

6.4 EXAMINATION OF A REMARKABLE GREAT LAKE-SPAWNED TORNADIC SUPERCELL: THE 2011 GODERICH ONTARIO F3 TORNADO EVENT

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1. INTRODUCTION

On the afternoon of 21 August 2011, a tornado formed over Lake Huron associated with an intensifying supercell. It moved onshore and ripped through the very centre of historic downtown Goderich, with a post-storm damage survey revealing F3 damage.

This tornadic supercell was remarkable on a number of counts. First, the tornado and its parent supercell developed and intensified over the Lake and well behind a cold front, both of which are very rarely seen in the Great Lakes area.

Second, tornado occurrence is quite infrequent in the Goderich area since the eastern shore of Lake Huron typically experiences stable marine air as surface-based storms develop inland.

Third, the tornadic supercell occurred in an area where commonly used severe weather forecast parameters suggested only a minimal risk of supercells or tornadoes. Yet it caused surprisingly severe damage along a 20+ km path, making it the strongest tornado in Ontario in 15 years.

Despite the unusual nature of this event, the Ontario Storm Prediction Centre was successful in issuing both a severe thunderstorm watch and a tornado warning before the storm made landfall, mainly due to enhanced situational awareness.

After an initial section describing the event, this paper will examine the synoptic-scale and mesoscale factors that led to the development of

this rare tornadic supercell, and will offer recommendations for improving the detection and forecasting of such storms.

2. EVENT DESCRIPTION

The Town of Goderich is located in southern Ontario, Canada, on the eastern shore of Lake Huron (Fig. 1a) and bills itself as 'Canada's prettiest town'. The terrain is relatively flat with the exception of a large 25 metre bluff along the lakeshore. Land use is primarily agricultural though Goderich (population approx. 8,000) does host a variety of industries including the world's largest salt mining operation. Goderich was a planned town, beginning with a town square from which roadways radiated. This square became known for its numerous mature trees and historic buildings (Fig. 1b).

A tornadic supercell developed over Lake Huron and moved directly toward Goderich, with the tornado making landfall at approx. 1555 LT (local time). The tornado, preceded by a short burst of heavy rain and hail (according to witnesses – see Blunt-Cooper and Cove, 2011), moved through the very centre of Goderich's historic square (Fig. 1c,d) before continuing east-southeast on to more rural areas, including the village of Benmiller. There were 37 injuries and one fatality. The fatality occurred at the salt mine. A worker was killed when the tornado felled a large ship-loading boom he was operating. The ship's captain reported that the anemometer on board the ship measured a wind gust of 150 knots (278 km/h) as the tornado passed by.

A damage survey was conducted by Environment Canada beginning shortly after the event and ending late the next day. There was significant damage at the salt mine on the shoreline but the lack of standard damage indicators there made intensity rating difficult. In

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the historic part of Goderich, a number of double-brick buildings had their roof and second floor walls removed – meeting the Environment Canada threshold for lower-end F3 intensity (250-280 km/h) on the Fujita Scale (Fujita, 1981; Environment Canada has yet to adopt the Enhanced Fujita scale though adoption is expected in the near future). In total, the damage path over land extended 20.5 km (Fig. 2). However, photographs and video (see Fig. 2) suggest that the tornado was present over the Lake for at least 5-10 minutes before coming ashore.

Reflectivity (Fig. 3) and radial velocity (Fig. 4) images from the Exeter Doppler radar at 1550 LT show a well-defined, intense supercell thunderstorm about to move onshore. As shown, the mesocyclone had a diameter of approx. 7 km with a maximum velocity difference of approx. 70 m s^{-1} (yellow circle). The tornado was likely occurring at this time in the region of strongest gate-to-gate shear (within the green circle, approx. 34 m s^{-1}).

3. SYNOPTIC-SCALE FACTORS

On the synoptic scale, a cold front had passed through the Goderich area earlier in the morning and was more than 400 km east of the Goderich area by 1400 LT (Fig. 5). At the same time, an upper trough and a strong cyclonic upper-level jet were beginning to arrive from Michigan (Fig. 5).

Morning rawinsonde data and forecast soundings from Environment Canada's GEM regional model (Côté et al. 1998) indicated some potential for severe thunderstorms with CAPE greater than $1,000 \text{ J kg}^{-1}$ and deep-layer shear greater than 25 m s^{-1} (Figs. 6 and 7). However, commonly used supercell and tornado forecasting parameters such as the Supercell Composite Parameter (SCP, Thompson et al. 2004), the Significant Tornado Parameter (STP, Thompson et al. 2004), and the Energy-Helicity Index (EHI, Davies 1993) from the US Storm Prediction Centre mesoanalysis system (Fig. 8) and the GEM regional model (not shown) all failed to indicate noteworthy potential for supercells or strong tornadoes.

The synoptic feature that stood out most was the strong ($50+ \text{ m s}^{-1}$) upper-level jet with its left exit over the Goderich area. We compared this pattern to the upper-level jet patterns associated

with 59 past F3 or greater Canadian tornadoes using 300 hPa images generated from the NCEP North American Regional Reanalysis data (Mesinger 2006). It was found that 85% of these tornadoes occurred in the exit region of a strong upper-level jet, demonstrating that there was at least one 'typical' aspect to this event. The 300 hPa reanalysis plots for the Goderich event and other well-known F3+ tornado events in Ontario are shown in Fig. 9.

