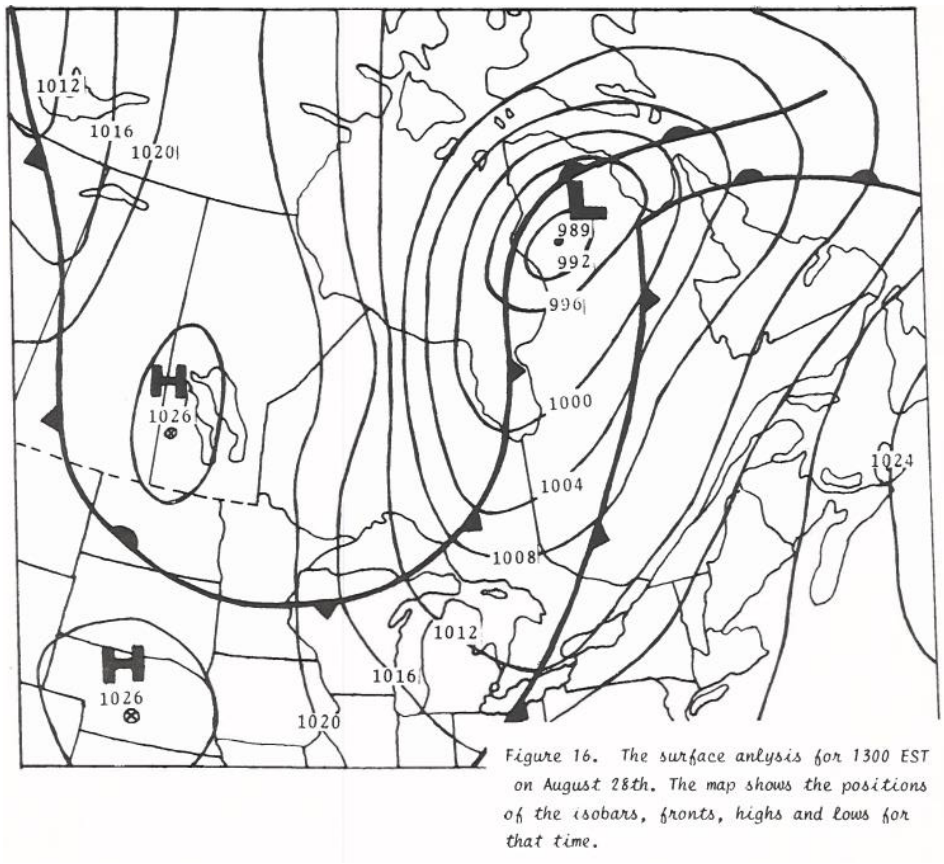
The GTA experienced a multi-cell thunderstorm between 2 PM (18Z) and 4 PM (20Z) on August 27 (Appendix Figure F 55). Given that the cold front associated with the storm was still over Lake Superior, the thunderstorm was likely an air-mass thunderstorm, meaning that it was not associated with a front or other synoptic-scale forcing. Nonetheless, it was severe enough to produce very heavy rain, hail, and strong winds. At least, one tornado or funnel cloud was even observed. A small area recorded >60 mm with this storm, causing flooding with the intense rainfall rates despite the storms moving at almost 80 km/h (Figure 8-24). There were also other scattered single-cell and multi-cell thunderstorms in southern Ontario. Even though no rain was recorded in the prior 12 days, which would correspond to a moisture condition of AMC I for August 27, local practice, at least in 1976, was to employ a moisture condition of AMC II in all calculations for storms with relatively long return periods such as this one. The storms on August 27 saturated the ground, corresponding to a moisture condition of AMC III for August 28. (Kilborn Limited, 1977).



Source: Killborn Limited, 1977

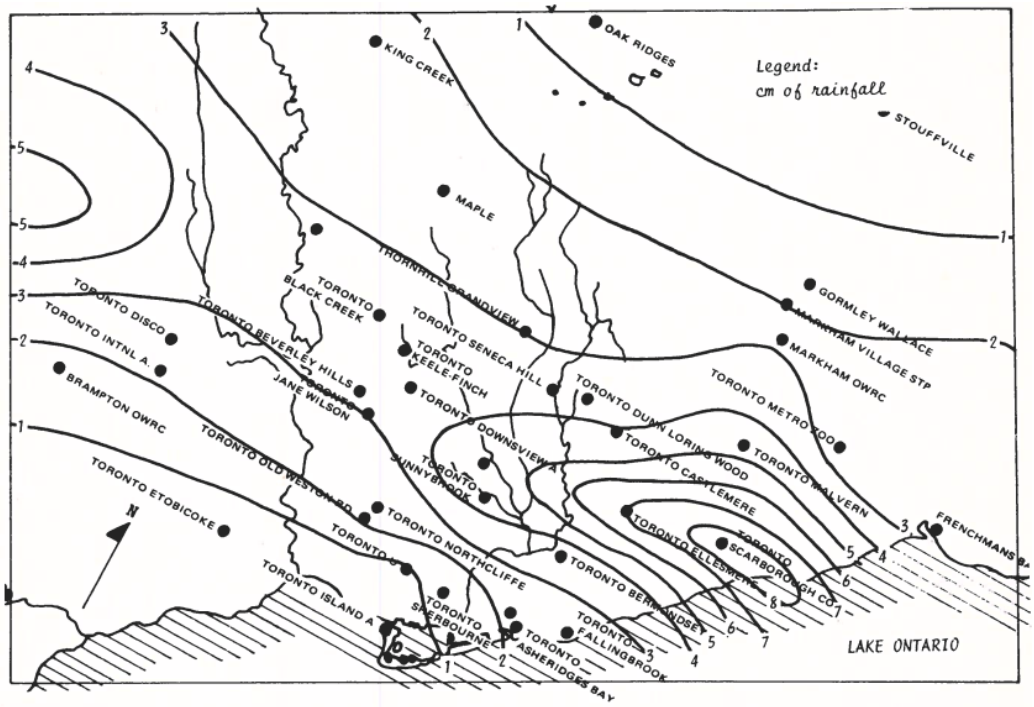
Figure 8-24: Total Rainfall Accumulation (August 27, 1976)

On August 28, although the system from the previous day over Manitoba had weakened to a sharp upper-level trough over western Ontario, there were still two cold fronts associated with this system (Figure 8-25), the easternmost of which triggered showers and thunderstorms in a continuous line oriented southwest to northeast that passed through the GTA by 2 PM (18Z) (Appendix Figure F 56). However, additional storms formed over the GTA even after the rest of the line passed off to the northeast, effectively creating a bend in the line that acted as a train of storms, prolonging the heavy rain over the GTA until after 5 PM (21Z), resulting in a localized maximum of >80 mm over the same areas that were hit hard on the previous day (Kilborn Limited, 1977; Figure 8-26).



Source: Kilborn Limited, 1977

Figure 8-25: Surface Map (August 28, 1976, 18Z)



Source: Kilborn Limited, 1977

Figure 8-26: Total Rainfall Accumulation Map (August 28, 1976)

8.7 Summary

Table 8-1 presents a comparison of various characteristics of the storms. All events in the storm comparison involved summer thunderstorms producing intense rainfall rates, with all events having a maximum 1-hour rainfall of at least 50 mm. Although some events were characterized by large storms and widespread rainfall, the intense rainfall rates over sufficiently long durations producing extreme rainfall amounts for all events occurred over narrow areas. This makes forecasting these events very challenging, as all weather models, even high-resolution ones, struggle to correctly identify the magnitude and/or location of localized extreme rainfall. The coarser resolution of models in the past made forecasting for the past events even more challenging, as showcased for the events from 2005 to 2014, for which archived model data is readily available. The models were the most skillful in predicting the August 19, 2005 event, at least showing widespread substantial rainfall given the stronger and more obvious larger-scale triggers for thunderstorms. Nonetheless, they greatly underestimated the magnitude of extreme rainfall. For other events, which were characterized by weaker and less obvious triggers for thunderstorms and less widespread thunderstorms, models did not show any heavy rainfall.

The events all occurred in an air mass ranging from moderately humid to very humid with sufficient atmospheric instability for thunderstorm development. The August 4, 2014 event featured only near-climatological amounts of atmospheric moisture, but training of thunderstorms over 5 hours led to extreme rainfall totals. Most events involved training of thunderstorms to prolong heavy rainfall rates over an area, though the August 4, 2009 and August 19, 2005 events did not have clear training of thunderstorms. A brief one-hour period of extreme rainfall rates on August 4, 2009 was sufficient for flash flooding, despite the event having the lowest total rainfall maximum. The August 19, 2005 event had two episodes of thunderstorms producing extreme rainfall rates within an exceptionally moist air mass, with both atmospheric moisture and maximum 1-hour rainfall being the highest among the events. In addition, the July 19-20, 1989 and August 27-28, 1976 both featured heavy rain-producing thunderstorms on two separate days. As noted by Doswell et al. (1996), the potential maximum total rainfall increases with both atmospheric moisture and the duration of training of thunderstorms. Wind speeds in the lower atmosphere ranged from weak to moderate among the events; although weak winds cause individual storms to move slower, weak winds are not necessary for training of storms to persist over an area.

In all events except the July 19-20, 1989 event, the extreme rainfall occurred on the warm side (i.e. to the south) of a front or surface low-pressure system. The July 19-20, 1989 event was an outlier characterized by an unusually slow-moving low-pressure system to the south combined with fixed terrain effects to lead to two prolonged periods of showers and thunderstorms. In some events, the large-scale environment contained clear large-scale triggers, mostly cold fronts, for thunderstorm development, but in other events, only localized mesoscale and terrain influences were found that could act as triggers, though the synoptic-scale environments did favor rising air. In addition, although some events were characterized by a moist or saturated ground prior to the extreme rainfall, others occurred after little or no rain fell for several days, indicating that the extreme nature of the rainfall rates and total rainfall amounts suffices on its own to cause damaging flash flooding.

Table 8-1: Summary of Storm Comparison by Characteristics

Storm	Aug 17, 2024	Jul 16, 2024	Aug 4, 2014	Jul 8, 2013	Aug 4, 2009	Aug 19, 2005	Jul 19-20, 1989	Aug 27-28, 1976
Meteorological environment	Very humid air from Gulf of Mexico, sufficient atmospheric instability for thunderstorms, weak weather disturbance in warm sector triggered thunderstorms that trained	Very humid air from Gulf of Mexico, sufficient instability for thunderstorms, storms triggered by small-scale cyclone originating from cluster of thunderstorms over the Midwest U.S, training of storms	Only moderately moist air, sufficient instability for thunderstorms, light winds, lake breeze circulation combined with outflow winds from other nearby storms cause storms to train over Burlington, Ontario area	Very humid air from Gulf of Mexico, sufficient instability for thunderstorms, weak large-scale forcing and winds, storms formed in warm sector with stationary front to the north possibly enhanced by lake breeze circulation, then trained over same area before combining with additional storms induced by cold front	Sufficiently moist and unstable air mass, storms formed ahead of cold front, no training of thunderstorms but extreme rainfall rates	Exceptionally humid air from Gulf of Mexico, sufficient instability for thunderstorms, synoptic-scale low-pressure system forcing light to moderate rain along warm front, then thunderstorms ahead of cold front, no training of storms but widespread substantial rainfall with localized extreme rainfall rates	Very humid air, sufficient instability for thunderstorms, slow-moving large-scale system extending from Midwest U.S. to southern Ontario for 2 days combined with enhancement from Lake Erie led to extremely persistent but localized region of showers and thunderstorms	Very humid air, sufficient instability for thunderstorms, storms formed without large-scale forcing on Aug 27, then along cold front Aug 28, strongest and longest-lasting storms targeted same part of TRCA on both days
Forecasts	Poor, with substantial rainfall expected but magnitude underestimated	Very poor, with models showing inconsistent rain amounts and all underestimating maximum	Very poor, all models much underestimating maximum	Very poor, with models showing inconsistent rain amounts and all underestimating maximum	Very poor, all models much underestimating maximum	Poor, with substantial rainfall expected but magnitude underestimated	NA	NA
Antecedent precipitation description	Dry (AMC I)	Normal (AMC II), but wet (AMC III) for previous day	Dry (AMC I)	Wet (AMC III)	Dry (AMC I)	Dry (AMC I)	Dry (AMC I)	Normal (AMC II) for Aug 27, Wet (AMC III) for Aug 28
Max total rainfall (mm)	135.7	104.2	192	138	67.6	153.4	450	~65 for Aug 27, ~80 for Aug 28
Max 1-hr rainfall (mm)	83.9	58.6	69.6	78.8	67.6	116.6	50.0	~70
Duration (hours)	8.7	5	7	10	1	15.5	30	NR

Storm	Aug 17, 2024	Jul 16, 2024	Aug 4, 2014	Jul 8, 2013	Aug 4, 2009	Aug 19, 2005	Jul 19-20, 1989	Aug 27-28, 1976
Region of max rainfall	Narrow band 12-15 km from Lake Ontario shoreline in Etobicoke, Mimico and Humber watersheds	Mississauga and southwest part of TRCA, especially Etobicoke and Mimico watersheds	Middle and upper portions of Roseland Creek, Tuck Creek just east of Ontario Highway 407	Western/central part of TRCA	Cooksville Creek Watershed in Mississauga	West to east band through middle of major TRCA watersheds, near northern boundary of city of Toronto	Harrow, Ontario (not in GTA or TRCA)	Highland Creek watershed
Size of area affected	Very narrow and localized, exact value NA	Widespread storms, but with smaller area of extreme rain, exact value NA	Very narrow and localized, 200 km^2 (25 km × 9 km)	Widespread storms, but with smaller area of extreme rain, 25000 km^2	Small and localized, exact value NA	Widespread storms, but with narrower area of extreme rain, exact value NA	Widespread storms, but extreme rainfall area is very small and localized, 700 km^2	Widespread storms, but with narrower area of extreme rain, exact value NA

Note: "NA" indicates "Not Available"

9. Climate Change Impact

There are several ways in which climate change can be expected to impact storm frequency and intensity over the TRCA jurisdiction. First, the global warming trends will translate into similar trends of average temperature and precipitation at the level of the TRCA jurisdiction. Second, climate change will affect global circulation patterns and thus the trajectory and reach of tropical and extratropical cyclones, one mechanism by which the high levels of humidity that allow for extreme rainfall events reach the TRCA jurisdiction.

9.1 Temperature and Precipitation

Temperatures in Toronto have been increasing trend since 1850, with an average temperature increase of 0.2 °C per decade (Lam et al., 2024). The increase in temperature is uneven throughout the year, with winter months warming the most. Between 1961-1990 and 1991-2020, the months with highest warming were December (+1.4 °C), February (+1.1 °C), January and September (+1.0 °C).

Temperature has a direct effect on precipitation events by increasing the amount of moisture that can be held in the atmosphere. This increase is governed by the Clausius-Clapeyron relation, that predicts a 7% increase in the water-holding capacity of the atmosphere for every 1 °C increase in temperature. The temperature increase over Toronto should therefore result into a higher precipitation amounts during extreme rainfall events. However, due to the complexity of precipitation patterns, which depend on many factors such as atmospheric circulation, this increase in temperature does not always translate into a corresponding increase in precipitation. For instance, yearly precipitation between 1961-1990 in Toronto averaged 818.9 mm, while between 1991-2020 it averaged 822.7 mm, only 0.5% more despite an average temperature increase of about 1 °C in the same period (Lam et al., 2024). Extreme precipitation, however, tends to follow better the Clausius-Clapeyron relationship, which is applicable to convection-driven precipitation. short-duration intense storms are also increasing in Toronto. Between 2005 and 2024 (20 years), Toronto has seen at least five intense storm events (August 2005, July 2013, August 2018, July 2024 and August 2024) that have exceeded the 100-year storm in parts of the city, which historically has a 1% chance of occurring in any given year.

The future climate in Toronto could differ significantly depending on human greenhouse gas (GHG) emissions. Future climate is projected using scenarios of human development called Shared Socioeconomic Pathways (SSP). For instance, SSP5-8.5 is a scenario of fossil-fueled development that leads to a level of radiative forcing (relative to the pre-industrial period) of 8.5 W/m^2, and SSP2-4.5 is middle-of-the-road scenario that keeps the historical social, economic and technological trends, leading to a radiative forcing of 4.5 W/m^2 by 2100. In Toronto, comparing the projected 2071-2100 average to the historical 1971-2000 average (climate normals used by Lam et al. (2024) report), these scenarios lead to an increase of +4 °C under the SSP2-4.5 scenario, or +6-7 °C under the SSP5-8.5 scenario.

For annual precipitation, the SSP2-4.5 and SSP5-8.5 scenarios result respectively in an increase of +11% and +16%, between 1971-2000 and 2071-2100. This increase is not uniform throughout the year, with most of the increase being concentrated in winter and spring, and summer precipitation projected to only increase by 1-3%. On the other hand, extreme precipitation for the same periods is projected to increase +18% under the SSP2-4.5 scenario and +27% under the SSP5-8.5 scenario (Lam et al., 2024).

9.2 Hurricanes and Extratropical Cyclones

Hurricanes are one of sources of extreme precipitation events. For instance, the high rainfall intensity of the July 16, 2024 and the August 17, 2024 storms were at least partly due to the high moisture content left in the atmosphere by the previous passing of hurricanes Beryl and Debby.

Hurricanes are tropical cyclones that develop in the warm waters of planet's oceans. The hurricanes affecting eastern North America originate from tropical depressions over the Atlantic Ocean that are advected westward by the trade winds. Upon reaching the warm waters in the Caribbean and the Gulf of Mexico, these depressions strengthen and may form tropical storms and hurricanes. The strength of the hurricanes (classified by their wind speed) mostly depends on the ocean temperature, as oceans provide the hurricanes with energy and humidity.

When making landfall, tropical cyclones lose their main energy source and experience higher surface friction, resulting in a faster loss of energy and weakening of the cyclone. Cyclones that travel along the coast can travel much further north without losing much energy, which results in a great number of these hurricanes (163 between 1900 and 2014) reaching the eastern coast of Canada (Rocha, 2017). In the TRCA region, being located about 500 km inland, the occurrence of tropical cyclones is much rarer, with only five tropical cyclones passing within 150 km of the TRCA region since 1851 (NOAA, 2025c). However, many tropical cyclones transition from tropical to extratropical cyclones before reaching the TRCA region, and these extratropical cyclones can strengthen and bring heavy precipitation to the area. Since 1851, 18 extratropical cyclones (of tropical origin) have passed within 150 km of the TRCA region (NOAA, 2025c) (Table 9-1).

Table 9-1: Extratropical Cyclones of Tropical Origin that Tracked within 150 km of the TRCA Region

Name	Date
Beryl	2024
Ike	2008
Ernesto	2006
Arlene	2005
Frances	2004
Isabel	2003
Opal	1995
Hugo	1989
Hazel	1954

Name	Date
Unnamed	1938
Unnamed	1932
Unnamed	1928
Unnamed	1926
Unnamed	1915
Unnamed	1903
Unnamed	1901
Unnamed	1900
Unnamed	1878

Recent observations and projections of future climate change point towards stronger and more rapidly intensifying hurricanes (Colbert, 2024; Bhatia et al., 2019). The increase in sea surface temperature and air temperature makes more energy available, leading to an increase in very intense hurricanes. The warmer atmosphere is also able to hold more water vapour, which in turn increases the moisture carried by the hurricanes and the rainfall rates in their path. Climate simulations indicate no increase in the frequency of hurricanes. However, due to environmental changes, hurricanes have migrated polewards by 53 km/decade in the northern hemisphere. Projected climate change is expected to exacerbate this trend, which would lead to a potential increase of hurricanes frequency in Canada and in the vicinity of the TRCA region (Kossin et al., 2014). Furthermore, the wind intensity, pressure difference, and rainfall rates associated to these hurricanes will likely increase (Knutson, 2022).

An extreme event attribution study for the very active hurricane season of 2020 has shown that climate change has increased the 3-day accumulated rainfall amounts and the tropical storm strength by 10 and 5%, respectively (Reed et al., 2022). The global warming level in 2020 was approximately +1 °C. This indicates that, at least for active or extreme years, the projected increases in rainfall rate and storm strength (i.e., wind speeds) by (Knutson, 2022) are potentially an underestimation.

In contrast to hurricanes, extratropical cyclones are formed between 30° N and 60° N by cyclogenesis, which describes the formation and intensification of a low-pressure system. These extratropical cyclones are advected eastward by the jet stream. Most of the storms occurring over the TRCA area originate from the Prairies or the Great Lakes, following a similar path. Consequently, changes to the location or strength of the jet stream will have consequences on the strength and trajectory of the extratropical cyclones. The strength of the jet stream is determined by the temperature gradient between the pole and the equator, and current trends and future projections show that the planet warms faster at the poles than at the equator, reducing the temperature gradient and potentially weakening the jet stream. A weaker jet stream could produce weaker extratropical cyclones due to the reduced baroclinicity, which is a measure of how misaligned the pressure gradient is from the air density gradient (proportional to the temperature gradient) and indicates the amount of "fuel" there is for a developing extratropical cyclone. At the same time, a weaker and more meandering jet stream could slow the eastern progression of the extratropical storms, allowing them to linger for a longer time over the same location, thus increasing their impacts (Doblas-Reyes et al, 2021).

Another uncertainty is the possible shift in the location of the jet stream. With a warmer Arctic, the jet stream has and will migrate northward, which could put the TRCA region into its path, and bring extratropical cyclones to it directly (Ulbrich et al., 2009; Woollings et al., 2023; Lee et al., 2021). However, other research suggests a potential south-eastward shift of the extratropical storms (Colle et al., 2015). No scientific consensus exists on which of these theories describes the physical process has been reached. Therefore, the impacts of climate change into the strength, frequency and trajectory of extratropical cyclones remains uncertain.

9.3 Thunderstorms

Thunderstorms are climate hazards in their own right due to the lightning, heavy rain, and high wind speed. Thunderstorms occur frequently in Southern Ontario with on average 30-35 storms per year (Maybank, 2015). In the summer months (late May to early September), when the conditions for these convective storms are most often present, warm and humid air may rise in towering cumulonimbus clouds into colder layers of the atmosphere, where precipitation is formed via the ice phase. The turbulent updrafts, heavier falling snow pellets and lighter rising ice crystals collide resulting in the exchange of electric charge. Subsequently differently charged regions develop with the region at the top of the cloud commonly positively charged, the central region negatively charged, and the lower region of the cloud and the ground positively charged. This electric charge is then released during a lightning strike when cosmic ray particles originating from the sun interact with the air molecule, leaving behind ionized trails and lower the air resistance (Pasko et al., 2025).

Determining how the frequency, intensity, and areal extent of thunderstorms and their associated features such as tornadoes will evolve with climate change is difficult as Global Climate Models (GCMs) cannot directly simulate these storms due to their small scales. Using Regional Climate Models (RCMs) and previous emission scenarios, an increasing trend in the amount of Convective Available Potential Energy (CAPE) has been found in particular of the summer months (June-July-August, JJA) (Glazer et al., 2021; Seeley et al., 2015). Similarly, a study looking into the co-occurrence of shear and CAPE shows increase in number of days with severe thunderstorm conditions across all seasons for the north shore of Lake Ontario (Diffenbaugh et al, 2013). Simulations using the latest emission scenarios (SSPs) have found a similarly robust trend of increasing CAPE across southern Ontario. This increase is not projected to be offset by limiting factors for the storm development such as convection inhibition (CIN) or vertical wind shear (Lepore et al., 2021). High-resolutions simulations project an increase in frequency and rainfall amount for convective systems over southern Canada (Prein et al., 2017).

Climate projections point towards an increase in severe thunderstorms while not necessarily showing an increase in overall thunderstorm frequency. However, the projections remain uncertain due to necessity of co-occurrence of multiple factors for the thunderstorm development.

10. Summary and Recommendations

10.1 Summary

During the summer of 2024, two extreme rainfall events affected the TRCA in just one month. Both events were characterized by thunderstorms depositing a localized area of maximum rainfall total of >100 mm causing flash flooding. The extreme rainfall area from the August 17, 2024 event was narrower and more localized than for the July 16, 2024 event. Meteorologically, both events were fueled by very humid air from Gulf of Mexico, sufficient instability for thunderstorms, a large-scale environment favorable for rainfall, and smaller-scale effects that led to a line of thunderstorms tracking over the same area, leading to hours of heavy rainfall rates. Although numerical weather models showed the outside possibility of heavy rainfall, they did not accurately predict the magnitude and/or location of either extreme rainfall event, leading to very challenging forecasts. Despite the August 17, 2024 event being more localized, the potential for heavy rainfall was communicated in public forecasts with ~1-day lead time, longer than with the July 16, 2024 event, in which heavy rainfall was not forecasted until the rain was about to start.

A total of 103 (July 16) and 98 (August 17) million m^3 of water fell over the TRCA jurisdiction during the days of the extreme rainfall events. Both events were centred in the same area with the highest intensities in both events being observed over the Mimico and Etobicoke watersheds. The highest rainfall was measured at the same station (Rathwood, 5 km south from the Toronto Pearson International Airport), and the Humber and Don watersheds received the most precipitation. The August 17 event was concentrated in a narrow band of precipitation 10-20 km north from the shoreline, while the July 16 event was more spread-out across these watersheds and towards Lake Ontario. This resulted in more intense rainfall for the August 17 event in the most impacted areas, while the July 17 resulted in more widespread though still very intense rainfall. This is reflected in the IDF curves at the Toronto City and the Toronto Pearson International Airport, where the July 16 storm reached the 100-year return level for the 6-hour event at both locations, while the August 17 storm did not reach the 1-year return level in the Toronto City station, but greatly surpassed the 100-year level for the durations between 1 and 24 hours at the Toronto Pearson International Airport.

Furthermore, a comparison with other extreme rain events in the GTA and one event in southwestern Ontario highlighted similarities and differences. Although some events were characterized by widespread storms and rainfall, in all events, only a small or narrow area experienced intense rainfall rates for a sufficiently long duration to produce extreme rainfall amounts, making forecasting, messaging, and preparation very challenging, like the 2024 storms. Though not all events featured thunderstorms training over the same area for hours, or an exceptionally humid air mass, both factors greatly increase the potential maximum total rainfall. Both larger-scale and smaller-scale influences were found to be important to the development of thunderstorms and potential for extreme rainfall. Finally, the extreme nature of the rainfall rates and total rainfall amounts suffices on its own to cause damaging flash flooding even without antecedent wet conditions.

Several factors that could potentially have influenced the summer 2024 storms were analyzed. The Urban Heat Island effect resulted in additional heat over the TRCA urban area, which might have contributed to storm intensification over Toronto by further enhancing the larger-scale factors such as the Mesoscale Convective Vortex and the frontal system. Lake Ontario was unusually warm in summer 2024 and is likely to have intensified the storms by further destabilizing the atmosphere through the injection of additional heat in the lower layer. It furthermore provided additional humidity that kept the air over the TRCA region moist and likely contributed to the high rainfall of the storm events. While lake breezes from Lake Ontario have the potential to destabilize the atmosphere and contribute to the triggering of storm events, no indication of an active lake breeze was found at the eve of the events. Finally, due to the path of the July 16 storm passing through the centre of the Ontario Peninsula, orographic lift was determined to have likely been a reinforcing factor for this storm.

Given that between 2005 and 2024 (20 years), Toronto has seen at least five intense storm events (August 2005, July 2013, August 2018, July 2024, and August 2024) that have exceeded the 100-year storm in parts of the city, two important questions arise: have such heavy rainfall events become more frequent, and will they become more frequent in the future with climate change? As shown by the July 16 and August 17 events and the storm comparison in Section 8, heavy, short-duration rainfall events occur in relatively small areas, with heaviest rainfall not occurring in the same location for each event. Therefore, a single station does not record the heaviest rainfall for most events, instead containing a mixture of measurements from the centres and edges of the events. Also, by definition, extreme

rainfall events are rare. This creates an extreme precipitation record at a single station that is statistically noisy, making it very difficult to identify statistically significant trends over time (Hogg and Hogg, 2010; Shephard et al, 2014; Sun et al, 2021; Cannon et al, 2024). Any increases in extreme rainfall due to the observed warming so far are small relative to the large internal variability at a given location or in small areas (Cannon et al, 2024).

In the GTA, as discussed in Section 7, this is complicated by the urban heat island and topographic features, ranging from the shore of Lake Ontario to the Oak Ridges moraine, that locally influence precipitation. In general, the highest extreme rainfall values are observed along and west of the Niagara escarpment, with lower values in the "rain shadow" region immediately to the east of the Niagara escarpment as well as locations close to Lake Ontario. However, no relationship between trends in short-duration extreme rainfall and the topography were found. More data and analysis would be required to make more definitive conclusions regarding topographic effects.

Despite the uncertainty in trends at a particular location or small area, there is greater confidence in trends on a regional to continental scale, as internal variability decreases with increasing spatial scale (Cannon et al, 2014). Extreme rainfall events have been becoming more intense and frequent in most of the world, including over a broad region of eastern North America covering the Midwest U.S., Great Lakes, Northeast U.S., and Ontario over the past 50-100 years (Kunkel et al., 2013, Soulis et al., 2016; Cao and Ma, 2009; Shephard et al, 2014; Sun et al, 2021; Cannon et al, 2024). Although the trend is usually not statistically significant at individual locations, the trend is often statistically significant in aggregated data from numerous weather stations on a regional scale (Kunkel et al., 2013; Shephard et al, 2014; Cannon et al, 2024). Also, the Northeast U.S. has experienced an ~55% increase in extreme precipitation between 1958 and 2016, the largest increase in the U.S. (Kunkel et al., 2013; Easterling et al. 2017). In addition, the inclusion of the most recent station data over the past 15-20 years yields stronger evidence for the increase in short-duration extreme rainfall compared to studies which relied on earlier data, indicating that the trend is becoming more robust as climate change continues to progress and increasing statistical confidence with longer records (Cannon et al, 2024; Sun et al, 2021). The increasing trends are larger for the short-duration events that cause flash floods compared to longer-duration events (Cannon et al, 2024). While these findings are not specific for the GTA, the GTA's location in Ontario and the Great Lakes region and proximity to the Northeast U.S. means that the general increasing trend is likely also applicable to the GTA.

However, unanswered questions remain in the scientific community regarding the mechanisms behind the increasing trend and spatial variability in the magnitude of the trend. Due to climate change, the amount of atmospheric water vapour, a key ingredient in extreme rainfall events, has increased in the Great Lakes region over the past 50-100 years (Kunkel et al., 2013). However, dynamical factors for ascending air needed to produce precipitation, dictated by characteristics of meteorological systems, are also important. Changes in these factors due to climate change cannot be ruled out but are uncertain (Kunkel et al., 2013). In addition to anthropogenic climate change, natural variability over a time scale of decades, such as the effects of internal decadal variability in the spatial Pacific Ocean sea-surface temperature pattern on the atmospheric circulation, is also potentially important. But their effects on precipitation are not fully understood (Kunkel et al., 1999; Hoerling et al., 2016; Sun et al, 2021). In the GTA specifically, the complex interaction between convective storms and topographic effects adds to the uncertainty.

Corresponding to the increasing trend of extreme precipitation events, climate change was a potential contributing factor to the summer 2024 storms and will very likely be to the future storms affecting the TRCA jurisdiction. The increase in local and global temperatures results in a higher moisture content of the atmosphere and higher convective available potential energy, contributing directly to the intensity of the storms. The intensification of hurricanes and extratropical storms implies that more of these will potentially be able to reach further north and inside the North American continent, either affecting directly extreme rainfall events or leaving an unstable and moisturized atmosphere that can later result in powerful storms, as was the case for the July 16 and August 17 storms. Current climate change projections indicate that the global climate will continue to warm during the 21st century, which would lead to an enhancement of all these effects.

10.2 Recommendations

From a forecasting and public messaging perspective, these events illustrate the challenge of predicting both the occurrence and location of extreme rainfall driven by localized training of warm-season thunderstorms. The most difficult forecasts involve weak or subtle mesoscale triggers for thunderstorms, during which it is not clear if thunderstorms will form. Hence, models often disagree on the occurrence and location of thunderstorms and do not predict them accurately. Even when the large-scale weather pattern clearly favors heavy rainfall, and models predict

heavy rainfall, localized rainfall maxima can be much greater than modeled. Both challenges are especially prevalent in summer, compounded by the increased potential for heavy rainfall rates due to higher atmospheric water vapour values in summer.

Despite the uncertainty, large-scale weather patterns do give clues on the amount of atmospheric water vapour and the possibility of thunderstorms and heavy rainfall. Extreme total rainfall requires extreme rainfall rates and/or a long duration, and the more both factors are present, the greater the maximum potential total rainfall. Therefore, an atmosphere with an unusually high amount of water vapour and the occurrence slow-moving, training, or back building thunderstorms are key ingredients to extreme rainfall events. In addition, a high surface dew point increases the likelihood of thunderstorms to form in the first place. When thunderstorms and/or heavy rainfall are forecasted, it is recommended that the TRCA staff continue to contact meteorologists at the Ontario Storm Prediction Centre (OSPC), inquiring about the weather forecast to obtain a better situational awareness than could be obtained via OSPC's public weather forecasts. Questions specific to thunderstorm activity should continue to include, how much water vapour there is in the atmosphere, the surface dew point, the likelihood of slow-moving, training, or back building thunderstorms (and the exact location where they could occur, if applicable), areal coverage of any extreme rainfall, and overall confidence level in the forecast.

Given the uncertainty, it is also beneficial to pay attention to the potential extreme rainfall forecasts not just within the TRCA region but also within a 100-km radius. When a potential heavy rainfall event is approaching (e.g. within 12 hours of forecasted start time) and during the event, it is recommended that the TRCA staff continue to have situational awareness of clusters of thunderstorms and associated small-scale weather systems surrounding the TRCA using radar, satellite, and station observations. This situational awareness is especially critical in summer, when forecasts are the most difficult and uncertain, and the local meteorological setup can change quickly. The situational awareness will continue to help the TRCA staff issue and/or adjust messaging regarding potential flooding risk, when necessary, more quickly, allowing the public and stakeholders to have more time to prepare, without overissuing warnings.

Given the high uncertainty that is often present with potential heavy rain events, especially in summer, a balance has to be struck between issuing messages and warnings when warranted and not overly alarming the public, creating too many false alarms and alarm fatigue. Given TRCA's procedures regarding thunderstorm and riverine flooding forecasts and issuance of messages and the high degree of dependence on public forecasts, there are few improvements readily available to TRCA. The inclusion of surface dewpoint temperature into the daily planning cycle of thunderstorm forecasts could be explored. Furthermore, reminding the public in advance of the thunderstorms season in the summer of the severity and uncertainty of the different levels of messaging could be useful. The public understanding of flood messages will become increasingly important as the increases in atmospheric moisture and perhaps also frequency of convective systems with climate change will lead to extreme rainfall events occurring more often and becoming more extreme in the future, while forecast uncertainty leading up to the events remains high.

To combat UHI effect within TRCA communities, a combination of nature-based and design-based strategies should be prioritized. Expanding tree canopy cover through clustered vegetation can provide shading, evapotranspiration, and cooling benefits while also supporting biodiversity. The benefits increase when trees and other vegetation are planted in clusters or groups as the localized microclimates created by these clusters are more stable (i.e., cool the surroundings for longer) and reduce the heat storage of nearby asphalt and concrete surfaces more effectively. Strategic placement of parks, shaded corridors, and green infrastructure helps lower localized air temperatures and enhance thermal comfort for residents while ensuring that existing ventilation via wind corridors and wind coming off Lake Ontario is not inhibited. Furthermore, the height and density of the vegetation must be considered during the urban design process as taller trees planted more densely provide deeper shade but can also impede airflow, trap heat and reduce ventilation. Furthermore, the integration of high-albedo and permeable materials in pavements, rooftops, and facades can further reduce heat absorption and improve stormwater management. These measures mitigate both heat buildup and flooding, supporting the efforts to build more adaptive and resilient communities in the face of intensifying extreme weather events.

The summer storms of 2024 were able to surpass the 100-year IDF curves twice in the same year for one station in the TRCA jurisdiction (Toronto City), showing the inadequacy of the current IDF curves. These curves should be updated with the rainfall maximums of 2024, as well as the data of all previous years (Toronto City has not been updated since 2021, Toronto Pearson International Airport since 2017). It is critical to continue to collect rainfall data to enable an accurate statistical analysis for updating the IDF curves.

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Appendix A

Data Completeness

Appendix A. Data Completeness

A.1 Rainfall

Stations with insufficient completeness (95%) were excluded from the analysis and are marked in red in the tables below, unless an alternative source (daily data for missing hourly data in the ECCC stations) was found.

A.1.1 TRCA

Appendix Table A 1: Completeness of TRCA Precipitation Data (5 min Resolution)

Location	Region	Municipality	Station	Data type	Completeness	
					Jul 16	Aug 17
Albion Hills	Peel	Caledon	HY002	Precipitation	100%	100%
Alex Duff Memorial Pool	Toronto	Toronto	HY003	Precipitation	100%	100%
Bayly and Church	Durham	Ajax	HY004	Precipitation	100%	100%
Brickworks	Toronto	Toronto	HY008	Precipitation	100%	100%
Brock West Landfill	Durham	Pickering	HY009	Precipitation	100%	100%
Bruce Mill CA	York	Whitchurch-Stouffville	HY011	Precipitation	100%	100%
Danforth and Coxwell	Toronto	Toronto	HY016	Precipitation	100%	100%
Dufferin Reservoir	York	Vaughan	HY021	Precipitation	100%	100%
G Ross Dam	Toronto	Toronto	HY027	Precipitation	100%	**0%**
Glen Haffy	Peel	Caledon	HY030	Precipitation	100%	100%
Goodwood Pumping Station	Durham	Uxbridge	HY031	Precipitation	100%	100%
Heart Lake CA	Peel	Brampton	HY033	Precipitation	100%	100%
Kennedy Pump Station	Toronto	Toronto	HY036	Precipitation	100%	100%
King and Albion-Vaughan	York	King	HY037	Precipitation	100%	100%
East Humber at Mill Road	York	King	HY038	Precipitation	100%	100%
Kortright	York	Vaughan	HY039	Precipitation	100%	100%
Laidlaw Bus Depot	Peel	Caledon	HY041	Precipitation	100%	100%
Little Rouge at 16th	York	Markham	HY043	Precipitation	100%	100%
Milne Dam	York	Markham	HY044	Precipitation	100%	100%
Mississauga Works Yard	Peel	Mississauga	HY046	Precipitation	100%	100%
Morningside Works Yard	Toronto	Toronto	HY050	Precipitation	100%	100%
Restoration Services	York	Vaughan	HY055	Precipitation	100%	100%
Stouffville Dam	York	Whitchurch-Stouffville	HY060	Precipitation	100%	100%
Sue Grange Farm	Peel	Caledon	HY061	Precipitation	100%	100%
Transport Canada	Durham	Pickering	HY063	Precipitation	100%	100%
West Humber at Hwy7	Peel	Brampton	HY067	Precipitation	100%	100%
York Pumping Station	York	Richmond Hill	HY069	Precipitation	100%	100%
York Region Works Yard	York	Richmond Hill	HY070	Precipitation	100%	100%
Oak Ridges	York	Richmond Hill	HY083	Precipitation	100%	100%
RL Clark WTP	Toronto	Toronto	HY086	Precipitation	100%	100%
Westmount Park	Toronto	Toronto	HY087	Precipitation	100%	100%
Black Creek Pioneer Village	Toronto	Toronto	HY088	Precipitation	100%	100%
Broadlands Community Centre	Toronto	Toronto	HY094	Precipitation	100%	100%
Caledon East Soccer Complex	Peel	Caledon	HY096	Precipitation	100%	100%
Rathwood	Peel	Mississauga	HY099	Precipitation	100%	100%
Petticoat Works Yard	Durham	Pickering	HY102	Precipitation	100%	100%
Balsam at 407	Durham	Pickering	HY121	Precipitation	100%	100%
Durham Works Yard	Durham	Ajax	HY122	Precipitation	100%	100%
Claremont Nature Centre	Durham	Pickering	HY124	Precipitation	100%	100%
Elmbank Community Centre	Toronto	Toronto	HY130	Precipitation	100%	100%

A.1.2 ECCC

Appendix Table A 2: Completeness of ECCC Precipitation Data (Hourly Resolution)

Station name	Climate ID	Data type	Completeness	
			Jul 16	Aug 17
PORT WELLER (AUT)	6136699	Precipitation	100%	100%
ST. CATHARINES / NIAGARA DISTRICT A	6137286	Precipitation	**0%**	**0%**
ST CATHARINES A	6137304	Precipitation	**37.5%**	**37.5%**
VINELAND STATION RCS	6139148	Precipitation	100%	100%
BRANTFORD AIRPORT	6140942	Precipitation	100%	100%
ELORA RCS	6142286	Precipitation	100%	100%
GUELPH TURFGRASS INSTITUTE	6143092	Precipitation	100%	100%
KITCHENER/WATERLOO	6144239	Precipitation	100%	100%
BURLINGTON PIERS (AUT)	6151061	Precipitation	**0%**	**0%**
HAMILTON A	6153193	Precipitation	0% *	0% *
HAMILTON RBG CS	6153301	Precipitation	100%	100%
KING CITY NORTH	6154150	Precipitation	100%	100%
OSHAWA	6155875	Precipitation	100%	100%
MONO CENTRE	6157000	Precipitation	100%	100%
TORONTO CITY	6158355	Precipitation	100%	100%
TORONTO CITY CENTRE	6158359	Precipitation	100%	100%
TORONTO INTL A	6158731	Precipitation	0% *	0% *
UXBRIDGE WEST	6159123	Precipitation	100%	100%

*Note: * indicates availability of daily data (1 observation)*

A.1.3 City of Toronto

Appendix Table A 3: Completeness of City of Toronto Precipitation Data (5 min Resolution)

ID	Station	Data type	Completeness	
			Jul 16	Aug 17
7677	RG_001	Precipitation	**85.42%**	98.96%
7678	RG_002	Precipitation	98.96%	98.96%
7679	RG_003	Precipitation	98.96%	98.96%
7680	RG_004	Precipitation	98.96%	98.96%
7681	RG_006	Precipitation	98.96%	98.96%
7682	RG_007	Precipitation	98.96%	98.96%
7683	RG_012	Precipitation	98.96%	98.96%
7684	RG_013	Precipitation	98.96%	98.96%
7685	RG_014	Precipitation	98.96%	98.96%
7686	RG_015	Precipitation	**91.67%**	98.96%
7687	RG_016	Precipitation	98.26%	98.96%
7674	RG_017	Precipitation	98.26%	98.96%
7675	RG_018	Precipitation	98.96%	98.96%
7676	RG_019	Precipitation	98.96%	98.96%
7688	RG_020	Precipitation	**93.75%**	**93.75%**
7690	RG_021	Precipitation	98.96%	98.96%
7691	RG_022	Precipitation	98.96%	98.96%
7692	RG_023	Precipitation	98.96%	98.96%
7693	RG_024	Precipitation	98.96%	98.96%
7694	RG_025	Precipitation	98.96%	98.96%
7695	RG_027	Precipitation	**0%**	98.96%
7696	RG_028	Precipitation	98.96%	98.96%
7697	RG_030	Precipitation	**0%**	**0%**
7698	RG_031	Precipitation	98.96%	98.96%

ID	Station	Data type	Completeness	
			Jul 16	Aug 17
7699	RG_033	Precipitation	98.96%	98.96%
7700	RG_034	Precipitation	98.96%	98.96%
7701	RG_035	Precipitation	98.96%	98.96%
7702	RG_036	Precipitation	98.96%	98.96%
7703	RG_037	Precipitation	98.96%	100%
7704	RG_038	Precipitation	98.61%	98.26%
7705	RG_039	Precipitation	100%	100%
7706	RG_040	Precipitation	100%	100%
7707	RG_041	Precipitation	98.96%	98.96%
7708	RG_042	Precipitation	100%	100%
7709	RG_044	Precipitation	100%	100%
7710	RG_045	Precipitation	**84.03%**	100%
7711	RG_046	Precipitation	100%	100%
7712	RG_047	Precipitation	**94.79%**	100%
7713	RG_048	Precipitation	100%	100%
7714	RG_049	Precipitation	95.49%	100%
7715	RG_051	Precipitation	100%	100%
7716	RG_052	Precipitation	100%	100%
8017	RG_054	Precipitation	98.26%	100%
8049	RG_055	Precipitation	100%	100%
8018	RG_056	Precipitation	100%	100%
14209	RG_057	Precipitation	100%	100%
14210	RG_058	Precipitation	100%	100%
14211	RG_059	Precipitation	100%	100%
14212	RG_060	Precipitation	100%	100%
14213	RG_061	Precipitation	100%	100%
22867	RG_062	Precipitation	**0%**	**0%**
24936	RG_063	Precipitation	**0%**	**0%**

A.1.4 City of Mississauga

Appendix Table A 4: Completeness of City of Mississauga Precipitation Data (5 min Resolution)

Location	Station	Data type	Completeness	
			Jul 16	Aug 17
Lakeview	RG01	Precipitation	100%	100%
Wolfedale	RG03	Precipitation	100%	100%
Mississauga Central	RG04	Precipitation	100%	100%
Winding Trail	RG05	Precipitation	100%	100%
Mississauga Valley	RG06	Precipitation	100%	100%
Streetsville	RG07	Precipitation	100%	100%
Tomken	RG08	Precipitation	100%	100%
Truscott	RG09	Precipitation	100%	100%
Erindale	RG10	Precipitation	100%	100%
Garry Morden FTC	RG11	Precipitation	100%	100%
CVC	RG12	Precipitation	100%	100%
Goreway	RG13	Precipitation	100%	100%
Port Credit	RG14	Precipitation	100%	100%

AECOM

Appendix B

Supplementary Material for Storms

Appendix B. Supplementary Material for Storms

B.1 July 16, 2024

B.1.1 METAR – Toronto City Airport

Appendix Table B 1: METAR for Toronto City Airport (July 16, 2024)

Station	Valid on	wxcodes
CYTZ	2024-07-16 00:00	M
CYTZ	2024-07-16 01:00	M
CYTZ	2024-07-16 01:37	M
CYTZ	2024-07-16 02:00	M
CYTZ	2024-07-16 02:04	M
CYTZ	2024-07-16 02:09	BR
CYTZ	2024-07-16 02:33	BR
CYTZ	2024-07-16 03:00	BR
CYTZ	2024-07-16 03:39	BR
CYTZ	2024-07-16 03:53	BR
CYTZ	2024-07-16 04:00	BR
CYTZ	2024-07-16 04:14	BR
CYTZ	2024-07-16 05:00	M
CYTZ	2024-07-16 06:00	M
CYTZ	2024-07-16 07:00	M
CYTZ	2024-07-16 08:00	M
CYTZ	2024-07-16 09:00	M
CYTZ	2024-07-16 09:09	BR
CYTZ	2024-07-16 09:19	BR
CYTZ	2024-07-16 10:00	M
CYTZ	2024-07-16 11:00	M
CYTZ	2024-07-16 12:00	M
CYTZ	2024-07-16 13:00	M
CYTZ	2024-07-16 13:01	VCTS
CYTZ	2024-07-16 13:05	TS
CYTZ	2024-07-16 13:08	-TSRA
CYTZ	2024-07-16 13:15	TSRA
CYTZ	2024-07-16 13:16	+TSRA
CYTZ	2024-07-16 13:17	+TSRA
CYTZ	2024-07-16 13:20	+TSRA
CYTZ	2024-07-16 13:22	+TSRA
CYTZ	2024-07-16 13:23	+TSRA
CYTZ	2024-07-16 13:24	+TSRA
CYTZ	2024-07-16 13:24	+TSRA
CYTZ	2024-07-16 13:32	-TSRA
CYTZ	2024-07-16 13:33	-TSRA
CYTZ	2024-07-16 13:34	-TSRA
CYTZ	2024-07-16 13:37	-TSRA
CYTZ	2024-07-16 13:39	-TSRA
CYTZ	2024-07-16 13:47	TS
CYTZ	2024-07-16 13:53	TS
CYTZ	2024-07-16 14:00	-TSRA