4. MESOSCALE FACTORS

Tornadoes in southern Ontario often occur in a southwest surface flow regime in the warm sector of a low pressure system. Lake breezes that typically develop on such days advect cool, stable marine air to the lee of the Lakes with lake-breeze fronts along the leading edges. Areas such as Goderich rarely see a tornado, let alone a significant tornado, because this marine air tends to suppress thunderstorms. In fact, in over 200 years, there have been only two F0 tornadoes recorded within a 40 km radius of Goderich. Tornado occurrences and idealized positions of lake-breeze fronts in a south-westerly flow are shown in Fig. 10. King et al. (2003) discuss the relationship between lake breezes and the Ontario tornado climatology.

According to surface observations from the morning and early afternoon of August 21st, onshore winds did advect cooler marine air over the Goderich area, but not due to lake breezes. Lake breeze development over Lake Huron was prevented due to the presence of numerous showers and thunderstorms and associated cloudiness. These showers and thunderstorms generated cold pools and associated outflow boundaries.

To assess the influence of these cold pools and outflow boundaries for this event, a mesoscale boundary analysis at 10-min intervals was created using the Aurora platform (Greaves et al. 2001). The full animation showing the evolution of mesoscale boundaries between 12 pm and 6 pm LT can be viewed at <http://goo.gl/075Pl>.

The animation shows the evolution of two supercell thunderstorms. The first developed over northern Lower Michigan at the intersection of two outflow boundaries with strong mid-level rotation evident at 1300 LT (indicated by broken magenta circle). The US National Weather

Service forecast office in Gaylord, Michigan, issued a tornado warning for that storm at 1257 LT, but no tornado or damage reports were received. The storm moved southeast over Lake Huron and began to dissipate.

At the same time, the boundary analysis shows that cold pools associated with earlier and ongoing convection combined and led to the development of a strong baroclinic zone, roughly from west-northwest to east-southeast across Lake Huron. The Goderich storm initiated along this boundary just east of the Michigan shoreline at 1330 LT. It rapidly intensified and developed mid-level rotation by 1400 LT (indicated by broken magenta circle). Environment Canada issued a severe thunderstorm watch for the Goderich region at 1402 LT.

It appears the remnants of the Michigan supercell merged with the Goderich supercell between 1420 and 1500 LT, as the Goderich supercell moved along and just to the north of the strong baroclinic zone. The Goderich supercell continued to intensify as it moved along the baroclinic zone. Due to enhanced situational awareness, the development of this supercell was closely monitored. A marine tornado warning was issued by Environment Canada at 1538 LT, and a tornado warning was issued for the Goderich region over land at 1548 LT. The tornado struck Goderich at 1555 LT.

A number of observational and modelling studies have suggested a connection between pre-existing boundaries and supercell tornadoes due to enhanced convergence and horizontal vorticity along such boundaries (e.g., Maddox et al. 1980, Markowski et al. 1998, Atkins et al. 1999, Rasmussen et al. 2000, Sills et al. 2004).

Synthesizing the results of these papers, the current conceptual model appears to be that if a supercell crosses a pre-existing boundary, rapid development of a low-level mesocyclone can occur with an increased chance of tornado-genesis. However, a supercell moving *along and just to the north* of a pre-existing boundary is likely to be more intense with a longer-lived low-level mesocyclone, increasing the chance of an intense, long-track tornado. As shown in Fig. 11, the Goderich supercell moved along and just to the north of a pre-existing boundary.

In addition, there is research indicating that storm mergers can be important for the

intensification of thunderstorms (Lemon 1976) and the generation of tornadoes (Lee et al. 2006). However, it appears that a merger involving a dissipating supercell approaching a dominant supercell from the left-rear flank, as seen with the Goderich event, is not one of the merger types that has been studied.

5. CONCLUSIONS / RECOMMENDATIONS

The Goderich F3 tornado was a rare event. It occurred well behind a cold front. The supercell and tornado developed over Lake Huron. The tornado climatology shows a very low frequency in Goderich area, and F3+ tornadoes are infrequent in Ontario in general. Widely used parameters (SCP, STP, EHI) suggested little chance of a significant supercell tornado due to the lack of resolved, significant storm-relative environmental helicity. So why did this event produce Ontario's first F3 tornado in 15 years at Goderich?

Clearly, there were complementary synoptic-scale and mesoscale processes at work during this event. Though CAPE was unimpressive, an approaching strong upper-level jet increased deep-layer lift and (unidirectional) shear. Our analysis of past cases suggests this is an important ingredient for F3+ tornadoes in Canada, with 85% having occurred in the exit region of a strong upper-level jet. And cold pools from earlier and ongoing convection combined to form a strong baroclinic zone across Lake Huron. Storm motion parallel and just to cool side of this 'convective bridge' across the Lake allowed the storm to intensify and develop strong rotation at all levels as it moved east towards Goderich.

In order to better forecast such storms, there is a need for better data and tools to monitor boundaries in real time and use them for nowcasting. Also, supercell and tornado forecasting parameters that are able to take into account the vorticity that pre-existing boundary contribute are needed to flag areas of concern.

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Figure 1. Top left shows location of Goderich in the Great Lakes region. Top right shows an aerial photo of Goderich before the tornado event (source unknown). Bottom right shows an aerial photo shortly after the tornado event, with the red line indicating the path and direction of the tornado (source Andrea Telford). Bottom left shows damage and debris in the town square (source Global Television).

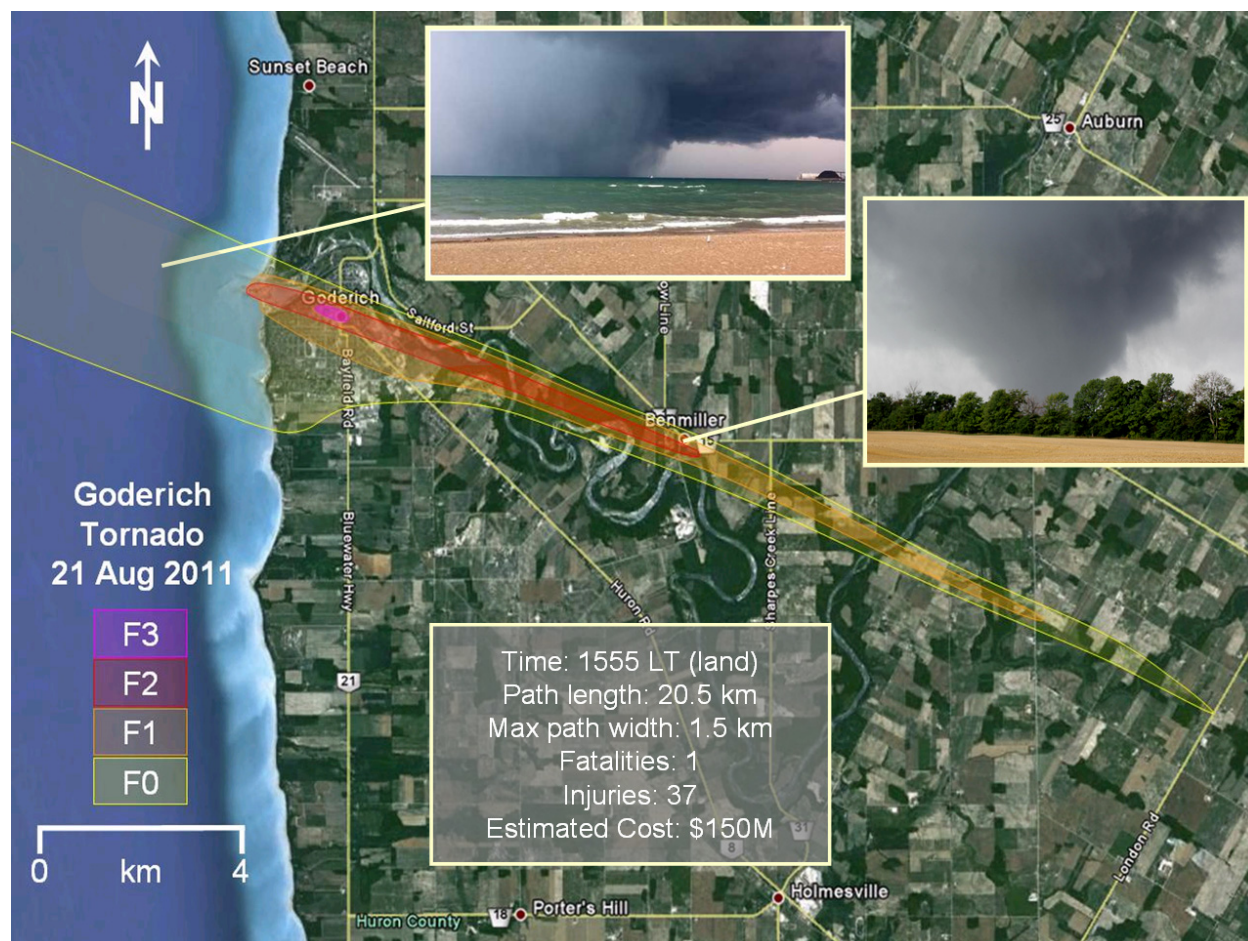


Figure 2. Map showing the assessed damage due to the Goderich tornado, extending more than 20 km over land. Inset at top centre is a video capture of the tornado over the Lake (source CKNX920). Inset at right is a photo of the tornado near Benmiller (source J. Gowanlock). The background map is provided by Google Earth (© Cnes/Spot Image, © 2012 Google, NOAA).