Station	Valid on	wxcodes
CYTZ	2024-07-16 14:09	+TSRA
CYTZ	2024-07-16 14:10	+TSRA
CYTZ	2024-07-16 14:13	+TSRA
CYTZ	2024-07-16 14:14	+TSRA
CYTZ	2024-07-16 14:20	+TSRA
CYTZ	2024-07-16 14:24	+TSRA
CYTZ	2024-07-16 14:28	+TSRA
CYTZ	2024-07-16 14:30	+TSRA
CYTZ	2024-07-16 14:31	-TSRA
CYTZ	2024-07-16 14:33	-TSRA
CYTZ	2024-07-16 14:40	-RA VCTS
CYTZ	2024-07-16 14:43	RA VCTS BR
CYTZ	2024-07-16 14:45	+RA VCTS BR
CYTZ	2024-07-16 14:49	+RA BR
CYTZ	2024-07-16 14:51	RA BR
CYTZ	2024-07-16 14:56	+RA BR
CYTZ	2024-07-16 14:59	+RA BR
CYTZ	2024-07-16 15:00	+RA BR
CYTZ	2024-07-16 15:02	+TSRA BR
CYTZ	2024-07-16 15:11	+TSRA BR
CYTZ	2024-07-16 15:15	+TSRA BR
CYTZ	2024-07-16 15:31	+RA VCTS BR
CYTZ	2024-07-16 15:34	+RA VCTS BR
CYTZ	2024-07-16 15:41	+RA BR
CYTZ	2024-07-16 16:00	+RA BR
CYTZ	2024-07-16 16:05	+RA BR
CYTZ	2024-07-16 16:11	+RA BR
CYTZ	2024-07-16 16:14	RA BR
CYTZ	2024-07-16 16:15	RA BR
CYTZ	2024-07-16 16:19	-RA BR
CYTZ	2024-07-16 16:24	RA BR
CYTZ	2024-07-16 16:25	+RA BR
CYTZ	2024-07-16 16:33	RA BR
CYTZ	2024-07-16 16:37	-RA BR
CYTZ	2024-07-16 17:00	-RA
CYTZ	2024-07-16 17:14	M
CYTZ	2024-07-16 18:00	M
CYTZ	2024-07-16 18:05	M
CYTZ	2024-07-16 18:16	M
CYTZ	2024-07-16 19:00	M
CYTZ	2024-07-16 20:00	M
CYTZ	2024-07-16 21:00	M
CYTZ	2024-07-16 22:00	M
CYTZ	2024-07-16 23:00	M

Note: Date and time stamps are in UTC.
Source: Iowa State University, 2025a

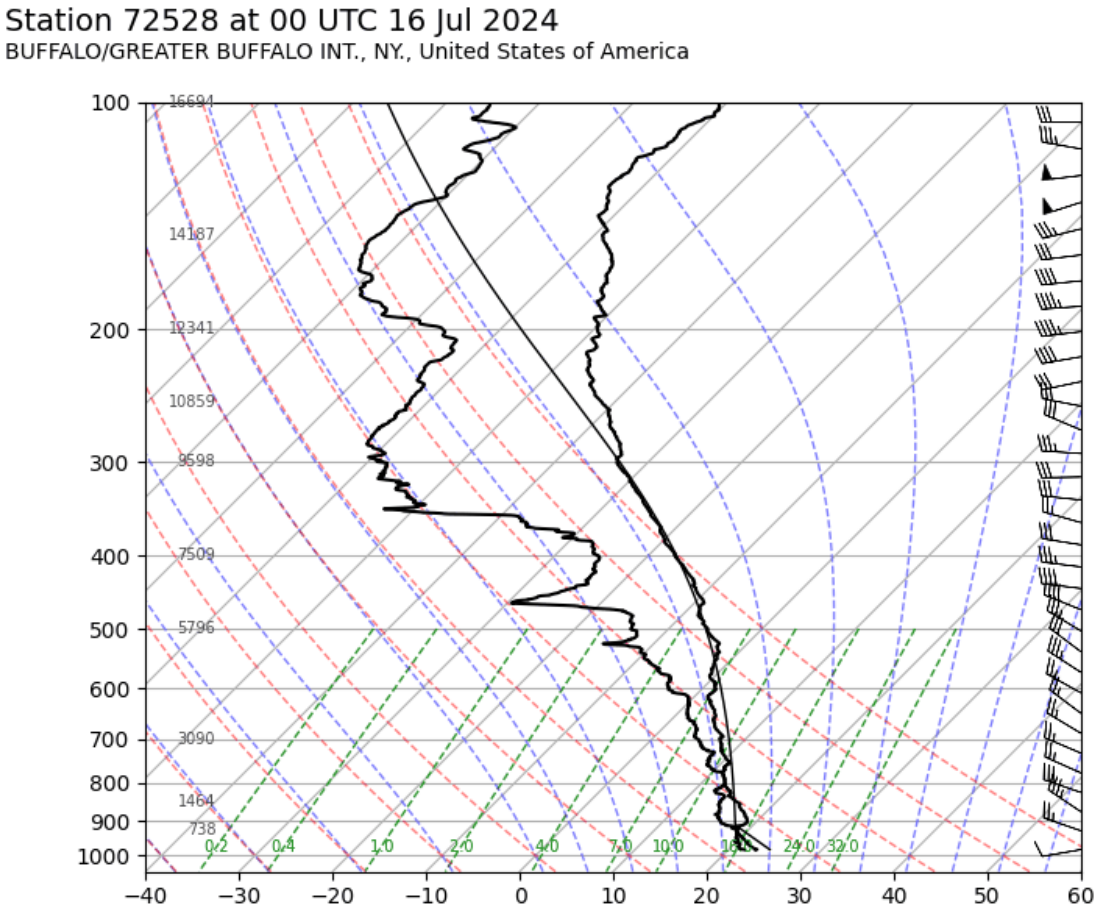
B.1.2 METAR – Toronto Pearson Airport

Appendix Table B 2: METAR for Toronto Pearson Airport (July 16, 2024)

Station	Valid on	wxcodes
CYYZ	2024-07-16 00:00	M
CYYZ	2024-07-16 01:00	M
CYYZ	2024-07-16 02:00	M
CYYZ	2024-07-16 03:00	M
CYYZ	2024-07-16 04:00	M
CYYZ	2024-07-16 05:00	M
CYYZ	2024-07-16 06:00	M
CYYZ	2024-07-16 07:00	M
CYYZ	2024-07-16 08:00	M
CYYZ	2024-07-16 09:00	M
CYYZ	2024-07-16 10:00	M
CYYZ	2024-07-16 11:00	M
CYYZ	2024-07-16 12:00	M
CYYZ	2024-07-16 12:43	TS
CYYZ	2024-07-16 13:00	TSRA
CYYZ	2024-07-16 13:02	+TSRA
CYYZ	2024-07-16 13:05	+TSRA
CYYZ	2024-07-16 13:07	+TSRA
CYYZ	2024-07-16 13:13	+TSRA
CYYZ	2024-07-16 13:17	-TSRA
CYYZ	2024-07-16 13:21	-TSRA
CYYZ	2024-07-16 13:36	M
CYYZ	2024-07-16 13:40	TS
CYYZ	2024-07-16 13:45	-TSRA
CYYZ	2024-07-16 13:47	TSRA
CYYZ	2024-07-16 13:50	+TSRA
CYYZ	2024-07-16 14:00	+TSRA
CYYZ	2024-07-16 14:11	+TSRA
CYYZ	2024-07-16 15:00	+TSRA
CYYZ	2024-07-16 15:06	+TSRA BR
CYYZ	2024-07-16 15:25	+SHRA BR
CYYZ	2024-07-16 15:50	+SHRA BR
CYYZ	2024-07-16 15:53	SHRA BR
CYYZ	2024-07-16 16:00	SHRA BR
CYYZ	2024-07-16 16:12	-SHRA BR
CYYZ	2024-07-16 17:00	M
CYYZ	2024-07-16 18:00	M
CYYZ	2024-07-16 19:00	M
CYYZ	2024-07-16 20:00	M
CYYZ	2024-07-16 21:00	M
CYYZ	2024-07-16 22:00	M
CYYZ	2024-07-16 23:00	M

Note: Date and time stamps are in UTC.
Source: Iowa State University, 2025a

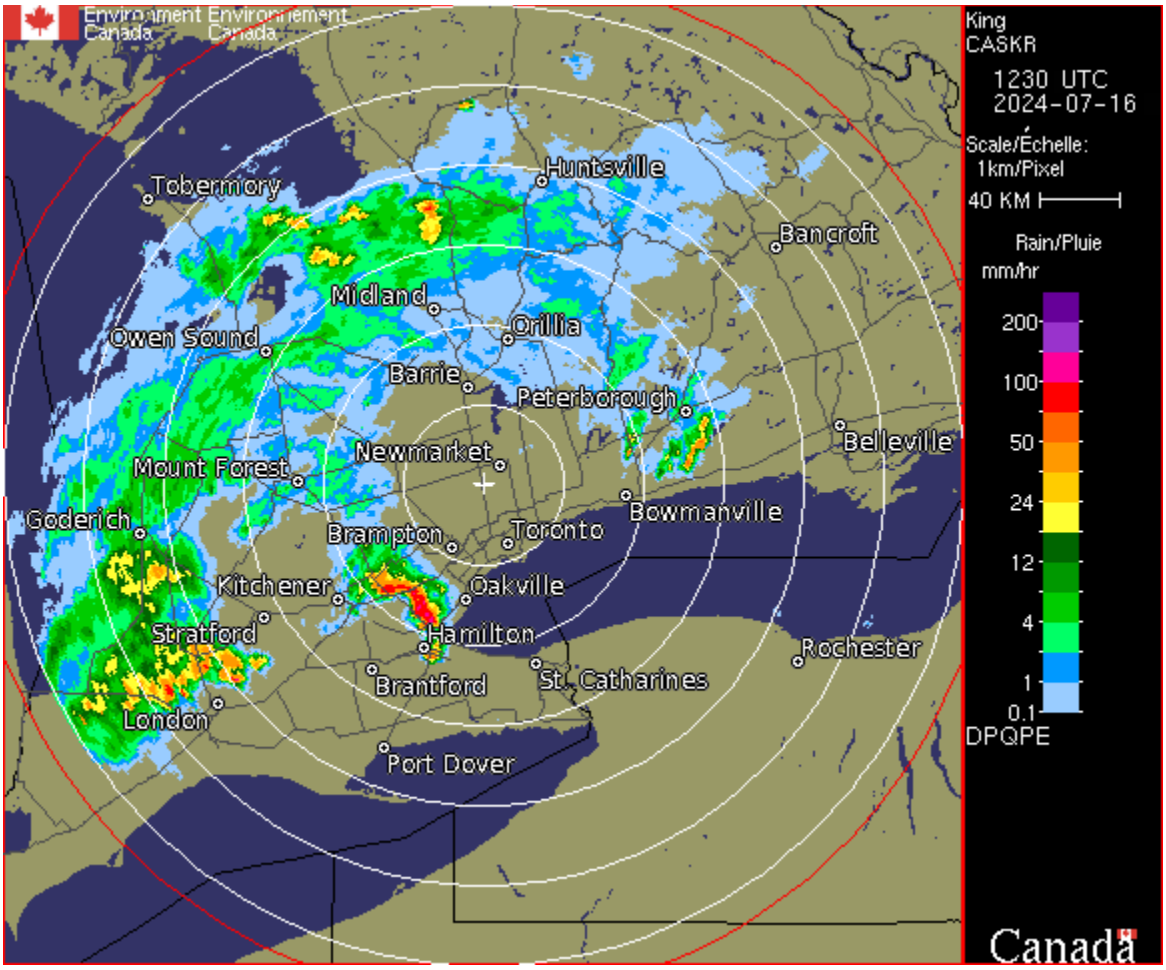
B.1.3 Soundings



Source: University of Wyoming, 2025

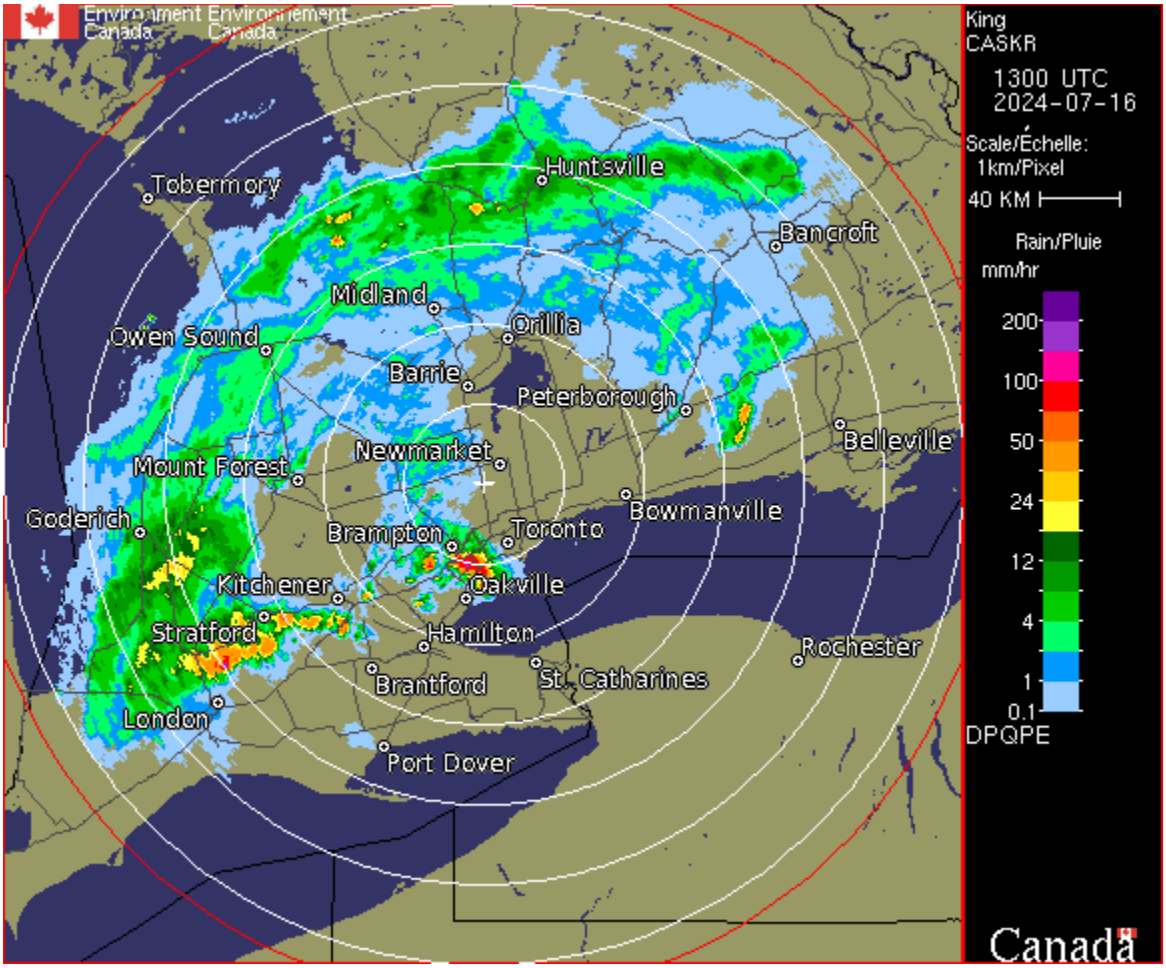
Appendix Figure B 1: Tephigram Sounding at the Buffalo/Greater Buffalo International Weather Station (July 16, 2024, 00 UTC)

B.1.4 Radar Images



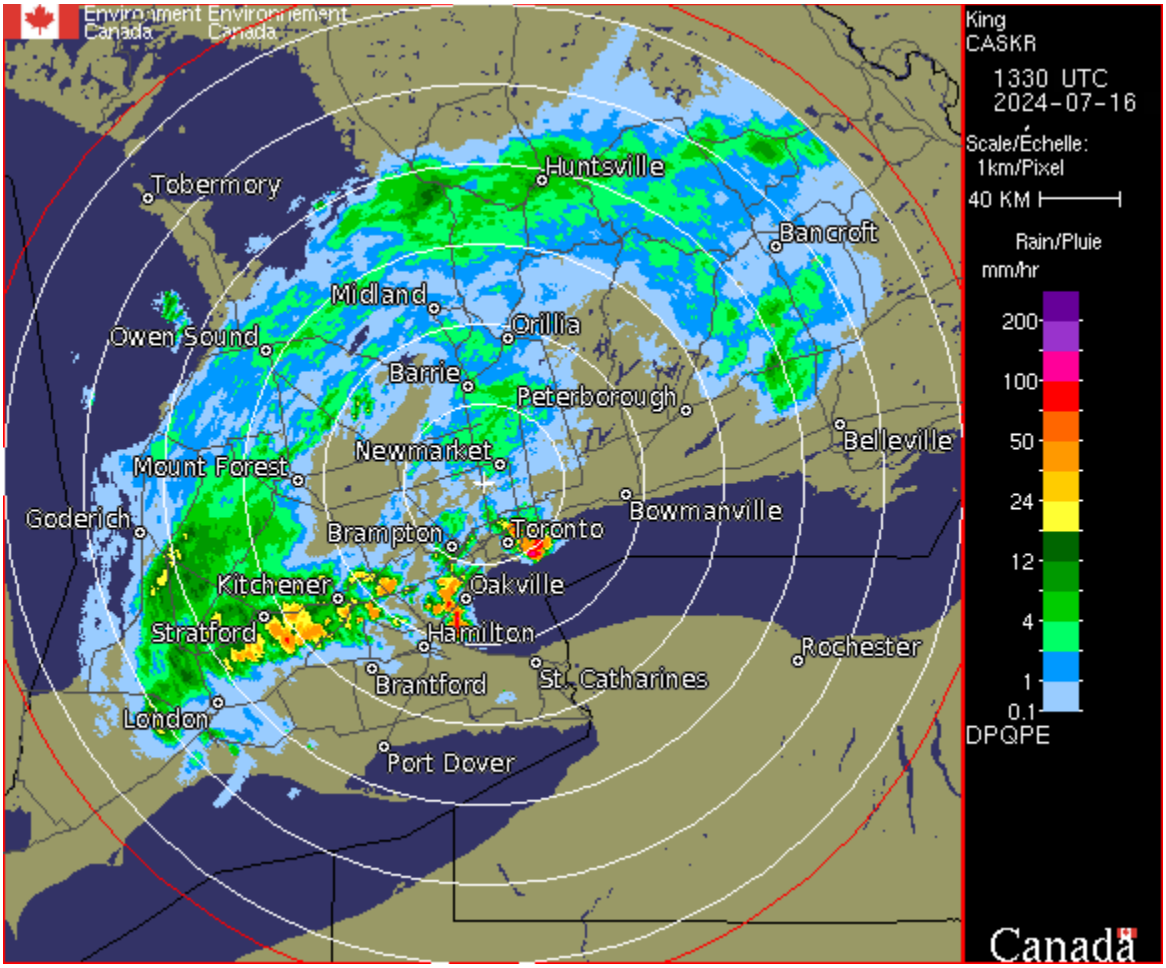
Source: ECCC, 2025c

Appendix Figure B 2: Dual Polarization Quantitative Precipitation Estimation (DPQPE) Archive King City Radar (July 16, 2024, 1230Z)



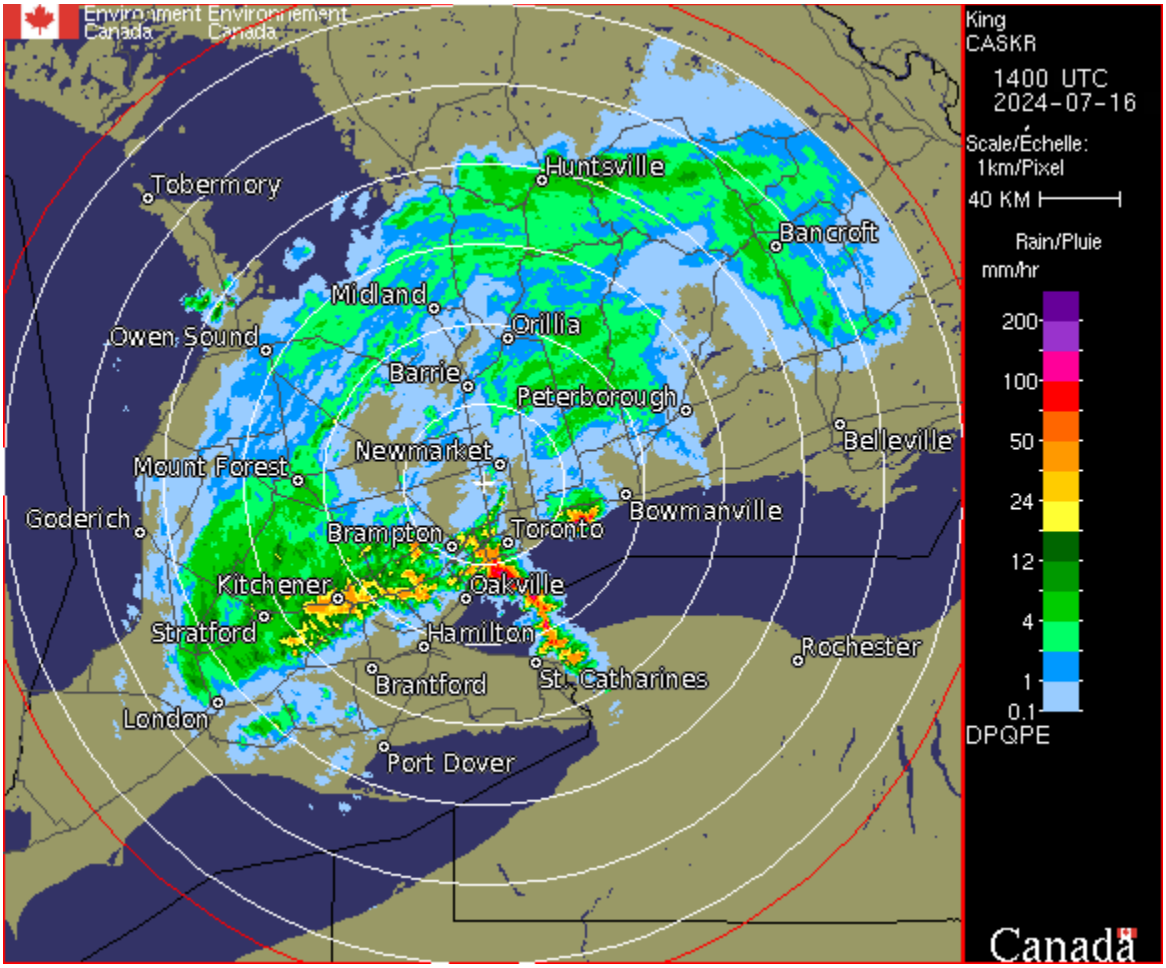
Source: ECCC, 2025c

Appendix Figure B 3: DPQPE Archive King City Radar (July 16, 2024, 1300Z)



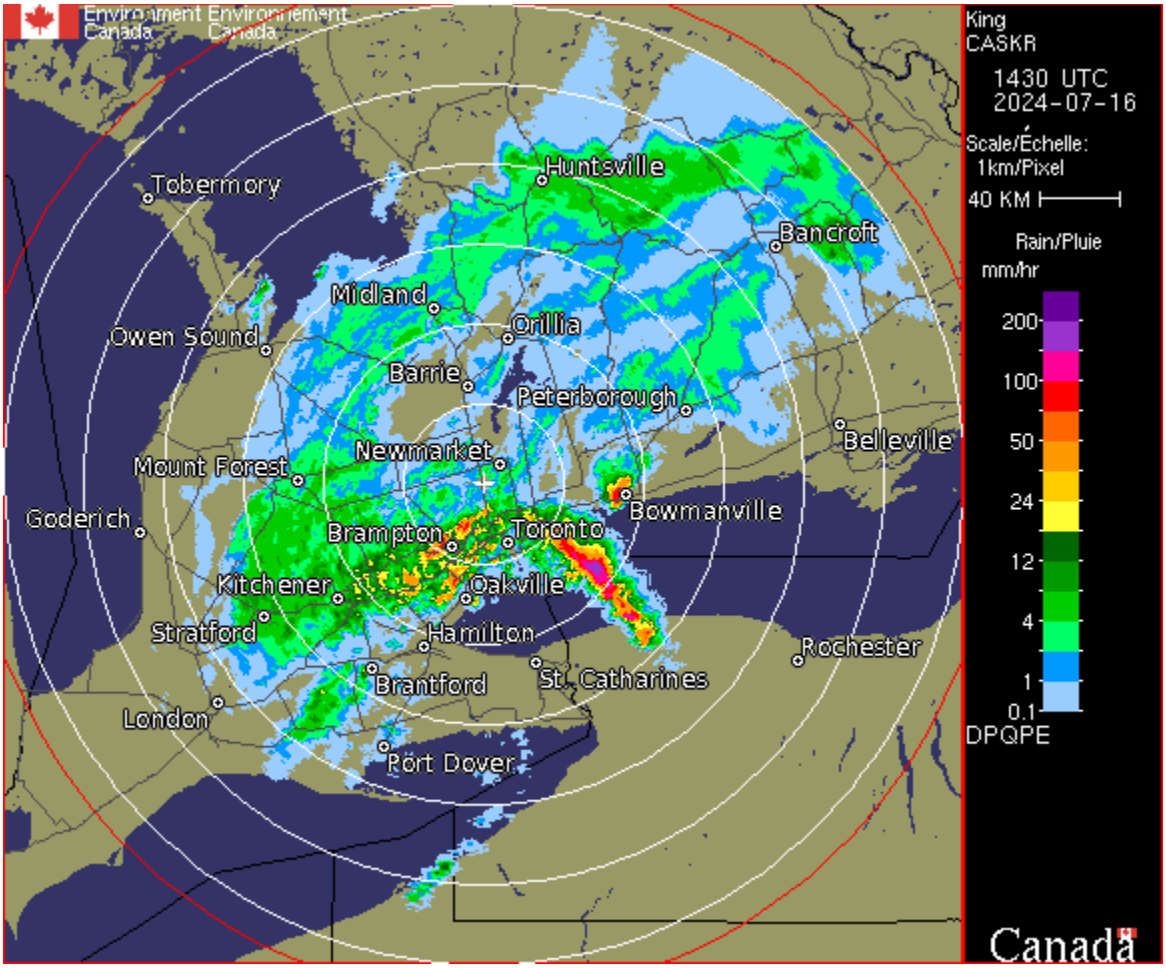
Source: ECCC, 2025c

Appendix Figure B 4: DPQPE Archive King City Radar (July 16, 2024, 1330Z)



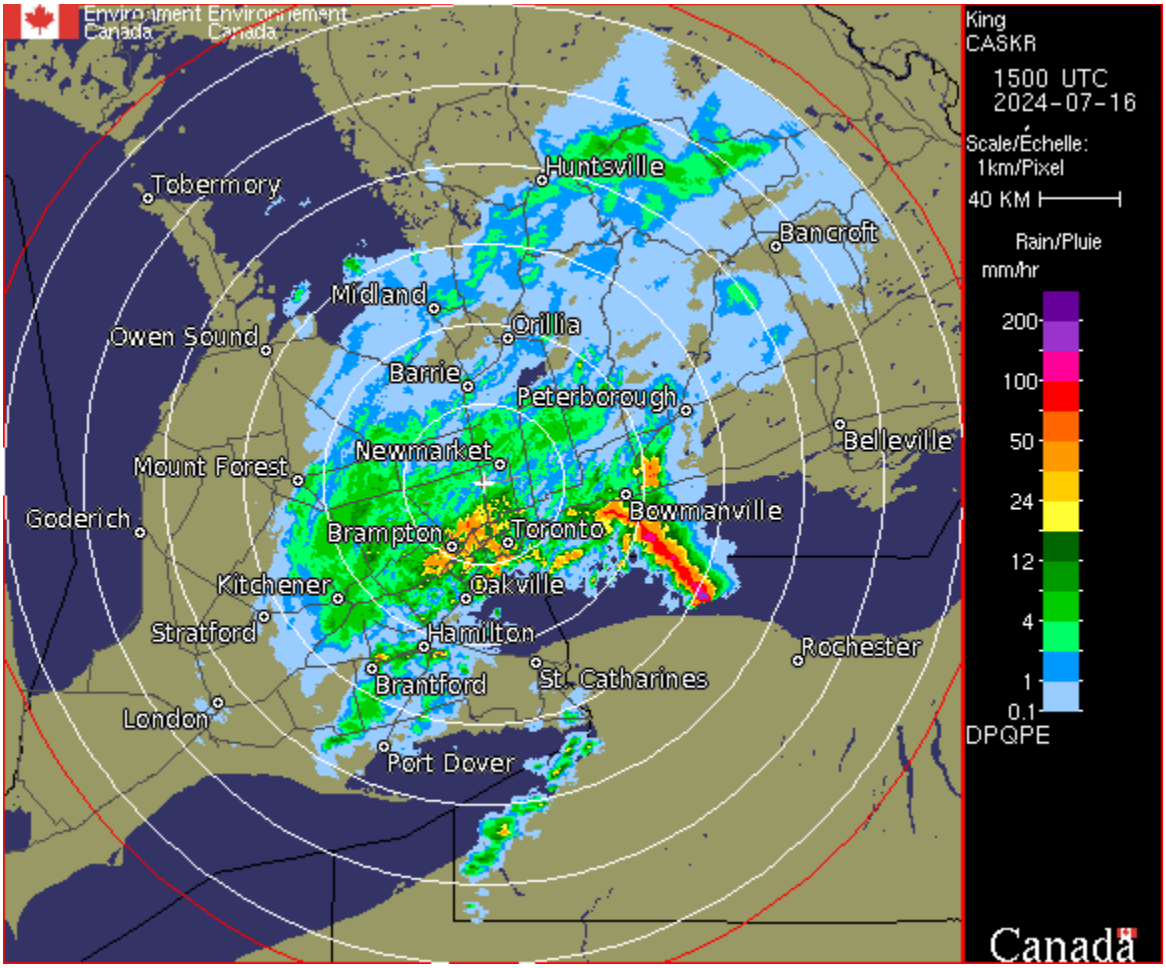
Source: ECCC, 2025c

Appendix Figure B 5: DPQPE Archive King City Radar (July 16, 2024, 1400Z)



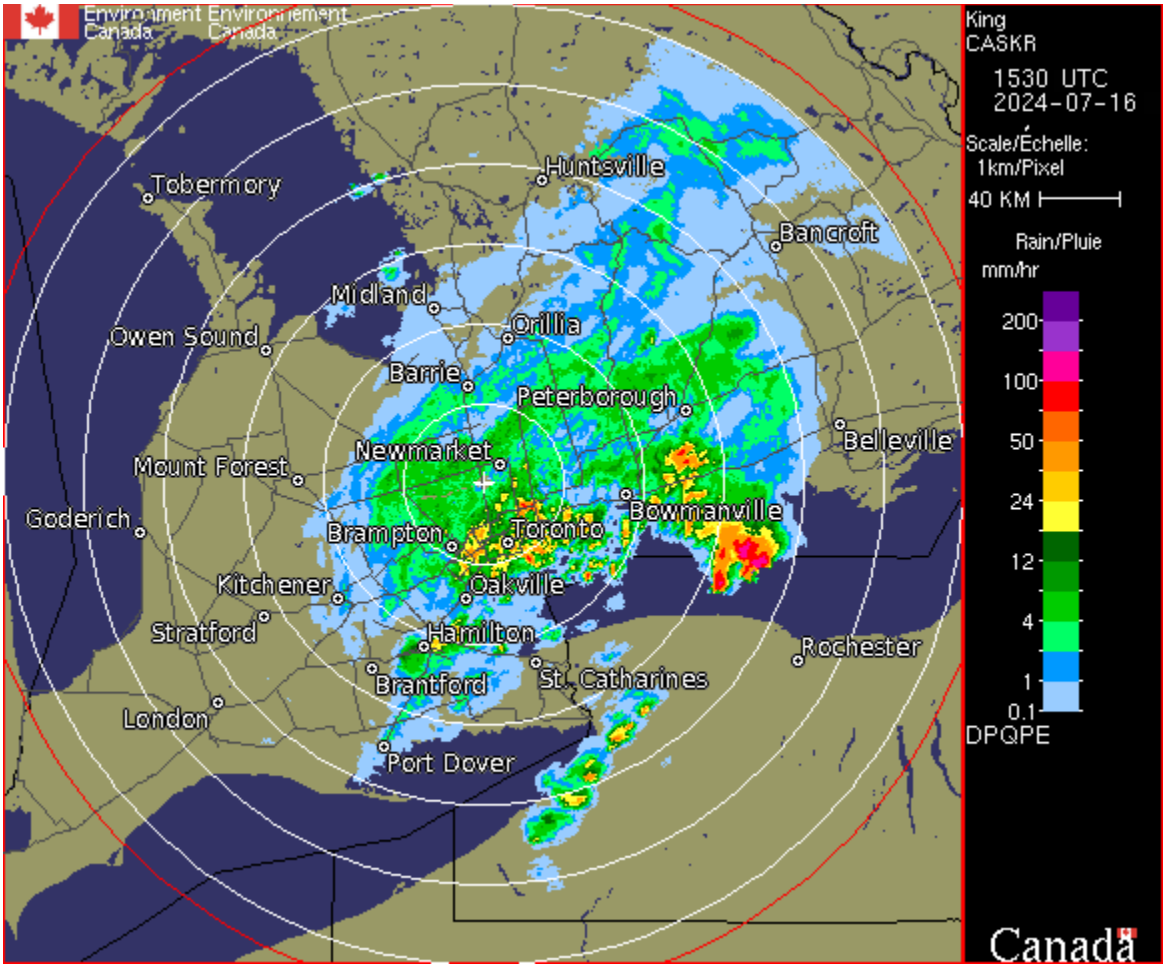
Source: ECCC, 2025c

Appendix Figure B 6: DPQPE Archive King City Radar (July 16, 2024, 1430Z)



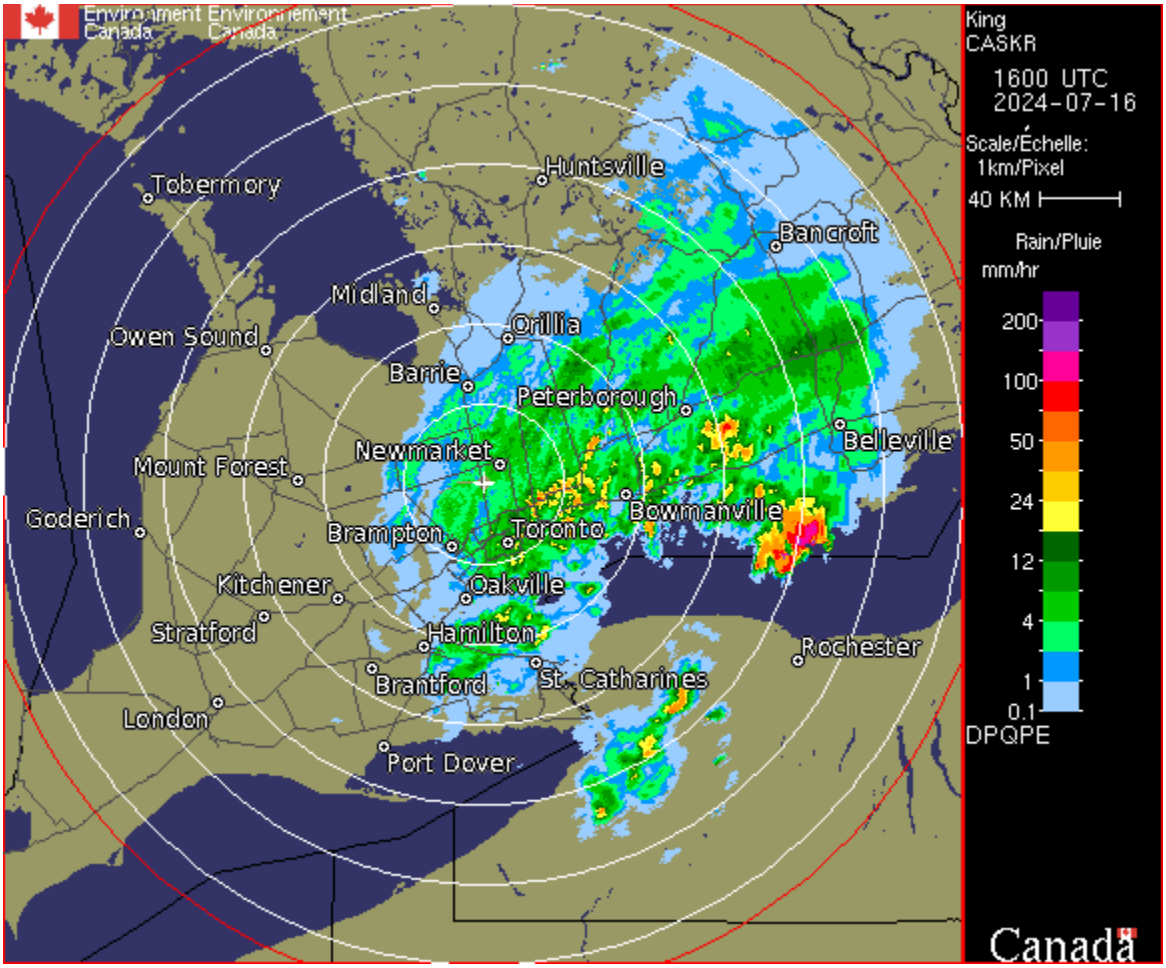
Source: ECCC, 2025c

Appendix Figure B 7: DPQPE Archive King City Radar (July 16, 2024, 1500Z)



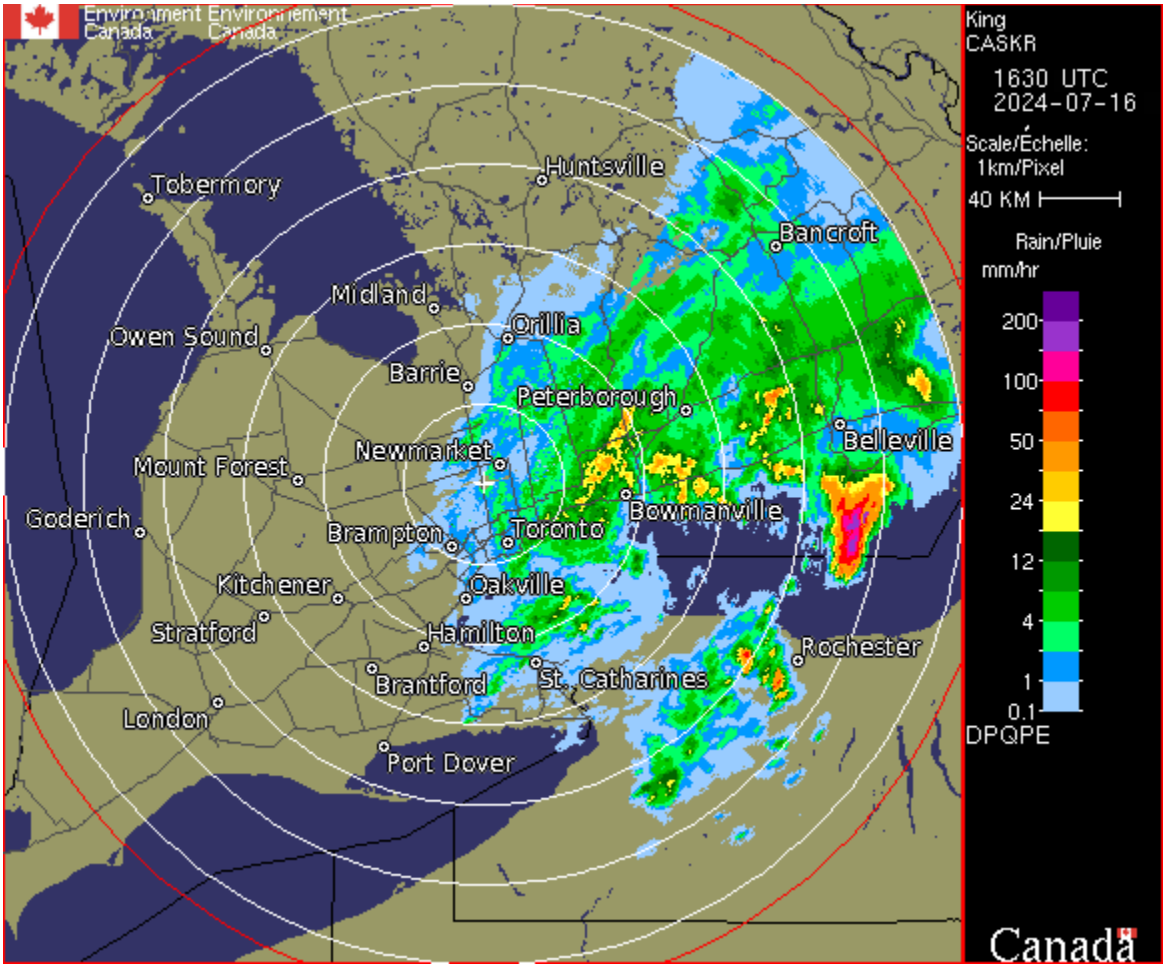
Source: ECCC, 2025c

Appendix Figure B 8: DPQPE Archive King City Radar (July 16, 2024, 1530Z)



Source: ECCC, 2025c

Appendix Figure B 9: DPQPE Archive King City Radar (July 16, 2024, 1600Z)



Source: ECCC, 2025c

Appendix Figure B 10: DPQPE Archive King City Radar (July 16, 2024, 1630Z)

B.2 August 17, 2024

B.2.1 METAR – Toronto City Airport

Appendix Table B 3: METAR for Toronto City Airport (August 17, 2024)

Station	Valid on	wxcodes
CYTZ	2024-08-17 00:00	RA BR
CYTZ	2024-08-17 00:01	RA BR
CYTZ	2024-08-17 00:34	-RA BR
CYTZ	2024-08-17 01:00	-RA
CYTZ	2024-08-17 01:07	RA BR
CYTZ	2024-08-17 01:32	-RA BR
CYTZ	2024-08-17 01:33	-RA BR
CYTZ	2024-08-17 01:56	M
CYTZ	2024-08-17 02:00	M
CYTZ	2024-08-17 02:11	M
CYTZ	2024-08-17 03:00	M
CYTZ	2024-08-17 04:00	M
CYTZ	2024-08-17 04:10	M
CYTZ	2024-08-17 04:25	M
CYTZ	2024-08-17 04:52	M
CYTZ	2024-08-17 05:00	M
CYTZ	2024-08-17 05:50	M
CYTZ	2024-08-17 06:00	M
CYTZ	2024-08-17 07:00	M
CYTZ	2024-08-17 07:01	M
CYTZ	2024-08-17 08:00	M
CYTZ	2024-08-17 08:53	BR
CYTZ	2024-08-17 08:59	BR
CYTZ	2024-08-17 09:00	BR
CYTZ	2024-08-17 09:12	BR
CYTZ	2024-08-17 09:24	BR
CYTZ	2024-08-17 09:44	BR
CYTZ	2024-08-17 10:00	BR
CYTZ	2024-08-17 10:02	BR
CYTZ	2024-08-17 10:35	BR
CYTZ	2024-08-17 11:00	BR
CYTZ	2024-08-17 11:07	BR
CYTZ	2024-08-17 12:00	M
CYTZ	2024-08-17 12:08	M
CYTZ	2024-08-17 12:11	M
CYTZ	2024-08-17 12:47	M
CYTZ	2024-08-17 13:00	M
CYTZ	2024-08-17 13:18	M
CYTZ	2024-08-17 14:00	M
CYTZ	2024-08-17 15:00	M
CYTZ	2024-08-17 15:46	M
CYTZ	2024-08-17 16:00	M
CYTZ	2024-08-17 16:28	TS
CYTZ	2024-07-16 16:35	TS
CYTZ	2024-08-17 16:43	VCTS
CYTZ	2024-08-17 16:56	TS
CYTZ	2024-08-17 17:00	TS
CYTZ	2024-08-17 17:15	TS

Station	Valid on	wxcodes
CYTZ	2024-08-17 17:25	TS
CYTZ	2024-08-17 17:40	TS
CYTZ	2024-08-17 17:51	TS
CYTZ	2024-08-17 17:54	VCTS
CYTZ	2024-08-17 18:00	VCTS
CYTZ	2024-08-17 18:03	TS
CYTZ	2024-08-17 18:31	TS
CYTZ	2024-08-17 19:00	TS

Station	Valid on	wxcodes
CYTZ	2024-08-17 19:01	VCTS
CYTZ	2024-08-17 19:13	-RA
CYTZ	2024-08-17 19:27	M
CYTZ	2024-08-17 20:00	M
CYTZ	2024-08-17 20:21	VCTS
CYTZ	2024-08-17 20:28	TS
CYTZ	2024-08-17 20:53	VCTS
CYTZ	2024-08-17 21:00	VCTS

Station	Valid on	wxcodes
CYTZ	2024-08-17 21:03	M
CYTZ	2024-08-17 21:22	VCTS
CYTZ	2024-08-17 21:26	TS
CYTZ	2024-08-17 21:51	TS
CYTZ	2024-08-17 22:00	TS
CYTZ	2024-08-17 22:21	M
CYTZ	2024-08-17 23:00	M

Note: Date and time stamps are in UTC.
Source: Iowa State University, 2025a

B.2.2 METAR – Toronto Pearson Airport

Appendix Table B 4: METAR for Toronto City Airport (August 17, 2024)

Station	Valid on	wxcodes
CYYZ	2024-08-17 00:00	-RA BR
CYYZ	2024-08-17 01:00	-RA BR
CYYZ	2024-08-17 01:48	M
CYYZ	2024-08-17 02:00	M
CYYZ	2024-08-17 02:12	M
CYYZ	2024-08-17 03:00	M
CYYZ	2024-08-17 04:00	M

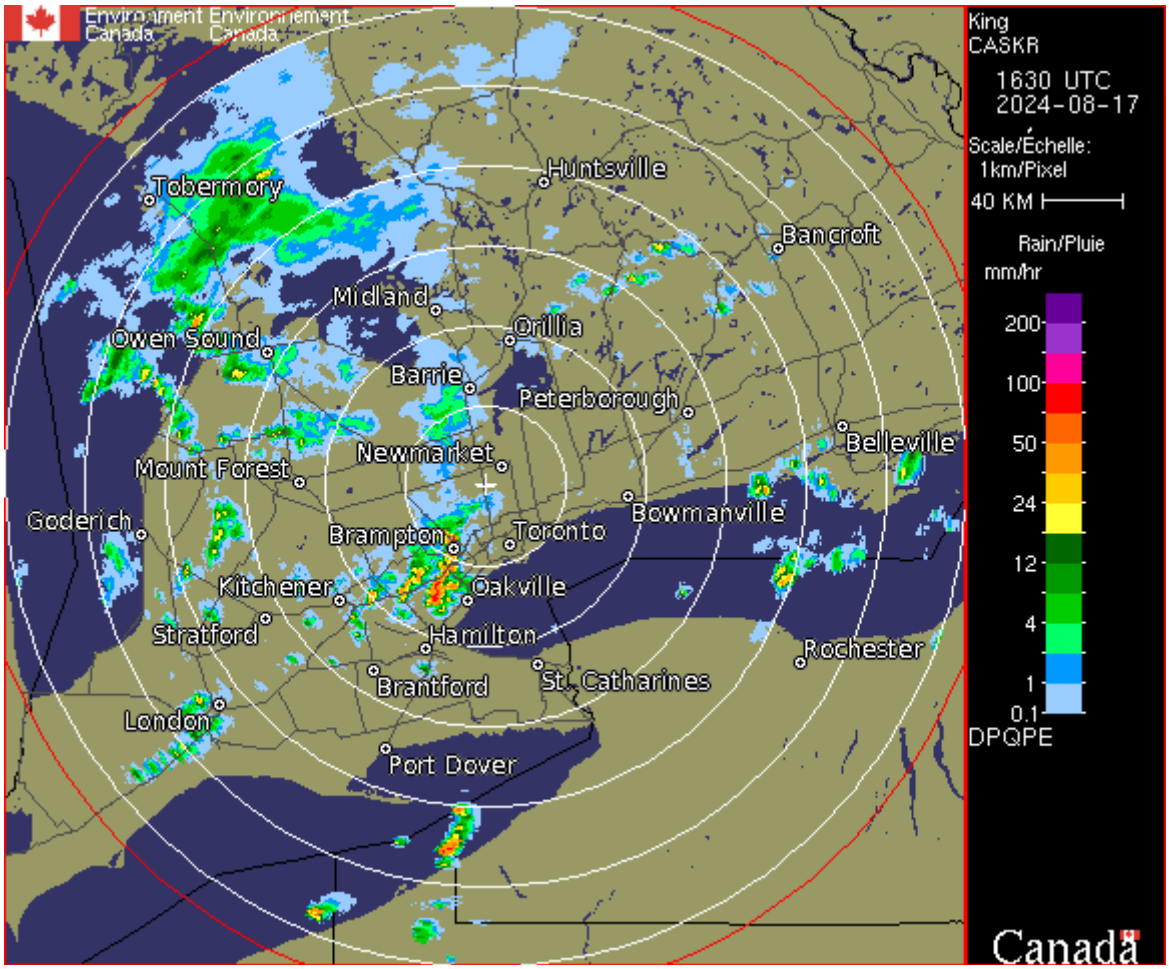
Station	Valid on	wxcodes
CYYZ	2024-08-17 04:46	M
CYYZ	2024-08-17 05:00	-RA
CYYZ	2024-08-17 05:21	M
CYYZ	2024-08-17 06:00	M
CYYZ	2024-08-17 07:00	M
CYYZ	2024-08-17 07:15	M
CYYZ	2024-08-17 08:00	M

Station	Valid on	wxcodes
CYYZ	2024-08-17 08:04	M
CYYZ	2024-08-17 08:47	M
CYYZ	2024-08-17 09:00	M
CYYZ	2024-08-17 10:00	M
CYYZ	2024-08-17 11:00	M
CYYZ	2024-08-17 11:41	-SHRA
CYYZ	2024-08-17 12:00	-SHRA BR