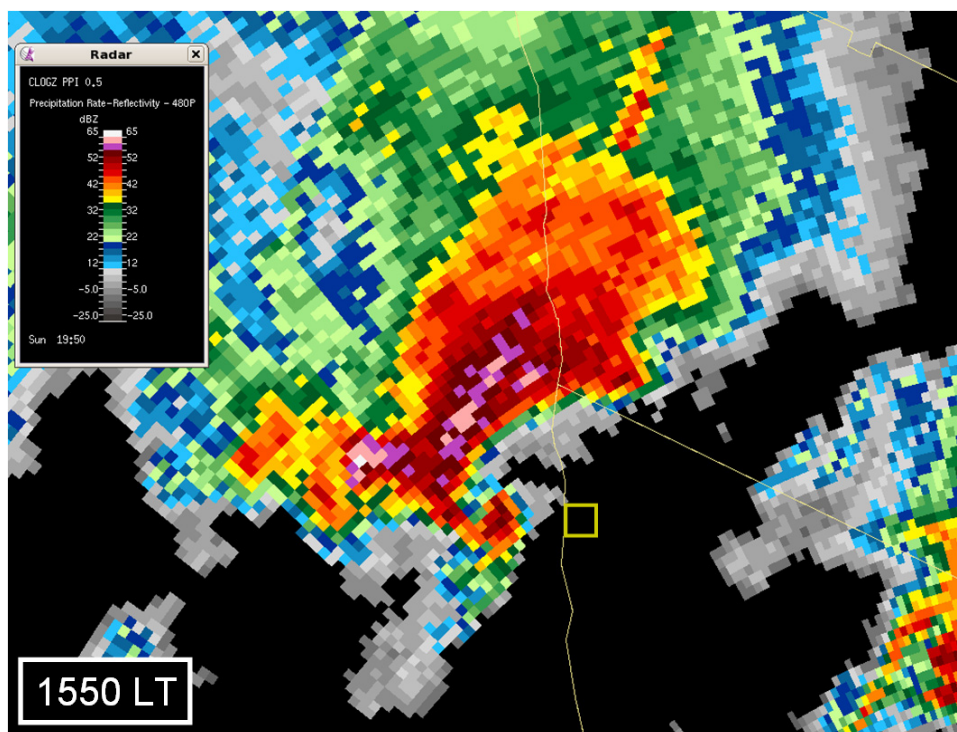


Figure 3. Image showing 0.5° reflectivity from the Exeter Doppler radar at 1550 LT. Goderich is marked by the yellow box. The radar colour legend is shown at left.

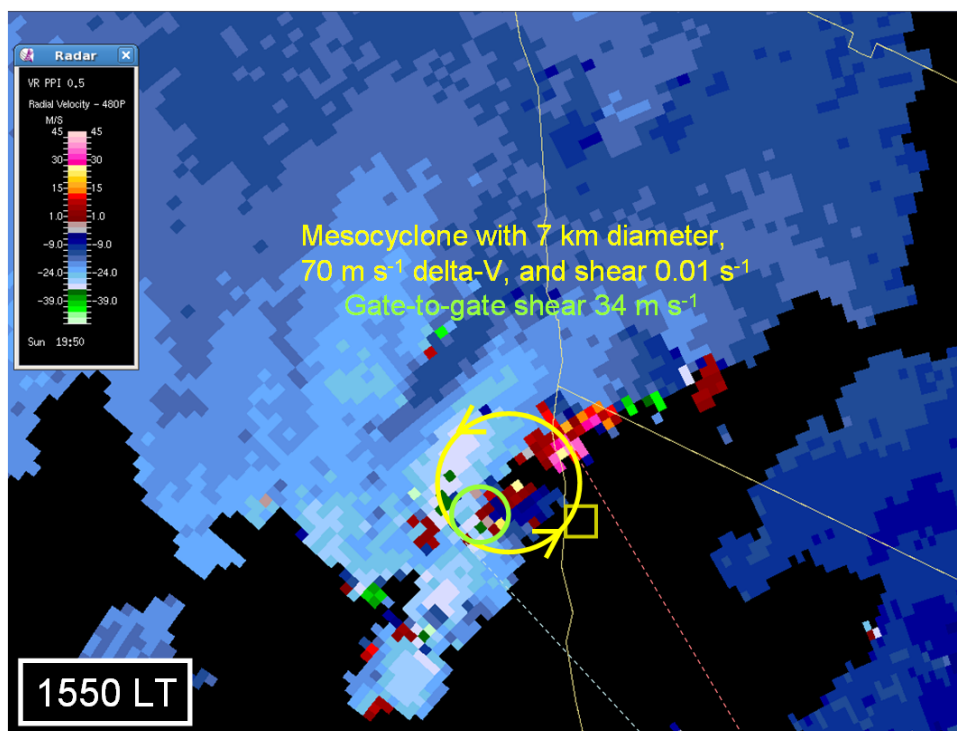


Figure 4. Image showing 0.5° radial velocity from the Exeter Doppler radar at 1550 LT. Goderich is marked by the yellow box. Red and blue dashed lines indicate away and toward radar radials, respectively. The yellow circle shows the core radius of the lower portions of the mid-level mesocyclone while the green circle indicates the location of maximum gate-to-gate shear. The radar colour legend is shown at left.