Station	Valid on	wxcodes
CYYZ	2024-08-17 12:12	-SHRA BR
CYYZ	2024-08-17 12:42	BR
CYYZ	2024-08-17 13:00	M
CYYZ	2024-08-17 13:45	M
CYYZ	2024-08-17 14:00	M
CYYZ	2024-08-17 15:00	M
CYYZ	2024-08-17 16:00	M
CYYZ	2024-08-17 16:10	-SHRA
CYYZ	2024-08-17 16:31	-TSRA
CYYZ	2024-08-17 16:49	TSRA
CYYZ	2024-08-17 16:51	+TSRA
CYYZ	2024-08-17 16:53	+TSRA
CYYZ	2024-08-17 17:00	+TSRA
CYYZ	2024-08-17 17:09	+TSRA
CYYZ	2024-08-17 17:17	+TSRA
CYYZ	2024-08-17 17:39	+TSRA
CYYZ	2024-08-17 17:53	TSRA
CYYZ	2024-08-17 18:00	+TSRA
CYYZ	2024-08-17 18:13	TSRA
CYYZ	2024-08-17 18:21	+TSRA
CYYZ	2024-08-17 18:32	+TSRA
CYYZ	2024-08-17 18:40	TSRA BR
CYYZ	2024-08-17 18:47	+TSRA
CYYZ	2024-08-17 18:52	SHRA BR
CYYZ	2024-08-17 19:00	-SHRA
CYYZ	2024-08-17 19:16	+SHRA BR
CYYZ	2024-08-17 19:23	-SHRA
CYYZ	2024-08-17 19:29	M
CYYZ	2024-08-17 19:42	-TSRA
CYYZ	2024-08-17 19:51	TSRA BR
CYYZ	2024-08-17 20:00	TSRA BR
CYYZ	2024-08-17 20:06	+TSRA
CYYZ	2024-08-17 20:09	+TSRA
CYYZ	2024-08-17 20:16	TSRA BR
CYYZ	2024-08-17 20:21	-TSRA
CYYZ	2024-08-17 20:35	-TSRA
CYYZ	2024-08-17 21:00	M
CYYZ	2024-08-17 22:00	M
CYYZ	2024-08-17 23:00	M

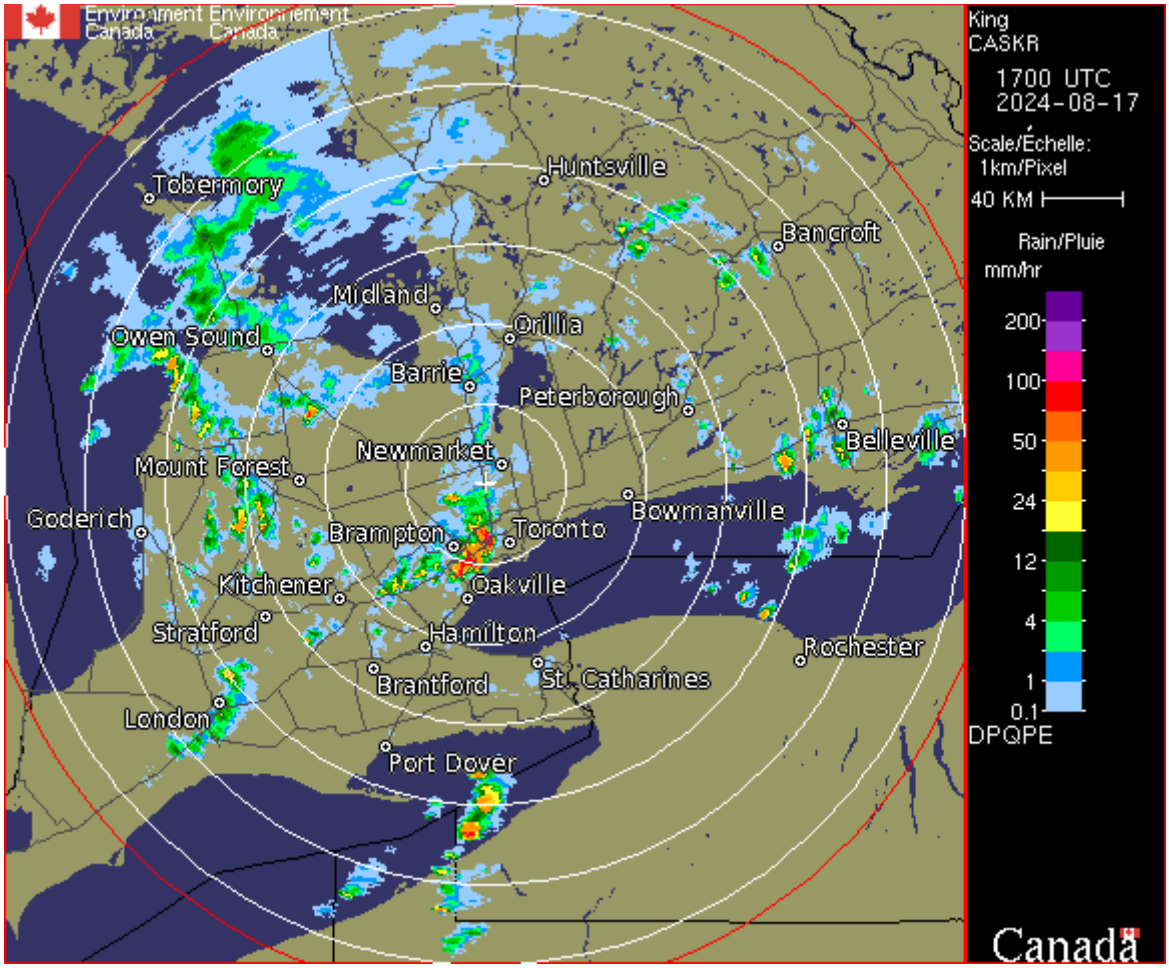
Note: Date and time stamps are in UTC.
Source: Iowa State University, 2025a

B.2.3 Radar Images



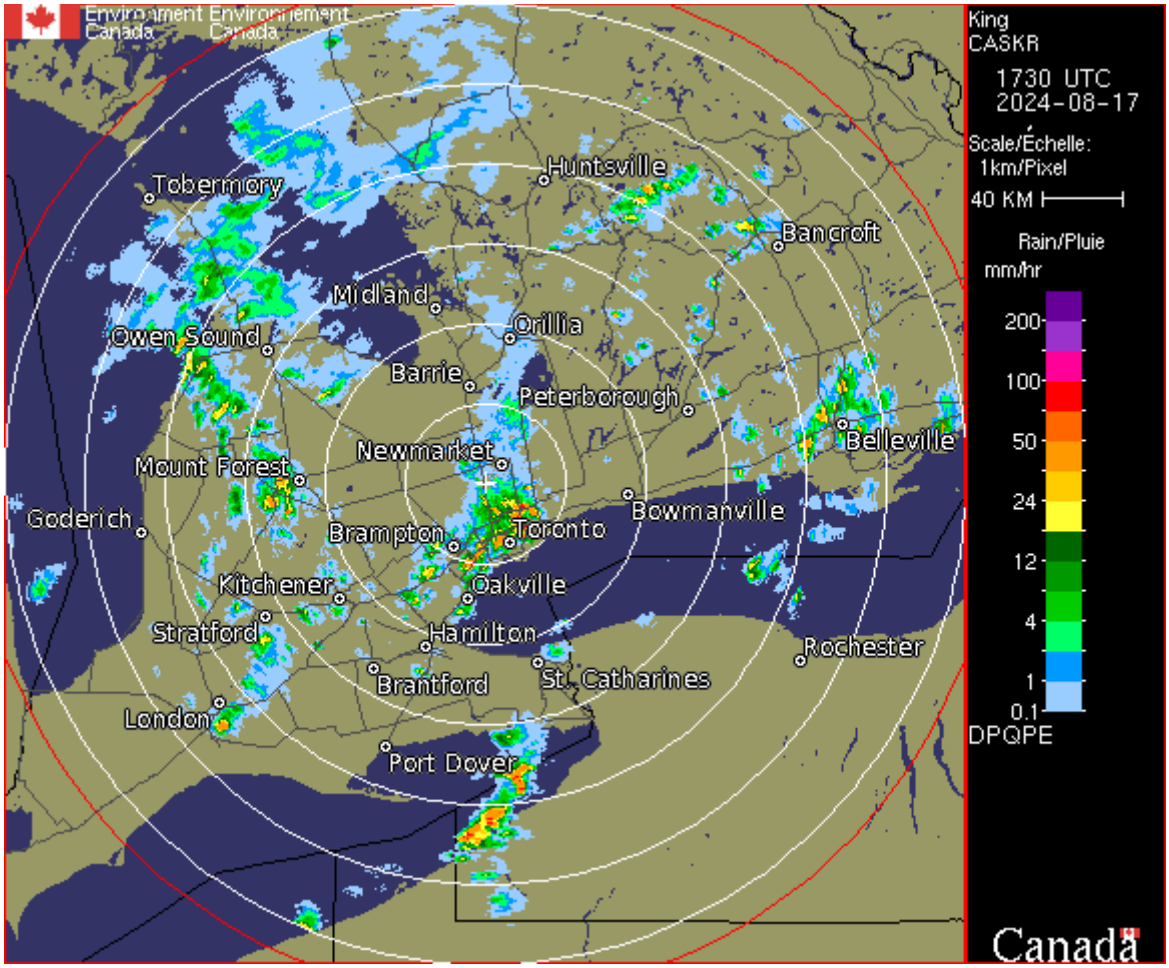
Source: ECCC, 2025c

Appendix Figure B 11: DPQPE Archive King City Radar (August 17, 2024, 1630Z)



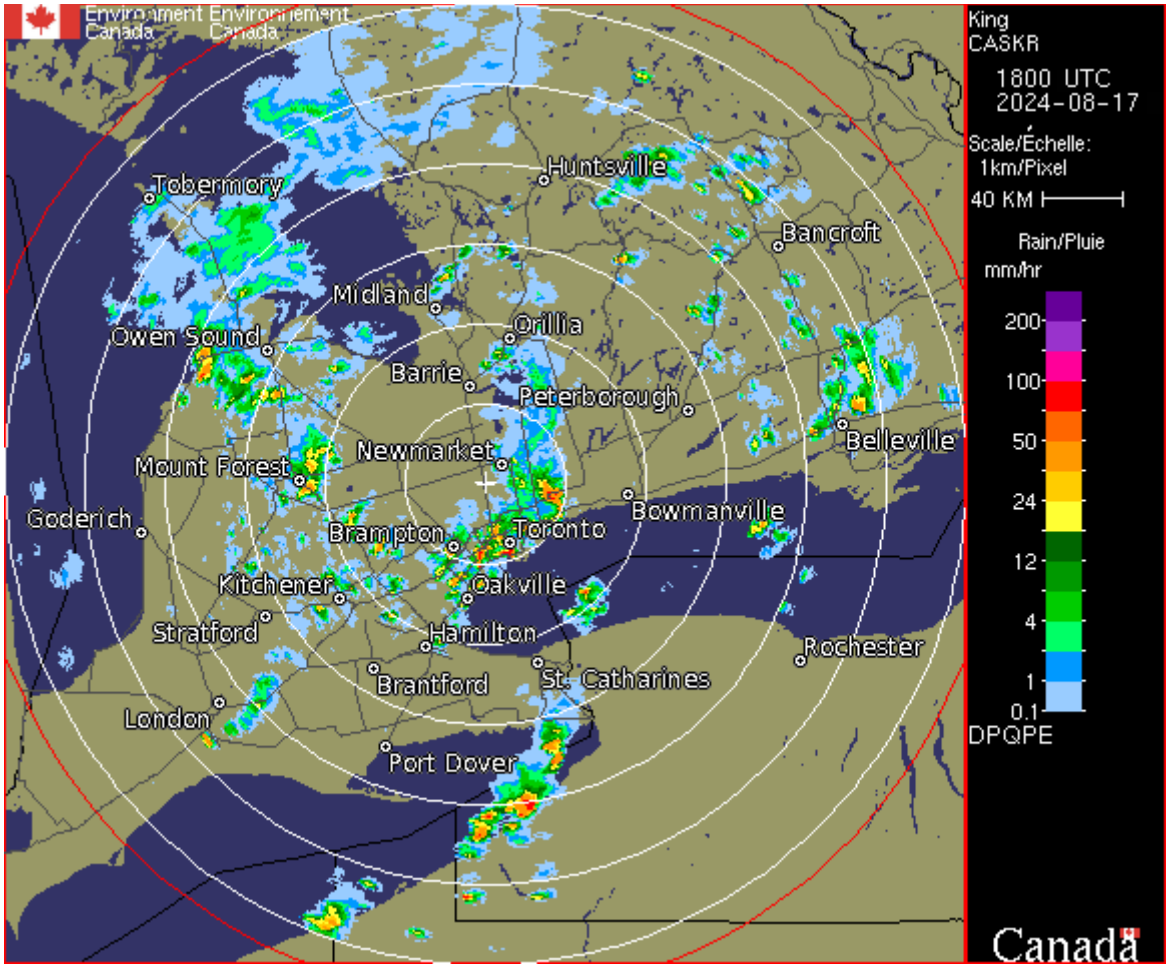
Source: ECCC, 2025c

Appendix Figure B 12: DPQPE Archive King City Radar (August 17, 2024, 1700Z)



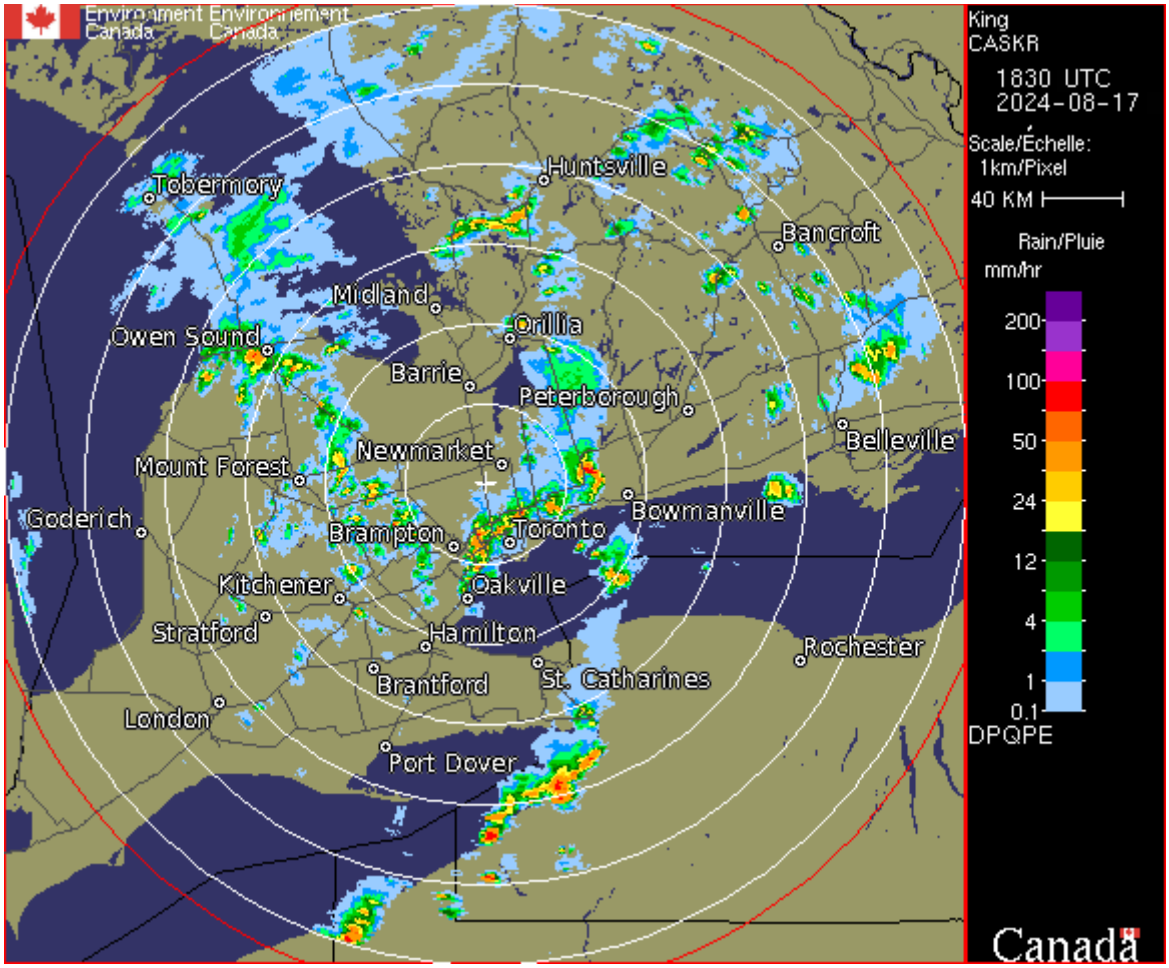
Source: ECCC, 2025c

Appendix Figure B 13: DPQPE Archive King City Radar (August 17, 2024, 1730Z)



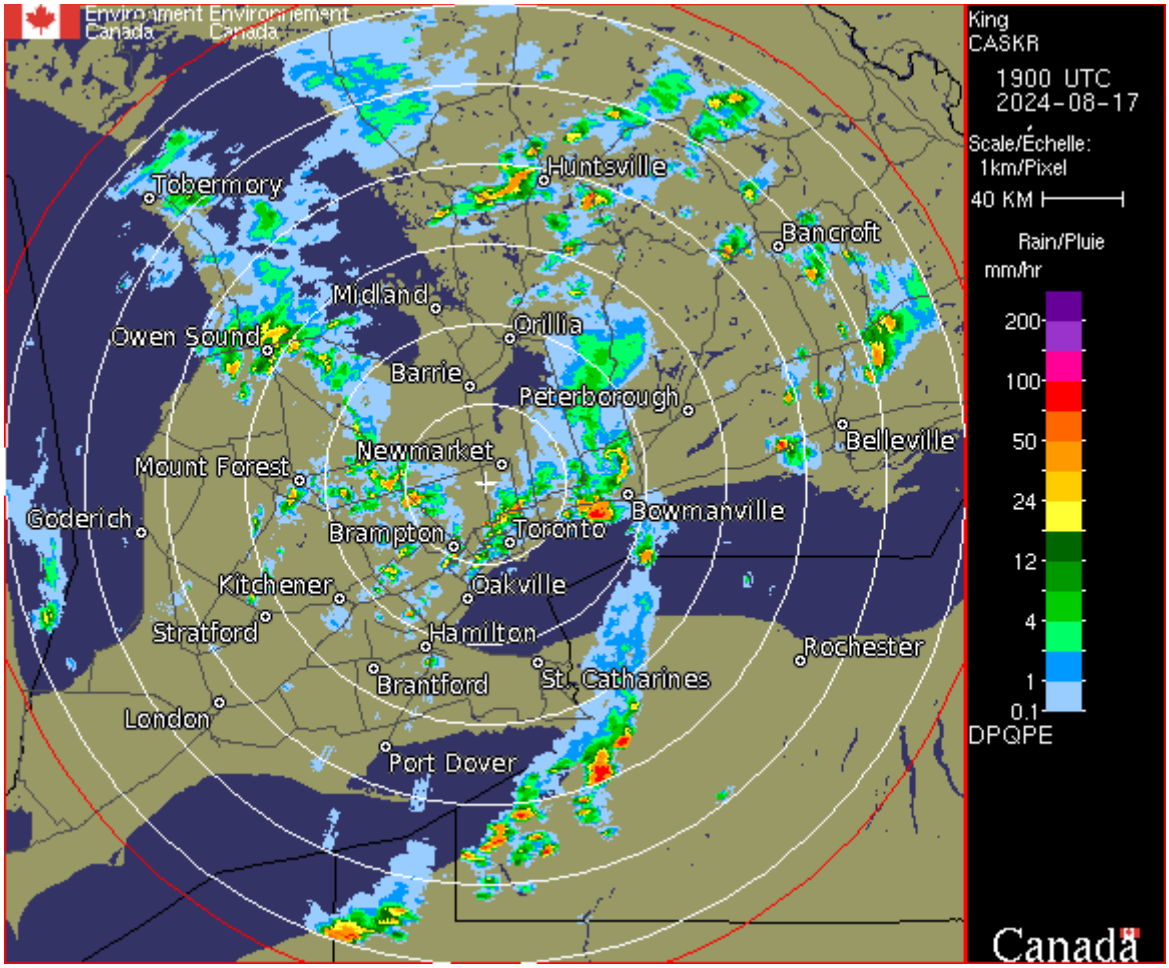
Source: ECCC, 2025c

Appendix Figure B 14: DPQPE Archive King City Radar (August 17, 2024, 1800Z)



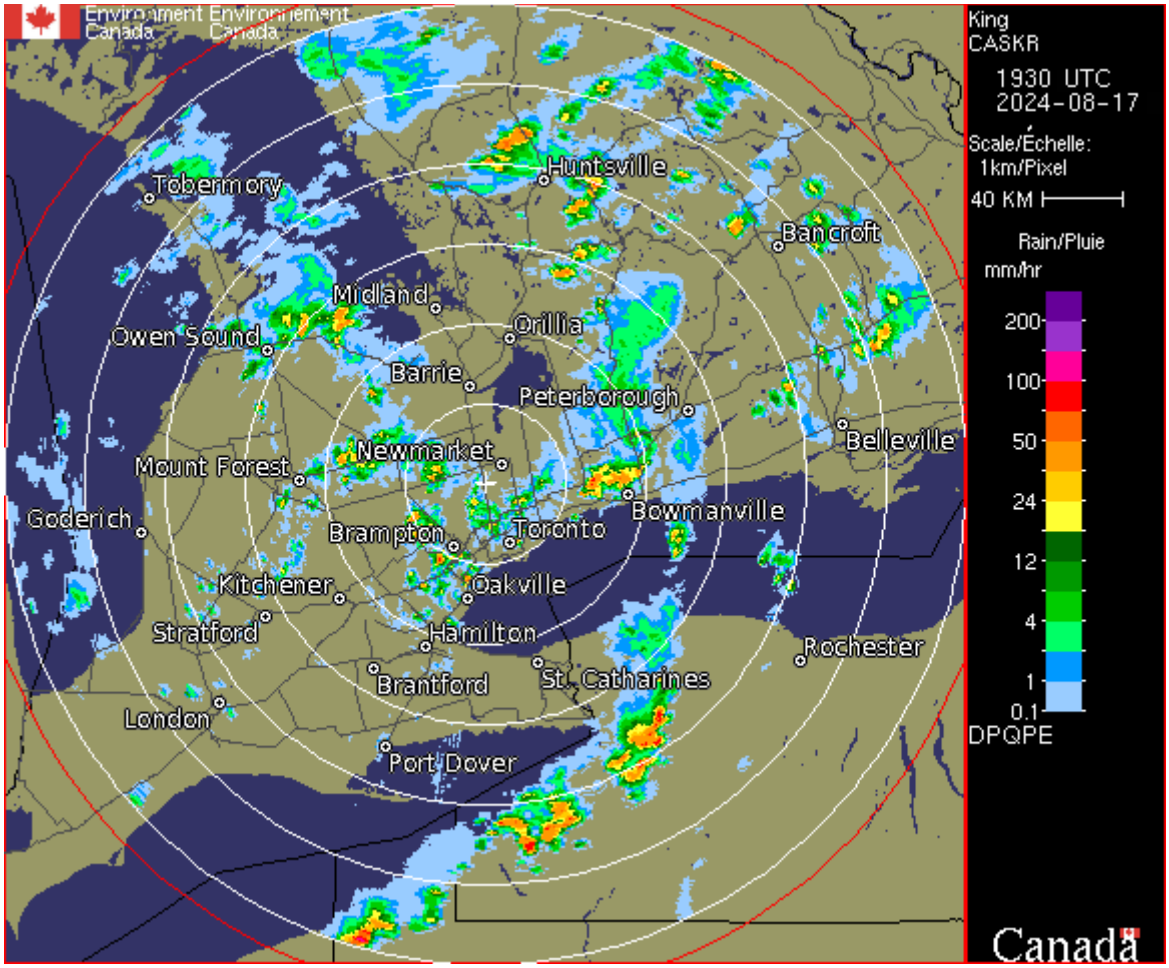
Source: ECCC, 2025c

Appendix Figure B 15: DPQPE Archive King City Radar (August 17, 2024, 1830Z)



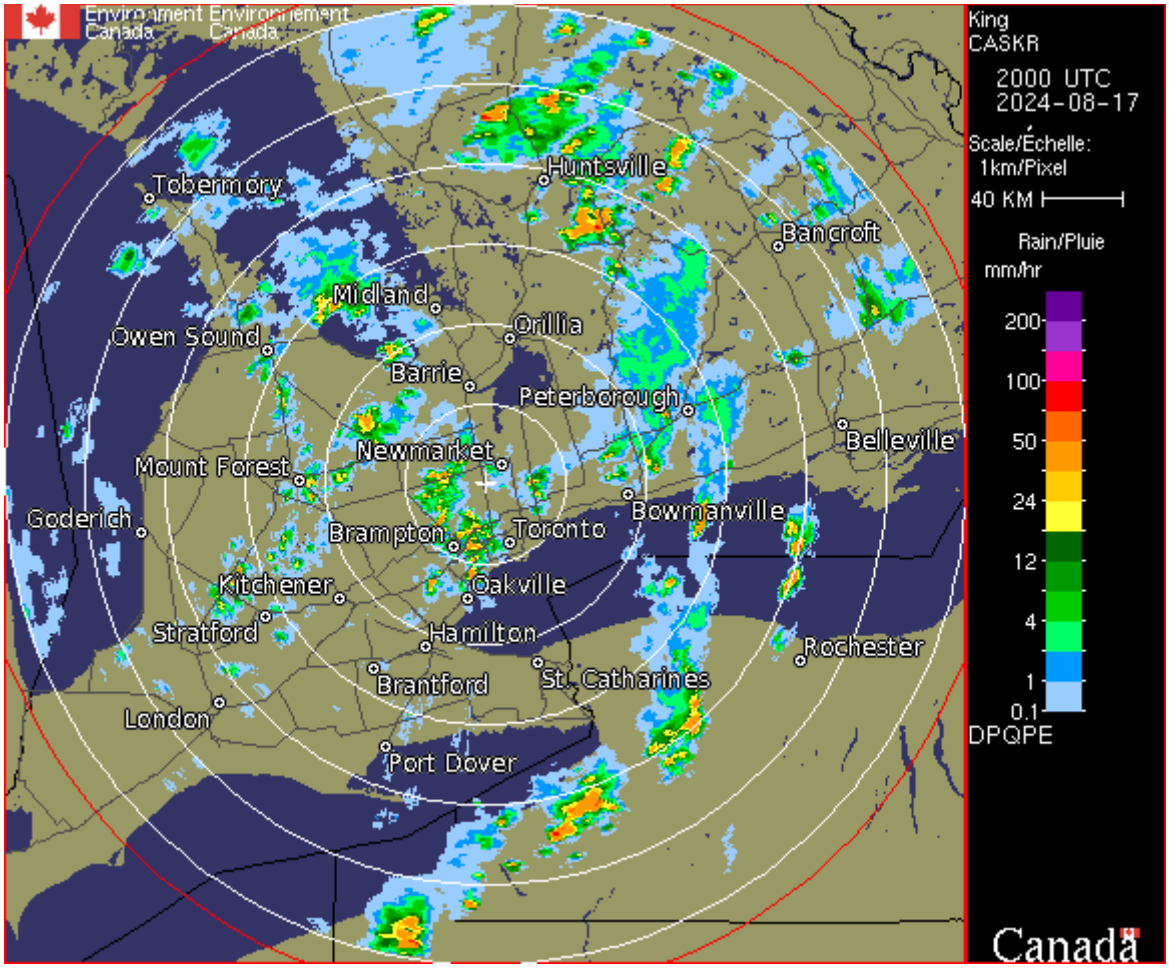
Source: ECCC, 2025c

Appendix Figure B 16: DPQPE Archive King City Radar (August 17, 2024, 1900Z)



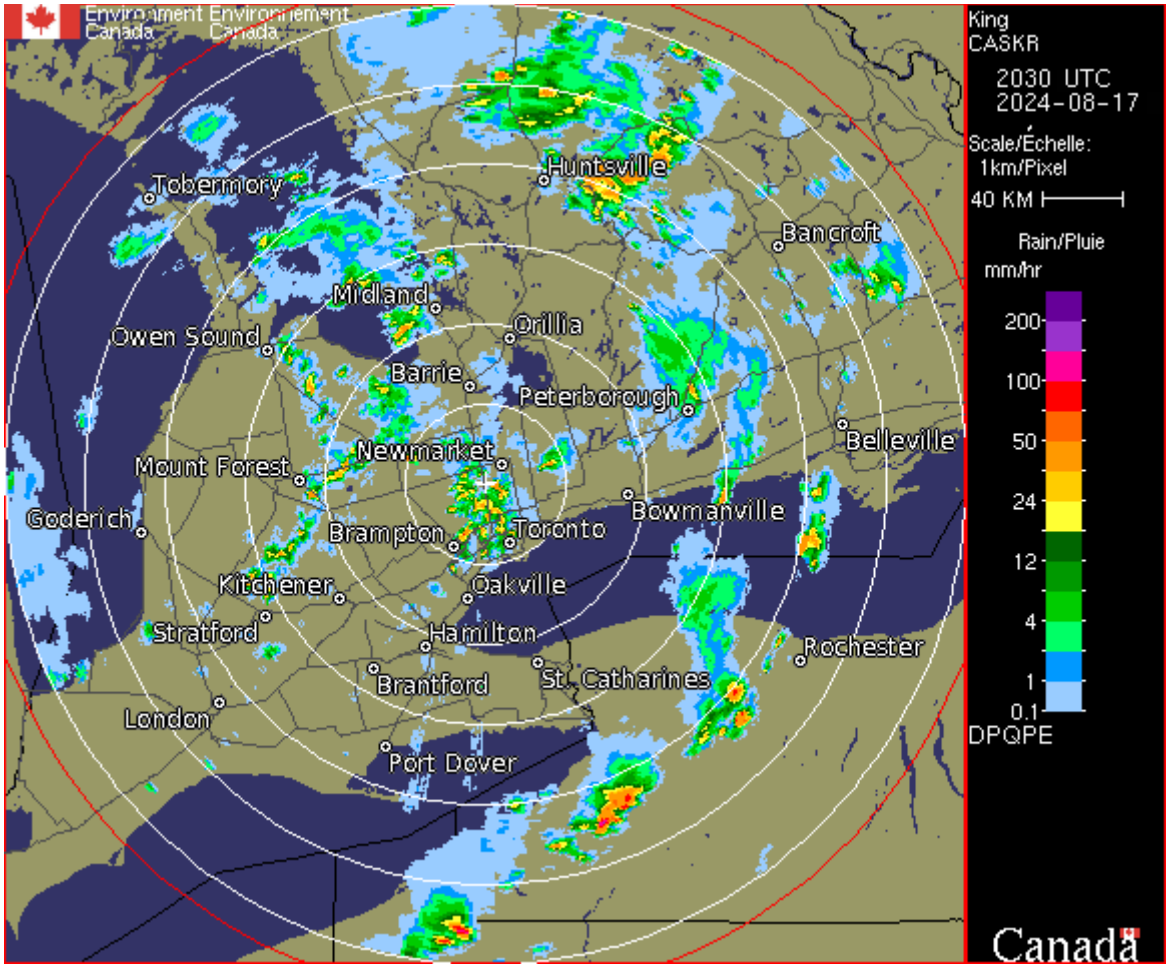
Source: ECCC, 2025c

Appendix Figure B 17: DPQPE Archive King City Radar (August 17, 2024, 1930Z)



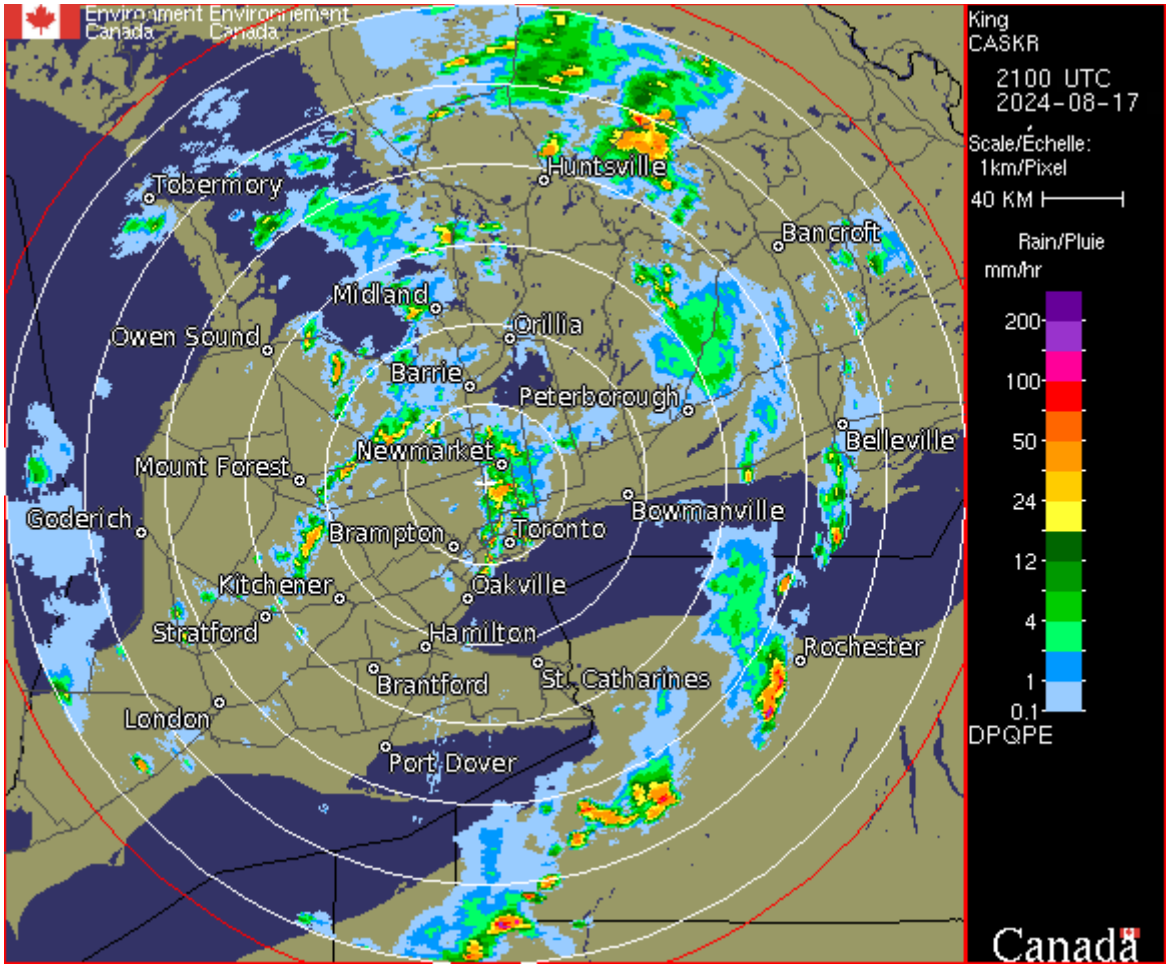
Source: ECCC, 2025c

Appendix Figure B 18: DPQPE Archive King City Radar (August 17, 2024, 2000Z)



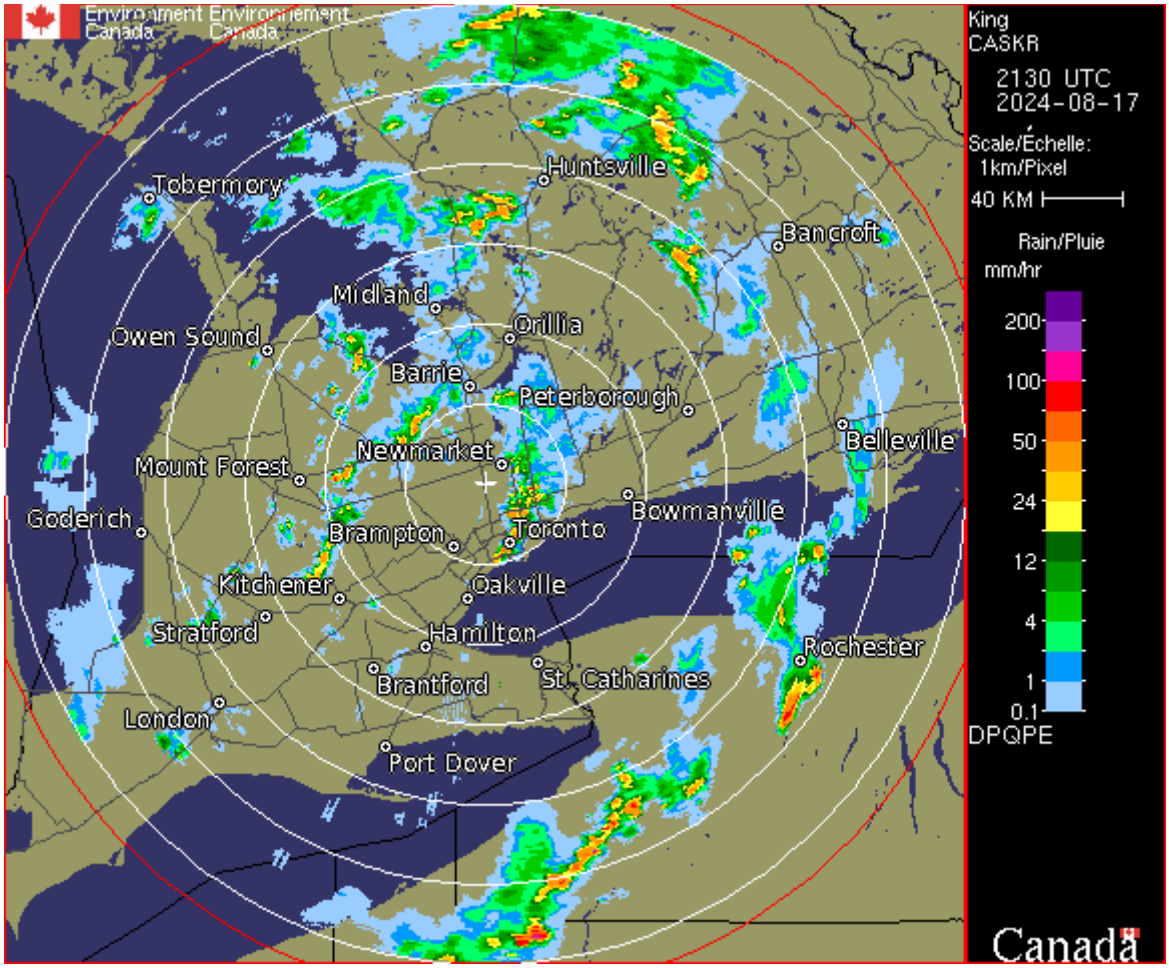
Source: ECCC, 2025c

Appendix Figure B 19: DPQPE Archive King City Radar (August 17, 2024, 2030Z)



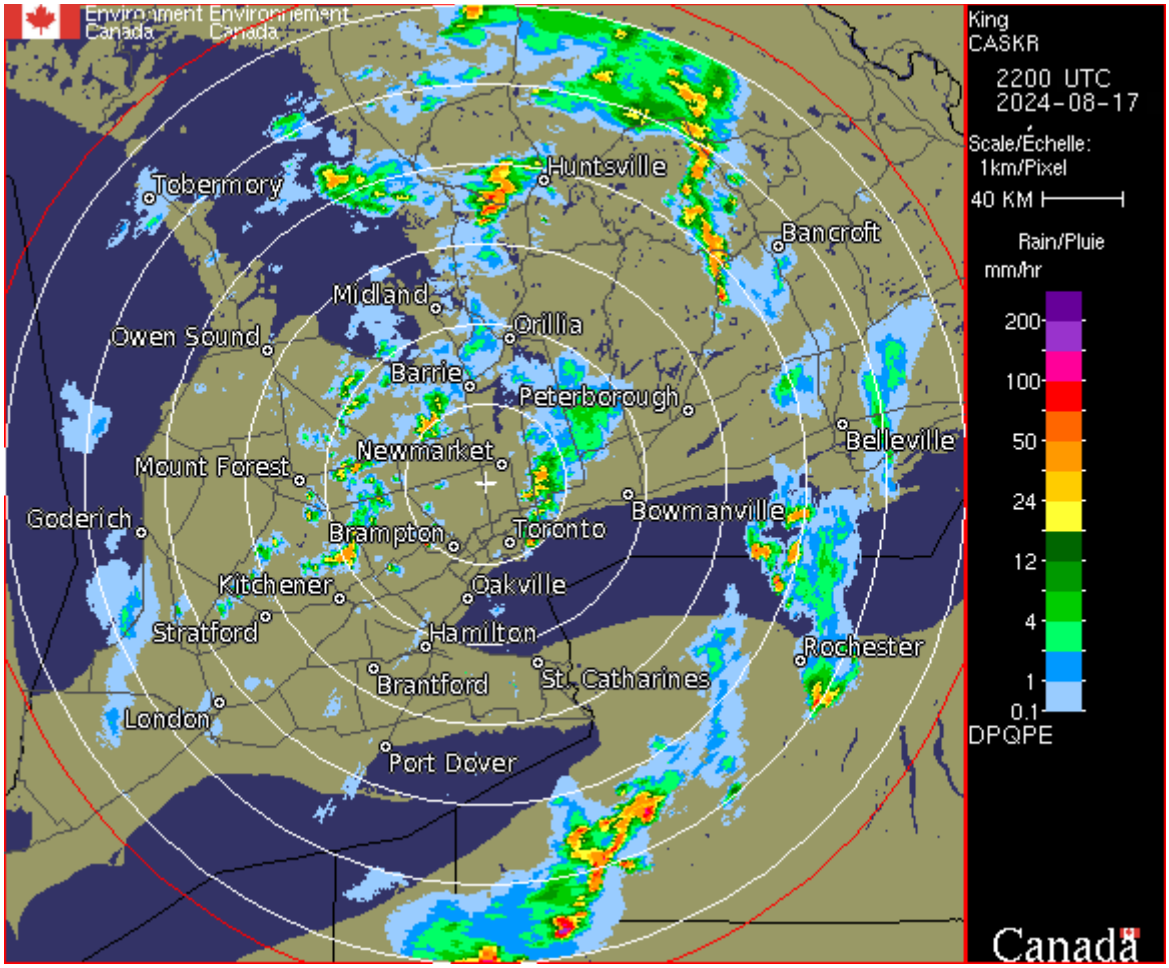
Source: ECCC, 2025c

Appendix Figure B 20: DPQPE Archive King City Radar (August 17, 2024, 2100Z)



Source: ECCC, 2025c

Appendix Figure B 21: DPQPE Archive King City Radar (August 17, 2024, 2130Z)



Source: ECCC, 2025c

Appendix Figure B 22: DPQPE Archive King City Radar (August 17, 2024, 2200Z)

AECOM

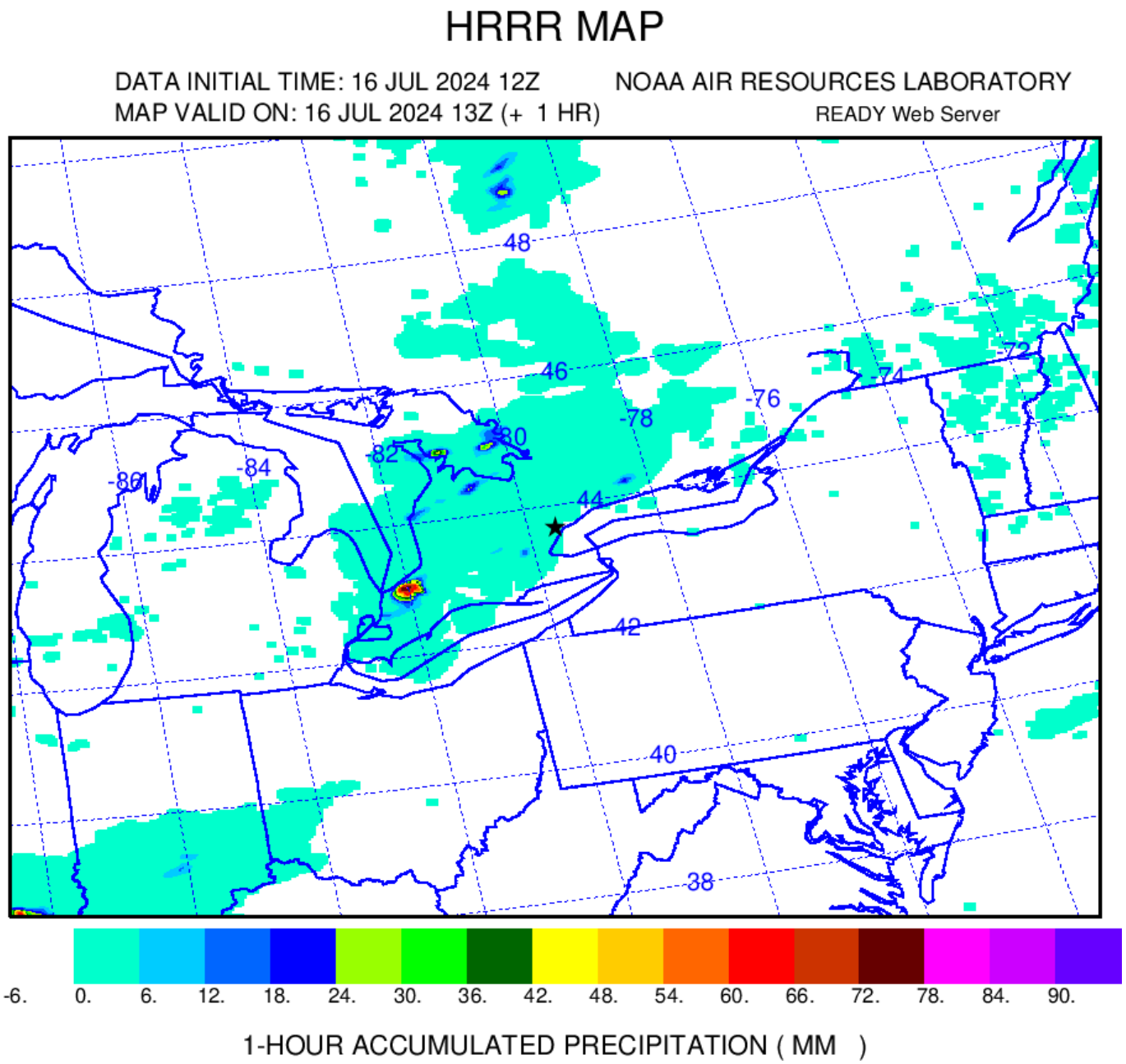
Appendix C

Numerical Forecast

Appendix C. Numerical Forecast

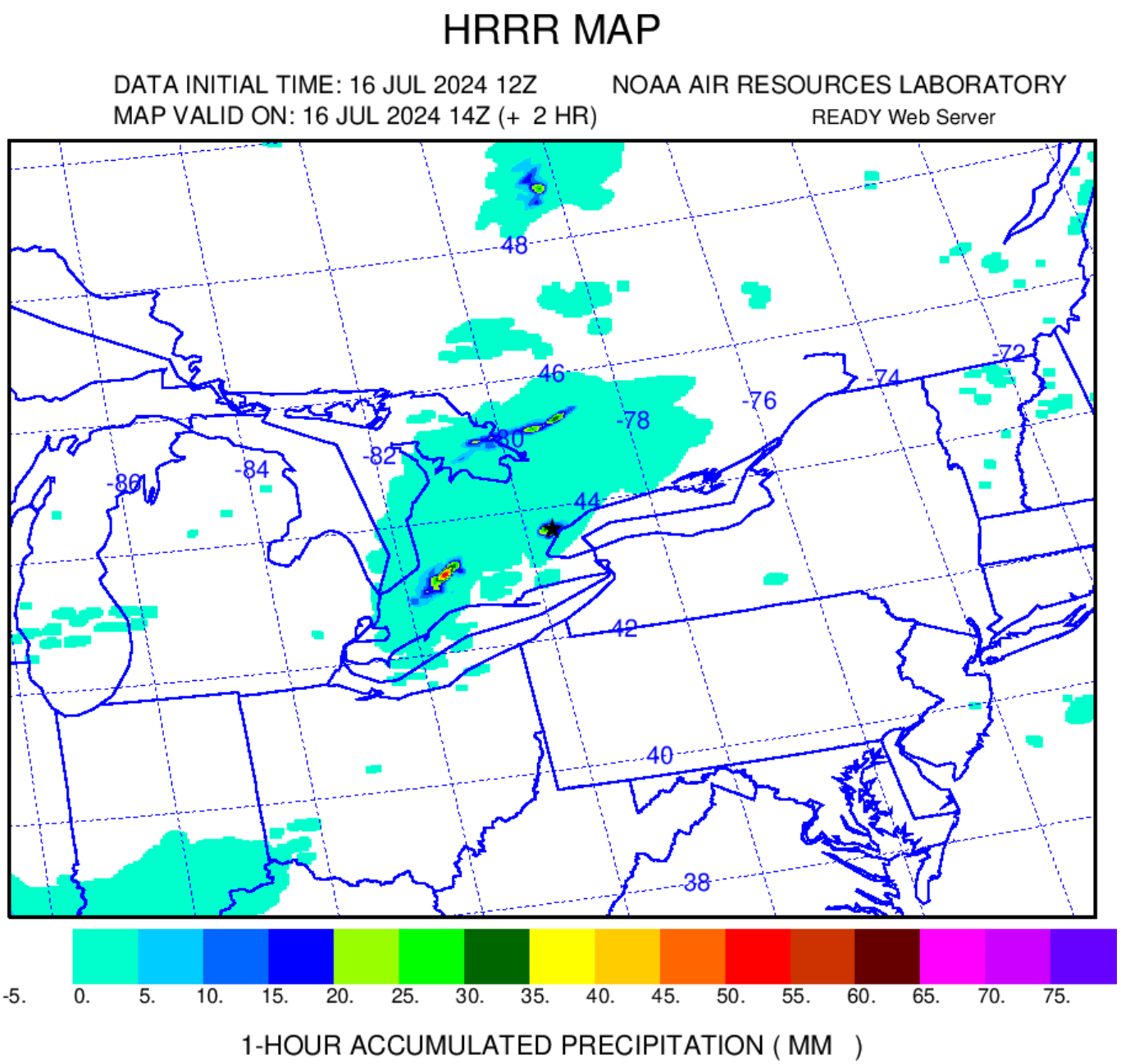
C.1 July 16, 2024

C.1.1 HRRR Model



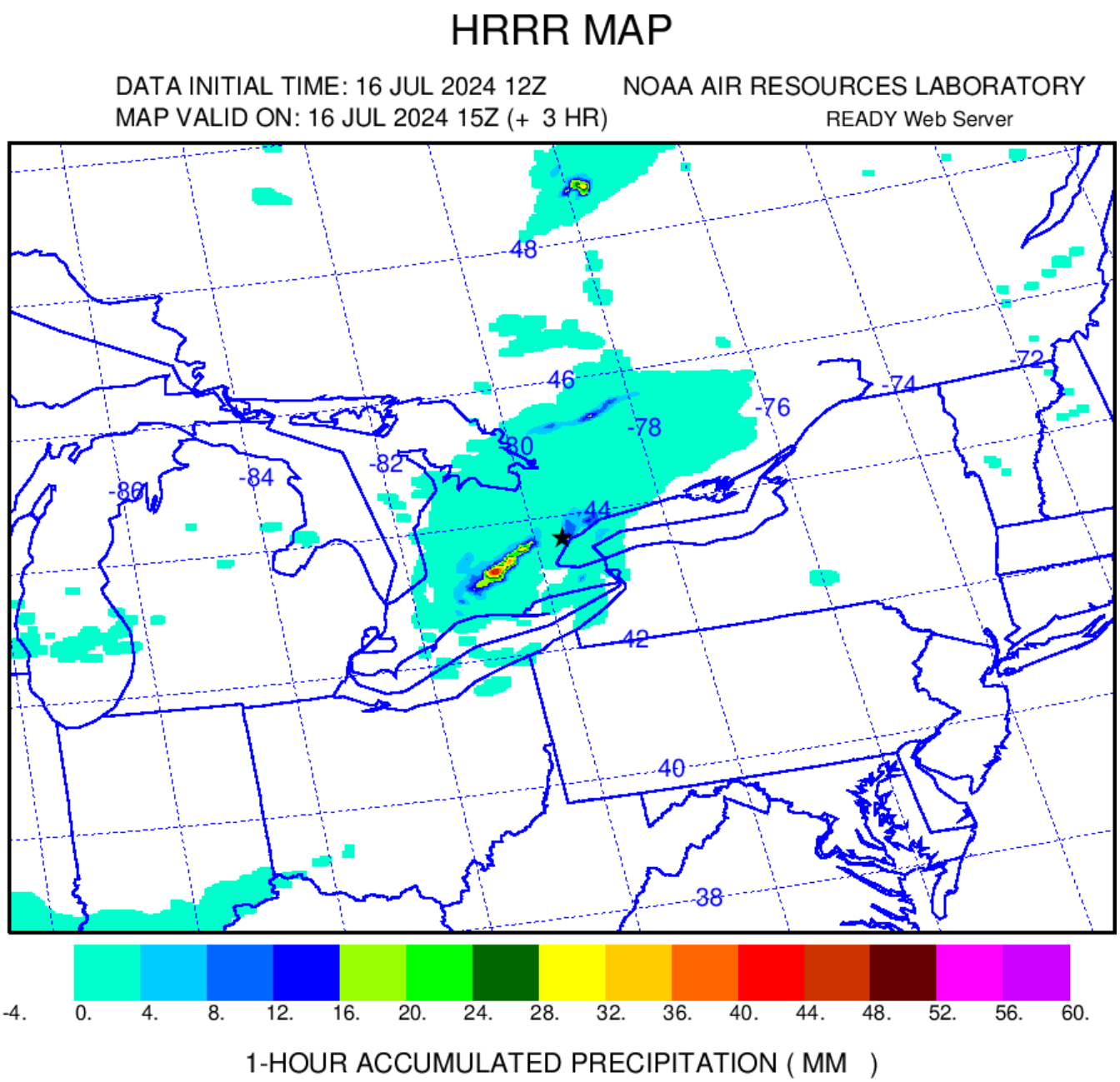
Note: *Issued on August 17 at 12Z by 3 km High-Resolution Rapid Refresh (HRRR).*
Source: *NOAA, 2025a*