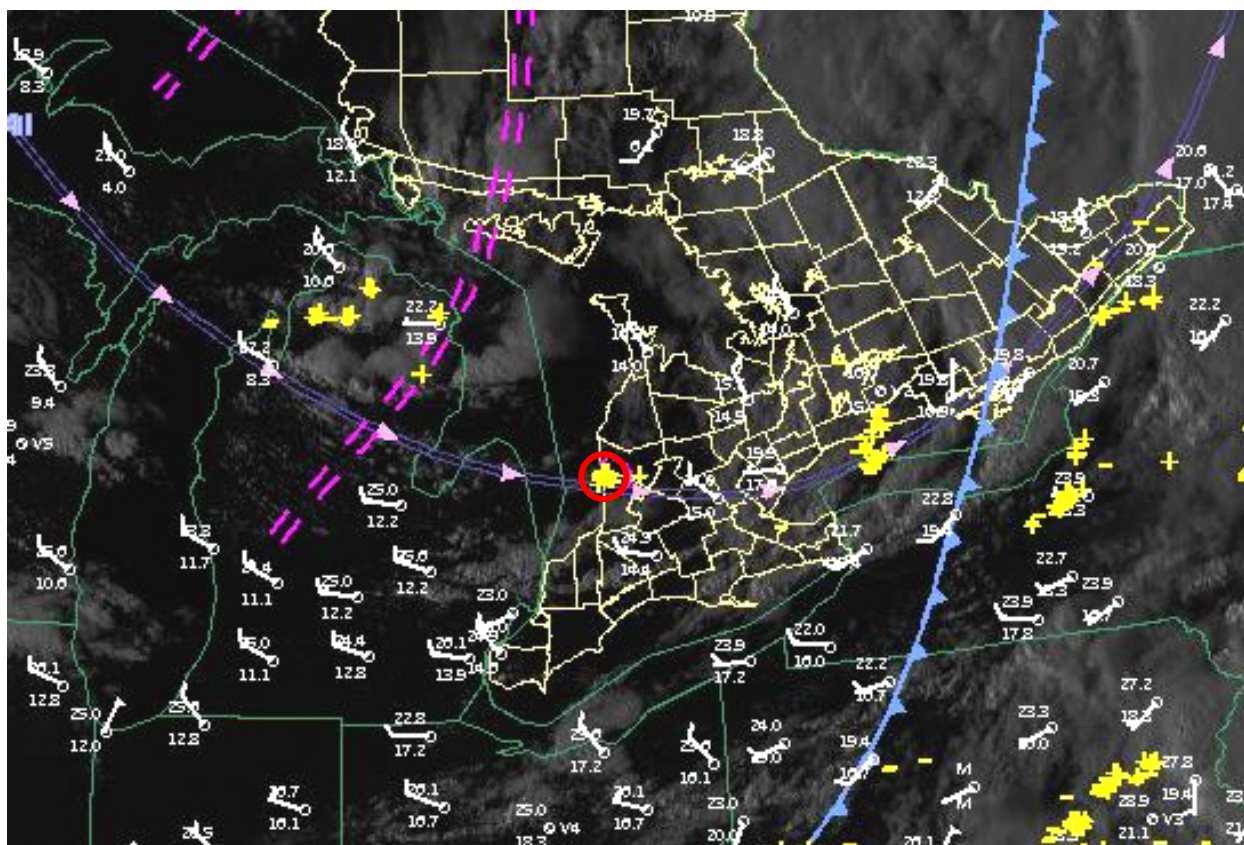


Fig. 5. Composite analysis for southern Ontario valid at 1600 LT on 21 August 2011. Shown are surface observations, visible satellite imagery and lightning. The cold front, upper troughs and upper jet are also shown. The red circle indicates the location of the Goderich storm.