Appendix Figure C 1: Forecasted One-hour Accumulated Precipitation from 12Z to 13Z (July 16, 2024)



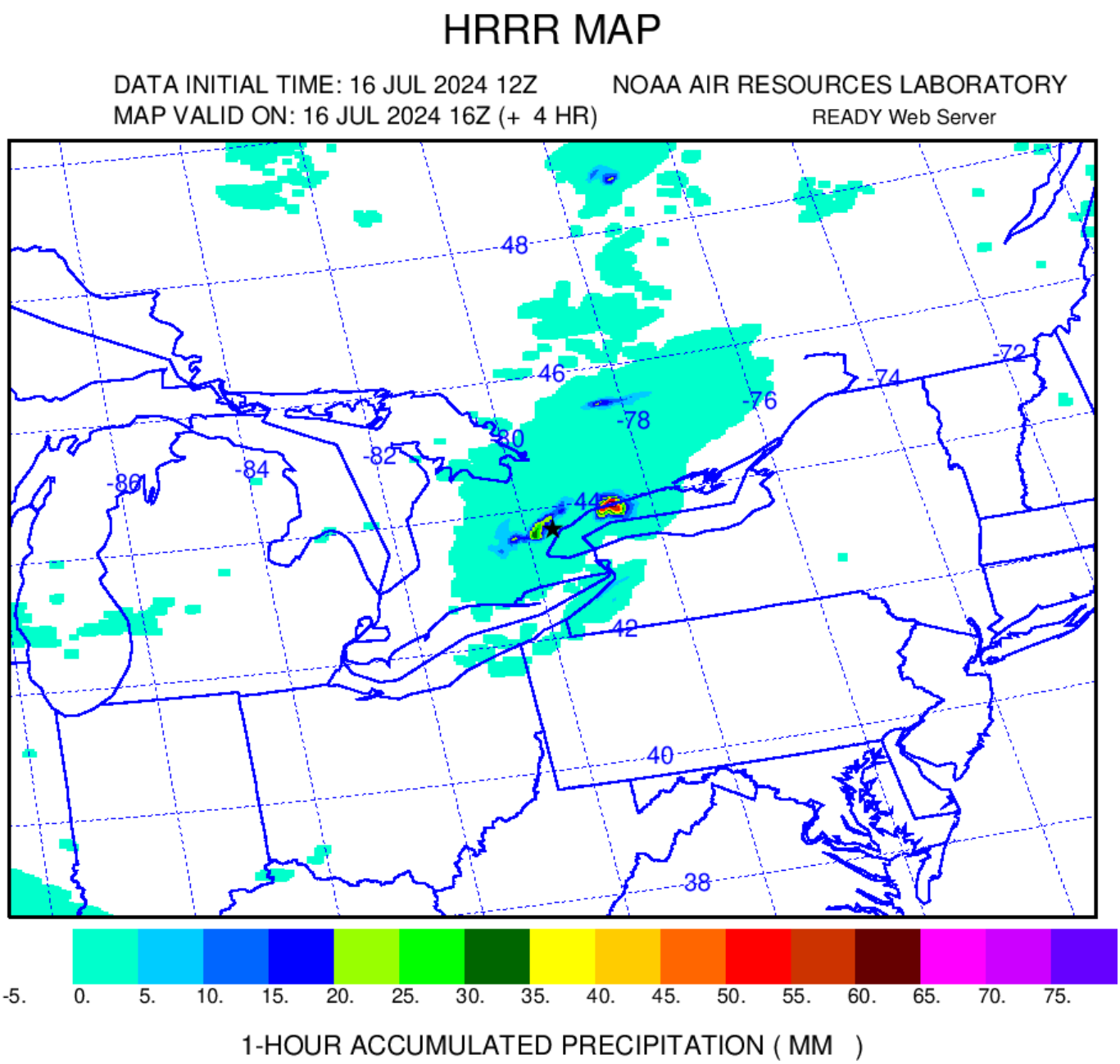
Note: *Issued on August 17 at 12Z by 3 km High-Resolution Rapid Refresh (HRRR).*
Source: *NOAA, 2025a*

Appendix Figure C 2: Forecasted One-hour Accumulated Precipitation from 13Z to 14Z (July 16, 2024)



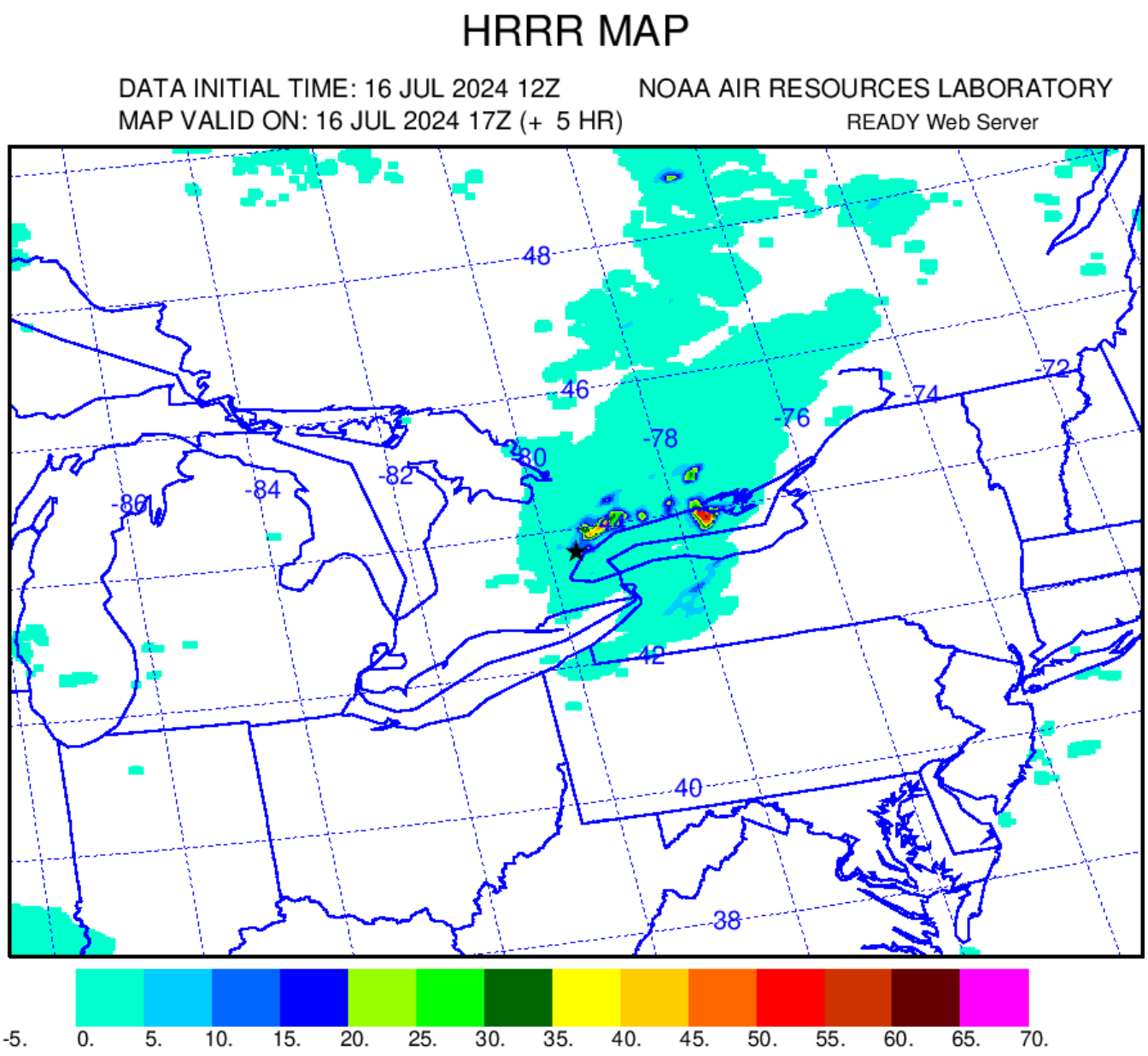
Note: *Issued on August 17 at 12Z by 3 km High-Resolution Rapid Refresh (HRRR).*
Source: *NOAA, 2025a*

Appendix Figure C 3: Forecasted One-hour Accumulated Precipitation from 14Z to 15Z (July 16, 2024)



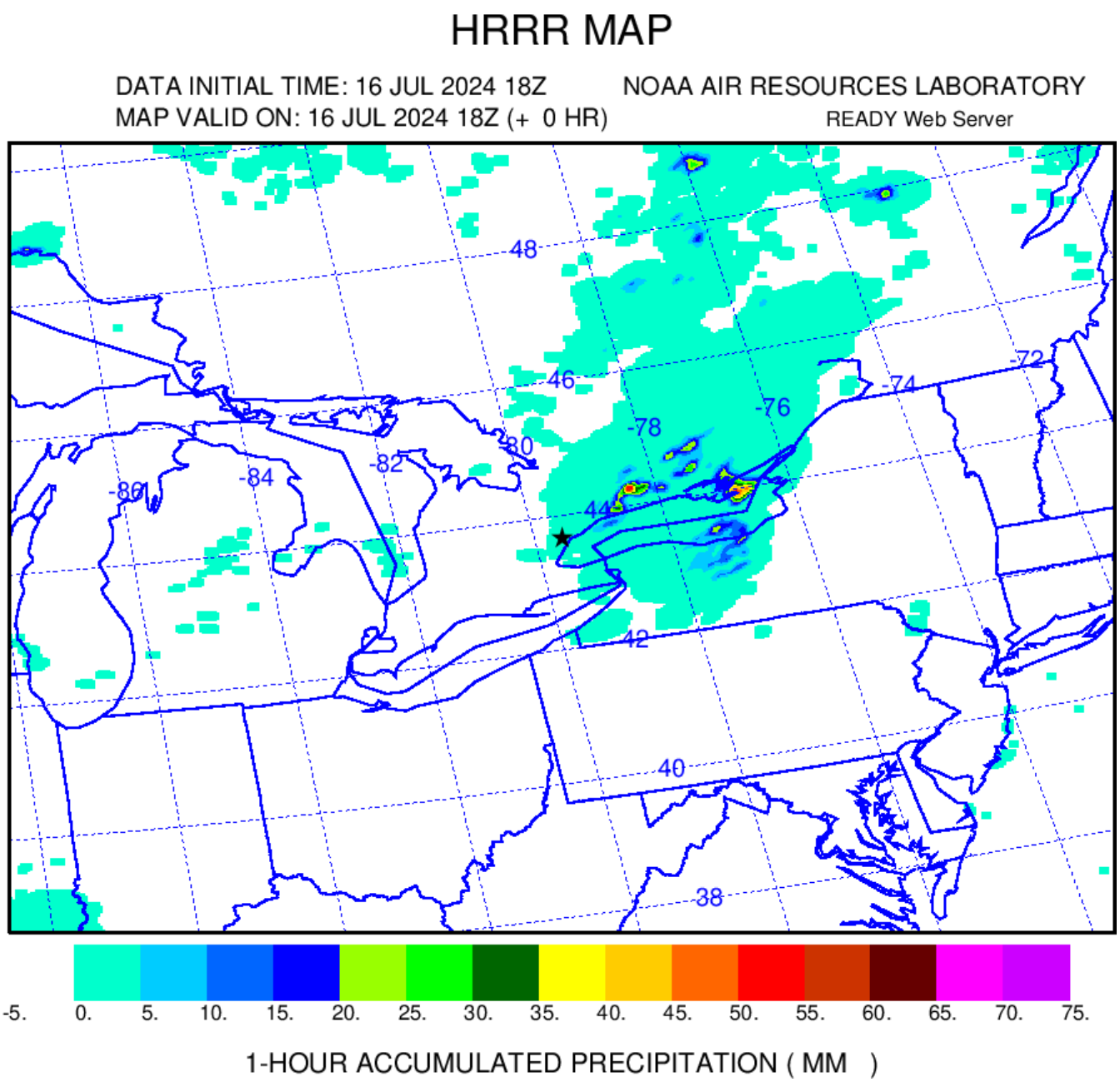
Note: *Issued on August 17 at 12Z by 3 km High-Resolution Rapid Refresh (HRRR).*
Source: *NOAA, 2025a*

Appendix Figure C 4: Forecasted One-hour Accumulated Precipitation from 15Z to 16Z (July 16, 2024)



Note: *Issued on August 17 at 12Z by 3 km High-Resolution Rapid Refresh (HRRR).*
Source: *NOAA, 2025a*

Appendix Figure C 5: Forecasted One-hour Accumulated Precipitation from 16Z to 17Z (July 16, 2024)

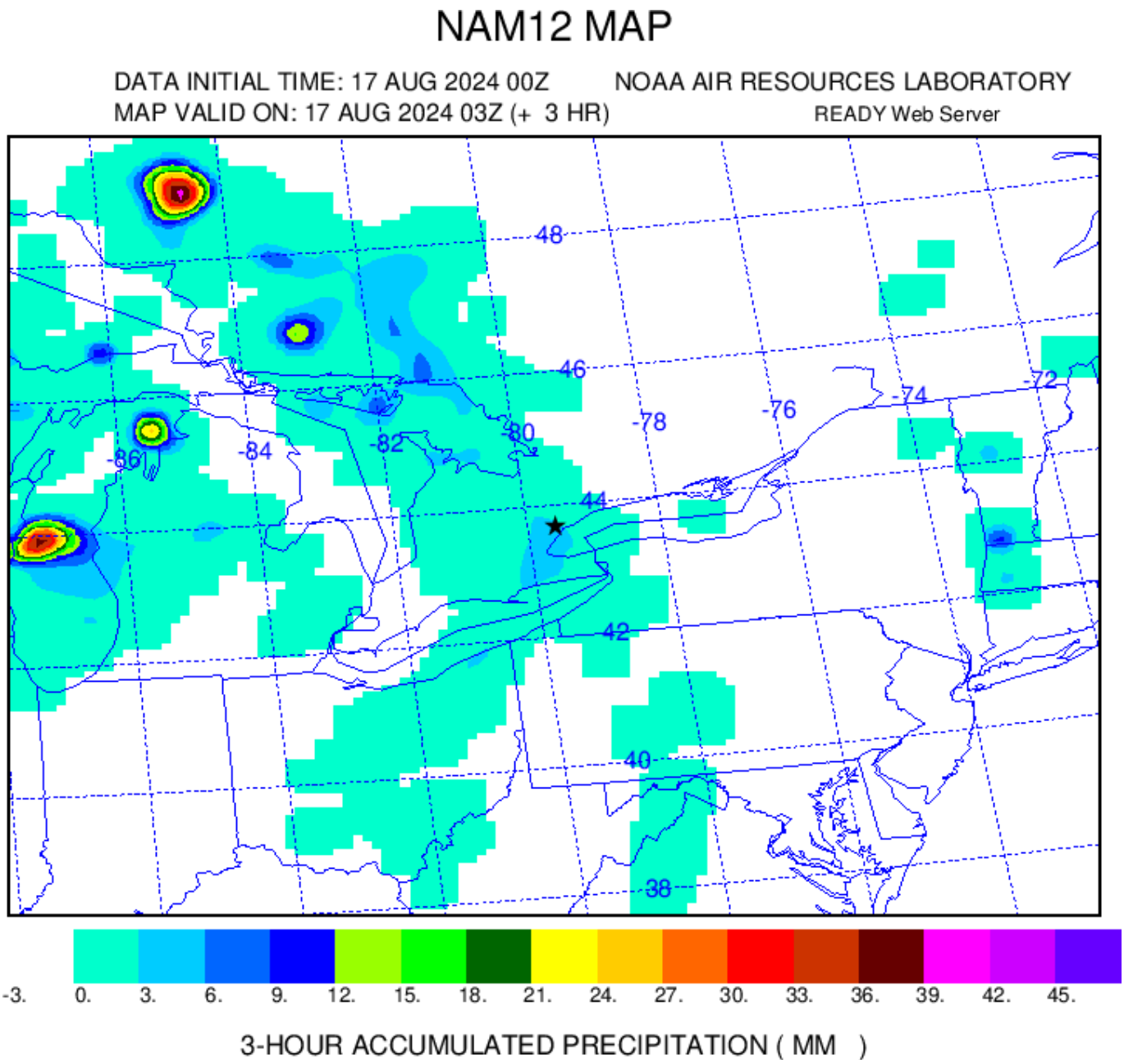


Note: *Issued on August 17 at 18Z by 3 km High-Resolution Rapid Refresh (HRRR).*
Source: *NOAA, 2025a*

Appendix Figure C 6: Forecasted One-hour Accumulated Precipitation from 17Z to 18Z (July 16, 2024)

C.2 August 17, 2024

C.2.1 NAM12 Model



Note: *Issued on August 17 on 00Z by the 12 km North American Model (NAM12).*

Source: *NOAA, 2025a*

Appendix Figure C 7: Forecasted Three-hour Accumulated Precipitation from 00Z to 03Z (August 17, 2024)

AECOM

Appendix D

Cumulative Event-day Precipitation

Appendix D. Cumulative Event-day Precipitation

D.1 July 16, 2024

D.1.1 TRCA

Appendix Table D 1: TRCA Precipitation Summary for July 16, 2024

Location	Region	Municipality	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
Albion Hills	Peel	Caledon	HY002	10.7	170	3.78
Alex Duff Memorial Pool	Toronto	Toronto	HY003	65.8	170	23.22
Bayly and Church	Durham	Ajax	HY004	72.0	175	24.69
Brickworks	Toronto	Toronto	HY008	80.3	210	22.95
Brock West Landfill	Durham	Pickering	HY009	34.7	205	10.16
Bruce Mill CA	York	Whitchurch-Stouffville	HY011	20.1	230	5.24
Danforth and Coxwell	Toronto	Toronto	HY016	70.6	190	22.29
Dufferin Reservoir	York	Vaughan	HY021	39.4	205	11.53
G Ross Dam	Toronto	Toronto	HY027	65.4	185	21.21
Glen Haffy	Peel	Caledon	HY030	10.4	140	4.46
Goodwood Pumping Station	Durham	Uxbridge	HY031	14.6	165	5.31
Heart Lake CA	Peel	Brampton	HY033	44.8	190	14.15
Kennedy Pump Station	Toronto	Toronto	HY036	54.7	210	15.63
King and Albion-Vaughan	York	King	HY037	8.2	120	4.10
East Humber at Mill Road	York	King	HY038	14.0	155	5.42
Kortright	York	Vaughan	HY039	33.0	145	13.66
Laidlaw Bus Depot	Peel	Caledon	HY041	17.0	195	5.23
Little Rouge at 16th	York	Markham	HY043	44.0	165	16.00
Milne Dam	York	Markham	HY044	54.2	170	19.13
Mississauga Works Yard	Peel	Mississauga	HY046	86.8	230	22.64
Morningside Works Yard	Toronto	Toronto	HY050	54.8	190	17.31
Restoration Services	York	Vaughan	HY055	35.2	165	12.80
Stouffville Dam	York	Whitchurch-Stouffville	HY060	13.0	215	3.62
Sue Grange Farm	Peel	Caledon	HY061	15.4	160	5.78
Transport Canada	Durham	Pickering	HY063	19.4	165	7.05
West Humber at Hwy7	Peel	Brampton	HY067	73.0	190	23.05
York Pumping Station	York	Richmond Hill	HY069	28.4	175	9.74
York Region Works Yard	York	Richmond Hill	HY070	20.2	140	8.66
Oak Ridges	York	Richmond Hill	HY083	22.7	210	6.49
RL Clark WTP	Toronto	Toronto	HY086	83.0	220	22.63
Westmount Park	Toronto	Toronto	HY087	78.6	185	25.49
Black Creek Pioneer Village	Toronto	Toronto	HY088	57.4	210	16.40
Broadlands Community Centre	Toronto	Toronto	HY094	62.3	205	18.23
Caledon East Soccer Complex	Peel	Caledon	HY096	10.6	125	5.09
Rathwood	Peel	Mississauga	HY099	101.5	210	29.00
Petticoat Works Yard	Durham	Pickering	HY102	53.3	205	15.60
Balsam at 407	Durham	Pickering	HY121	40.1	205	11.74

Location	Region	Municipality	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
Durham Works Yard	Durham	Ajax	HY122	47.9	210	13.69
Claremont Nature Centre	Durham	Pickering	HY124	26.0	180	8.67
Elmbank Community Centre	Toronto	Toronto	HY130	67.2	225	17.91

D.1.2 ECCC

Appendix Table D 2: ECCC Precipitation Summary for July 16, 2024

Station name	Climate ID	Precipitation (mm)	Duration (min)	Rate (mm/h)
BARRIE-ORO	6136699	18.3	360	3.05
ST. CATHARINES / NIAGARA DISTRICT A	6137286	NA	NA	NA
ST CATHARINES A	6137304	NA	NA	NA
VINELAND STATION RCS	6139148	9.2	240	2.30
BRANTFORD AIRPORT	6140942	41.9	360	6.98
ELORA RCS	6142286	15.7	240	3.93
GUELPH TURFGRASS INSTITUTE	6143092	56.7	360	9.45
KITCHENER/WATERLOO	6144239	65.7	360	10.95
BURLINGTON PIERS (AUT)	6151061	NA	NA	NA
HAMILTON A	6153193	49.8	NA	NA
HAMILTON RBG CS	6153301	13.8	420	1.97
KING CITY NORTH	6154150	10.6	360	1.77
OSHAWA	6155875	37.9	360	6.32
MONO CENTRE	6157000	6.9	420	0.99
TORONTO CITY	6158355	83.6	240	20.90
TORONTO CITY CENTRE	6158359	87.0	240	21.75
TORONTO INTL A	6158731	97.8	NA	NA
UXBRIDGE WEST	6159123	14.9	480	1.86

D.1.3 City of Toronto

Appendix Table D 3: City of Toronto Precipitation Summary for July 16, 2024

ID	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
7677	RG_001	72.77	NA	NA
7678	RG_002	76.99	215	21.49
7679	RG_003	79.22	220	21.61
7680	RG_004	77.31	230	20.17
7681	RG_006	75.33	210	21.52
7682	RG_007	63.64	225	16.97
7683	RG_012	62.18	225	16.58
7684	RG_013	75.06	225	20.02
7685	RG_014	76.93	215	21.47
7686	RG_015	64.30	215	17.94
7687	RG_016	75.59	195	23.26
7674	RG_017	67.65	220	18.45
7675	RG_018	67.25	225	17.93
7676	RG_019	51.14	240	12.79

ID	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
7688	RG_020	46.56	165	16.93
7690	RG_021	57.51	235	14.68
7691	RG_022	70.21	210	20.06
7692	RG_023	49.97	205	14.63
7693	RG_024	62.87	225	16.77
7694	RG_025	59.47	215	16.60
7695	RG_027	NA	NA	NA
7696	RG_028	52.74	240	13.19
7697	RG_030	NA	NA	NA
7698	RG_031	53.91	260	12.44
7699	RG_033	69.47	205	20.33
7700	RG_034	46.96	230	12.25
7701	RG_035	43.03	225	11.47
7702	RG_036	58.77	230	15.33
7703	RG_037	64.96	245	15.91
7704	RG_038	43.63	230	11.38
7705	RG_039	75.08	235	19.17
7706	RG_040	65.75	235	16.79
7707	RG_041	43.00	225	11.47
7708	RG_042	69.43	245	17.00
7709	RG_044	66.22	240	16.55
7710	RG_045	73.12	NA	NA
7711	RG_046	73.46	240	18.37
7712	RG_047	81.03	245	19.84
7713	RG_048	96.76	230	25.24
7714	RG_049	84.21	255	19.81
7715	RG_051	45.81	290	9.48
7716	RG_052	96.98	245	23.75
8017	RG_054	74.61	250	17.91
8049	RG_055	69.32	220	18.90
8018	RG_056	57.91	245	14.18
14209	RG_057	91.61	240	22.90
14210	RG_058	74.17	235	18.94
14211	RG_059	63.50	250	15.24
14212	RG_060	49.23	240	12.31
14213	RG_061	51.78	235	13.22
22867	RG_062	NA	NA	NA
24936	RG_063	NA	NA	NA

D.1.4 City of Mississauga

Appendix Table D 4: City of Mississauga Precipitation Summary for July 16, 2024

Location	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
Lakeview	RG01	59.60	160	22.35
Wolfedale	RG03	67.00	165	24.36
Mississauga Central	RG04	42.37	170	14.95

Location	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
Winding Trail	RG05	78.08	185	25.32
Mississauga Valley	RG06	76.80	190	24.25
Streetsville	RG07	104.20	180	34.73
Tomken	RG08	89.82	210	25.66
Truscott	RG09	51.60	145	21.35
Erindale	RG10	63.65	170	22.46
Garry Morden FTC	RG11	60.40	200	18.12
CVC	RG12	82.65	190	26.10
Goreway	RG13	86.79	215	24.22
Port Credit	RG14	58.31	150	23.33

D.2 August 17, 2024

D.2.1 TRCA

Appendix Table D 5: TRCA Precipitation Summary for August 17, 2024

Location	Region	Municipality	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
Albion Hills	Peel	Caledon	HY002	20.20	125	9.70
Alex Duff Memorial Pool	Toronto	Toronto	HY003	15.60	75	12.48
Bayly and Church	Durham	Ajax	HY004	15.20	65	14.03
Brickworks	Toronto	Toronto	HY008	6.58	50	7.90
Brock West Landfill	Durham	Pickering	HY009	21.40	110	11.67
Bruce Mill CA	York	Whitchurch-Stouffville	HY011	30.10	190	9.51
Danforth and Coxwell	Toronto	Toronto	HY016	3.40	20	10.20
Dufferin Reservoir	York	Vaughan	HY021	35.10	270	7.80
G Ross Dam	Toronto	Toronto	HY027	NA	NA	NA
Glen Haffy	Peel	Caledon	HY030	17.20	70	14.74
Goodwood Pumping Station	Durham	Uxbridge	HY031	48.60	170	17.15
Heart Lake CA	Peel	Brampton	HY033	25.40	120	12.70
Kennedy Pump Station	Toronto	Toronto	HY036	43.50	190	13.74
King and Albion-Vaughan	York	King	HY037	33.60	170	11.86
East Humber at Mill Road	York	King	HY038	29.00	195	8.92
Kortright	York	Vaughan	HY039	53.20	175	18.24
Laidlaw Bus Depot	Peel	Caledon	HY041	16.60	180	5.53
Little Rouge at 16th	York	Markham	HY043	36.60	160	13.73
Milne Dam	York	Markham	HY044	48.20	175	16.53
Mississauga Works Yard	Peel	Mississauga	HY046	67.80	220	18.49
Morningside Works Yard	Toronto	Toronto	HY050	30.20	80	22.65
Restoration Services	York	Vaughan	HY055	48.20	190	15.22
Stouffville Dam	York	Whitchurch-Stouffville	HY060	44.57	265	10.09
Sue Grange Farm	Peel	Caledon	HY061	22.20	105	12.69
Transport Canada	Durham	Pickering	HY063	22.80	170	8.05
West Humber at Hwy7	Peel	Brampton	HY067	44.80	180	14.93
York Pumping Station	York	Richmond Hill	HY069	39.80	165	14.47
York Region Works Yard	York	Richmond Hill	HY070	45.40	220	12.38

Location	Region	Municipality	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
Oak Ridges	York	Richmond Hill	HY083	32.80	205	9.60
RL Clark WTP	Toronto	Toronto	HY086	4.91	85	3.47
Westmount Park	Toronto	Toronto	HY087	64.60	195	19.88
Black Creek Pioneer Village	Toronto	Toronto	HY088	77.20	270	17.16
Broadlands Community Centre	Toronto	Toronto	HY094	46.40	150	18.56
Caledon East Soccer Complex	Peel	Caledon	HY096	25.60	105	14.63
Rathwood	Peel	Mississauga	HY099	135.70	215	37.87
Petticoat Works Yard	Durham	Pickering	HY102	21.40	100	12.84
Balsam at 407	Durham	Pickering	HY121	21.40	85	15.11
Durham Works Yard	Durham	Ajax	HY122	24.20	115	12.63
Claremont Nature Centre	Durham	Pickering	HY124	37.00	135	16.44
Elmbank Community Centre	Toronto	Toronto	HY130	71.00	245	17.39

D.2.2 ECCC

Appendix Table D 6: ECCC Precipitation Summary for August 17, 2024

Station name	Climate ID	Precipitation (mm)	Duration (min)	Rate (mm/h)
BARRIE-ORO	6136699	4.1	180	1.37
ST. CATHARINES / NIAGARA DISTRICT A	6137286	NA	NA	NA
ST CATHARINES A	6137304	26.6	60	26.60
VINELAND STATION RCS	6139148	4.5	120	2.25
BRANTFORD AIRPORT	6140942	0.1	60	0.10
ELORA RCS	6142286	17.3	300	3.46
GUELPH TURFGRASS INSTITUTE	6143092	10.9	240	2.73
KITCHENER/WATERLOO	6144239	14.4	360	2.40
BURLINGTON PIERS (AUT)	6151061	NA	NA	NA
HAMILTON A	6153193	1.4	NA	NA
HAMILTON RBG CS	6153301	0.5	60	0.50
KING CITY NORTH	6154150	26.4	420	3.77
OSHAWA	6155875	29.9	180	9.97
MONO CENTRE	6157000	9.4	300	1.88
TORONTO CITY	6158355	3.5	180	1.17
TORONTO CITY CENTRE	6158359	0.0	0	0.00
TORONTO INTL A	6158731	128.3	NA	NA
UXBRIDGE WEST	6159123	14.8	420	2.11

D.2.3 City of Toronto

Appendix Table D 7: City of Toronto Precipitation Summary for August 17, 2024

ID	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
7677	RG_001	31.28	200	9.38
7678	RG_002	13.24	155	5.13
7679	RG_003	3.23	90	2.15
7680	RG_004	15.13	150	6.05
7681	RG_006	0.56	105	0.32

ID	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
7682	RG_007	1.43	20	4.28
7683	RG_012	75.41	335	13.51
7684	RG_013	106.77	295	21.72
7685	RG_014	95.76	260	22.10
7686	RG_015	50.36	260	11.62
7687	RG_016	12.31	145	5.09
7674	RG_017	62.58	275	13.65
7675	RG_018	14.91	135	6.63
7676	RG_019	91.18	305	17.94
7688	RG_020	95.10	270	21.13
7690	RG_021	78.60	315	14.97
7691	RG_022	53.23	305	10.47
7692	RG_023	26.60	120	13.30
7693	RG_024	116.61	270	25.91
7694	RG_025	67.13	270	14.92
7695	RG_027	89.43	270	19.87
7696	RG_028	81.52	520	9.41
7697	RG_030	NA	NA	NA
7698	RG_031	42.48	325	7.84
7699	RG_033	36.16	325	6.68
7700	RG_034	36.92	200	11.08
7701	RG_035	38.98	155	15.09
7702	RG_036	0.28	40	0.42
7703	RG_037	38.77	320	7.27
7704	RG_038	10.28	115	5.36
7705	RG_039	45.49	265	10.30
7706	RG_040	1.12	30	2.23
7707	RG_041	15.23	810	1.13
7708	RG_042	10.37	90	6.91
7709	RG_044	60.91	320	11.42
7710	RG_045	54.96	275	11.99
7711	RG_046	107.97	320	20.24
7712	RG_047	63.44	310	12.28
7713	RG_048	60.77	250	14.58
7714	RG_049	57.12	305	11.24
7715	RG_051	74.23	305	14.60
7716	RG_052	107.72	310	20.85
8017	RG_054	76.17	260	17.58
8049	RG_055	64.71	305	12.73
8018	RG_056	108.07	305	21.26
14209	RG_057	0.15	5	1.75
14210	RG_058	46.42	310	8.98
14211	RG_059	0.15	10	0.90
14212	RG_060	38.16	225	10.18
14213	RG_061	6.74	85	4.76
22867	RG_062	NA	NA	NA
24936	RG_063	NA	NA	NA

D.2.4 City of Mississauga

Appendix Table D-8: City of Mississauga Precipitation Summary for August 17, 2024

Location	Station	Precipitation (mm)	Duration (min)	Rate (mm/h)
Lakeview	RG01	17.40	85	12.28
Wolfedale	RG03	38.80	165	14.11
Mississauga Central	RG04	65.31	165	23.75
Winding Trail	RG05	73.29	175	25.13
Mississauga Valley	RG06	63.80	170	22.52
Streetsville	RG07	90.00	110	49.09
Tomken	RG08	73.39	150	29.35
Truscott	RG09	14.40	90	9.60
Erindale	RG10	25.09	125	12.04
Garry Morden FTC	RG11	52.40	165	19.05
CVC	RG12	51.62	150	20.65
Goreway	RG13	64.25	210	18.36
Port Credit	RG14	6.77	55	7.39

Appendix E

Data for IDF curves

Appendix E. Data for IDF curves

E.1 TORONTO CITY

Appendix Table E 1: Annual Precipitation Maxima (mm) at TORONTO CITY Station

Year	5 min	10 min	15 min	30 min	1 h	2 h	6 h	12 h	24 h
1940	13.7	15.7	21.3	30.5	30.5	30.5	31.7	NA	35.1
1941	11.4	18.3	21.6	37.1	45.7	56.4	62.2	62.2	62.2
1942	14.2	23.1	28.7	33.5	37.6	40.6	51.6	51.6	70.1
1943	6.6	12.4	14.7	17.8	22.6	22.9	32.0	34.3	47.5
1944	11.7	15.7	20.8	21.8	26.7	35.6	41.7	51.6	51.6
1945	6.3	9.1	10.4	12.7	17.3	22.6	38.9	60.7	67.6
1946	7.6	15.0	16.0	19.8	33.3	39.4	42.2	42.2	42.4
1947	6.3	11.9	13.5	13.5	14.7	19.3	29.7	37.6	61.0
1948	7.9	10.9	13.0	16.8	19.6	30.0	30.0	43.4	46.0
1949	4.6	7.4	9.1	12.4	18.5	18.8	33.5	39.6	42.2
1950	13.5	14.7	18.3	27.4	36.8	37.3	37.8	43.4	46.2
1951	10.4	13.5	15.5	23.1	30.0	31.0	34.8	46.5	49.5
1952	11.4	15.2	22.9	32.3	33.8	33.8	33.8	37.1	42.9
1953	8.1	9.7	13.5	15.7	23.1	26.7	27.7	41.7	43.2
1954	8.1	8.4	10.2	13.0	23.4	40.4	67.1	83.1	97.0
1955	8.6	14.7	18.0	23.1	25.7	28.7	41.7	57.9	63.8
1957	10.2	14.0	17.3	22.1	28.7	32.8	40.6	48.5	63.5
1960	8.4	11.9	14.0	16.8	22.1	36.8	61.5	61.5	61.5
1961	10.4	10.9	11.4	17.3	23.9	27.9	38.1	38.4	38.4
1962	22.4	25.7	28.7	38.4	40.6	41.9	41.9	56.6	56.6
1963	7.1	11.2	13.2	13.7	14.5	19.0	21.6	28.4	37.8
1964	9.7	10.9	11.2	15.7	16.5	18.3	38.1	39.1	48.5
1965	9.1	10.4	12.2	12.7	17.8	18.5	24.4	24.4	34.0
1967	15.0	16.5	18.3	21.1	21.8	23.1	27.9	31.5	41.1
1968	7.9	11.7	15.5	24.4	37.1	56.1	67.6	71.1	71.1
1969	8.1	10.4	10.4	11.7	14.0	20.8	32.0	36.6	37.3
1970	18.3	22.1	25.4	26.4	26.4	35.1	48.8	60.7	75.2
1971	6.1	8.9	12.2	16.8	19.0	21.3	26.9	31.7	34.8
1972	5.3	9.1	10.9	15.0	21.8	30.7	31.5	31.5	40.4
1973	6.6	9.9	14.7	16.8	23.1	26.9	29.7	36.6	44.7
1974	20.8	26.7	34.3	44.7	50.0	50.0	51.1	58.4	58.7
1975	7.6	13.0	17.0	24.4	30.5	35.6	52.3	57.1	57.1
1976	6.9	8.9	9.7	11.7	13.7	19.8	22.4	33.0	40.6
1977	20.8	27.9	38.9	40.9	45.0	45.0	50.0	59.9	59.9
1978	7.2	10.2	12.0	13.4	17.4	21.0	24.8	29.6	30.2
1979	13.1	15.1	15.1	21.6	24.5	24.6	24.6	35.6	36.6

Year	5 min	10 min	15 min	30 min	1 h	2 h	6 h	12 h	24 h
1980	5.8	9.4	11.0	20.4	31.9	33.4	34.0	37.1	38.0
1981	16.2	21.8	29.9	34.5	36.4	38.0	46.2	46.4	60.9
1982	12.4	19.8	27.4	29.3	30.6	32.9	44.1	47.0	47.0
1983	13.8	16.4	17.3	21.3	22.0	24.4	28.8	30.6	30.6
1984	9.4	10.2	10.9	15.2	15.2	16.7	24.7	30.9	32.2
1985	8.5	12.3	12.7	13.8	16.7	23.3	25.2	25.4	38.4
1986	13.7	18.9	27.7	45.8	58.9	62.6	77.8	78.0	82.4
1987	6.7	10.2	14.1	15.9	16.0	17.0	24.7	27.6	29.6
1988	7.8	12.0	12.8	13.4	13.6	16.9	27.4	34.0	36.8
1989	6.2	8.8	9.2	13.7	23.3	34.6	47.2	47.4	47.4
1990	7.4	9.4	10.4	11.8	13.7	15.6	21.3	29.9	45.1
1991	12.1	19.0	21.2	24.6	26.1	26.2	32.7	35.0	38.6
1992	6.4	9.0	11.2	18.7	24.6	26.7	38.6	39.4	42.4
1993	9.7	12.7	14.9	17.3	25.7	35.1	-99.9	-99.9	54.0
1994	13.3	15.6	19.6	20.7	22.0	22.2	26.6	30.0	32.3
1995	8.0	12.0	17.6	25.6	31.6	38.8	42.0	55.6	67.6
1996	11.1	15.5	17.7	22.9	31.6	35.5	41.3	67.8	78.0
1997	4.2	6.1	8.0	9.3	11.6	20.5	25.4	35.8	39.0
1998	7.5	10.4	13.5	14.6	16.4	16.8	17.7	28.4	36.8
2000	9.0	14.7	16.7	22.4	26.0	32.8	53.9	54.1	70.2
2001	7.7	9.7	9.9	13.0	21.7	34.2	46.6	52.4	61.9
2002	7.2	11.5	15.7	20.4	20.4	26.6	27.3	33.7	33.9
2003	6.0	9.2	10.2	11.0	13.4	20.6	27.0	33.2	33.4
2004	6.8	9.8	10.4	11.6	12.8	14.2	23.6	28.6	29.0
2005	8.4	13.2	18.4	21.6	24.8	24.8	25.4	32.6	35.8
2006	6.4	11.0	12.4	15.6	22.8	27.4	31.6	42.6	44.7
2007	9.2	16.2	22.6	35.0	40.6	41.6	42.6	56.4	58.6
2009	9.6	13.6	16.4	23.0	29.2	29.2	30.8	30.8	56.4
2010	9.6	13.0	13.0	20.8	37.2	41.4	45.4	58.4	63.4
2011	8.6	11.8	13.6	16.8	20.0	24.0	30.6	34.6	48.8
2012	7.8	13.2	15.8	21.2	25.0	28.4	38.0	40.2	45.8
2013	13.2	18.0	20.6	36.6	52.6	87.0	95.2	96.0	96.6
2014	8.0	12.2	12.8	22.4	23.0	25.4	33.0	33.2	33.4
2016	7.2	11.8	13.4	16.0	16.2	16.4	27.2	31.0	31.2
2017	5.6	8.0	10.4	13.2	24.4	26.4	32.8	52.2	53.8
2018	8.6	14.2	15.8	19.0	31.8	44.0	45.8	48.8	64.4
2019	9.6	15.2	17.2	17.2	17.8	20.8	33.6	37.4	38.6
2020	8.8	11.8	14.2	16.8	19.4	21.8	25.4	36.6	53.2
2021	5.2	9.2	10.0	13.2	15.2	17.8	29.2	37.2	44.8
2024	6.5	12.6	17.8	34.6	53.1	62.9	83.6	83.6	83.6

E.2 TORONTO INTL A

Appendix Table E 2: Annual Precipitation Maxima (mm) at TORONTO CITY Station

Year	5m	10m	15m	30m	1h	2h	6h	12h	24h
1950	7.6	11.7	15.2	18.5	21.3	22.4	33.8	39.4	41.4
1951	10.4	16.0	21.8	24.6	25.9	27.7	34.3	36.1	41.7
1954	9.4	11.7	14.5	22.9	31.2	33.8	80.8	110.7	137.4
1955	7.1	11.7	15.7	20.3	20.6	20.6	35.1	52.8	58.7
1956	11.9	17.8	21.1	24.4	24.6	30.0	46.0	46.5	46.7
1957	7.4	10.2	13.0	17.8	21.3	28.7	46.0	53.8	54.1
1958	5.8	6.1	6.1	8.1	8.9	11.2	20.3	30.0	32.3
1959	7.1	8.4	8.6	9.9	10.4	14.0	22.4	27.9	29.5
1960	6.1	11.2	13.5	17.8	27.2	38.6	43.9	43.9	43.9
1961	9.4	10.7	11.2	17.0	19.6	24.6	30.0	33.5	33.5
1962	17.0	20.8	23.4	31.5	32.5	33.0	46.2	80.3	88.9
1963	10.7	14.2	19.8	21.8	22.4	33.5	33.8	37.1	38.4
1964	8.4	9.7	12.7	20.6	21.8	25.1	36.1	42.4	54.9
1965	9.4	10.9	11.4	12.2	15.5	18.3	23.9	35.8	46.2
1966	4.6	6.3	7.9	9.1	15.0	23.6	36.6	36.8	49.8
1967	12.4	13.5	15.2	16.5	17.8	22.9	30.2	33.8	43.2
1968	10.7	17.5	23.1	34.3	45.7	48.5	65.0	67.3	67.6
1969	5.3	10.7	15.5	22.9	31.0	44.2	47.5	48.5	49.3
1970	18.5	25.9	30.2	40.4	47.5	49.8	58.7	63.0	80.8
1971	11.7	13.7	17.3	24.4	31.5	32.5	37.1	38.4	42.4
1972	4.8	6.9	7.6	11.7	11.9	16.0	26.2	34.3	38.9
1973	8.1	9.4	11.9	17.0	19.3	27.9	33.5	35.6	39.6
1974	8.9	13.0	16.3	26.9	27.4	30.0	43.4	56.1	57.2
1975	8.9	16.5	18.0	20.3	20.3	22.6	38.4	47.8	48.5
1976	8.4	14.5	17.8	21.3	21.3	21.3	22.9	32.5	42.4
1977	11.4	18.8	28.2	30.7	33.3	33.3	44.4	49.3	49.3
1978	6.9	13.0	15.1	16.6	17.3	18.7	25.5	29.0	38.6
1979	11.5	20.0	28.5	40.0	40.1	40.1	40.1	40.1	43.8
1980	10.2	18.4	21.4	28.2	36.3	66.9	92.8	101.8	119.9
1981	NA	NA	NA	28.8	31.3	32.8	36.3	36.4	36.4
1982	5.1	10.1	14.1	26.3	37.4	45.7	56.9	57.1	57.1
1983	12.0	13.5	17.9	28.5	29.3	29.6	29.6	30.0	34.0
1984	6.0	10.1	13.8	18.3	18.7	19.2	19.3	26.8	34.0
1985	11.7	17.9	21.2	26.5	26.8	33.5	36.4	40.5	40.5
1986	14.1	20.2	26.3	30.1	30.5	47.7	68.8	71.6	72.0
1987	12.9	20.2	24.2	35.6	35.8	35.8	37.2	37.2	41.4
1988	7.9	15.7	23.3	29.3	29.4	29.4	30.8	30.8	32.4
1989	13.1	20.5	21.4	21.7	21.7	21.8	27.1	27.3	42.4
1990	7.4	11.6	13.4	15.8	25.3	25.7	25.7	29.2	44.2