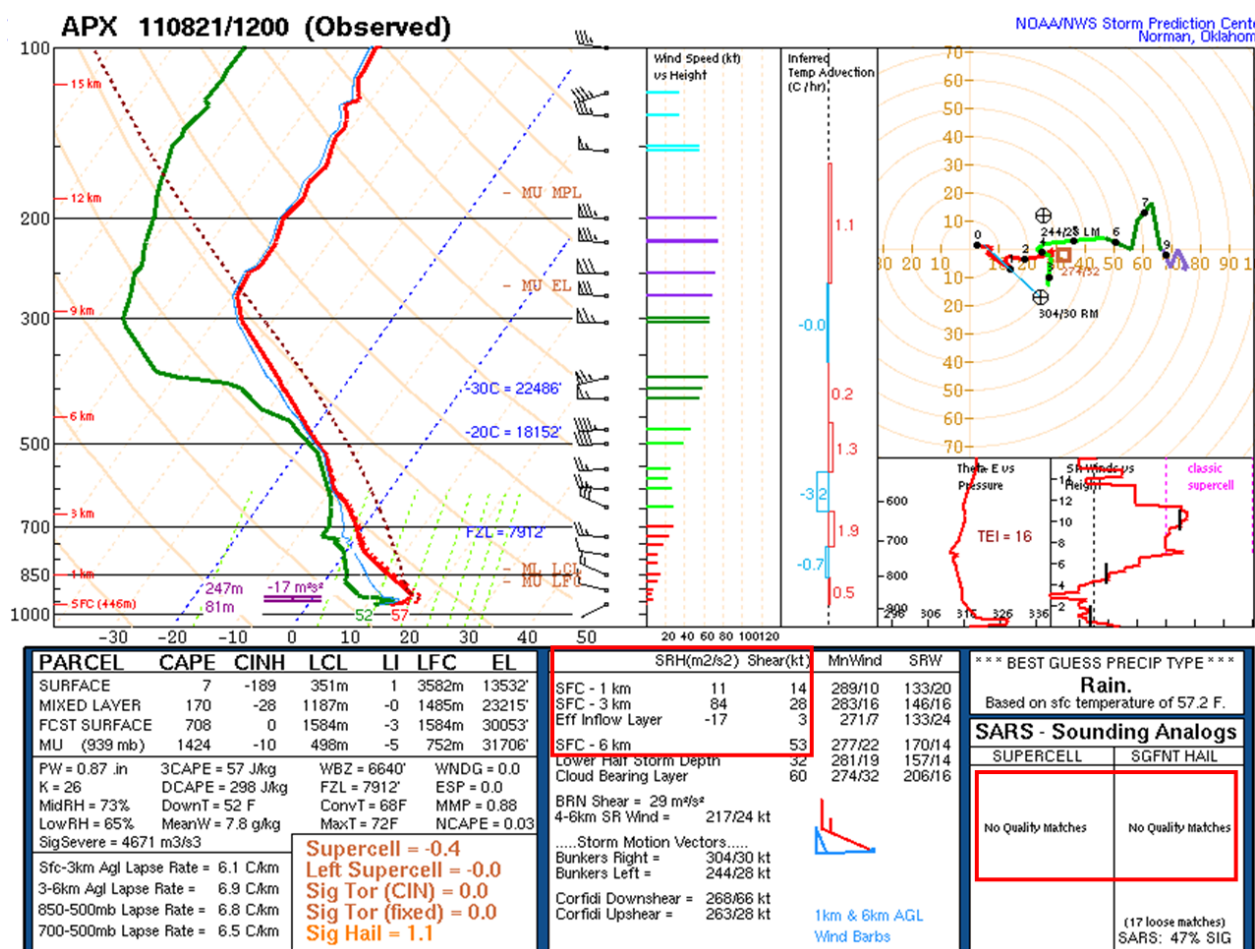


Figure 6. Image from US Storm Prediction Centre showing an analysis of 0800 LT (1200 UTC) rawinsonde data from Alpena, Michigan. Red boxes show areas of interest: at left, relatively low storm-relative helicity and relatively high SFC-6km wind shear, at right, no SARS sounding analogs matching past severe weather soundings with this sounding.

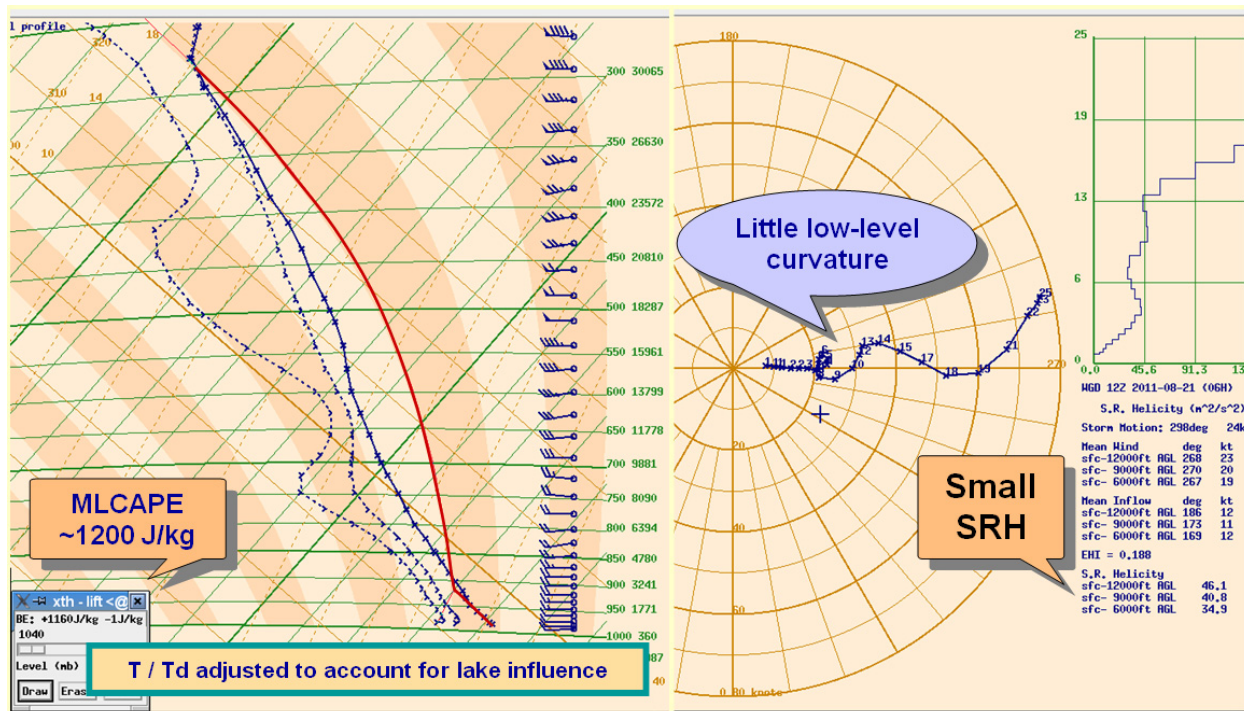


Figure 7. Forecast temperature, dew point and wind profiles from Environment Canada's GEM regional model (Côté et al. 1998). The red line at left indicates the parcel ascent curve.