Year	5m	10m	15m	30m	1h	2h	6h	12h	24h
1991	8.8	12.5	16.5	19.0	19.0	23.7	41.5	44.3	44.3
1992	10.1	11.2	13.5	16.7	20.9	31.1	40.9	42.6	58.0
1993	6.4	8.3	11.5	17.5	22.0	32.8	37.2	38.4	47.7
1994	8.9	10.0	12.0	19.5	22.9	24.7	27.8	28.8	39.1
1995	13.4	19.4	20.7	28.8	32.3	32.5	61.2	75.5	78.8
1996	5.4	6.9	8.3	12.9	15.5	15.7	31.1	59.3	66.6
1997	5.1	6.2	7.5	9.0	12.6	18.9	22.0	27.0	32.7
1998	7.0	13.9	16.8	20.6	21.2	21.2	21.2	32.1	44.1
1999	6.7	10.1	11.6	13.8	18.0	25.2	37.4	44.3	52.4
2000	7.8	13.6	15.6	17.4	21.8	27.0	44.0	44.0	59.4
2001	3.3	5.2	7.0	8.5	9.3	12.5	20.8	29.4	40.5
2002	4.5	6.6	7.6	10.5	12.4	13.6	22.9	29.0	29.0
2003	7.5	11.5	14.8	17.1	23.4	24.6	29.0	34.5	34.7
2004	7.5	12.0	15.1	26.3	30.8	30.8	30.8	30.8	32.0
2006	6.9	9.3	10.2	12.0	12.5	13.5	29.3	35.0	36.2
2007	8.1	9.6	11.8	18.0	18.6	21.0	33.4	41.4	46.6
2008	8.1	12.1	14.4	17.7	26.9	28.9	28.9	42.6	69.2
2009	10.1	18.2	20.6	24.3	27.6	27.6	28.0	40.0	40.9
2010	7.8	12.6	16.3	25.9	37.3	47.6	53.2	53.2	53.2
2011	7.9	10.1	12.0	13.0	14.7	19.2	22.8	40.4	51.1
2012	14.2	18.5	21.3	27.7	30.5	35.4	41.8	42.9	43.9
2013	14.6	21.8	28.2	49.9	78.6	101.7	125.6	126.0	126.5
2014	5.4	7.1	8.8	11.5	14.9	19.2	25.5	34.1	34.8
2015	7.2	10.4	13.5	18.0	19.7	20.5	35.2	35.8	41.0
2016	7.2	11.1	16.5	20.5	25.4	26.7	32.9	35.7	35.7
2017	8.0	12.1	12.6	14.4	24.7	28.7	32.4	36.9	44.7
2024	15.4	26.0	28.2	43.4	79.3	109.8	127.7	128.3	128.3

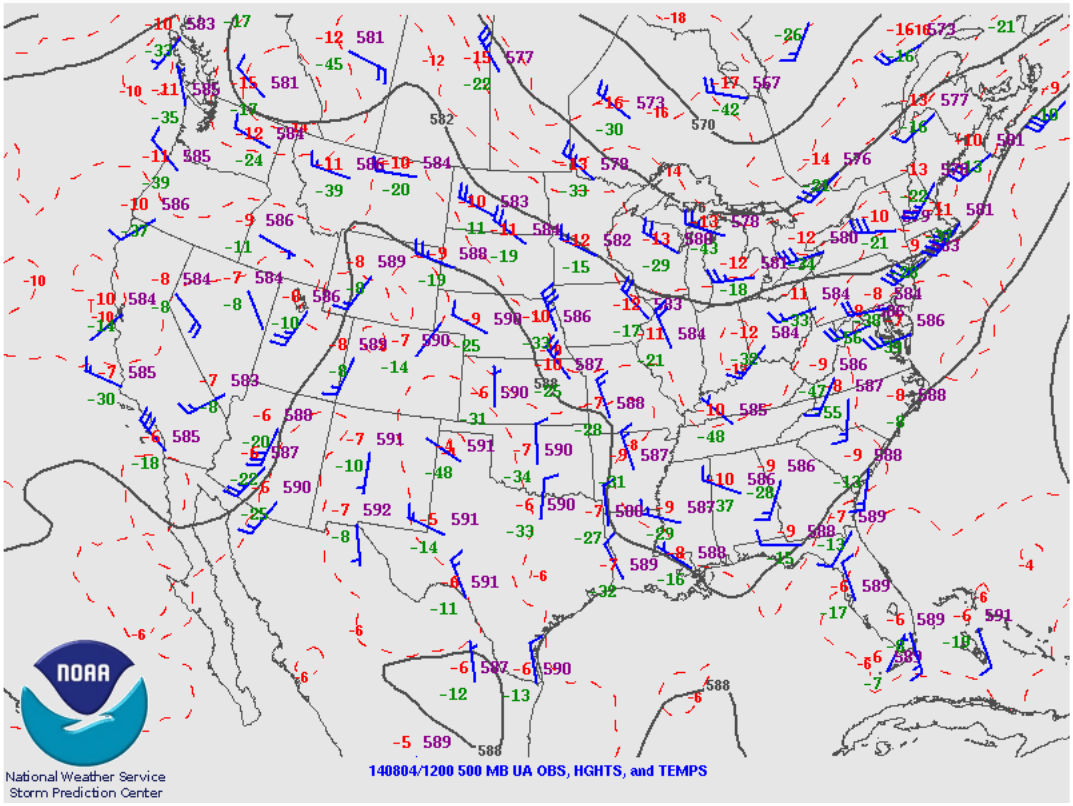
Appendix F

Storm Comparison

Appendix F. Storm Comparison

F.1 August 4, 2014

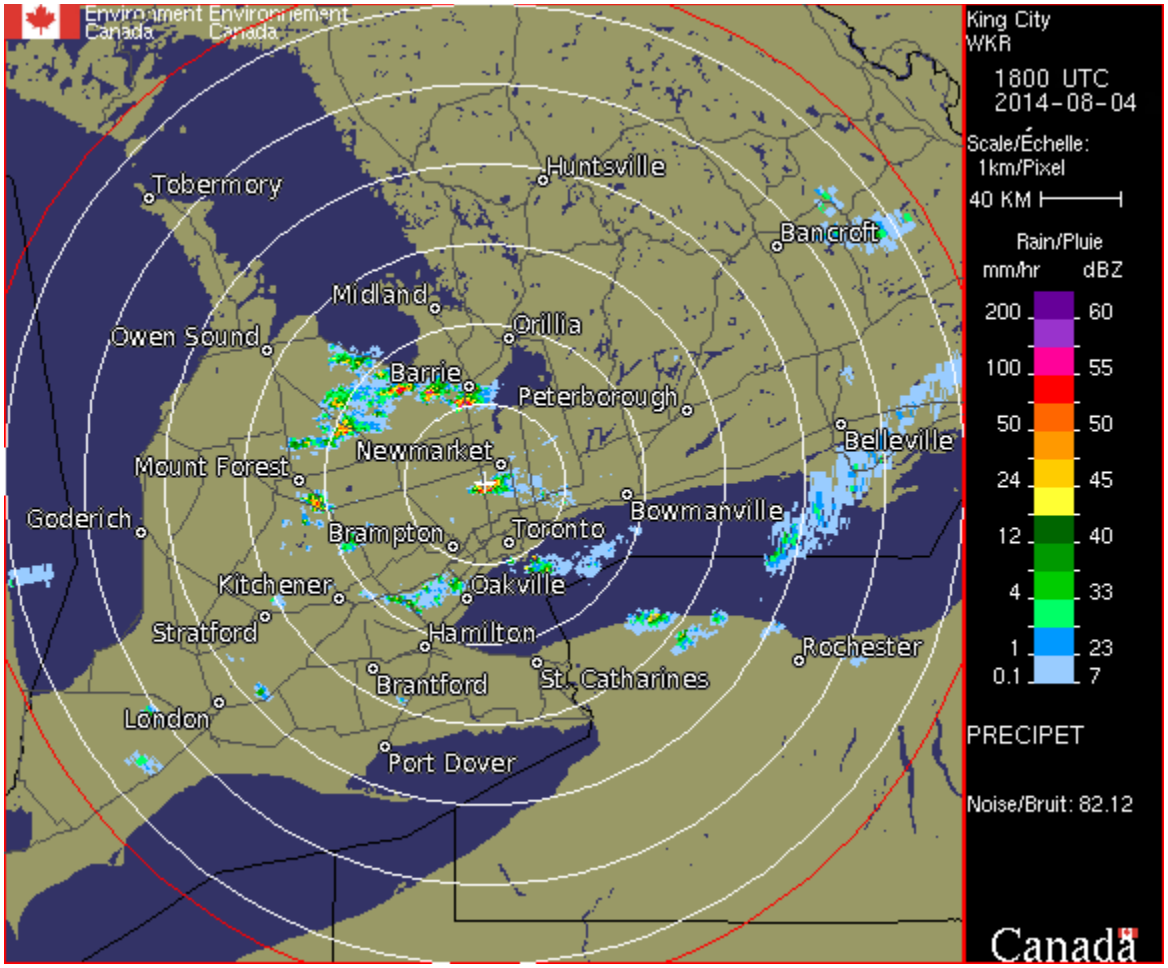
F.1.1 Weather Maps



Source: Storm Prediction Center, 2025b

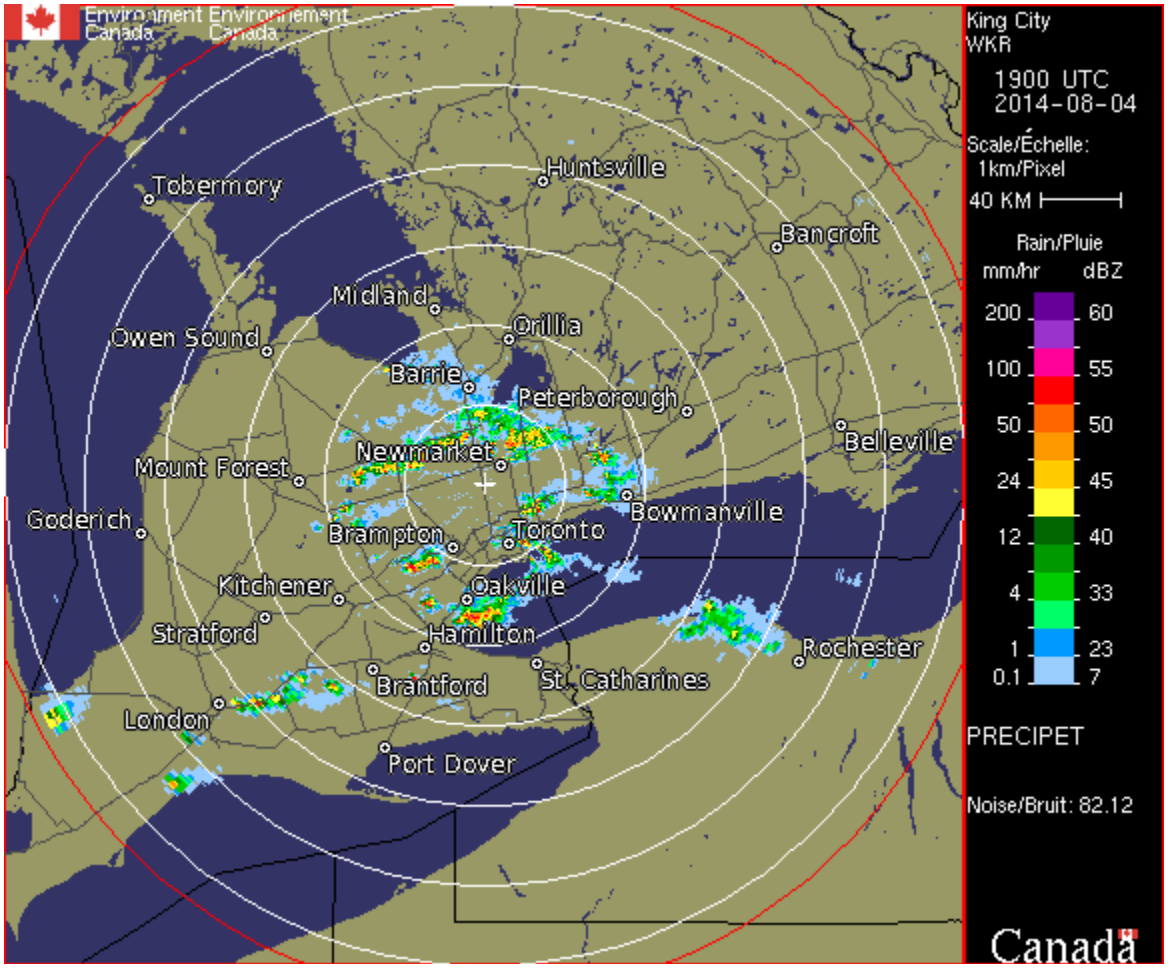
Appendix Figure F 1: 500-hPa Map (August 4, 2014, 12Z)

F.1.2 Radar Images



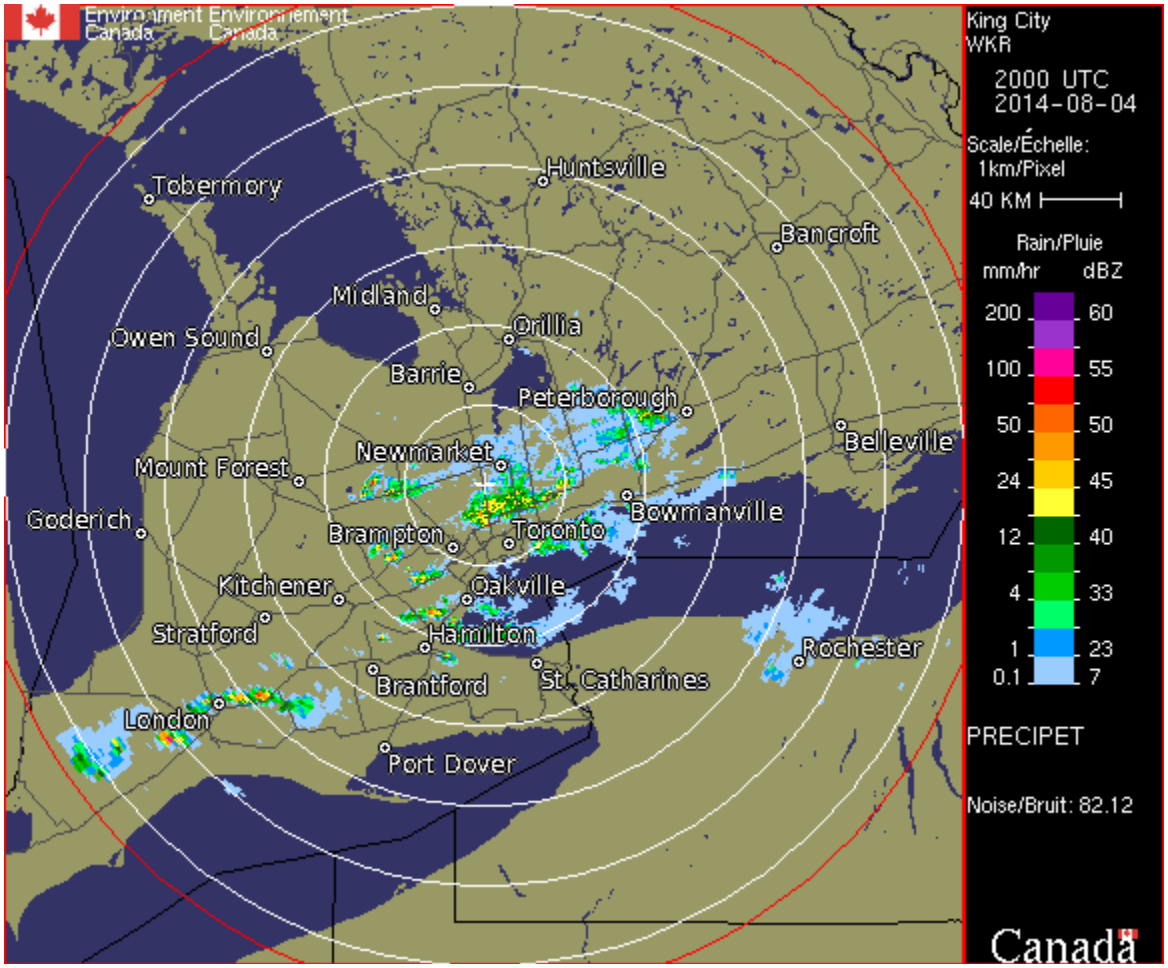
Source: ECCC, 2025c

Appendix Figure F 2: DPQPE Archive King City Radar (August 4, 2014, 1800 UTC)



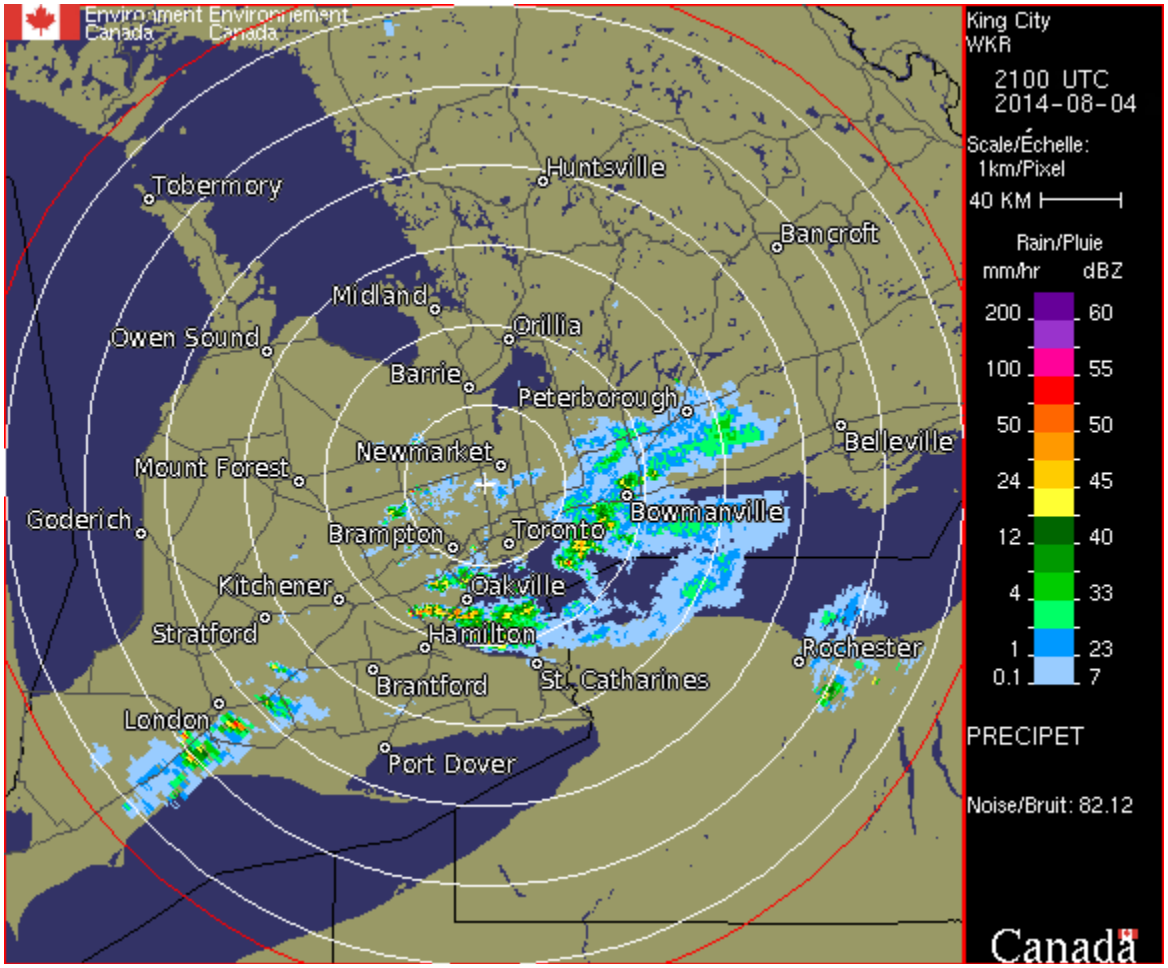
Source: ECCC, 2025c

Appendix Figure F 3: DPQPE Archive King City Radar (August 4, 2014, 1900 UTC)



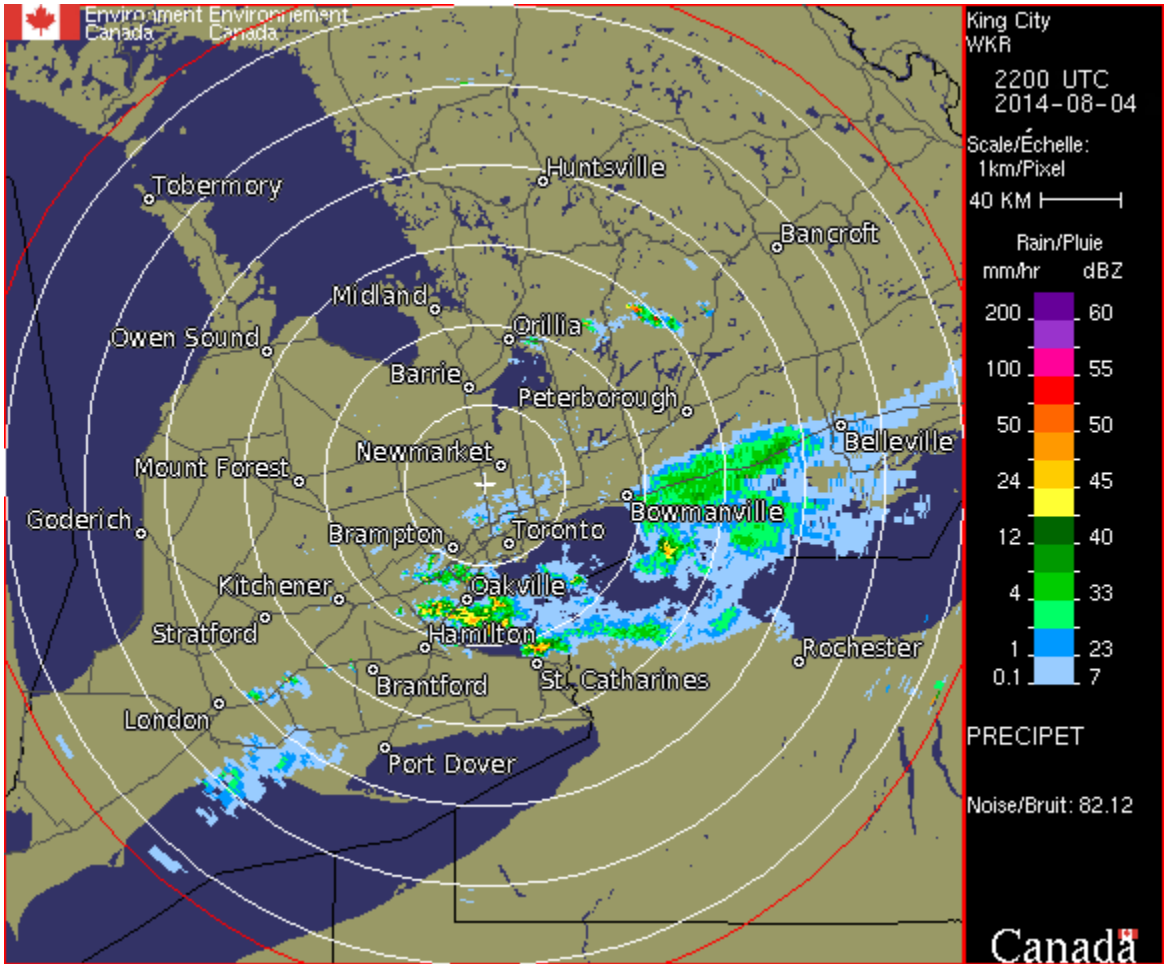
Source: ECCC, 2025c

Appendix Figure F 4: DPQPE Archive King City Radar (August 4, 2014, 2000 UTC)



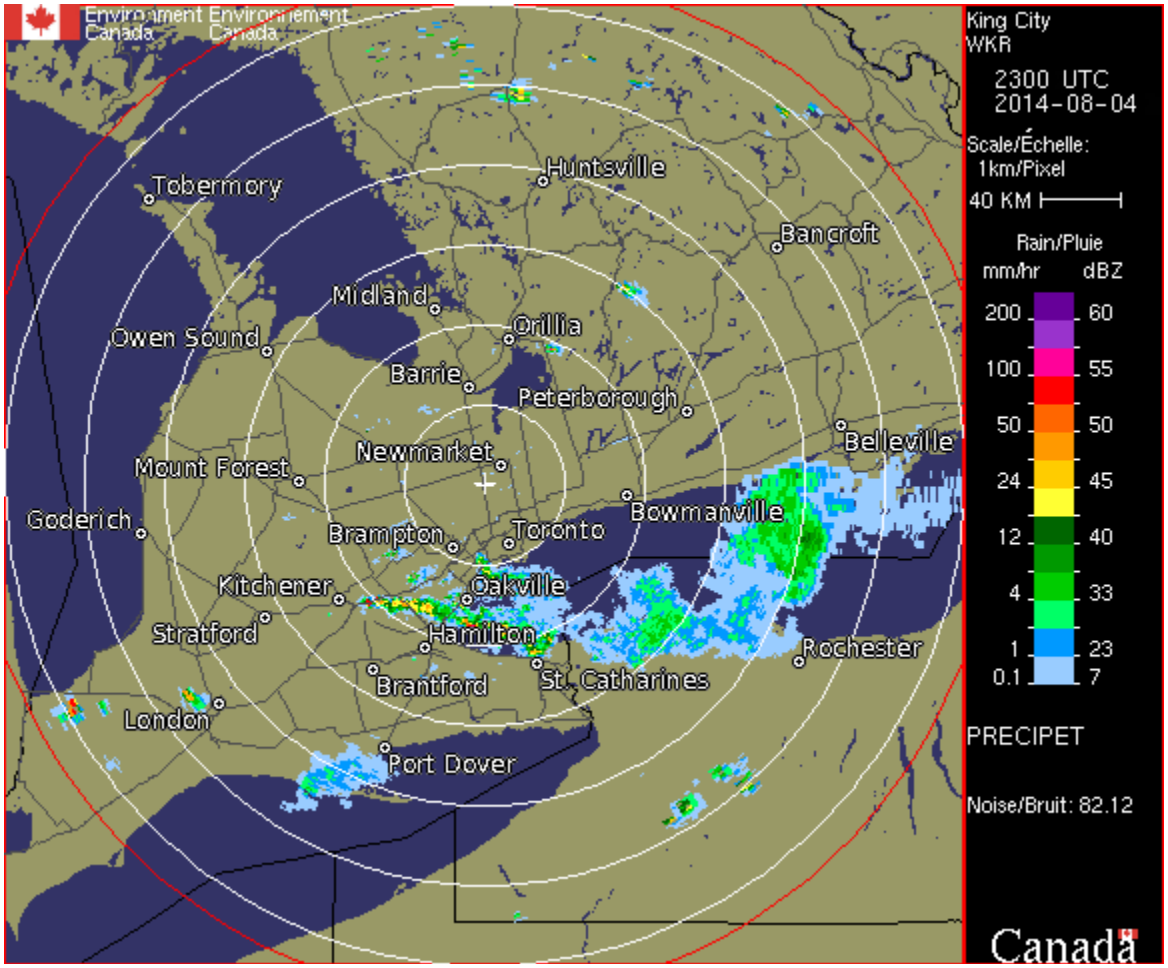
Source: ECCC, 2025c

Appendix Figure F 5: DPQPE Archive King City Radar (August 4, 2014, 2100 UTC)



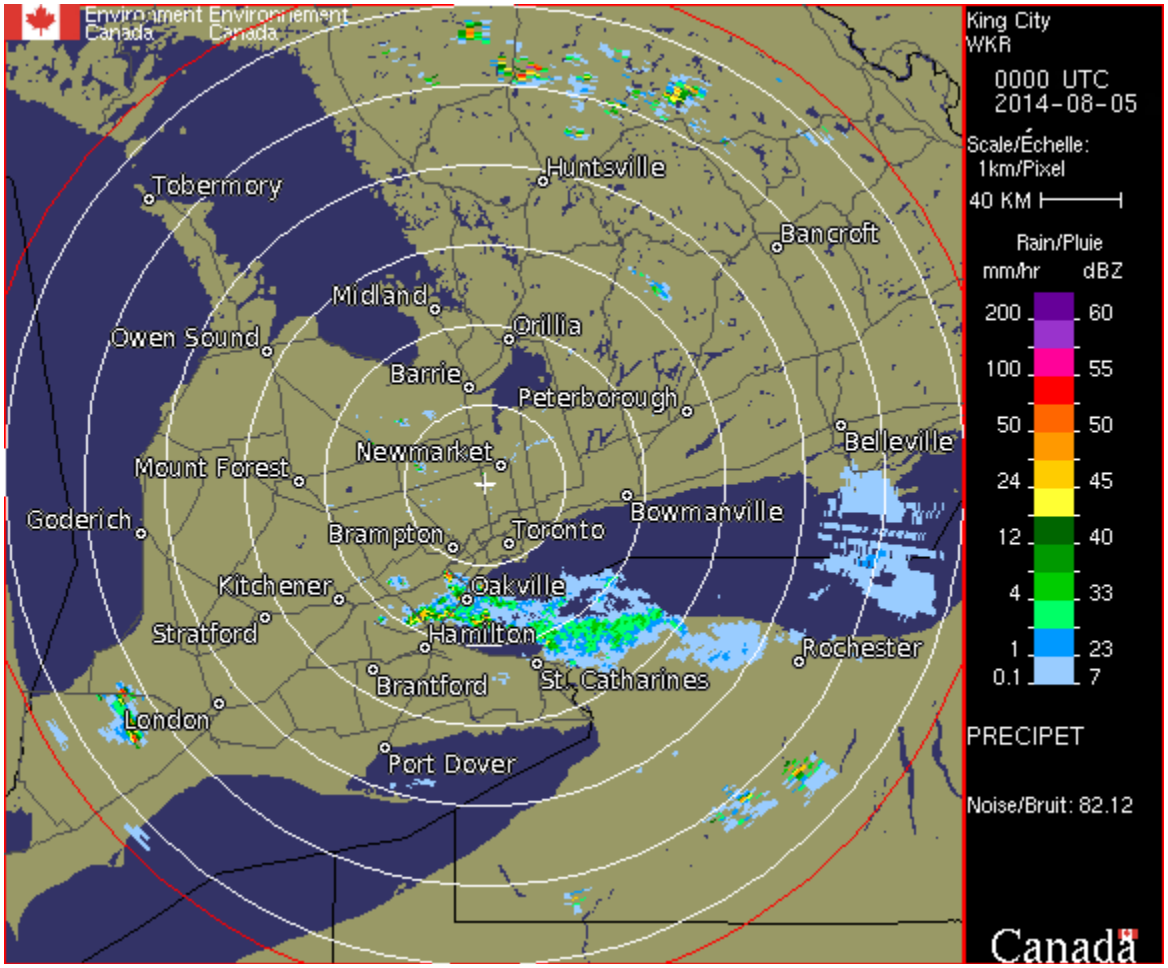
Source: ECCC, 2025c

Appendix Figure F 6: DPQPE Archive King City Radar (August 4, 2014, 2200 UTC)



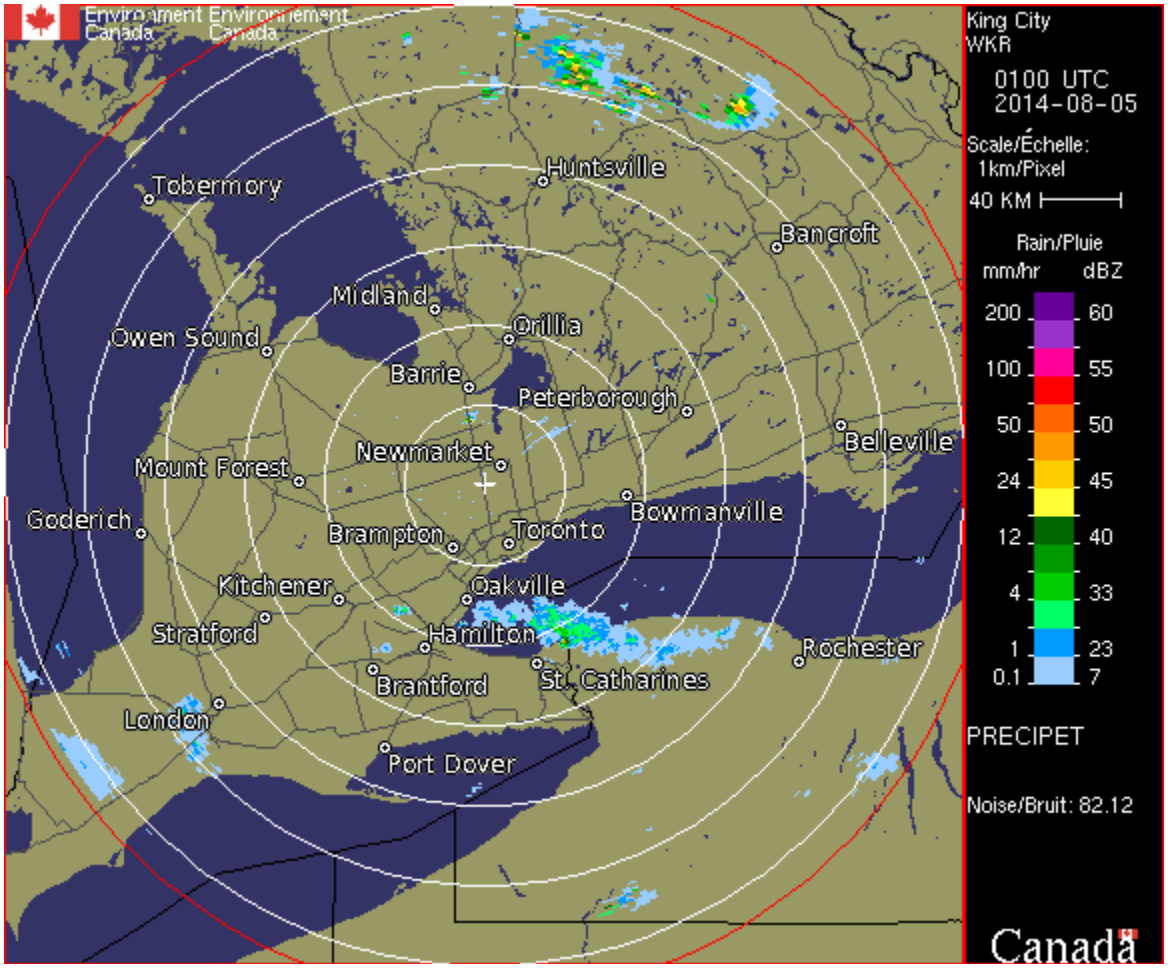
Source: ECCC, 2025c

Appendix Figure F 7: DPQPE Archive King City Radar (August 4, 2014, 2300 UTC)



Source: ECCC, 2025c

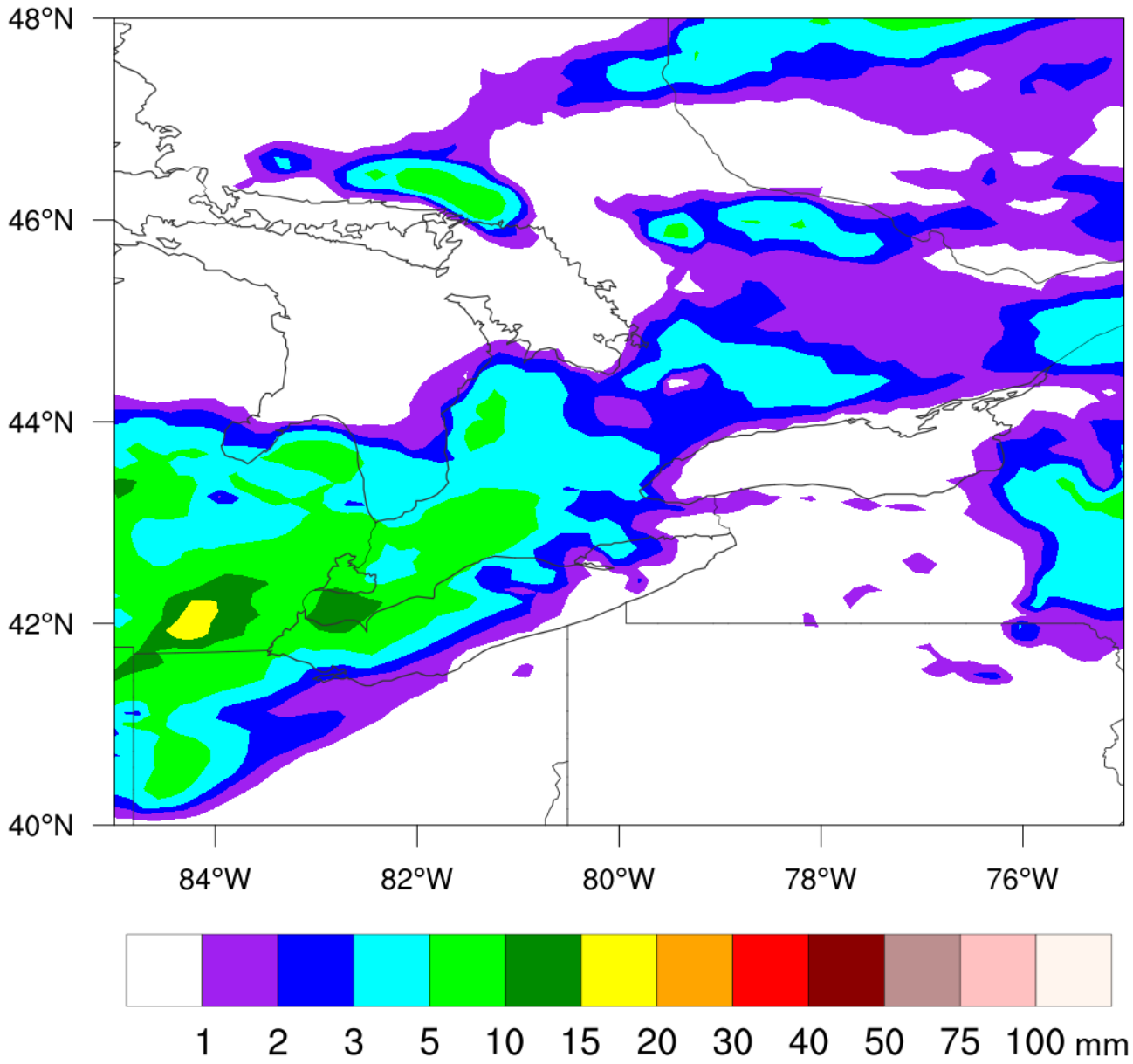
Appendix Figure F 8: DPQPE Archive King City Radar (August 5, 2014, 0000 UTC)



Source: ECCC, 2025c

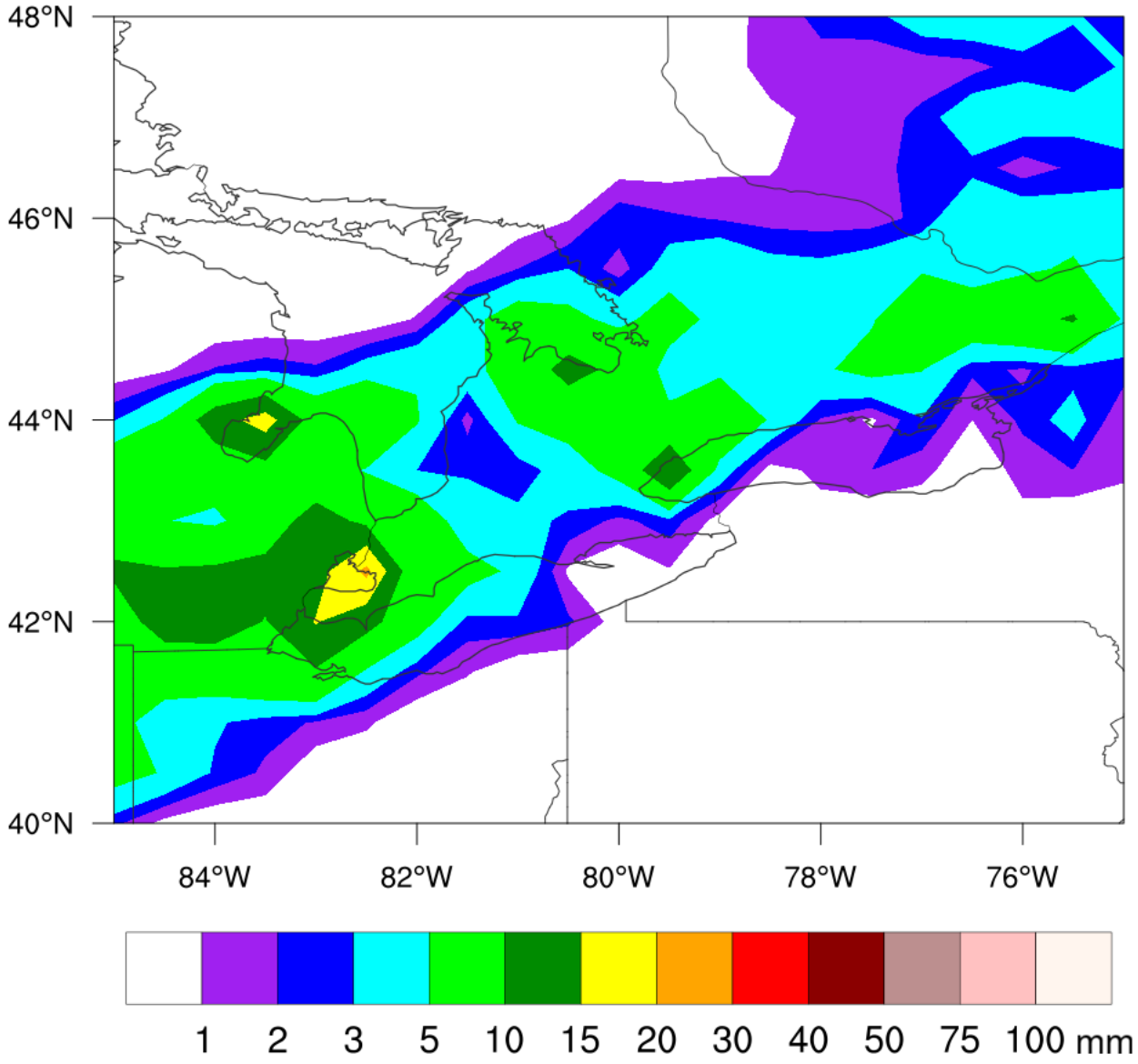
Appendix Figure F 9: DPQPE Archive King City Radar (August 5, 2014, 0100 UTC)

F.1.3 Model Precipitation Maps



Source: NOAA, 2025e

Appendix Figure F 10: 24-hour Precipitation Forecast from August 4, 2014, 12Z to August 5, 2014, 12Z by the NAM Model Initialized August 4, 2014, 12Z

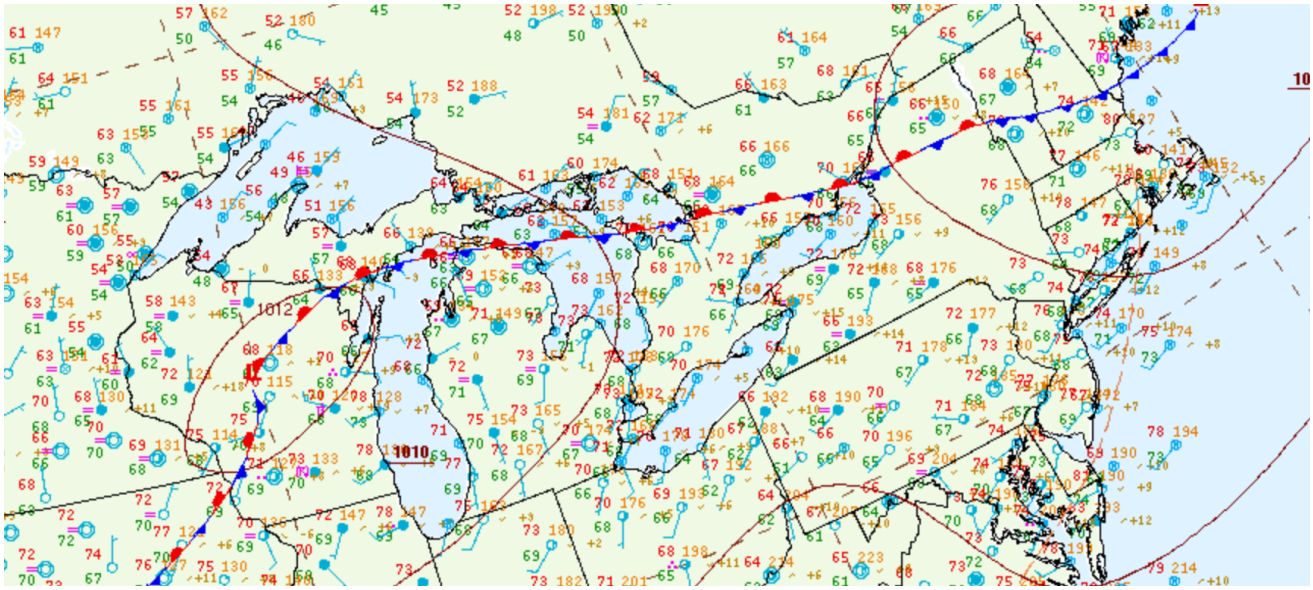


Source: NOAA, 2025d

Appendix Figure F 11: 24-hour Precipitation Forecast from August 4, 2014 12Z to August 5, 2014 12Z by the GFS Model Initialized August 4, 2014 12Z

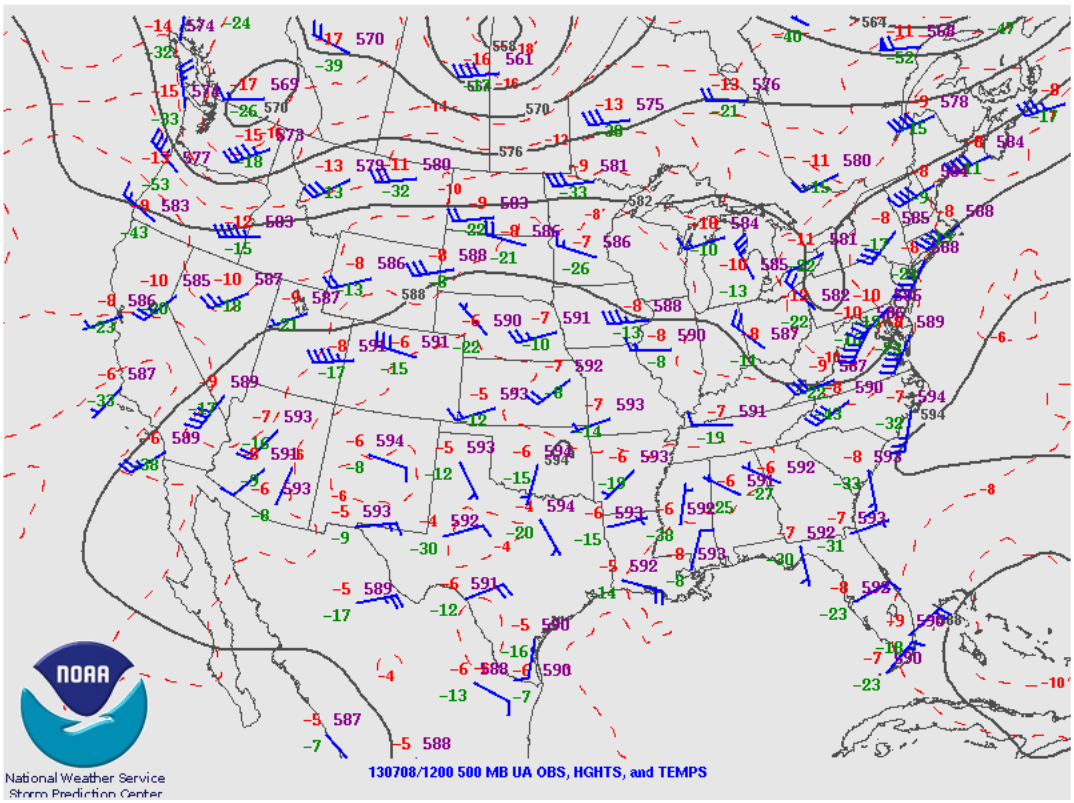
F.2 July 8, 2013

F.2.1 Weather Maps



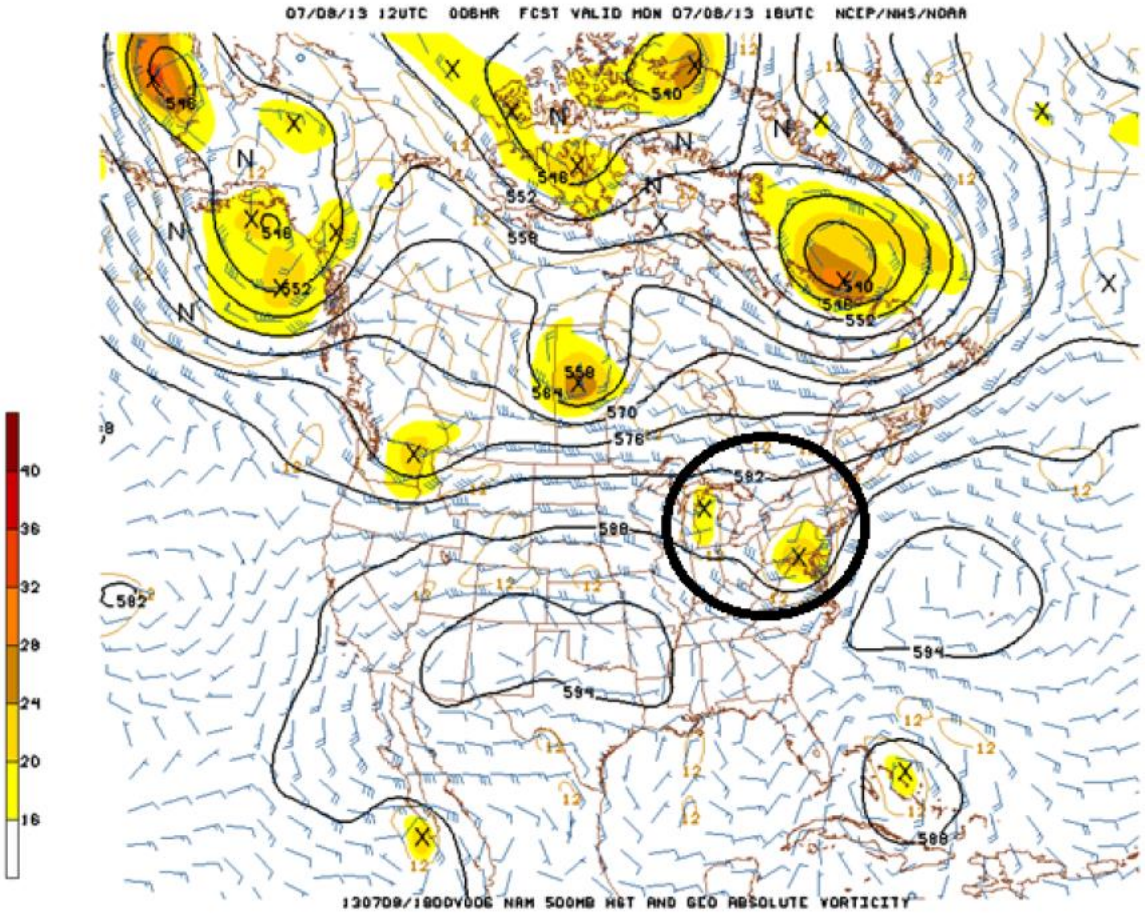
Note: The dark red lines indicate isobars, the red lines indicate warm front, and the blue lines indicate cold front.
Source: Weather Prediction Center, 2022

Appendix Figure F 12: Surface Map (July 8, 2013, 12Z)



Source: Storm Prediction Center, 2025b

Appendix Figure F 13: 500-hPa Map (July 8, 2013, 12Z)

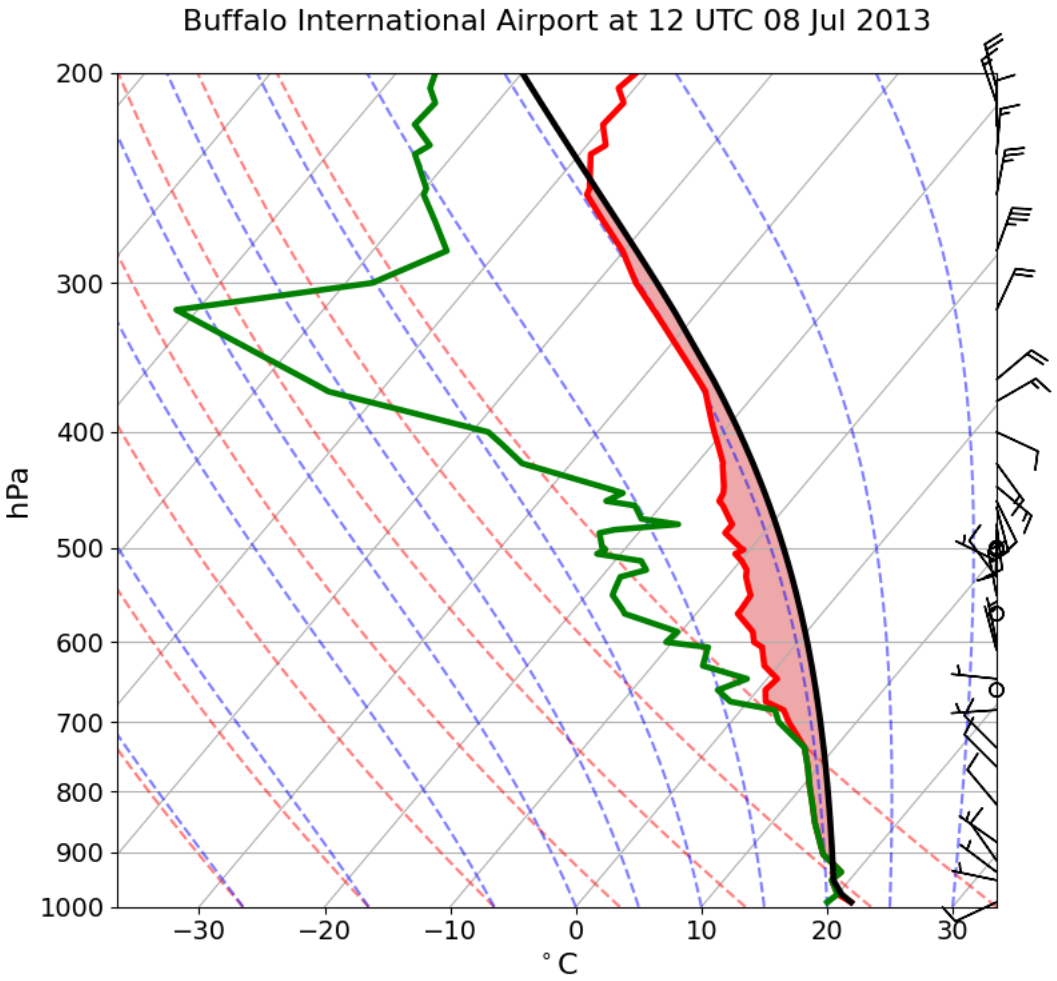


Note: *The black circle highlights the upper-level trough passing over the GTA, and two regions of positive vorticity (counterclockwise rotation) are shown in yellow with the vorticity centres shown with an "X".*

Source: *AMEC, 2014*

Appendix Figure F 14: 6-hour NAM Model Forecast 500-hPa Map valid at July 8, 2013, 18Z with the NAM Initialized July 8, 2013, 12Z

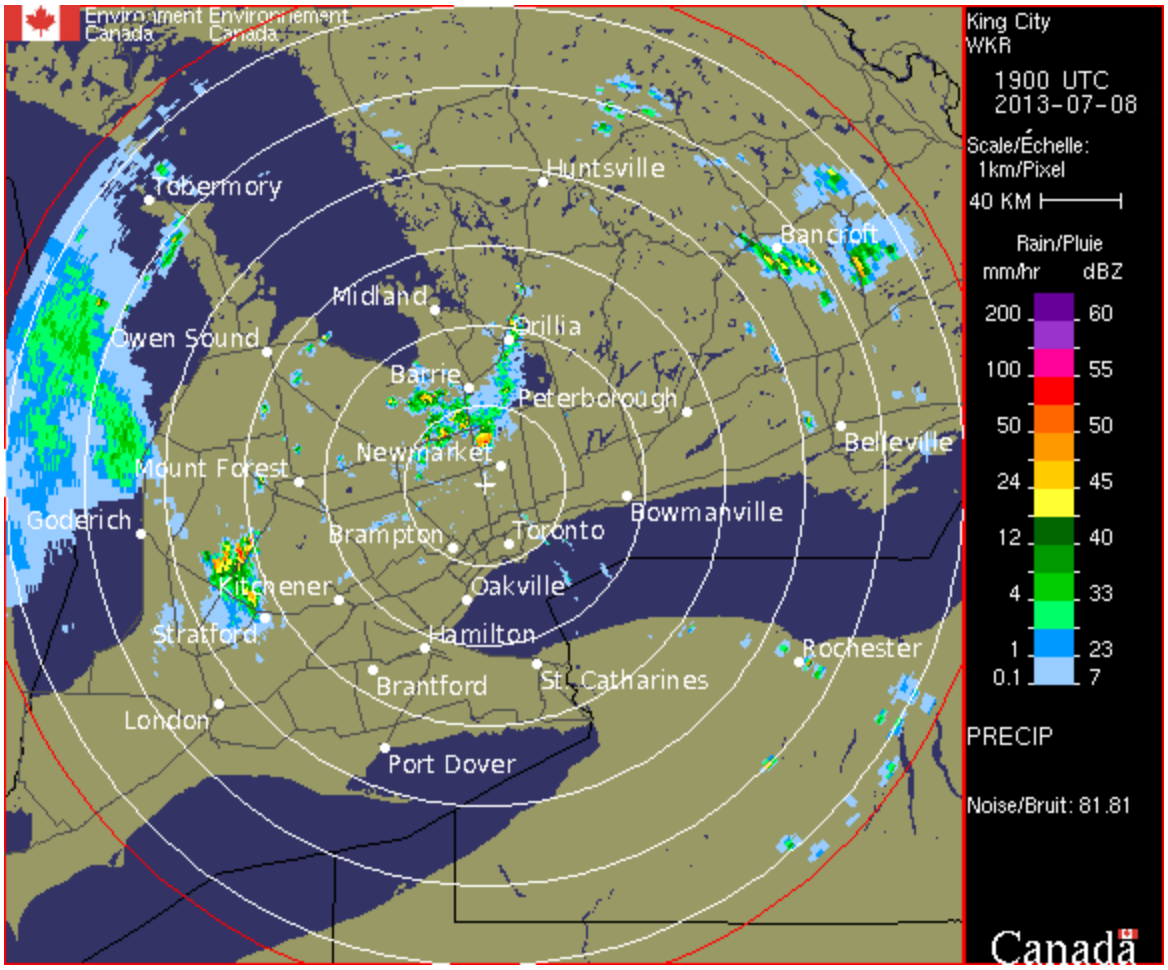
F.2.2 Tephigram Soundings



Note: The fuchsia area indicates the Convective Available Potential Energy (CAPE).
Source: University of Wyoming, 2025

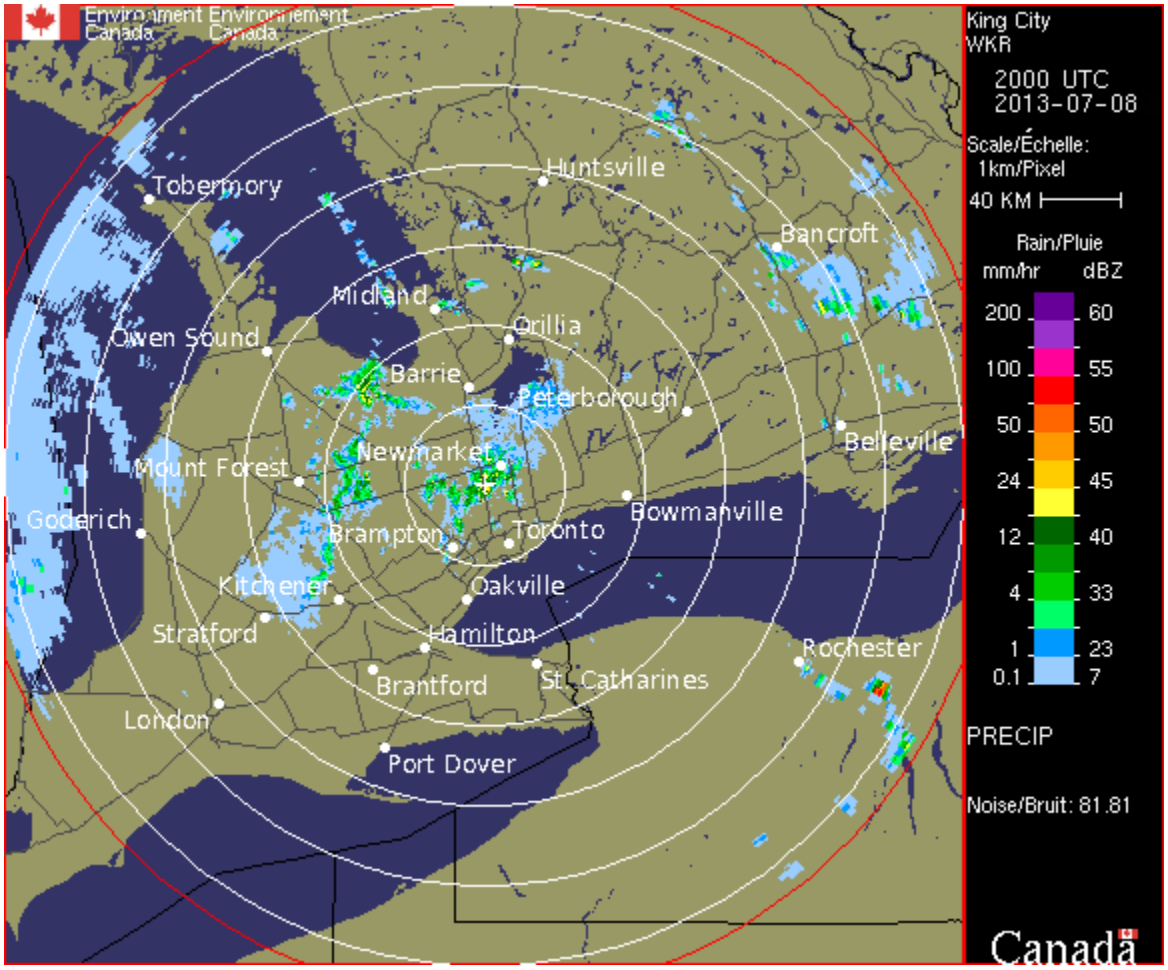
Appendix Figure F 15: Tephigram Sounding at the Buffalo/Greater Buffalo International Radiosonde Site (July 8, 2013, 12Z)

F.2.3 Radar Images



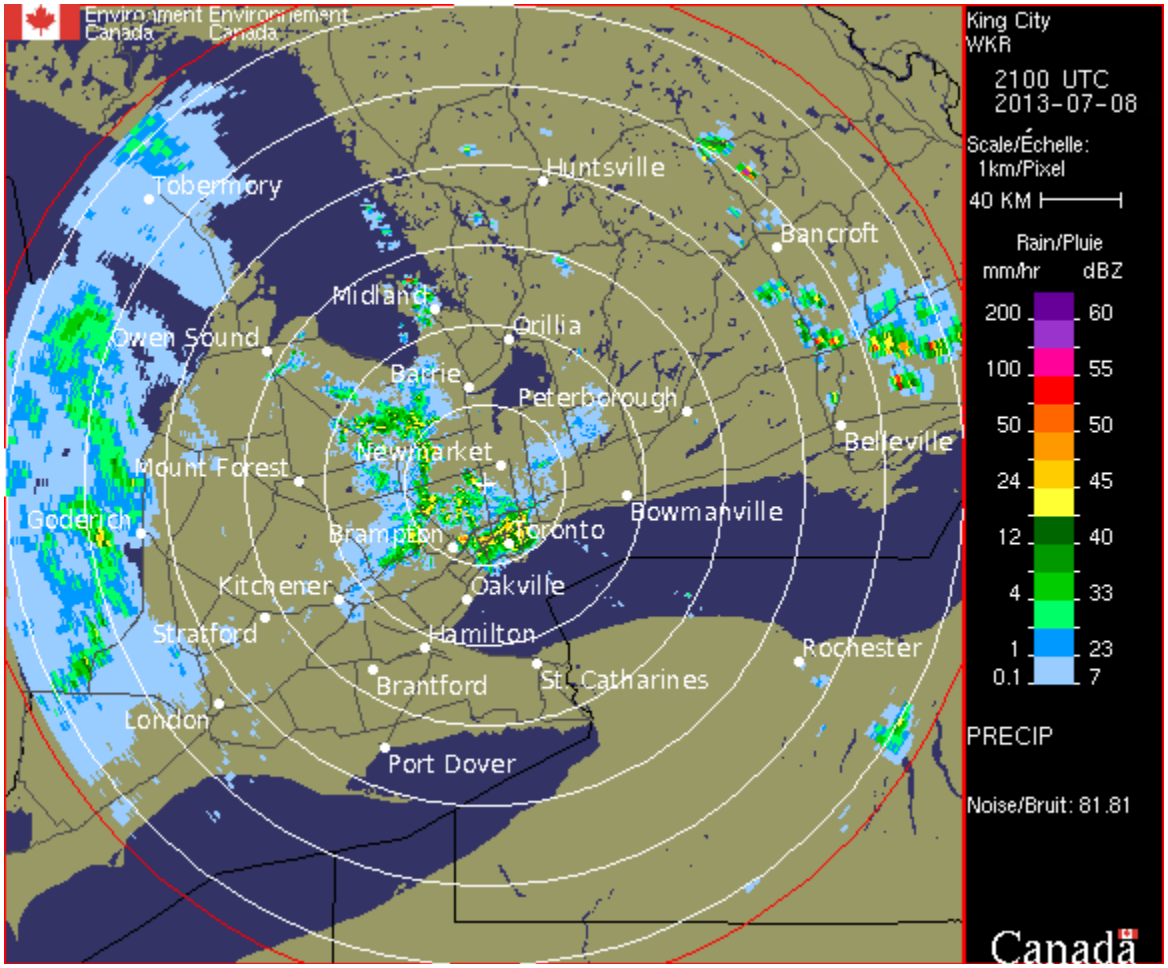
Source: ECCC, 2025c

Appendix Figure F 16: DPQPE Archive King City Radar (July 8, 2013, 1900 UTC)



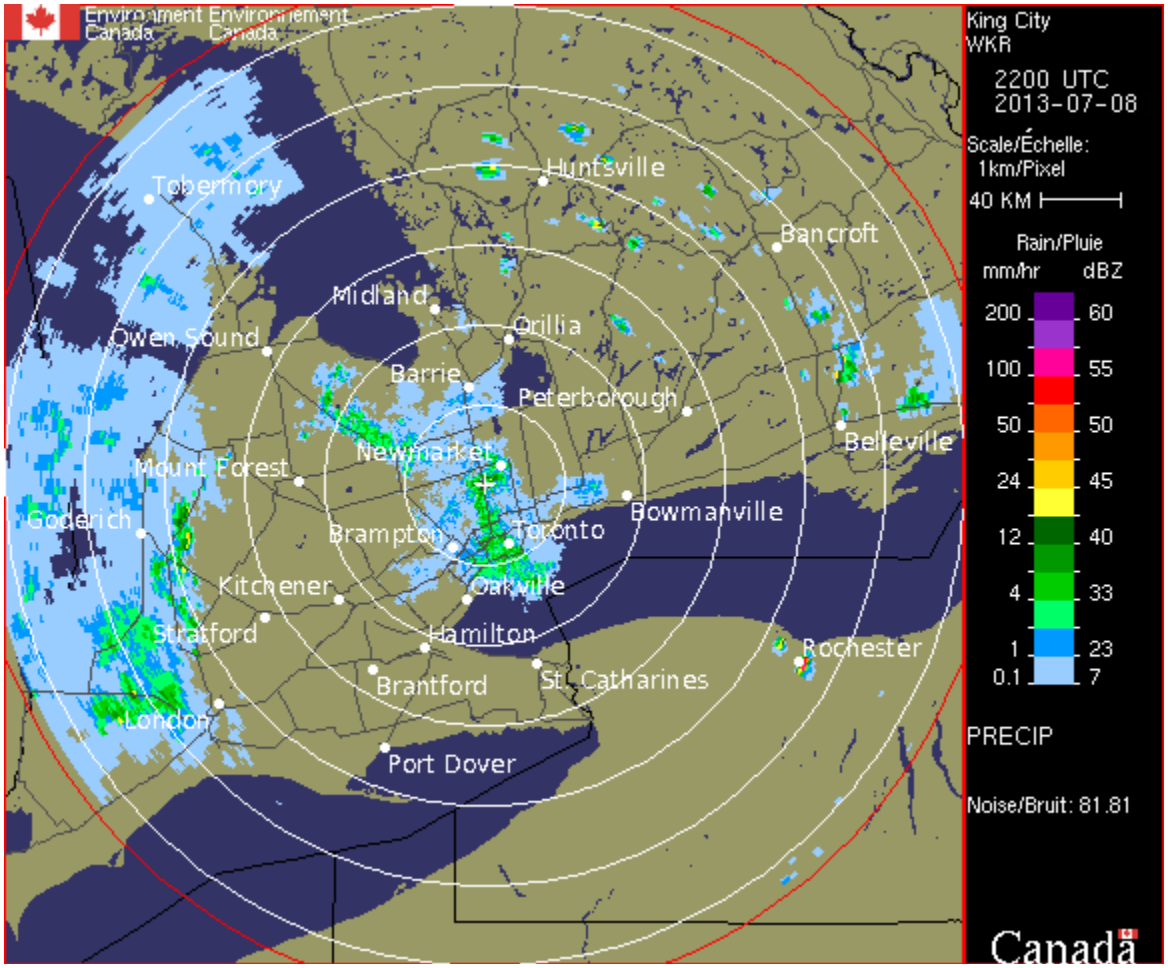
Source: ECCC, 2025c

Appendix Figure F 17: DPQPE Archive King City Radar (July 8, 2013, 2000 UTC)



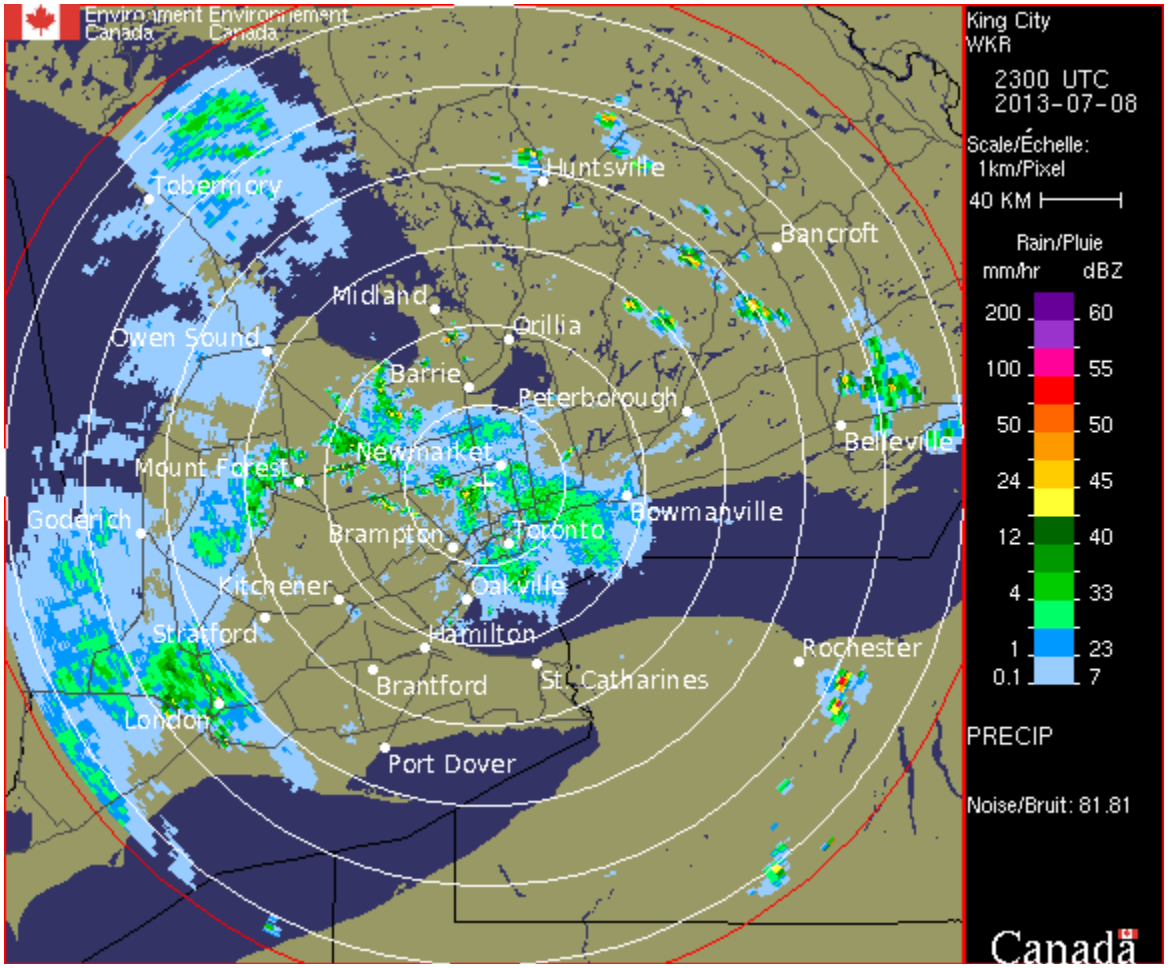
Source: ECCC, 2025c

Appendix Figure F 18: DPQPE Archive King City Radar (July 8, 2013, 2100 UTC)



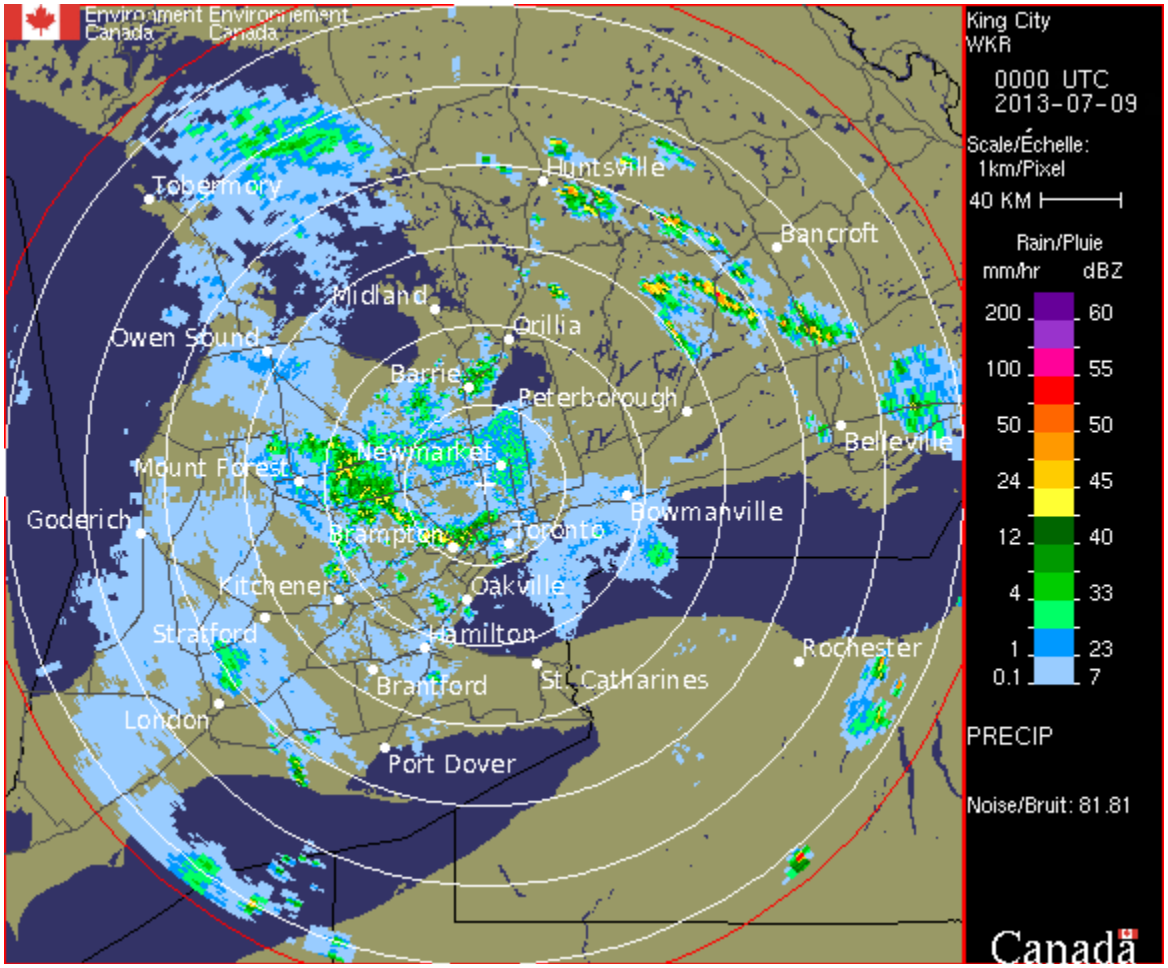
Source: ECCC, 2025c

Appendix Figure F 19: DPQPE Archive King City Radar (July 8, 2013, 2200 UTC)



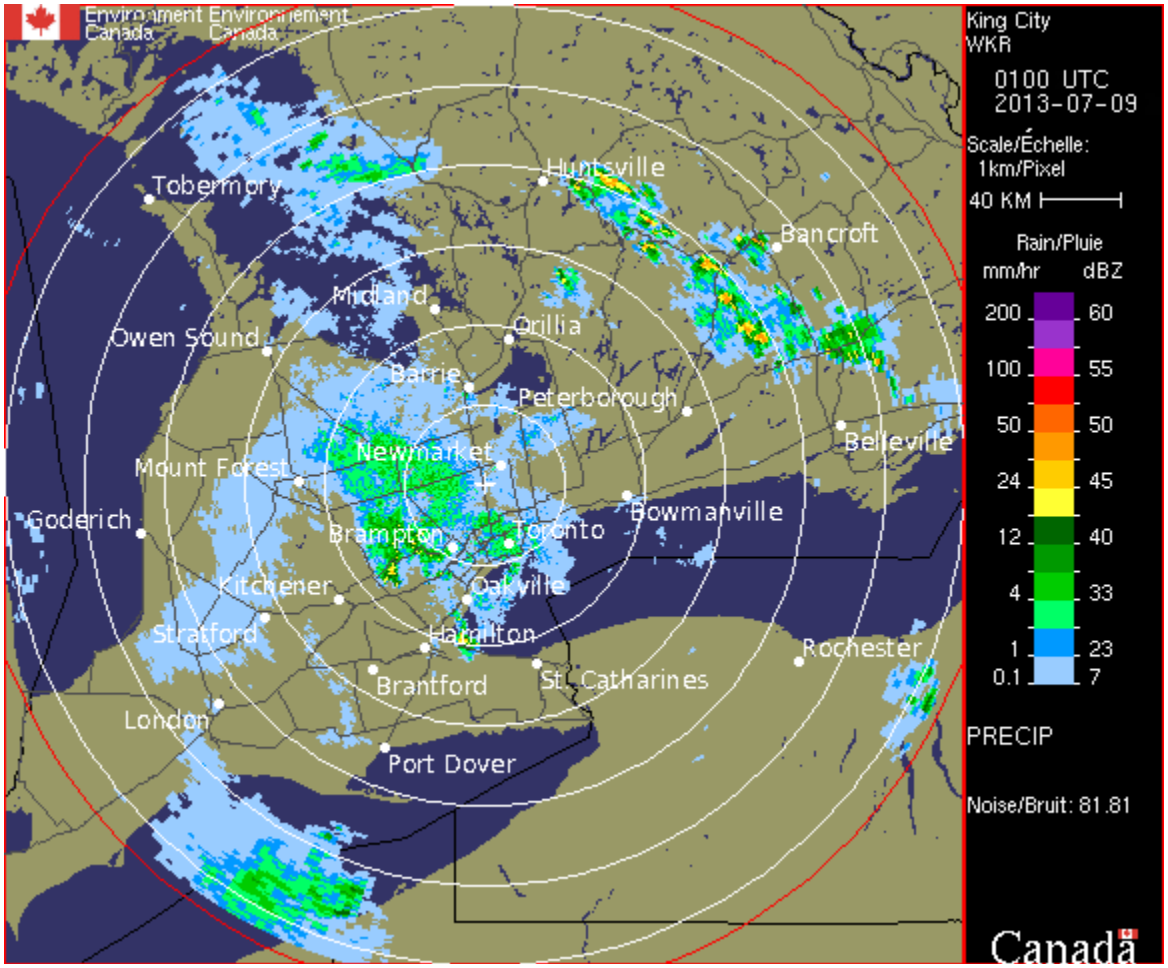
Source: ECCC, 2025c

Appendix Figure F 20: DPQPE Archive King City Radar (July 8, 2013, 2300 UTC)



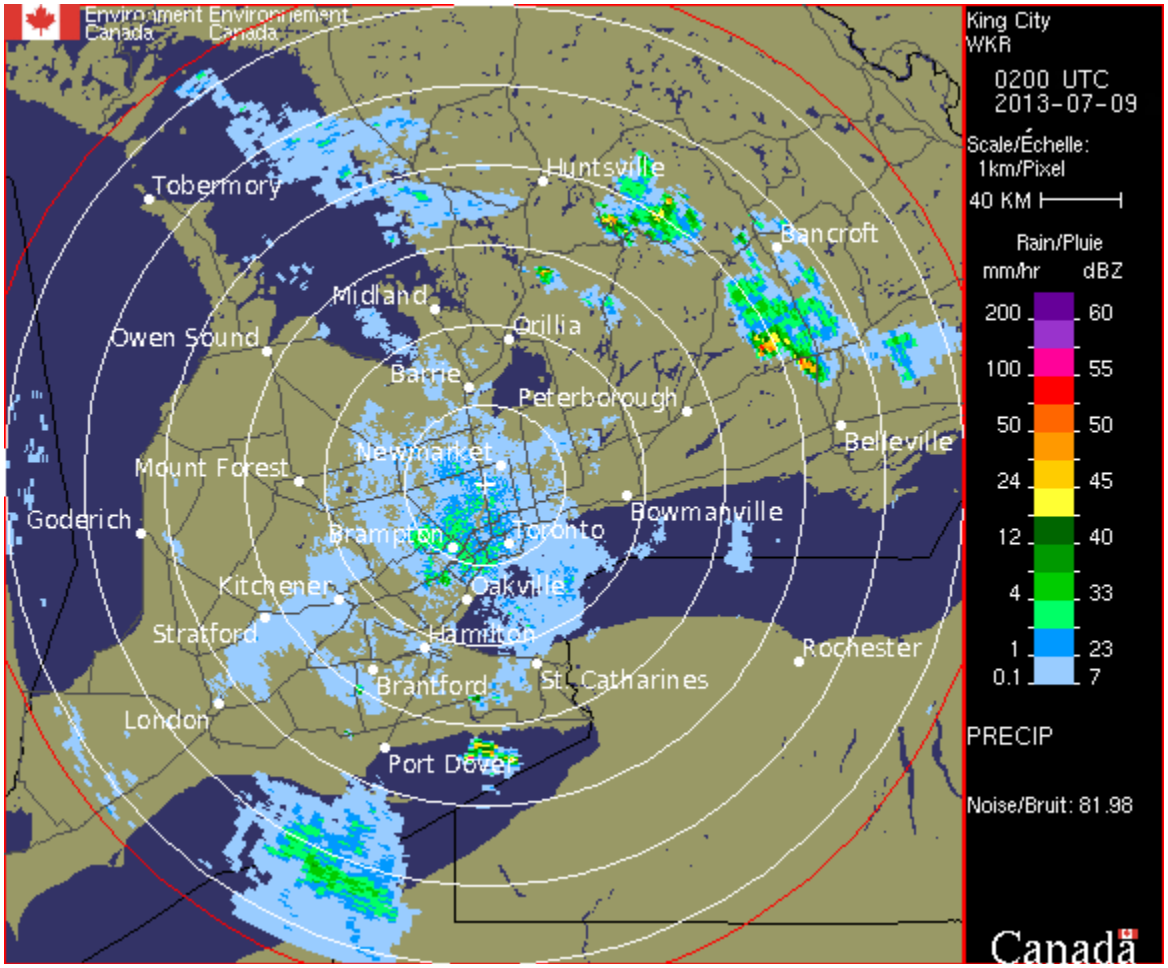
Source: ECCC, 2025c

Appendix Figure F 21: DPQPE Archive King City Radar (July 9, 2013, 0000 UTC)



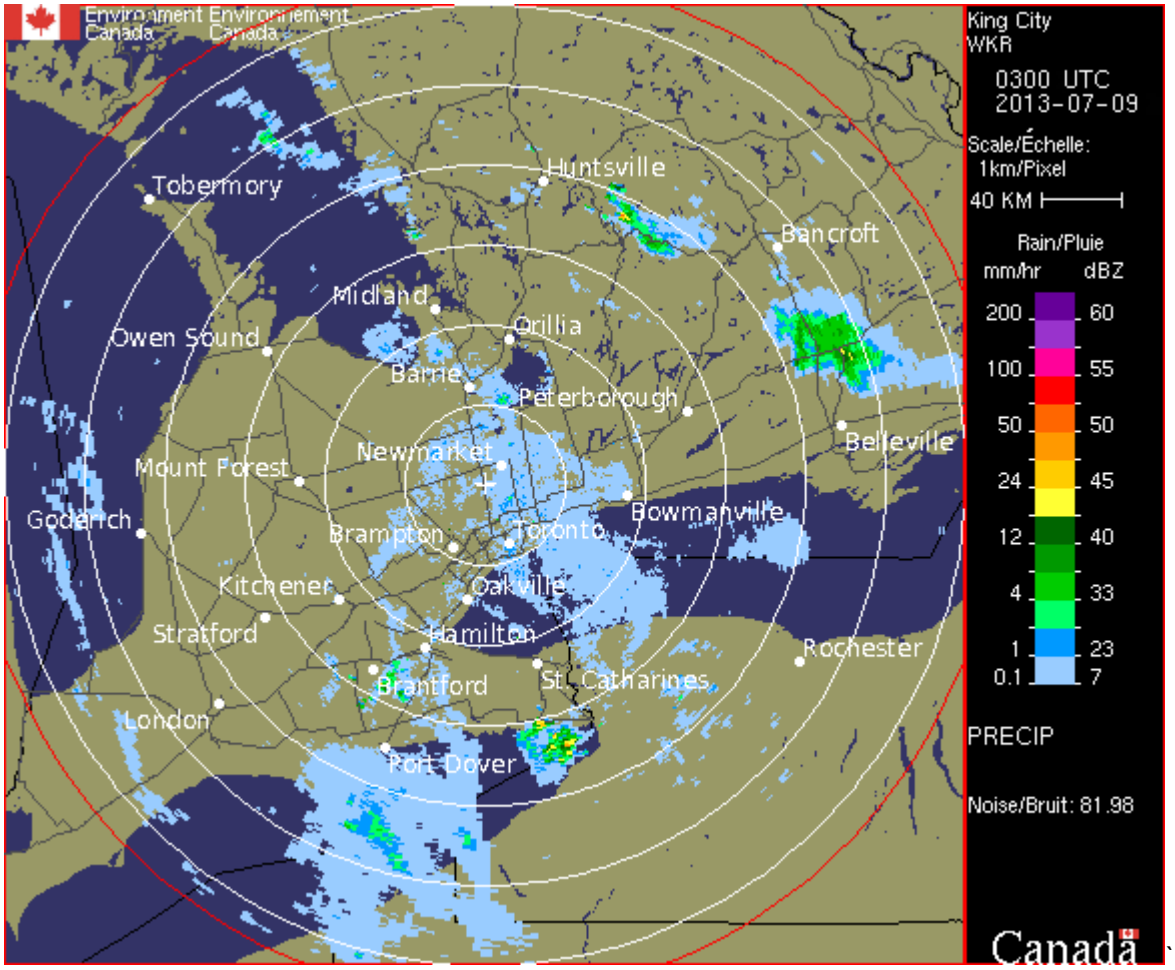
Source: ECCC, 2025c

Appendix Figure F 22: DPQPE Archive King City Radar (July 9, 2013, 0100 UTC)



Source: ECCC, 2025c

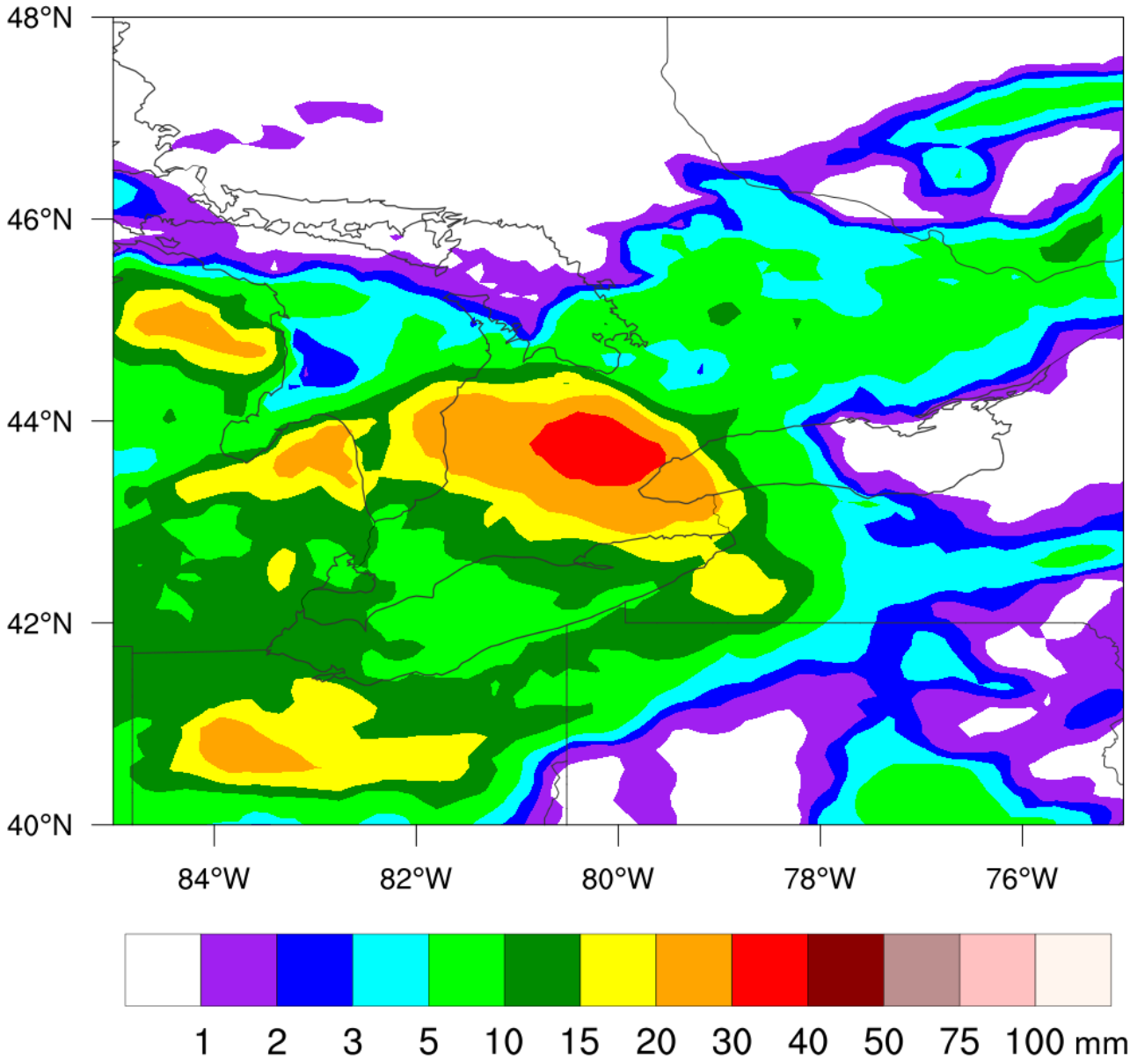
Appendix Figure F 23: DPQPE Archive King City Radar (July 9, 2013, 0200 UTC)



Source: ECCC, 2025c

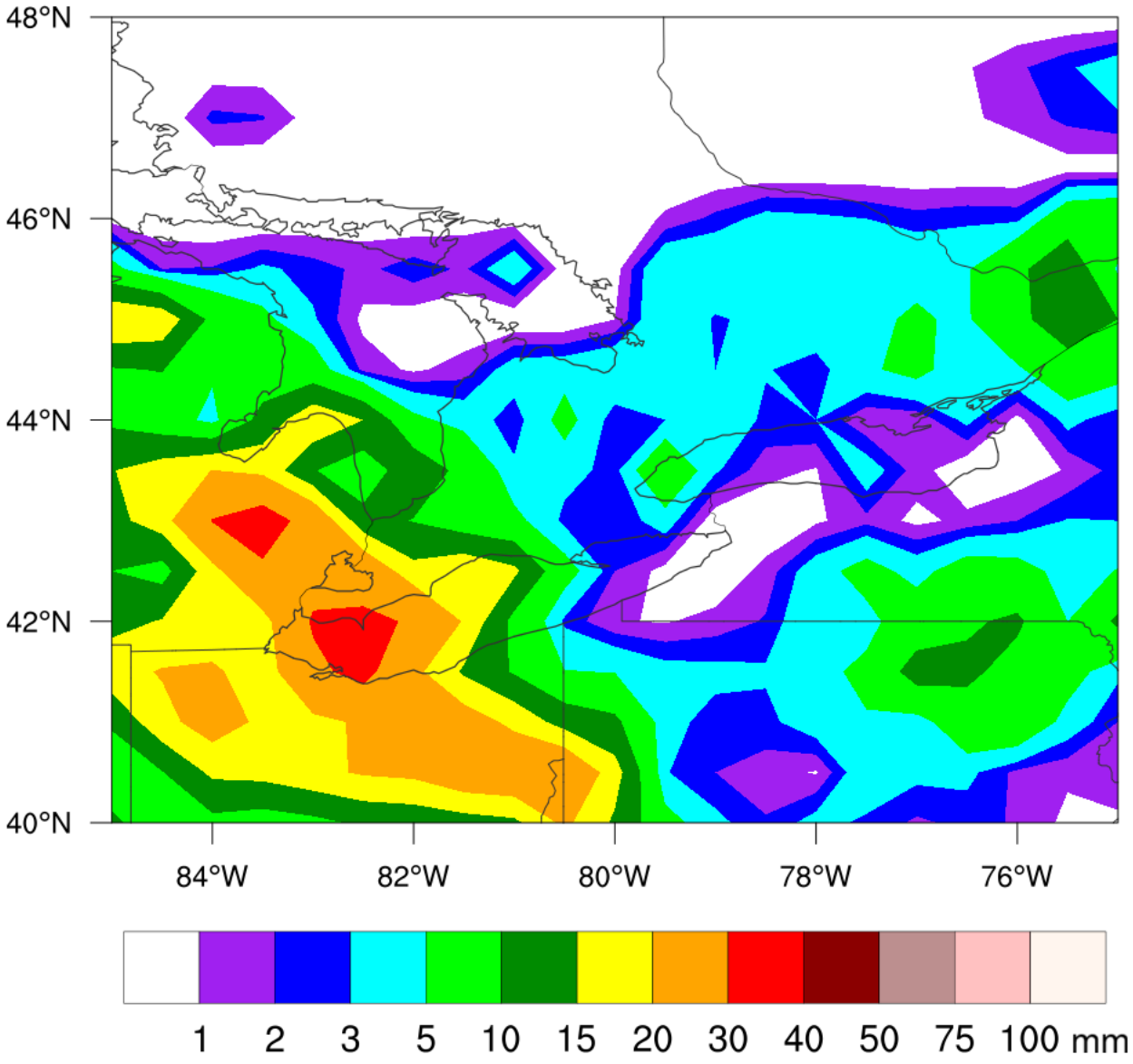
Appendix Figure F 24: DPQPE Archive King City Radar (July 9, 2013, 0300 UTC)

F.2.4 Model Precipitation Maps



Source: NOAA, 2025e

Appendix Figure F 25: 24-hour Precipitation Forecast from July 8, 2013, 12Z to July 9, 2013, 12Z by the NAM Model Initialized July 8, 2013, 12Z