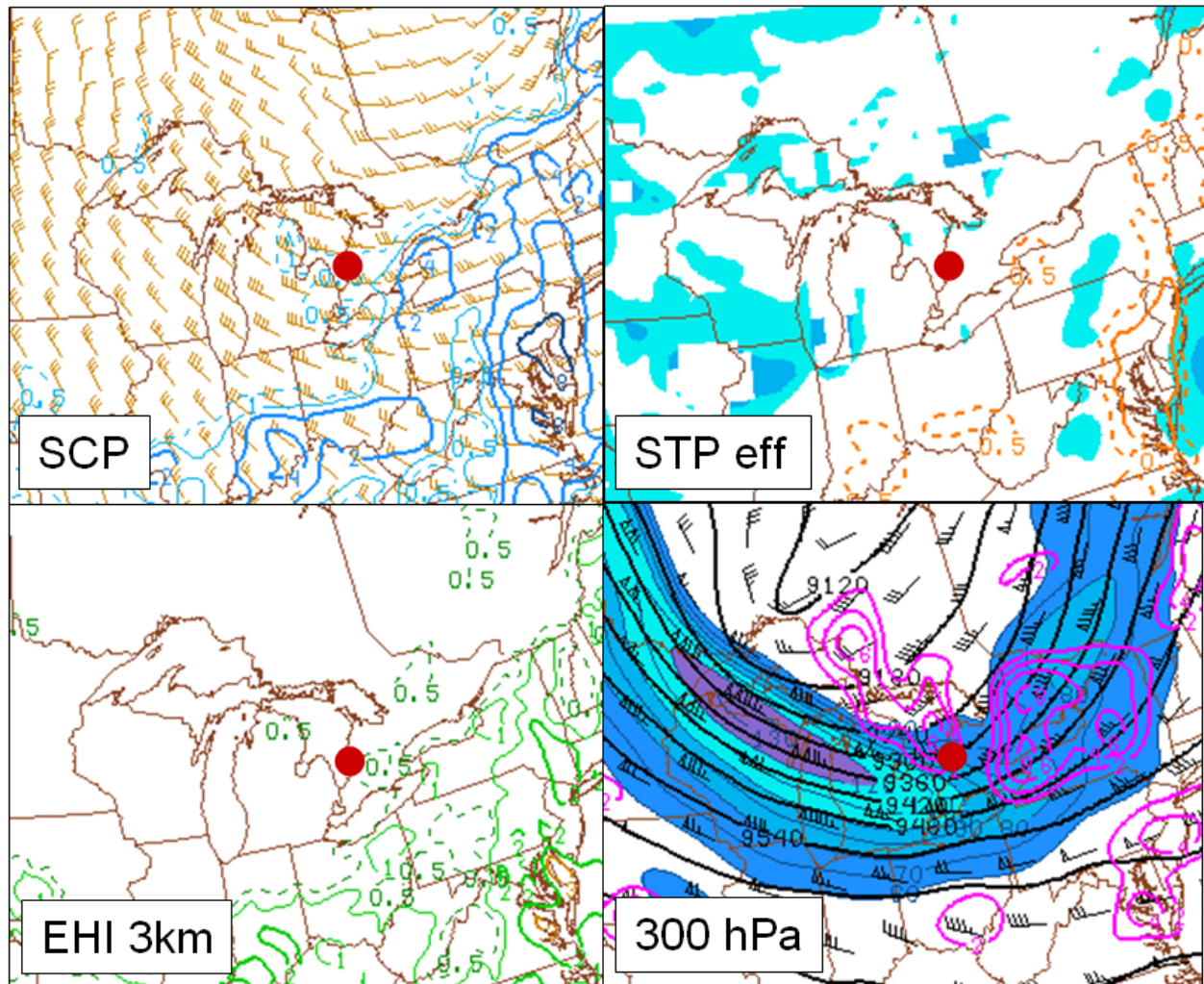


Figure 8. US Storm Prediction Centre Mesoanalysis images depicting the Supercell Composite Parameter, the Significant Tornado Parameter (effective layer), Energy-Helicity Index and the 300 hPa winds, isotachs, and upper-level divergence (magenta contours) valid at 1600 LT. The red dot indicates the location of Goderich.