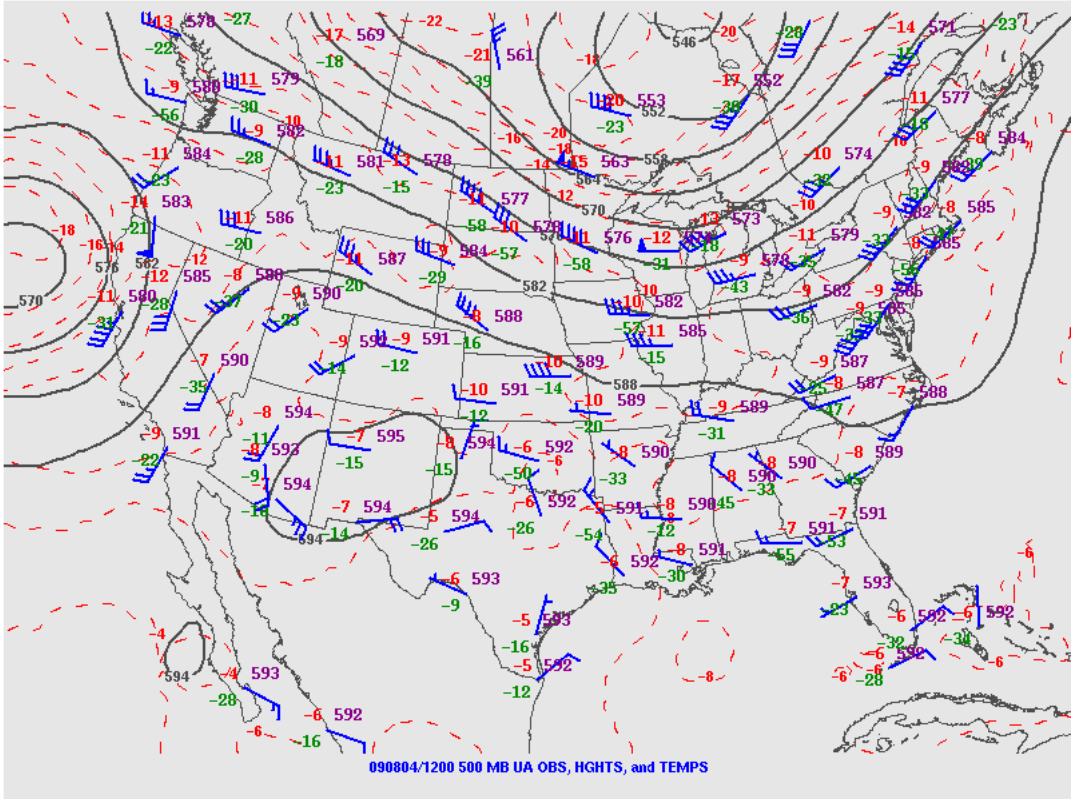


Source: NOAA, 2025d

Appendix Figure F 26: 24-hour Precipitation Forecast from July 8, 2013, 12Z to July 9, 2013, 12Z by the GFS Model Initialized July 8, 2013, 12Z

F.3 August 4, 2009

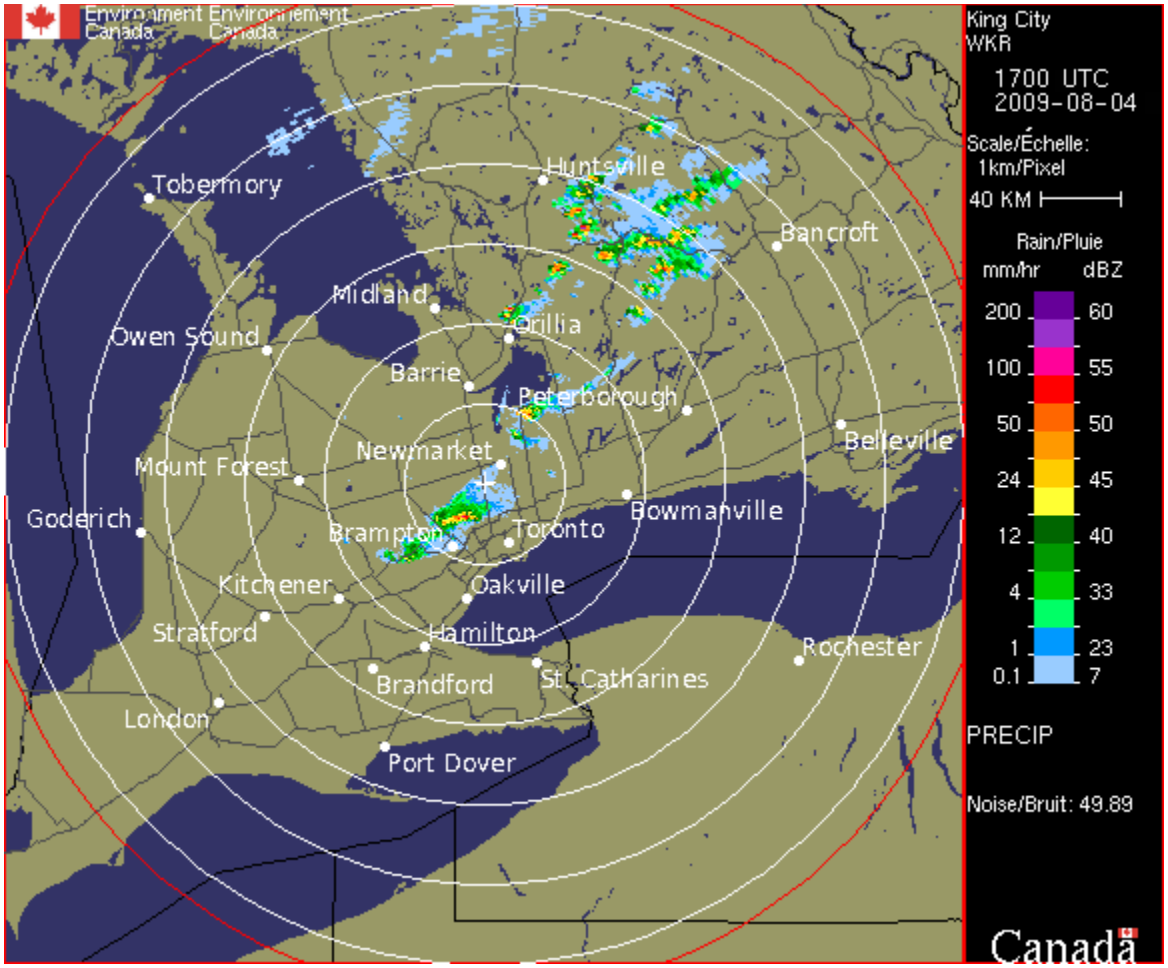
F.3.1 Weather Maps



Source: Storm Prediction Center, 2025b

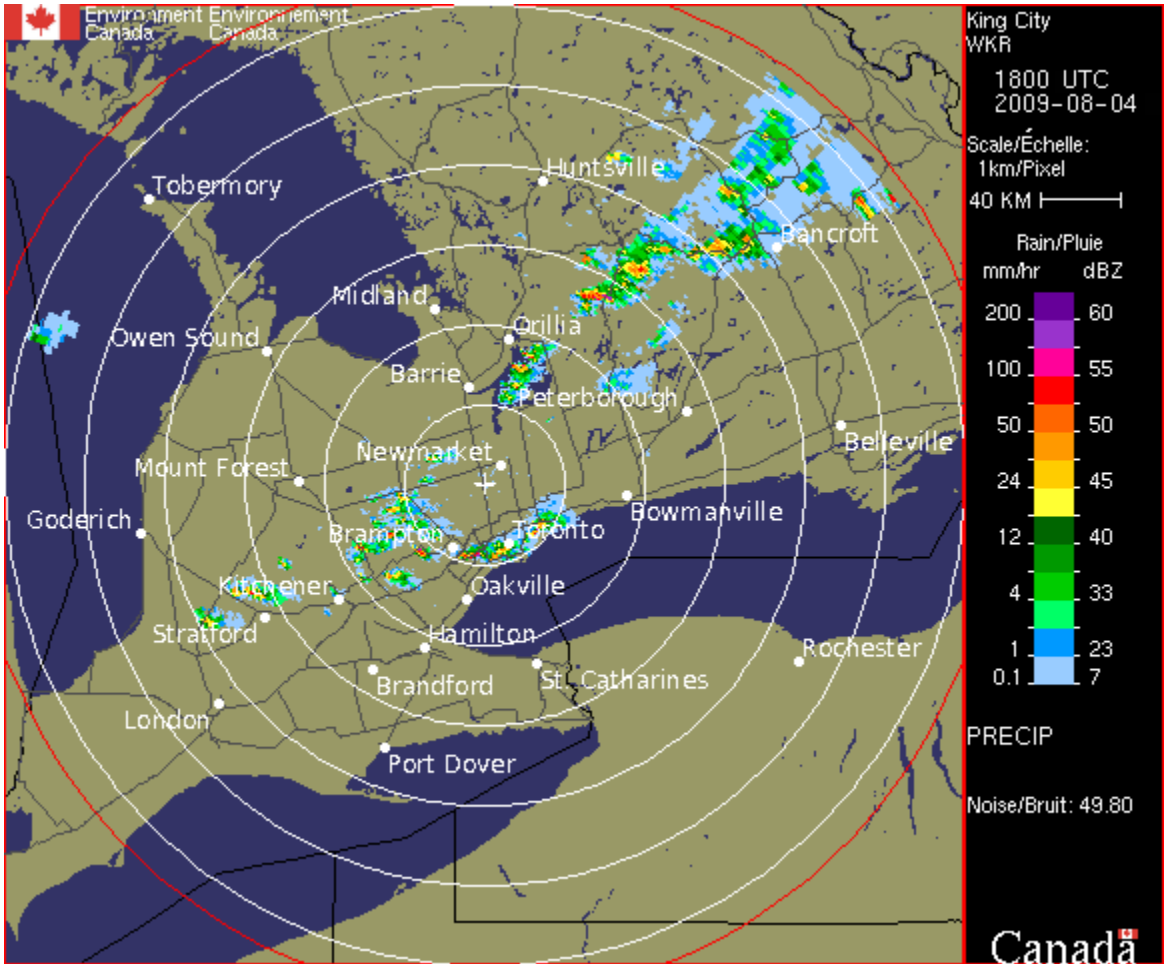
Appendix Figure F 27: 500-hPa Map (August 4, 2009, 12Z)

F.3.2 Radar Images



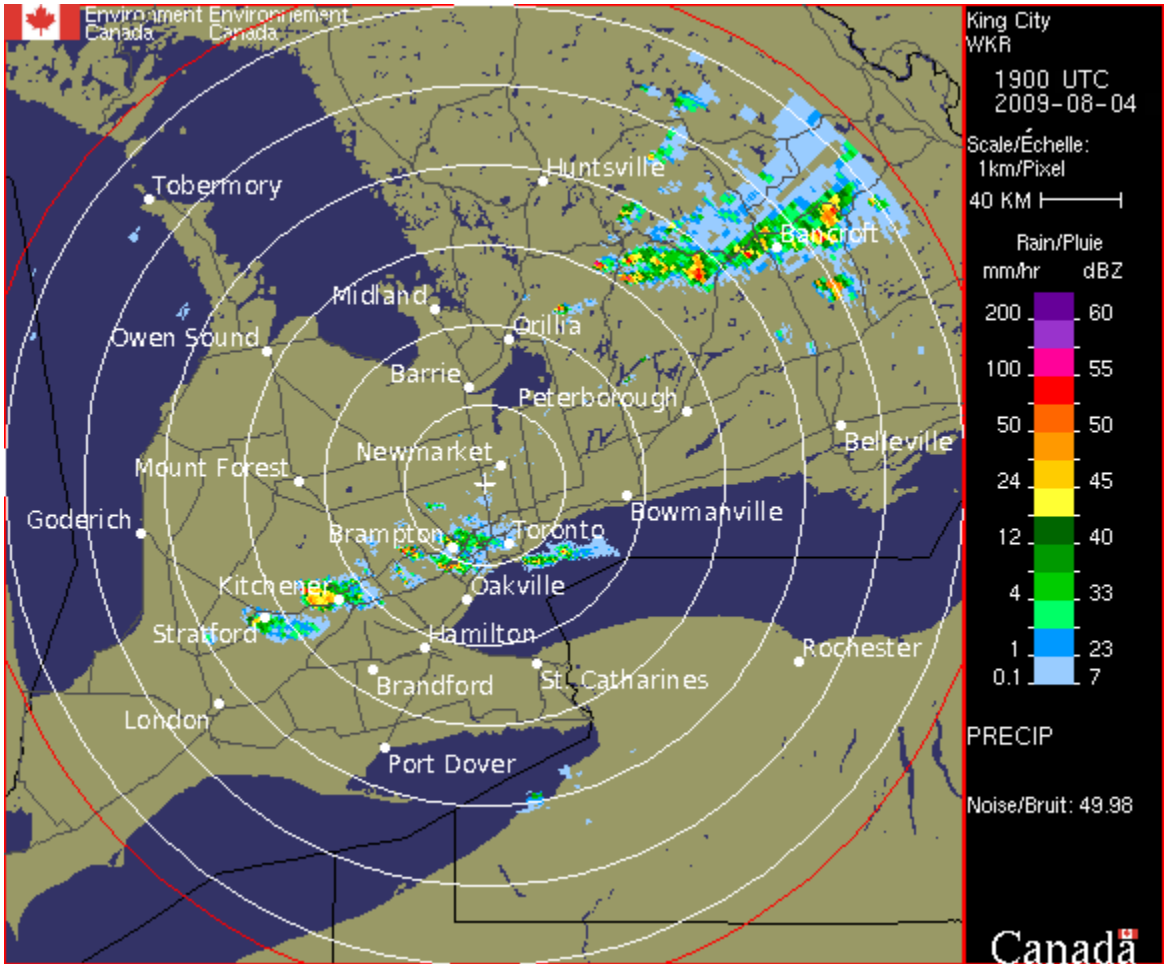
Source: ECCC, 2025c

Appendix Figure F 28: DPQPE Archive King City Radar (August 4, 2009, 1700 UTC)



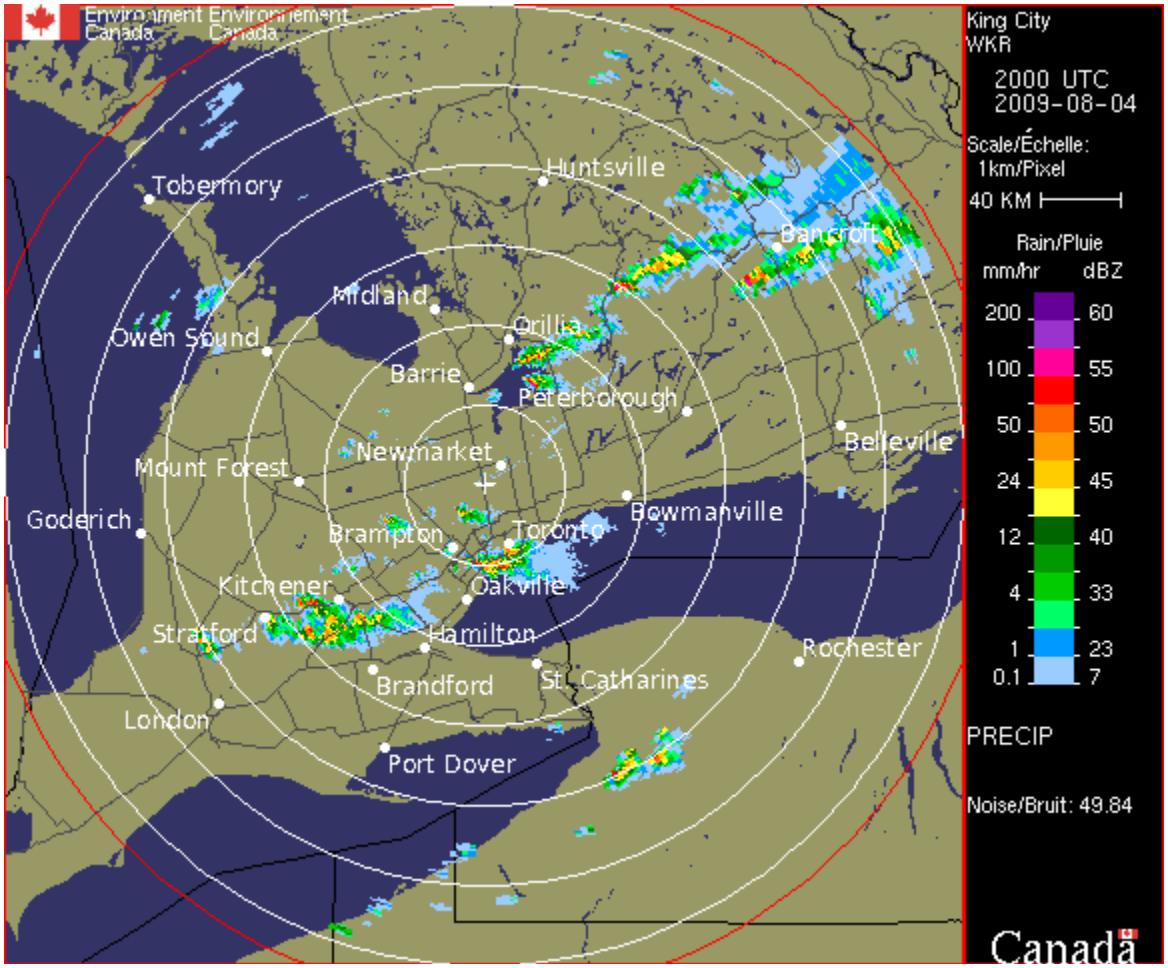
Source: ECCC, 2025c

Appendix Figure F 29: DPQPE Archive King City Radar (August 4, 2009, 1800 UTC)



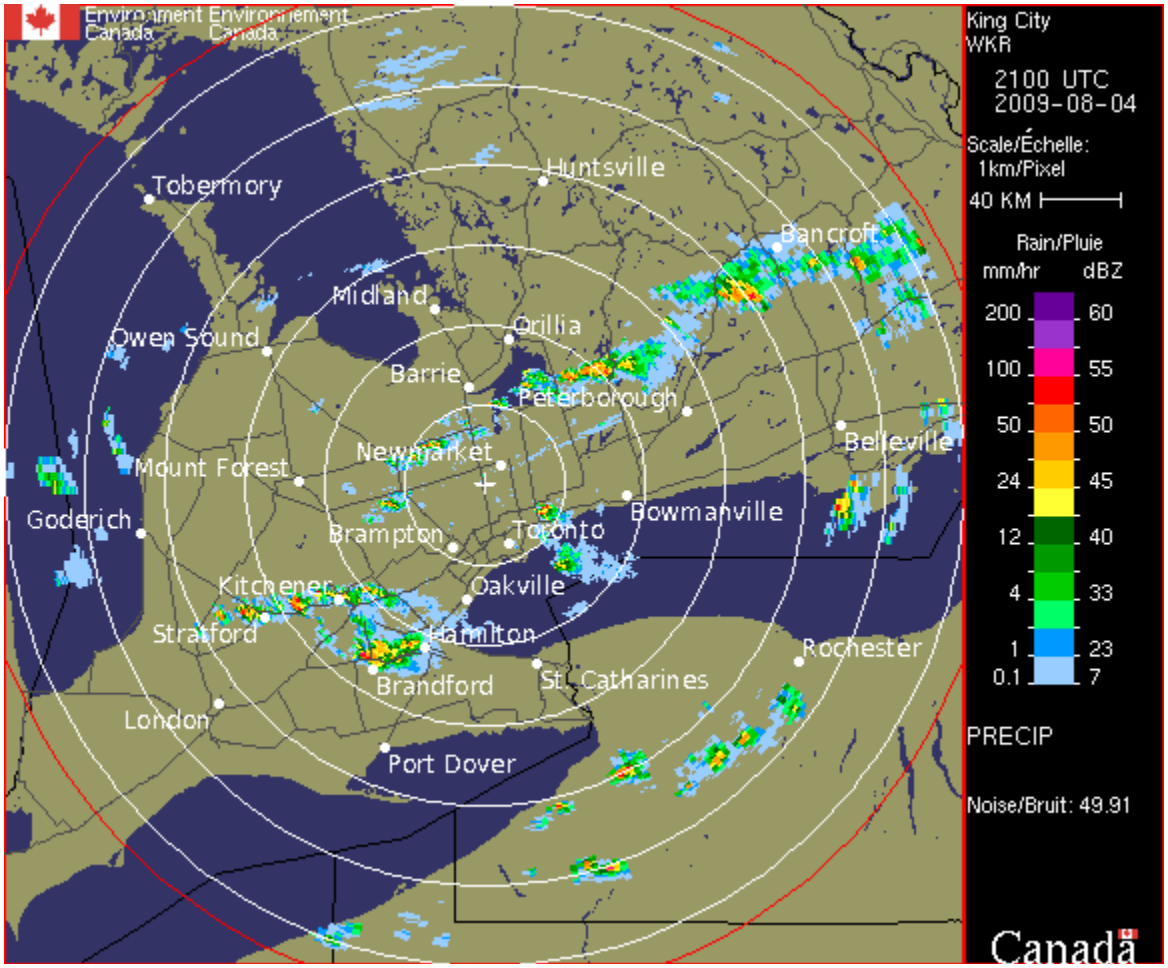
Source: ECCC, 2025c

Appendix Figure F 30: DPQPE Archive King City Radar (August 4, 2009, 1900 UTC)



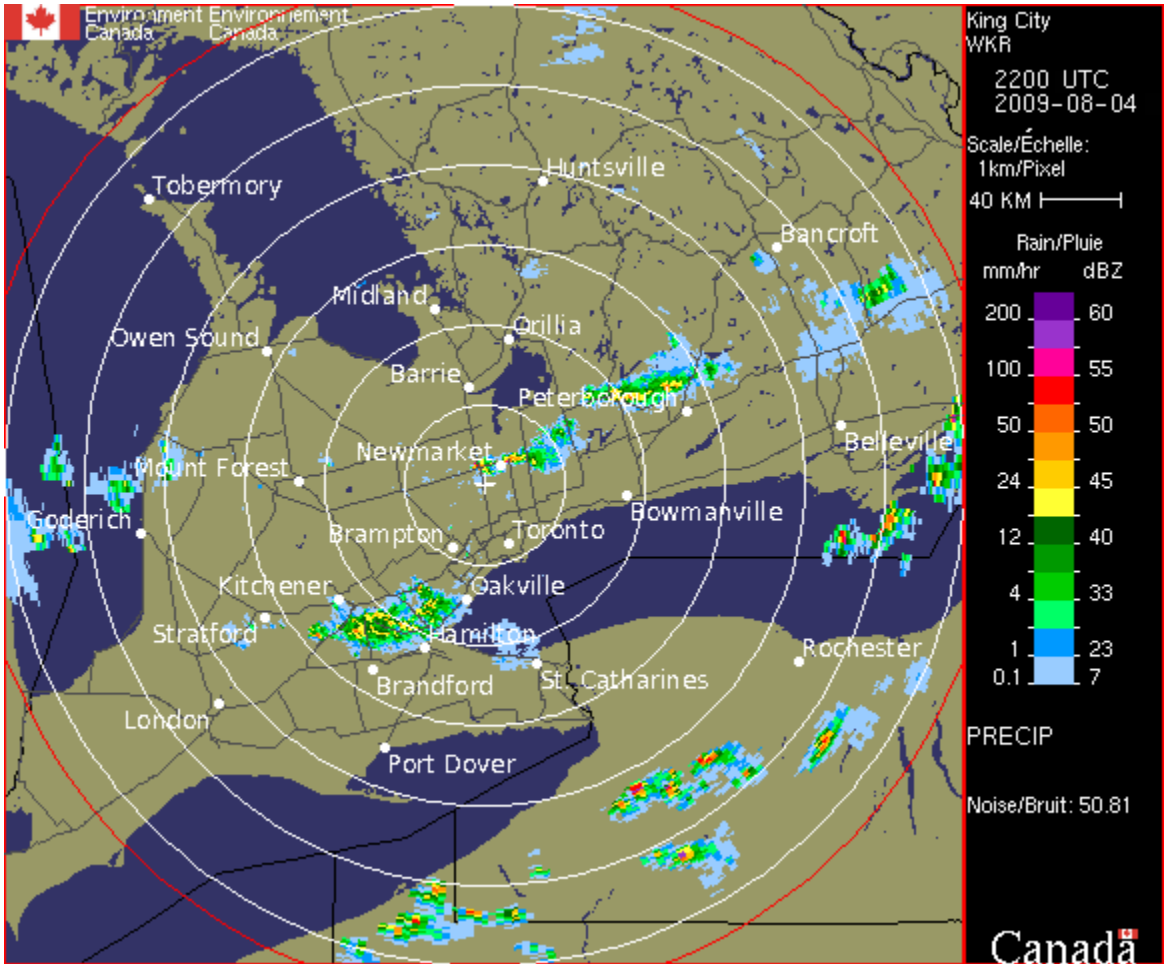
Source: ECCC, 2025c

Appendix Figure F 31: DPQPE Archive King City Radar (August 4, 2009, 2000 UTC)



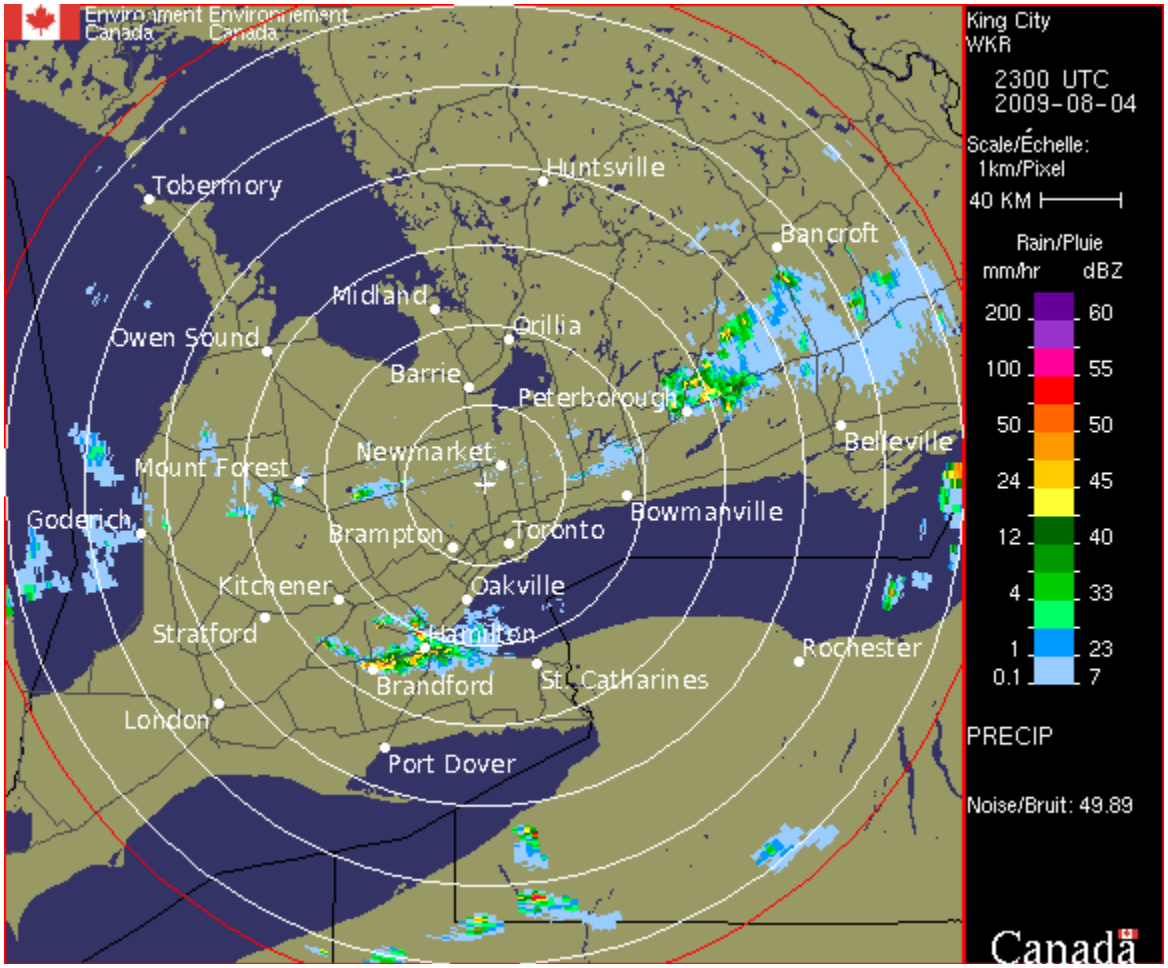
Source: ECCC, 2025c

Appendix Figure F 32: DPQPE Archive King City Radar (August 4, 2009, 2100 UTC)



Source: ECCC, 2025c

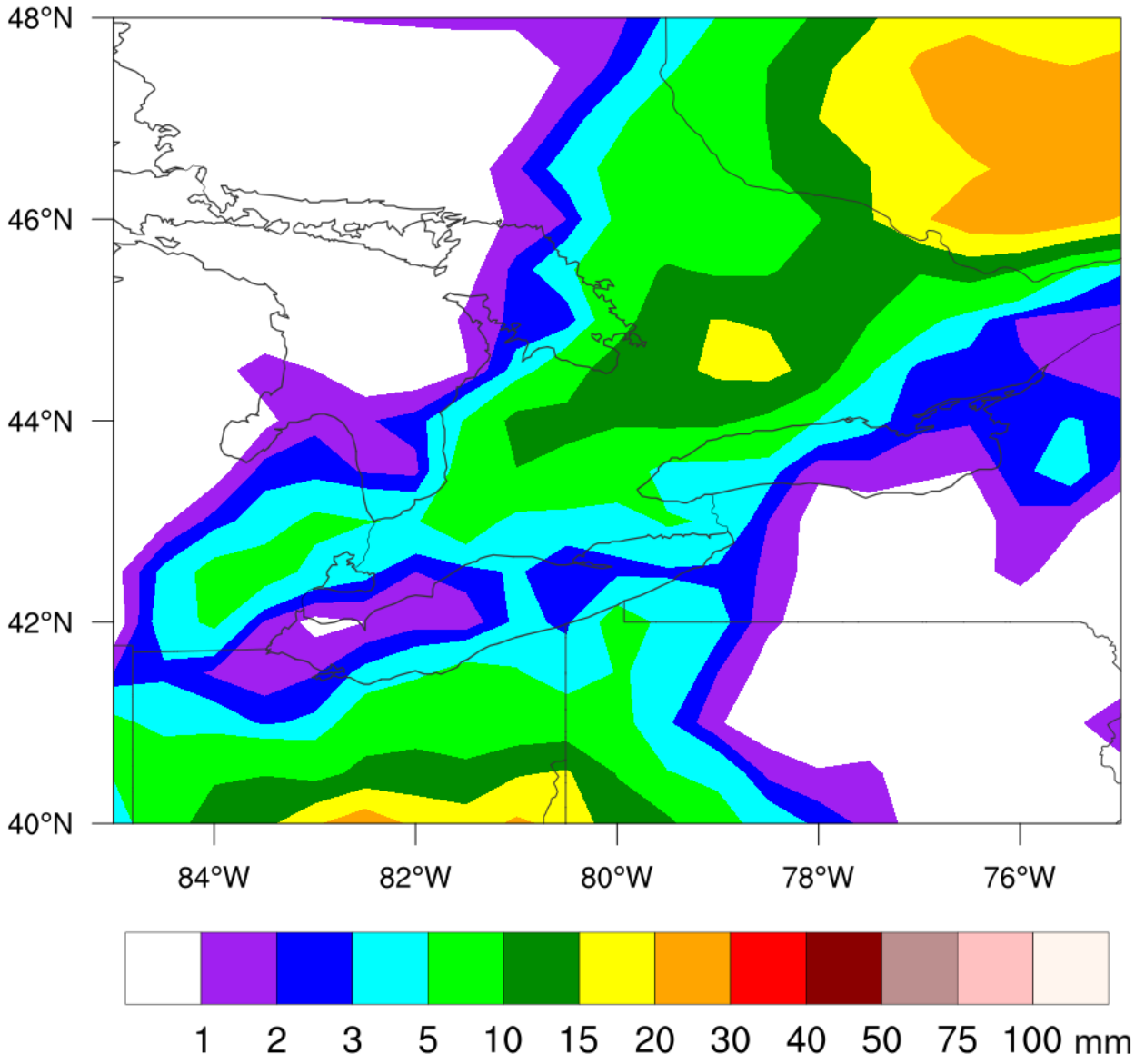
Appendix Figure F 33: DPQPE Archive King City Radar (August 4, 2009, 2200 UTC)



Source: ECCC, 2025c

Appendix Figure F 34: DPQPE Archive King City Radar (August 4, 2009, 2300 UTC)

F.3.3 Model Precipitation Maps

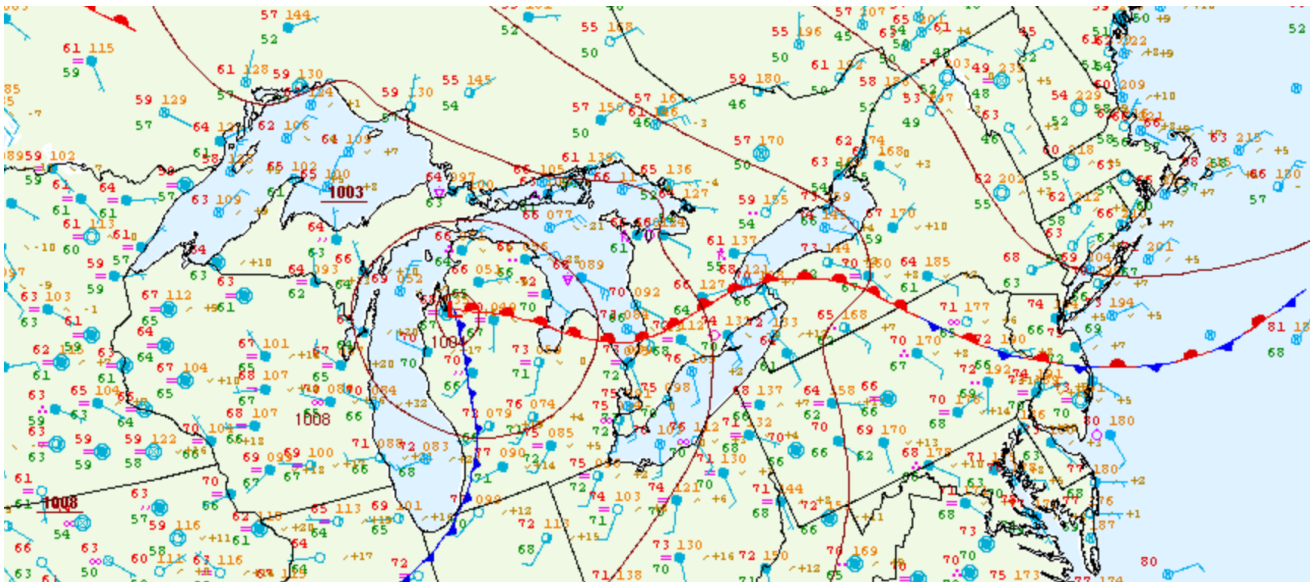


Source: NOAA, 2025d

Appendix Figure F 35: 24-hour Precipitation Forecast from August 4, 2009, 12Z to August 5, 2009, 12Z by the GFS Model Initialized August 4, 2009, 12Z

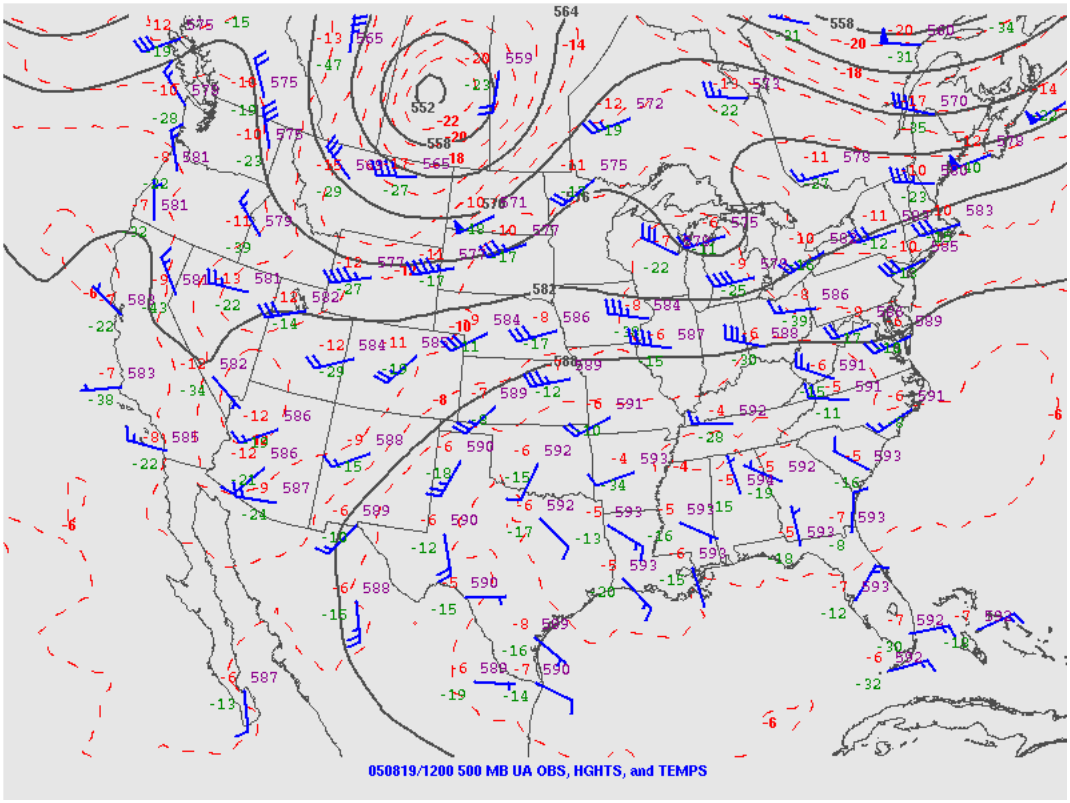
F.4 August 19, 2005

F.4.1 Weather Maps



Note: The dark red lines indicate isobars, the red lines indicate warm front, and the blue lines indicate cold front.
Source: Weather Prediction Center, 2022

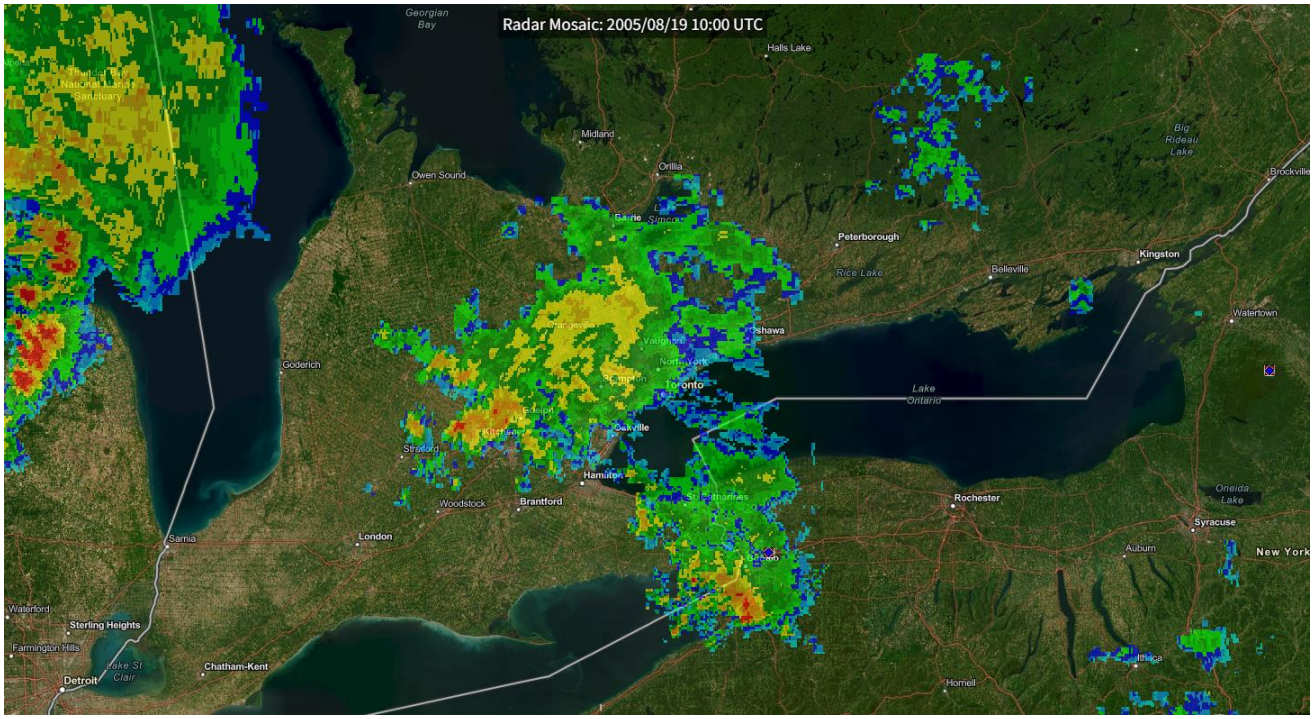
Appendix Figure F 36: Surface Map (August 19, 2005, 12Z)



Source: Storm Prediction Center, 2025b

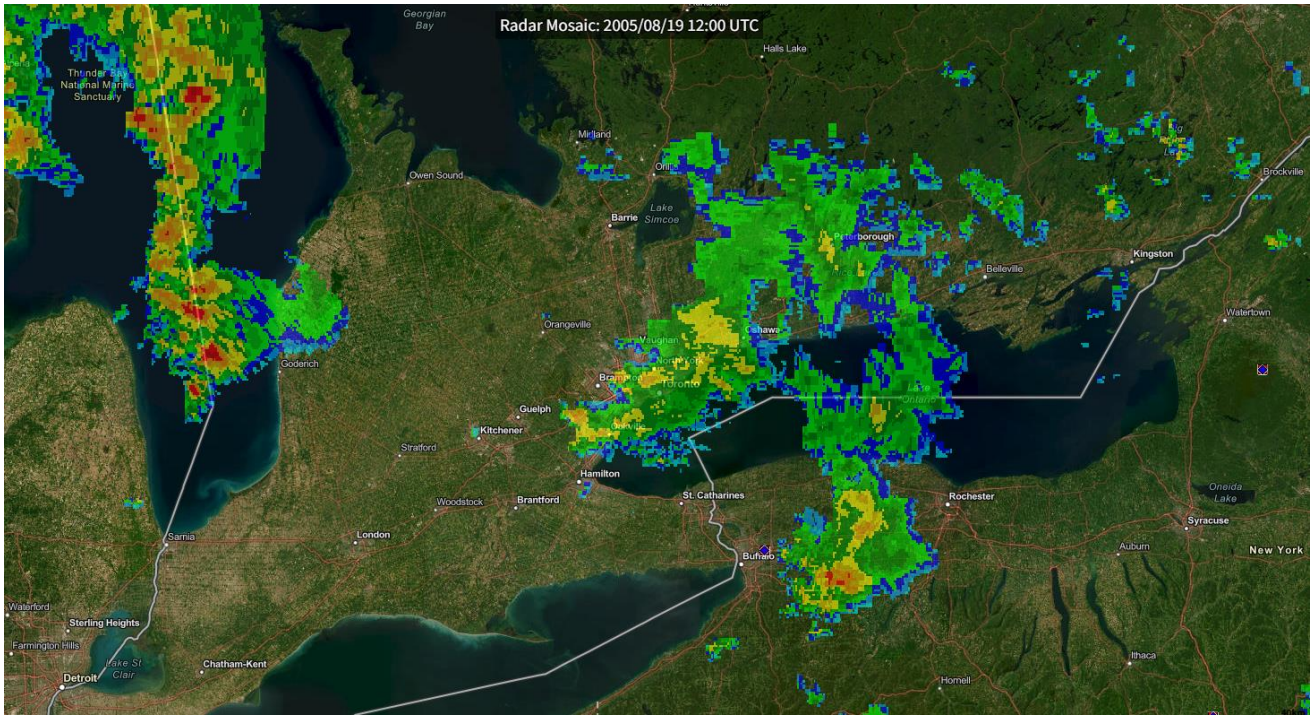
Appendix Figure F 37: 500-hPa Map (August 19, 2005, 12Z)

F.4.2 Radar Images



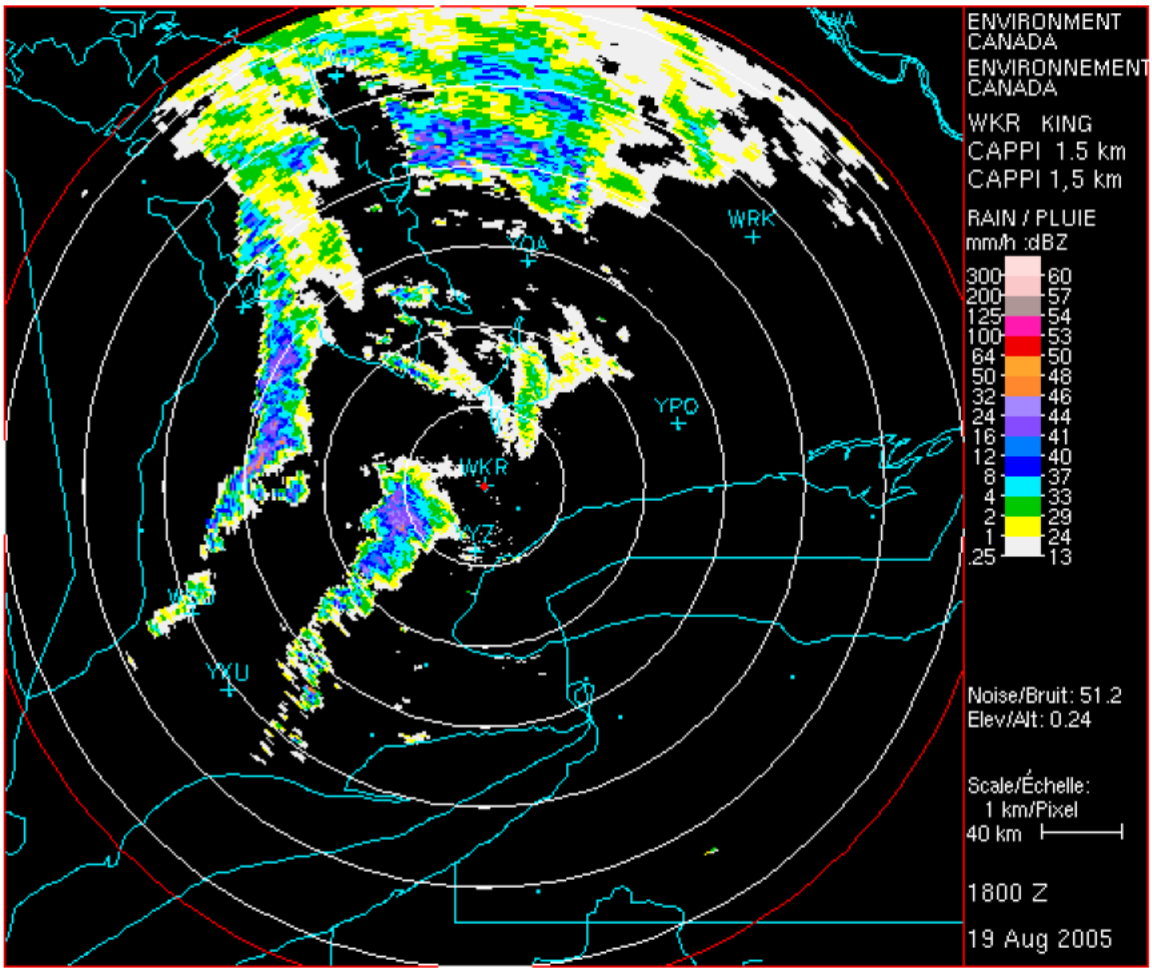
Source: NCEI, 2025

Appendix Figure F 38: NEXRAD Composite Radar (August 19, 2005, 1000 UTC)



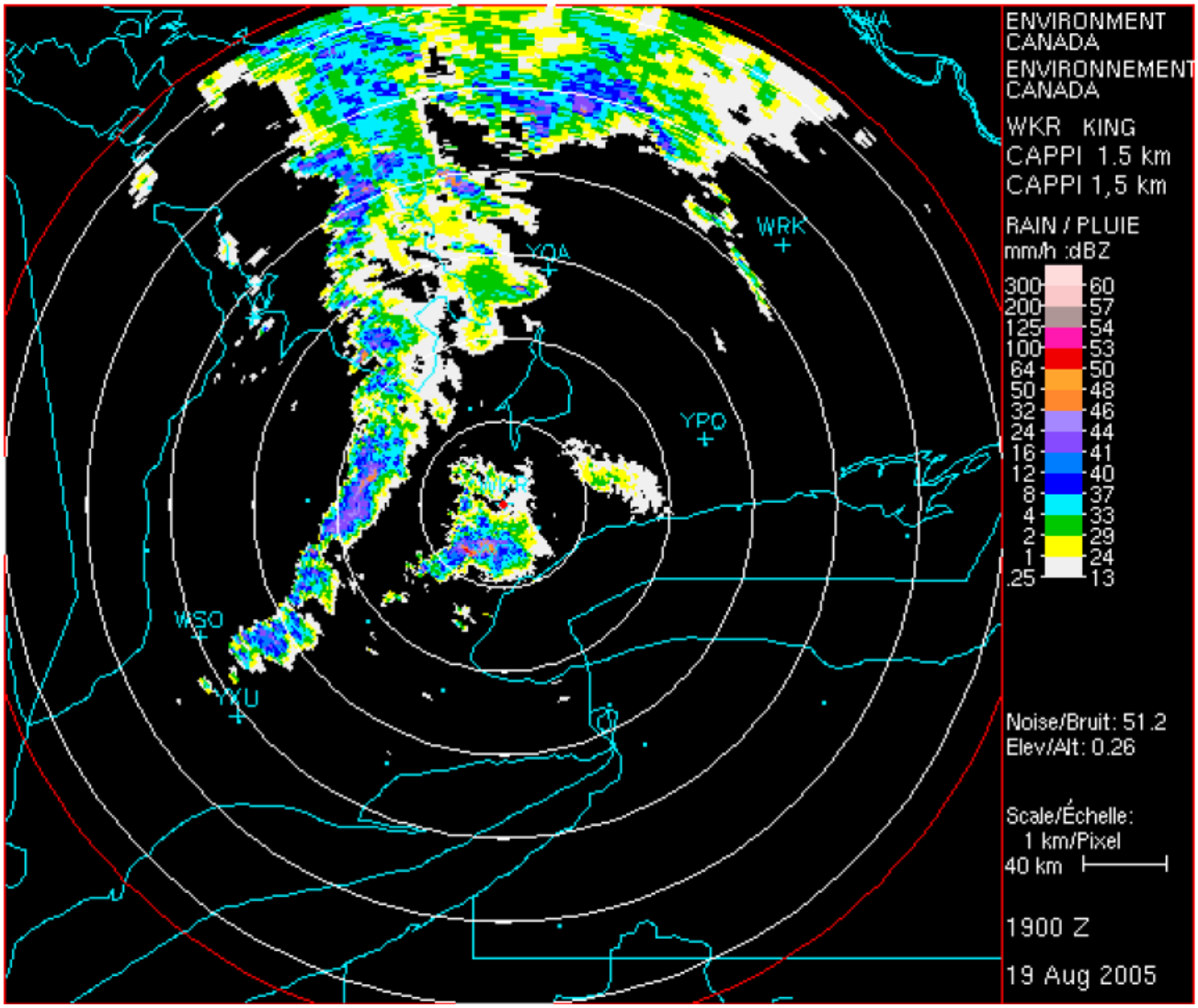
Source: NCEI, 2025

Appendix Figure F 39: NEXRAD Composite Radar (August 19, 2005, 1200 UTC)



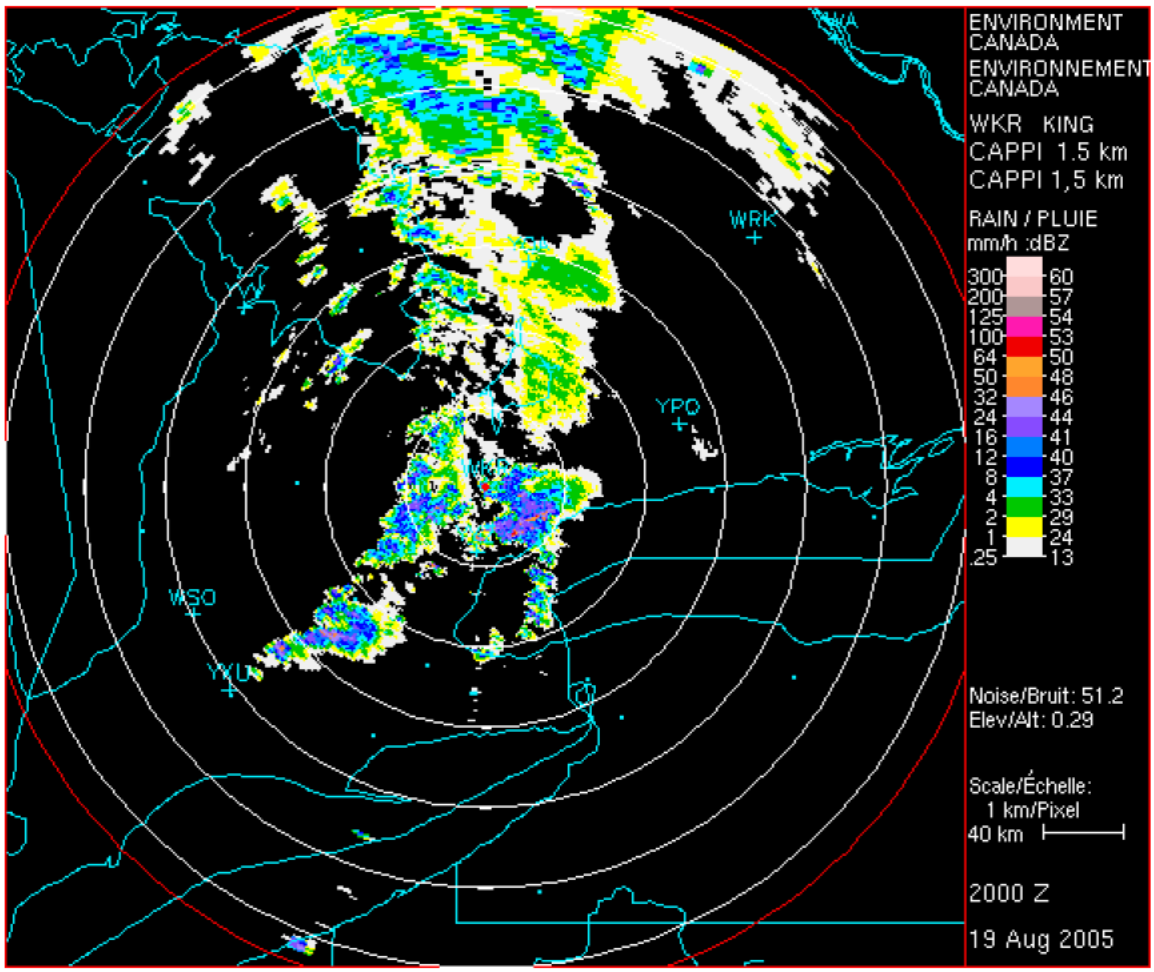
Source: Clarifica Water Resources and Environmental Counseling, 2006

Appendix Figure F 40: King City CAPPI Radar Image (August 19, 2005, 1800 UTC)



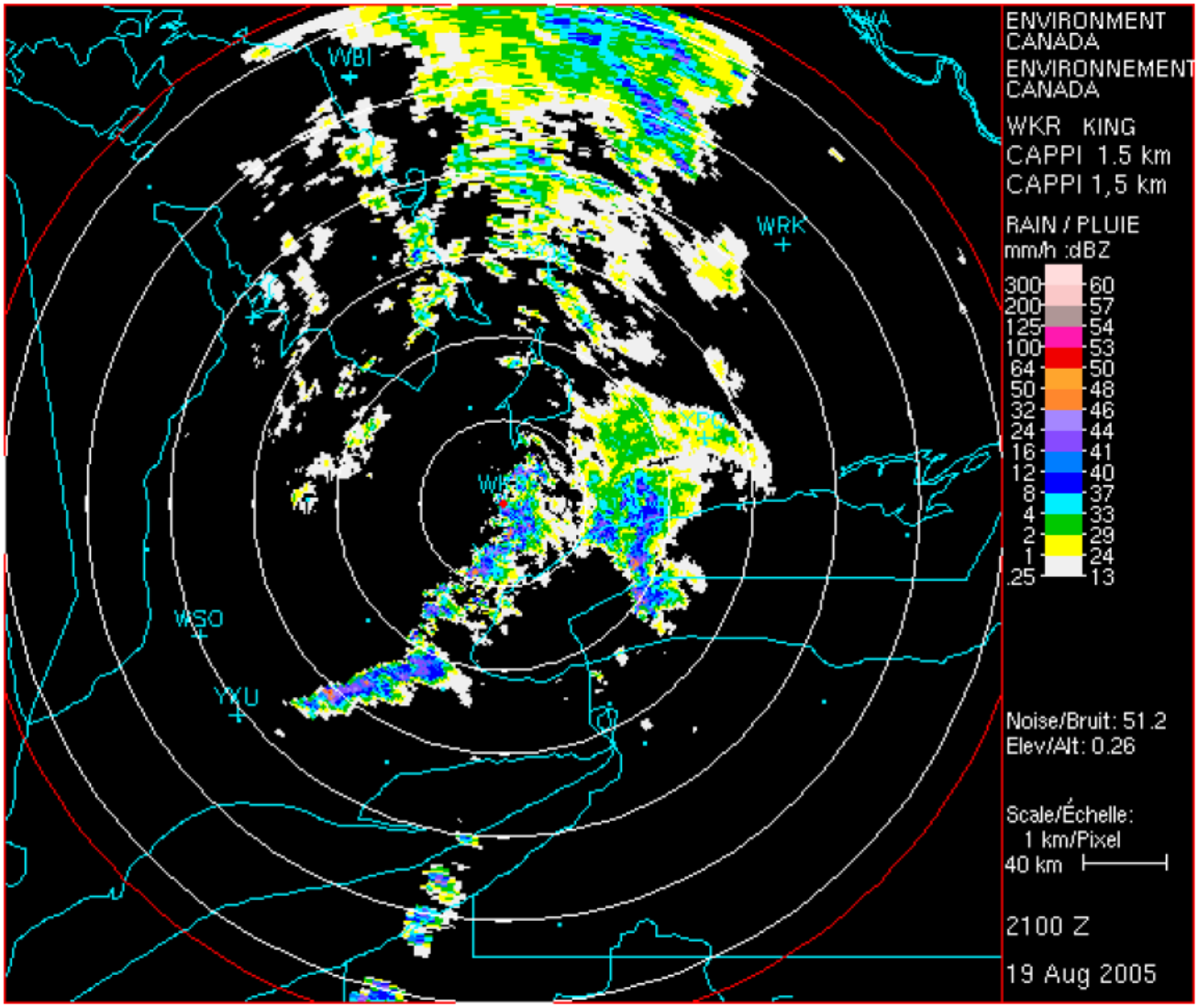
Source: Clarifica Water Resources and Environmental Counseling, 2006

Appendix Figure F 41: King City CAPPI Radar Image (August 19, 2005, 1900 UTC)



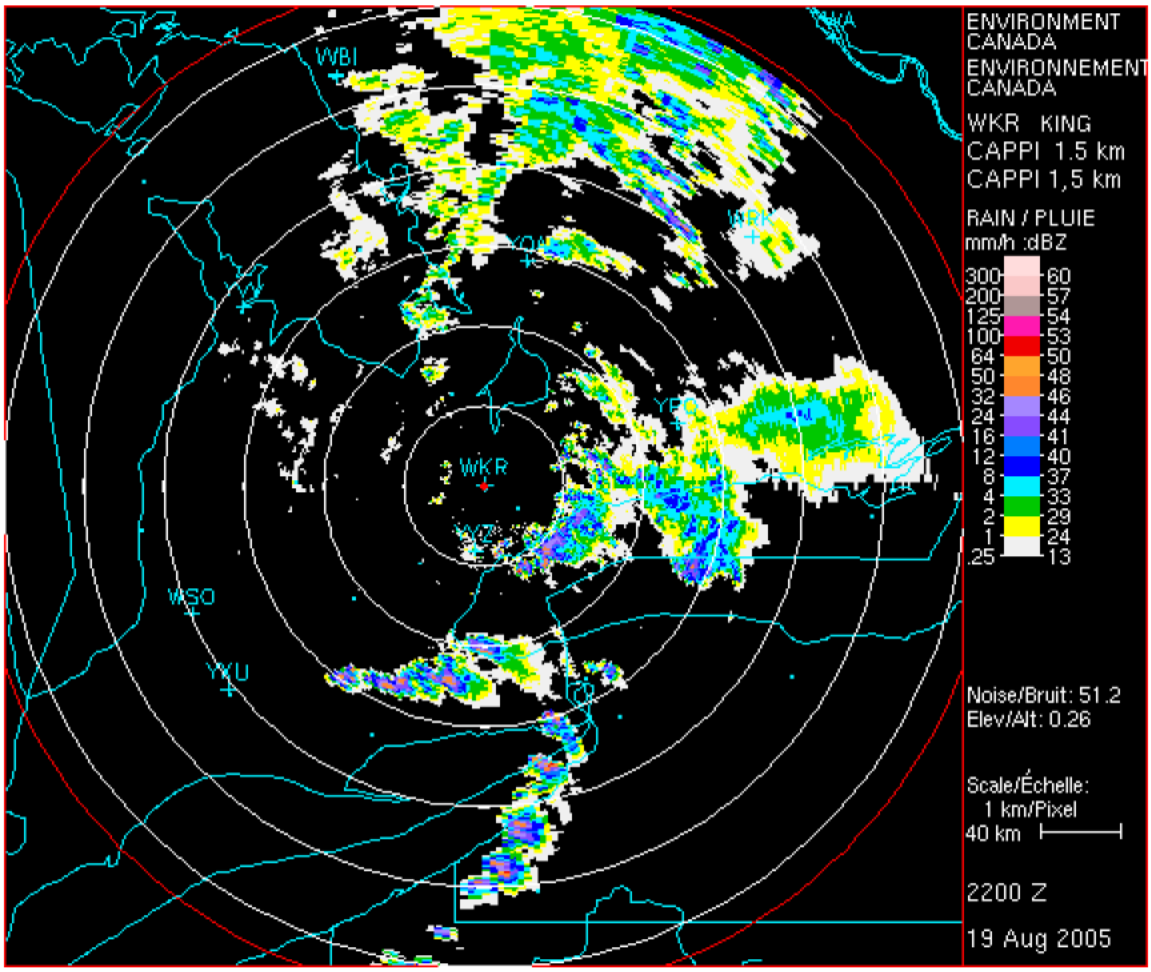
Source: Clarifica Water Resources and Environmental Counseling, 2006

Appendix Figure F 42: King City CAPPI Radar Image (August 19, 2005, 2000 UTC)



Source: Clarifica Water Resources and Environmental Counseling, 2006

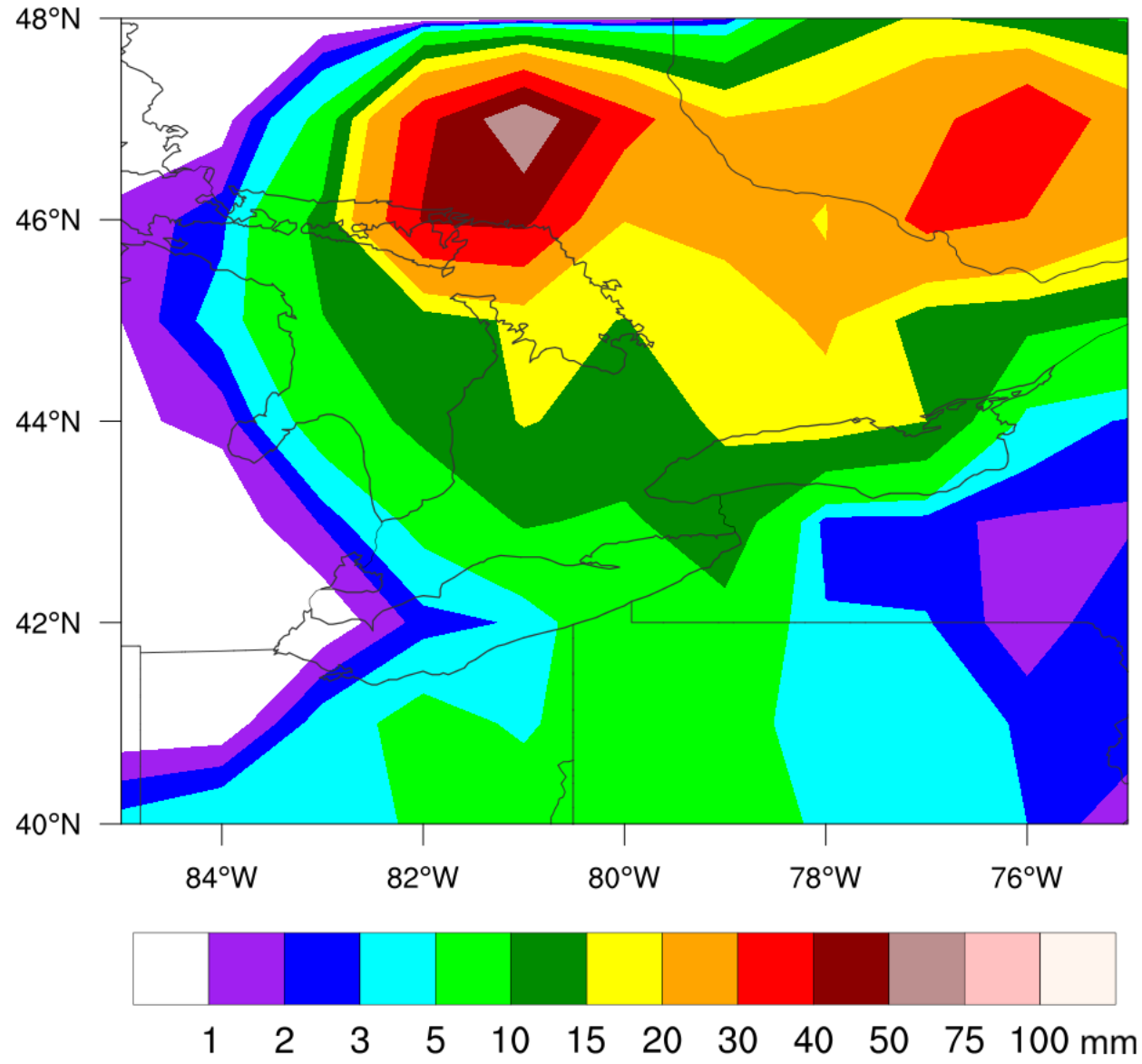
Appendix Figure F 43: King City CAPPI Radar Image (August 19, 2005, 2100 UTC)



Source: Clarifica Water Resources and Environmental Counseling, 2006

Appendix Figure F 44: King City CAPPI Radar Image (August 19, 2005, 2200 UTC)

F.4.3 Model Precipitation Maps

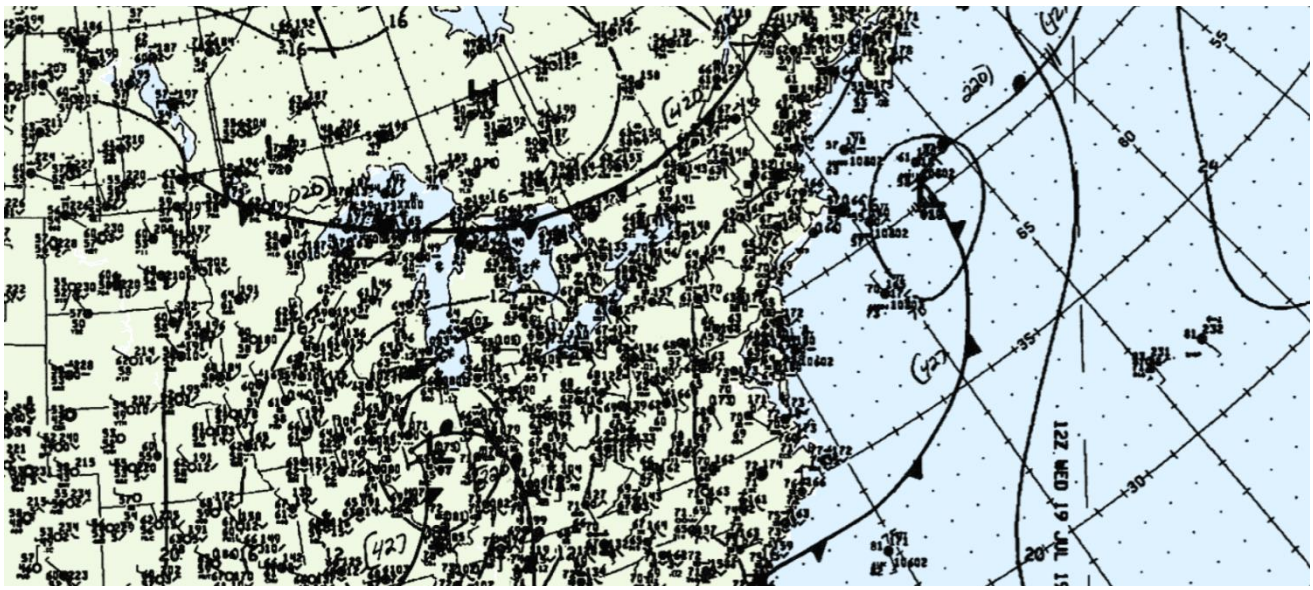


Source: NOAA, 2025d

Appendix Figure F 45: 24-hour Precipitation Forecast from August 19, 2005, 12Z to August 20, 2005, 12Z by the GFS Model Initialized August 19, 2005, 12Z

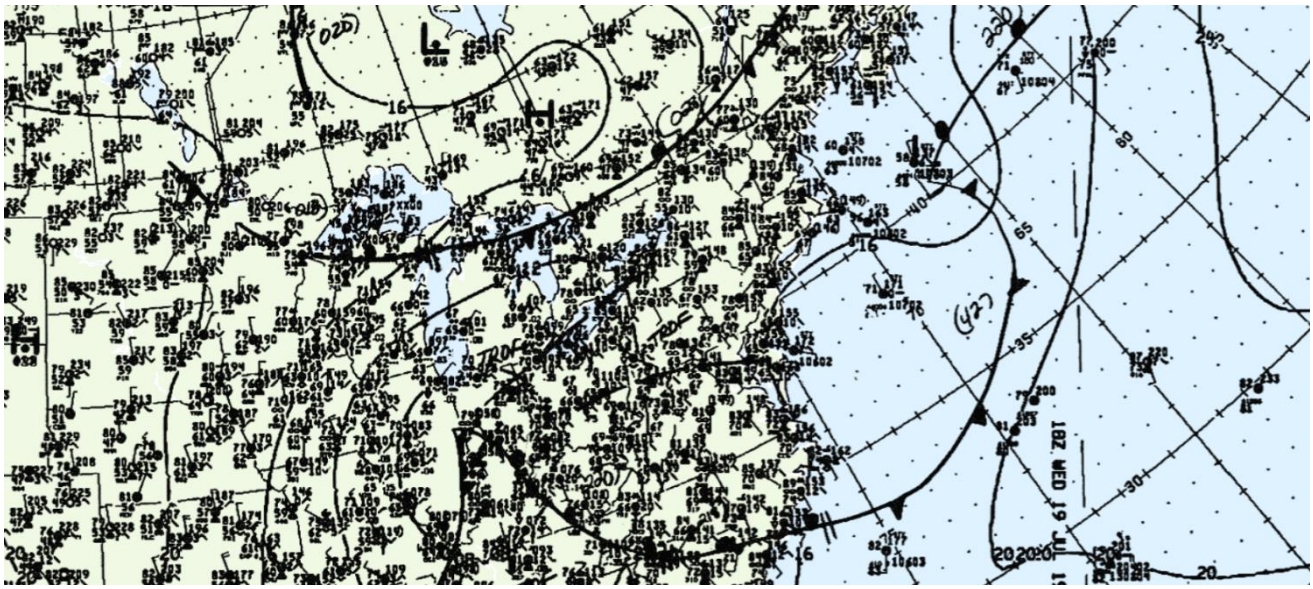
F.5 July 19-20, 1989

F.5.1 Weather maps



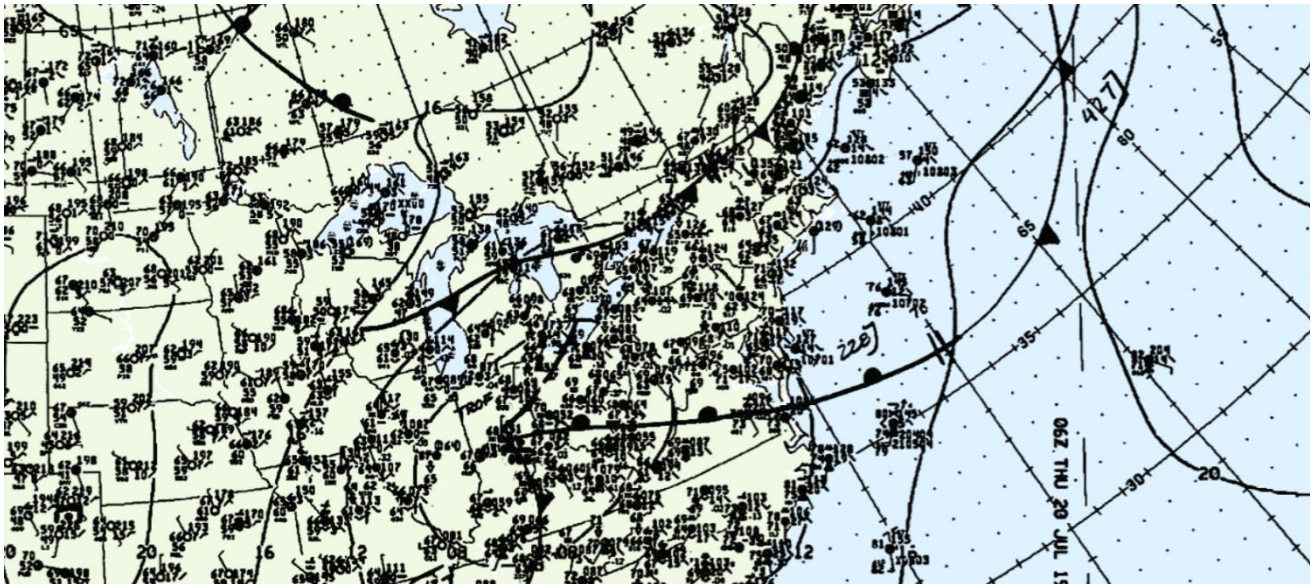
Source: Weather Prediction Center, 2022

Appendix Figure F 46: Surface Map (July 19, 1989, 12Z)



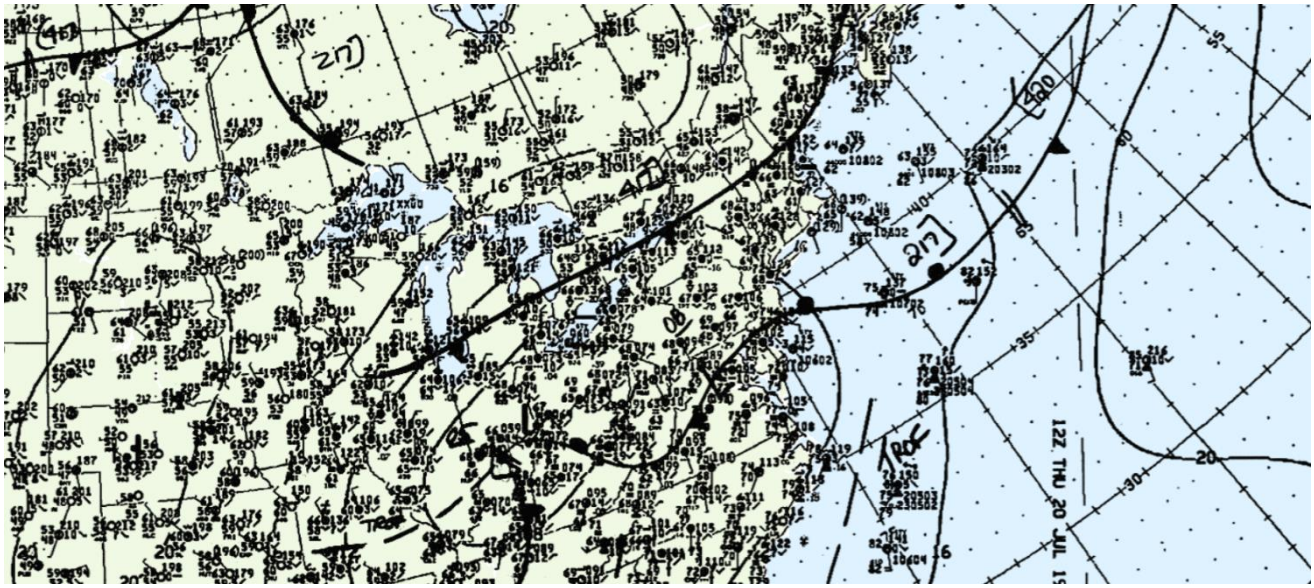
Source: Weather Prediction Center, 2022

Appendix Figure F 47: Surface Map (July 19, 1989, 18Z)



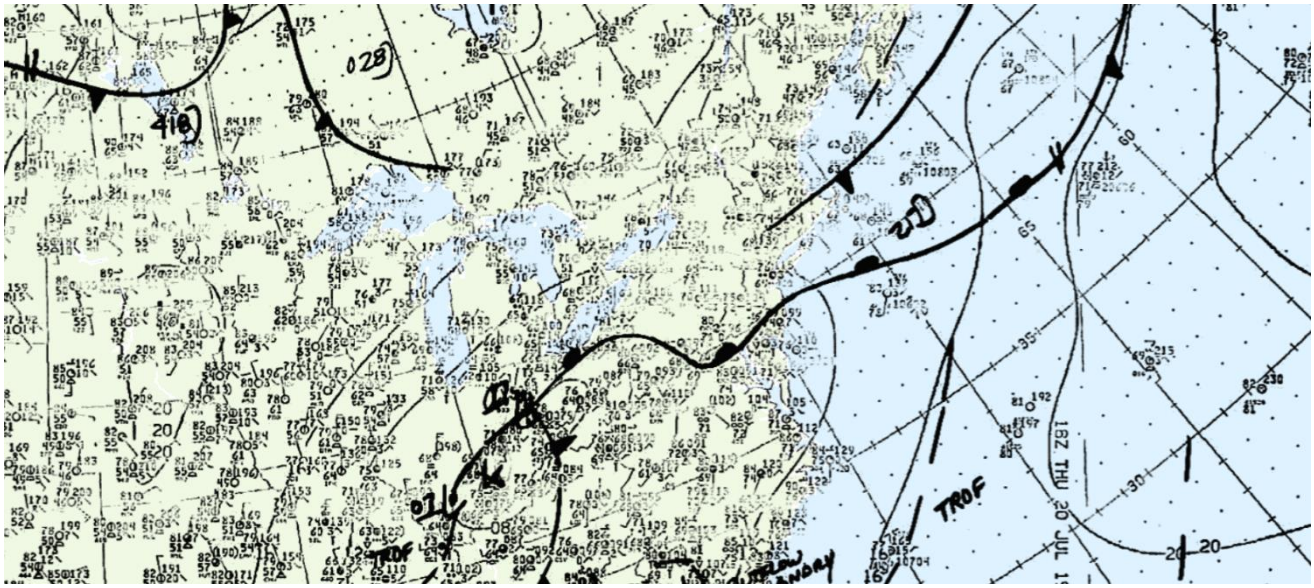
Source: Weather Prediction Center, 2022

Appendix Figure F 48: Surface Map (July 20, 1989, 06Z)



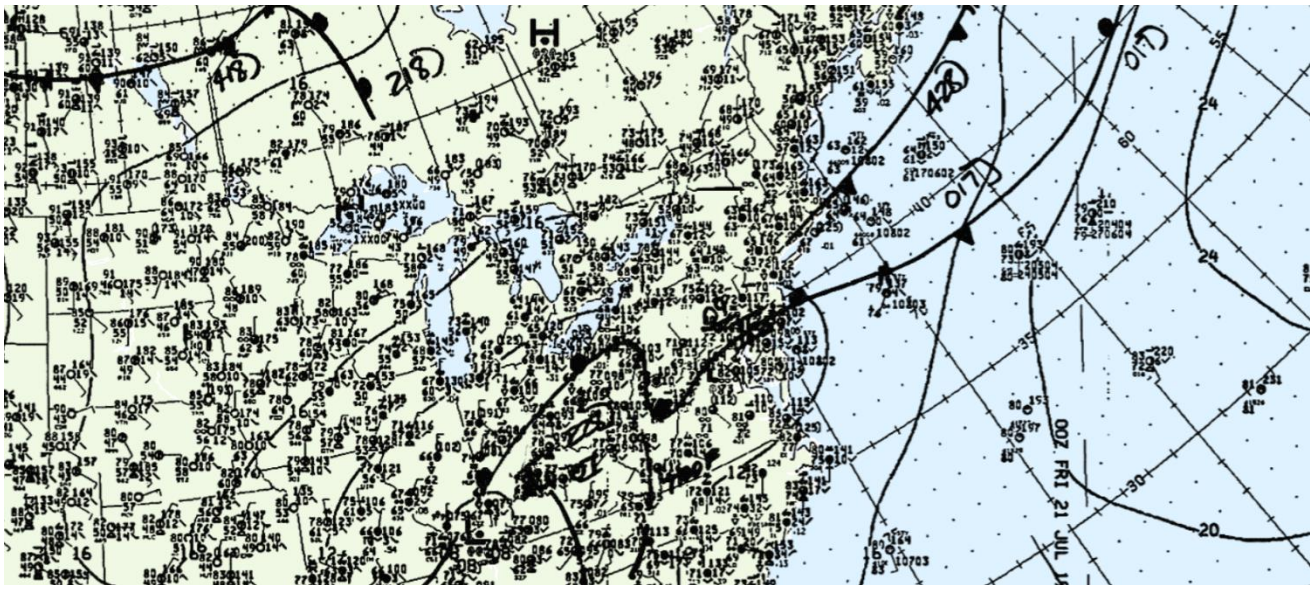
Source: Weather Prediction Center, 2022

Appendix Figure F 49: Surface Map (July 20, 1989, 12Z)



Source: Weather Prediction Center, 2022

Appendix Figure F 50: Surface Map (July 20, 1989, 18Z)

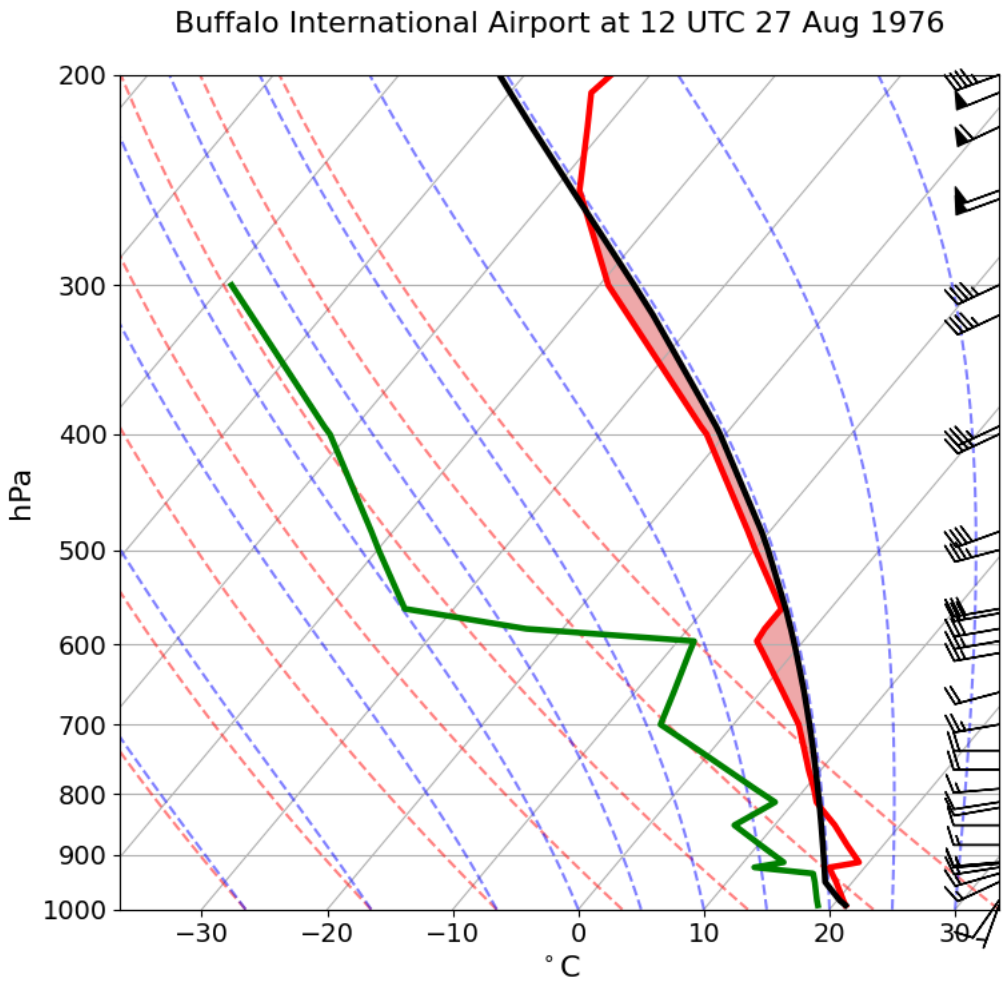


Source: Weather Prediction Center, 2022

Appendix Figure F 51: Surface Map (July 21, 1989, 00Z)

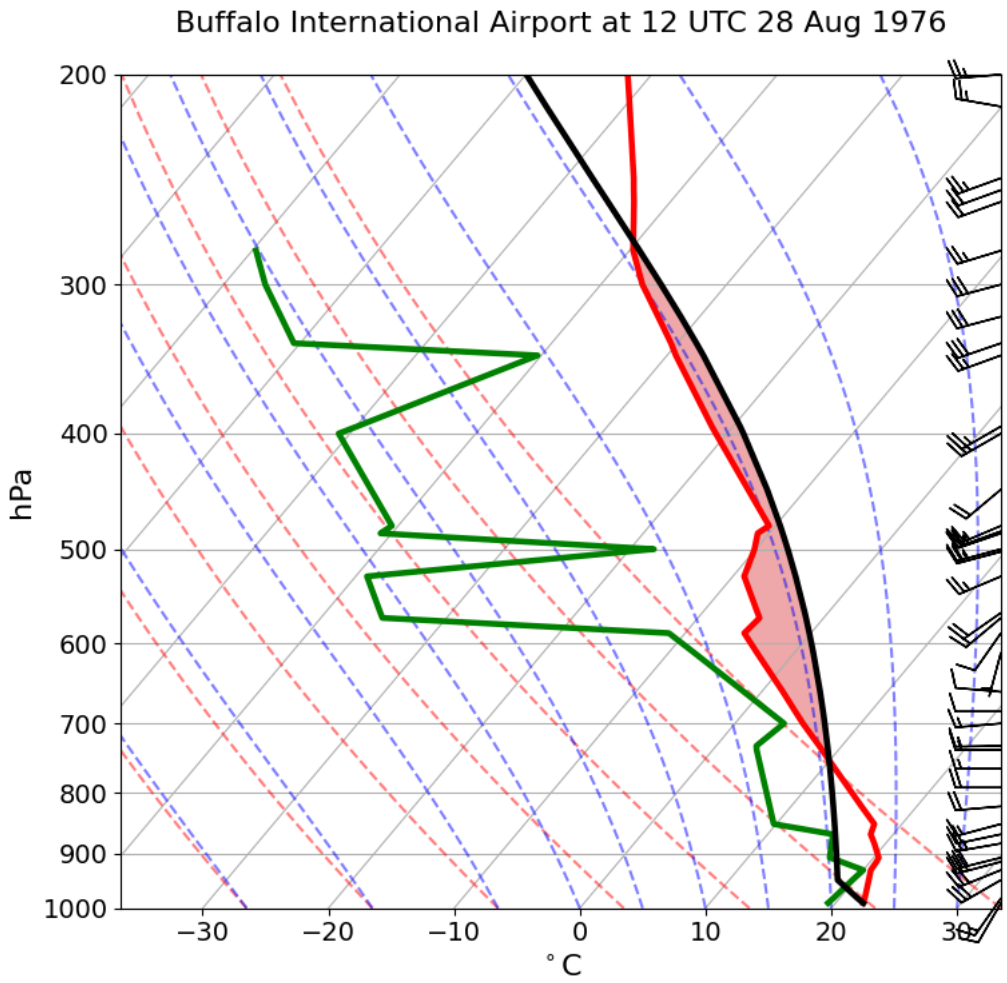
F.6 August 27-28, 1976

F.6.1 Tephigram Soundings



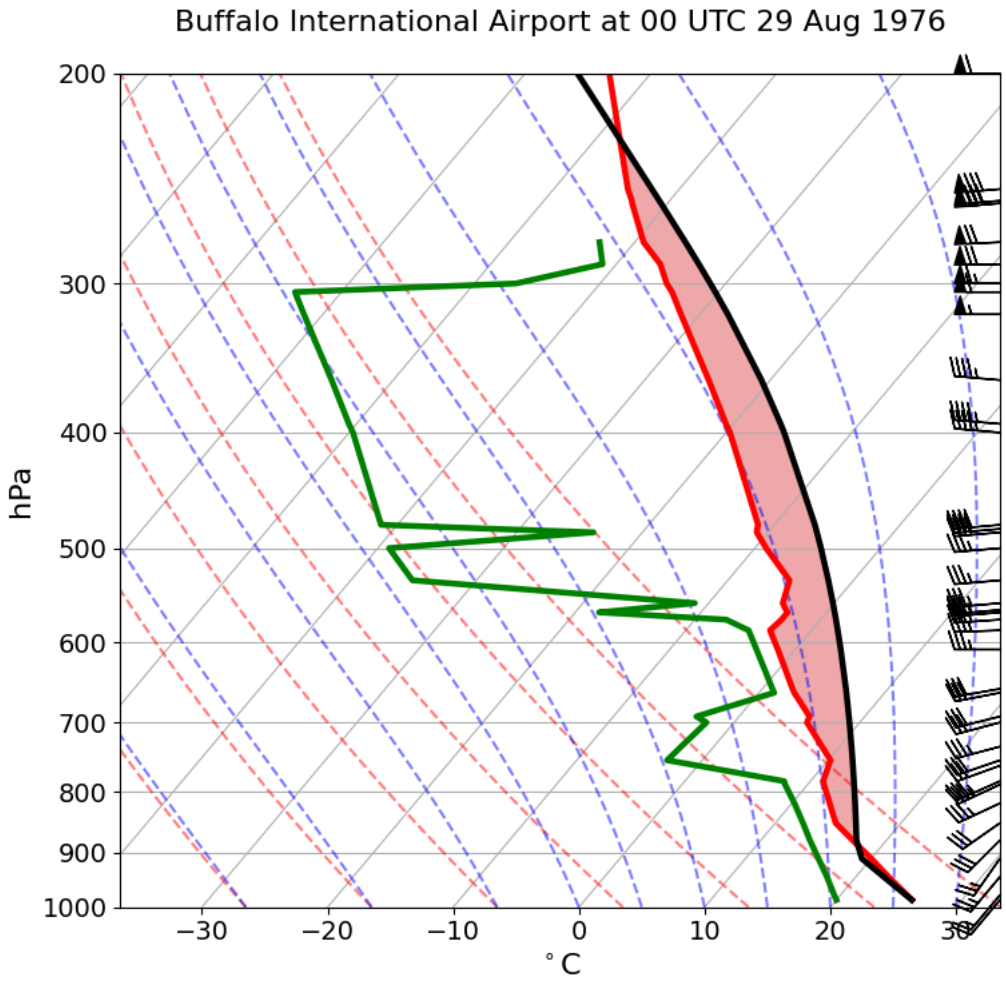
Note: The fuchsia area indicates the Convective Available Potential Energy (CAPE)`
Source: University of Wyoming, 2025

Appendix Figure F 52: Tephigram Sounding at the Buffalo/Greater Buffalo International Radiosonde Site (August 27, 1976, 12Z)



Note: *The fuchsia area indicates the Convective Available Potential Energy (CAPE)`*
Source: *University of Wyoming, 2025*

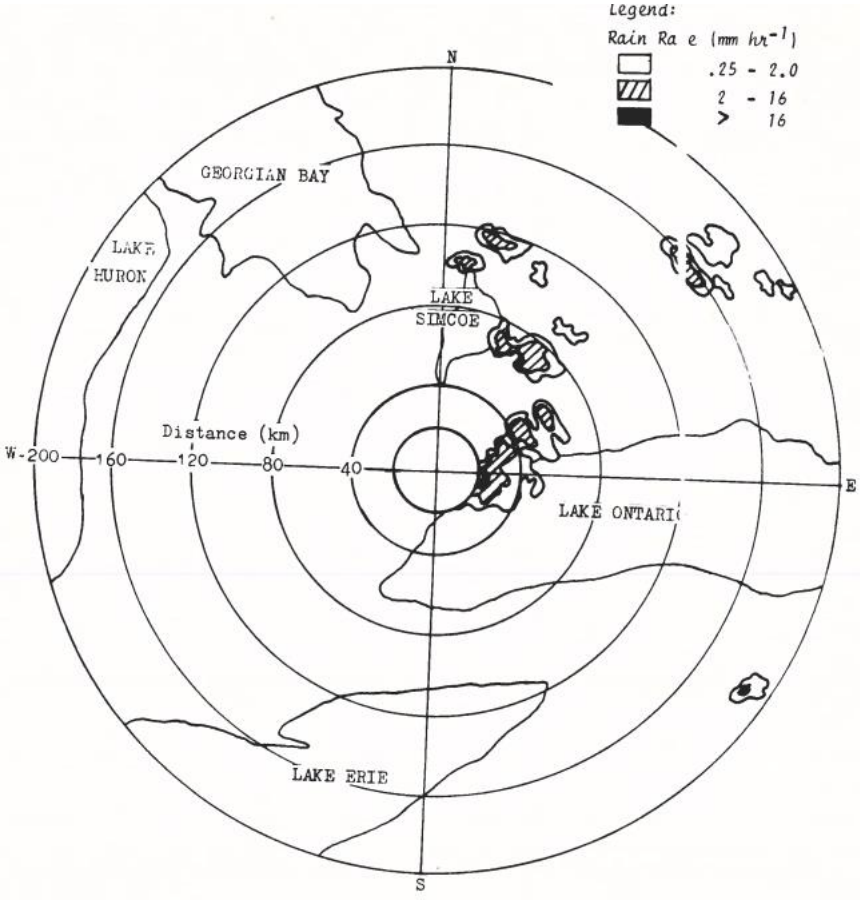
Appendix Figure F 53: Tephigram Sounding at the Buffalo/Greater Buffalo International Radiosonde Site (August 28, 1976, 12Z)



Note: *The fuchsia area indicates the Convective Available Potential Energy (CAPE)`*
Source: *University of Wyoming, 2025*

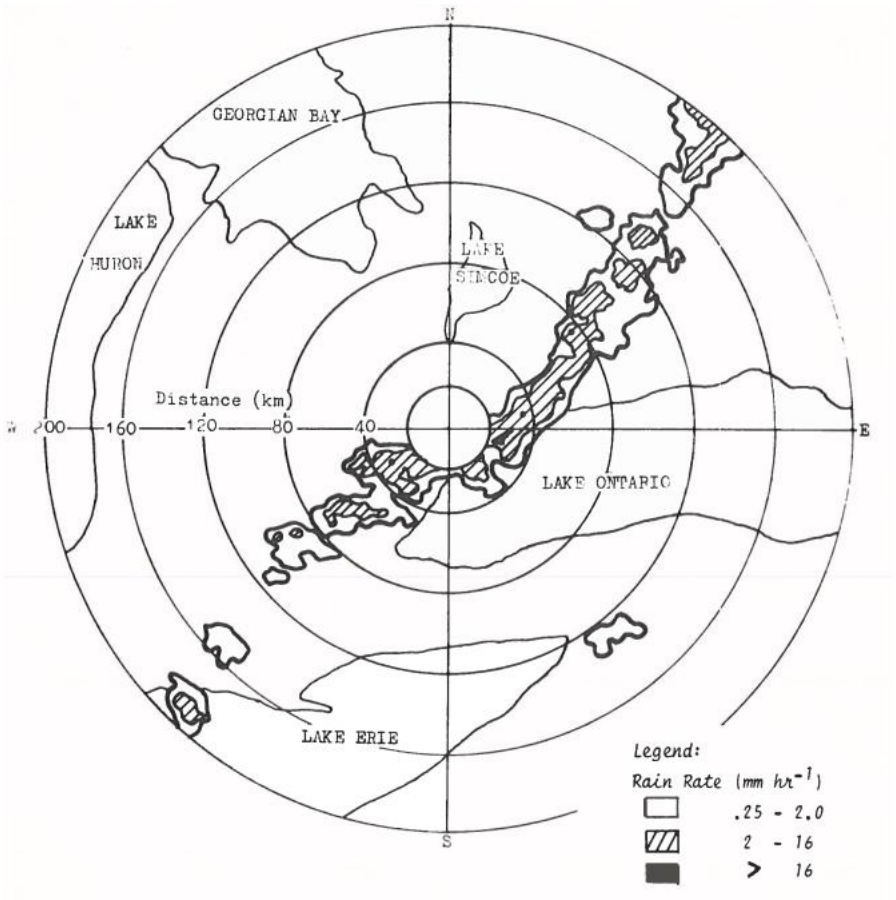
Appendix Figure F 54: Tephigram Sounding at the Buffalo/Greater Buffalo International Radiosonde Site (August 29, 1976, 00Z)

F.6.2 Radar Images



Source: Kilborn Limited, 1977

Appendix Figure F 55: 1.5 km CAPPI Radar Image (August 27, 1976, 1858 UTC)



Source: Kilborn Limited, 1977

Appendix Figure F 56: 1.5 km CAPPI Radar Image (August 28, 1976, 1816 UTC)

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