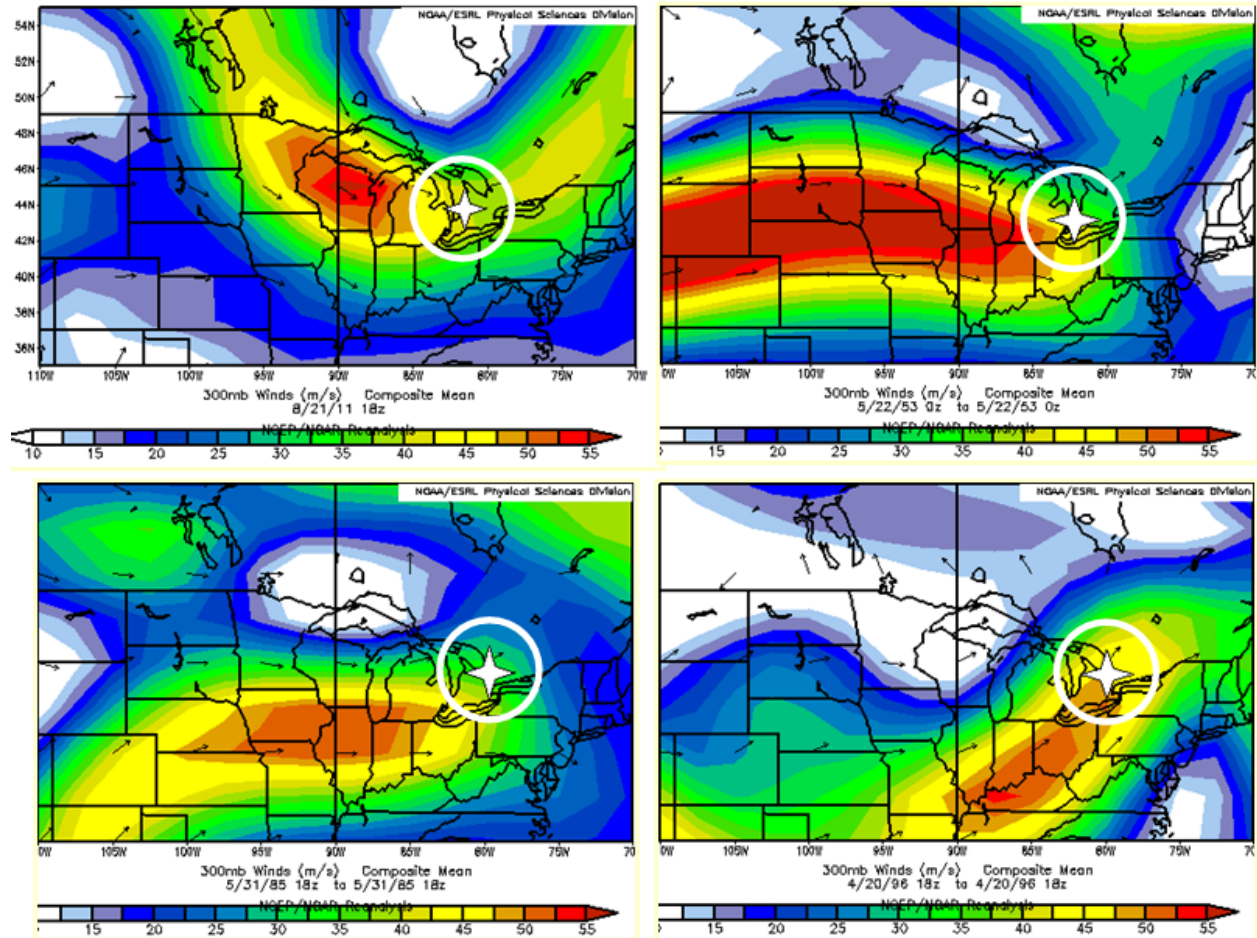


Figure 9. Images from the North American Regional Reanalysis showing the 300 hPa upper-level jet for 21 Aug 2011 (upper left), 22 May 1953 (upper right), 31 May 1985 (lower left) and 20 Apr 1996 (lower right), all of which had one or more F3 or greater tornadoes at the location of the white marker. In each case, the tornado or tornadoes occurred in the exit region of the upper-level jet.

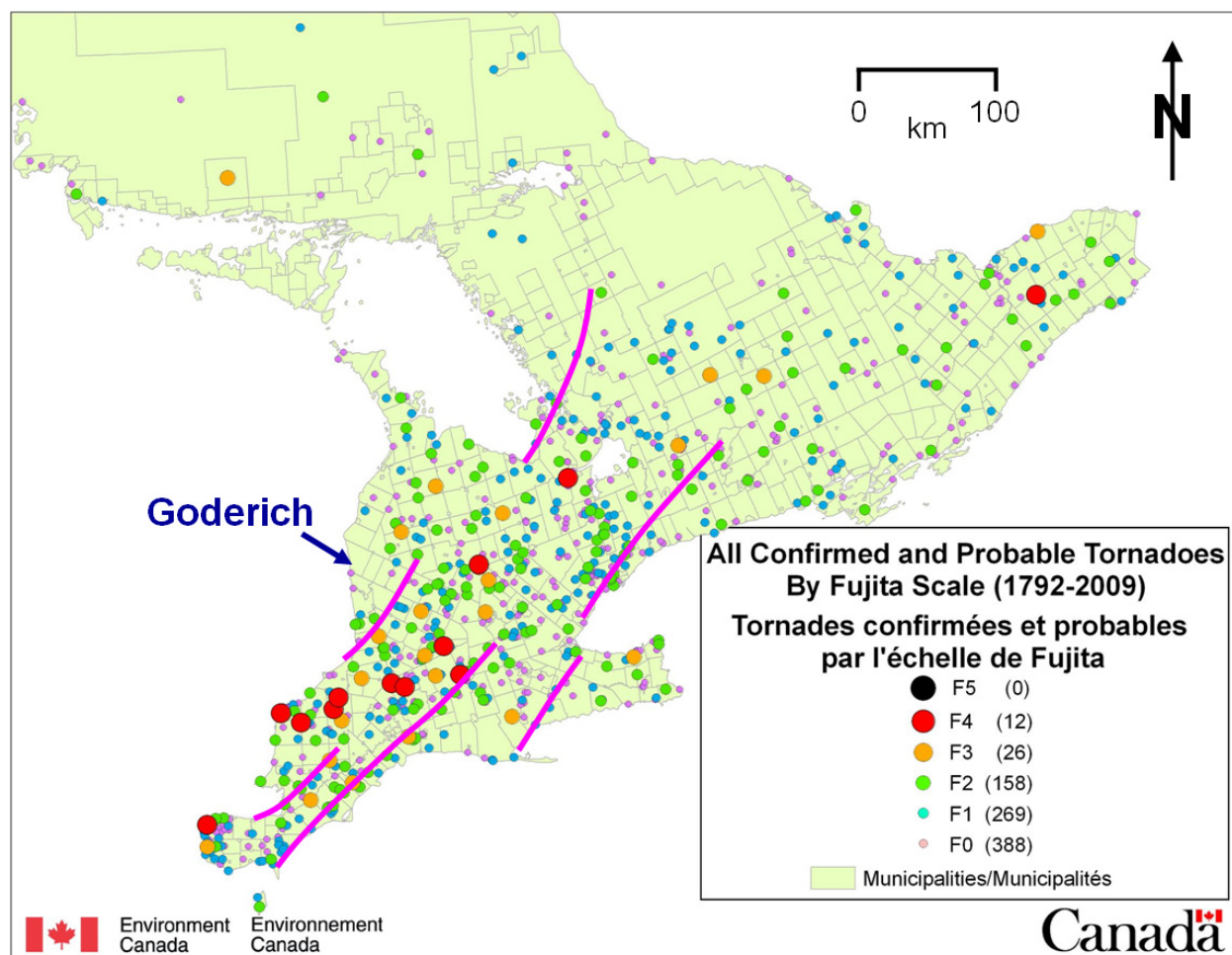


Figure 10. Image showing all confirmed and probable tornado occurrences in southern Ontario between 1792 and 2009 by F-scale rating. Idealized lake-breeze front positions in a southwesterly gradient flow are shown in magenta.

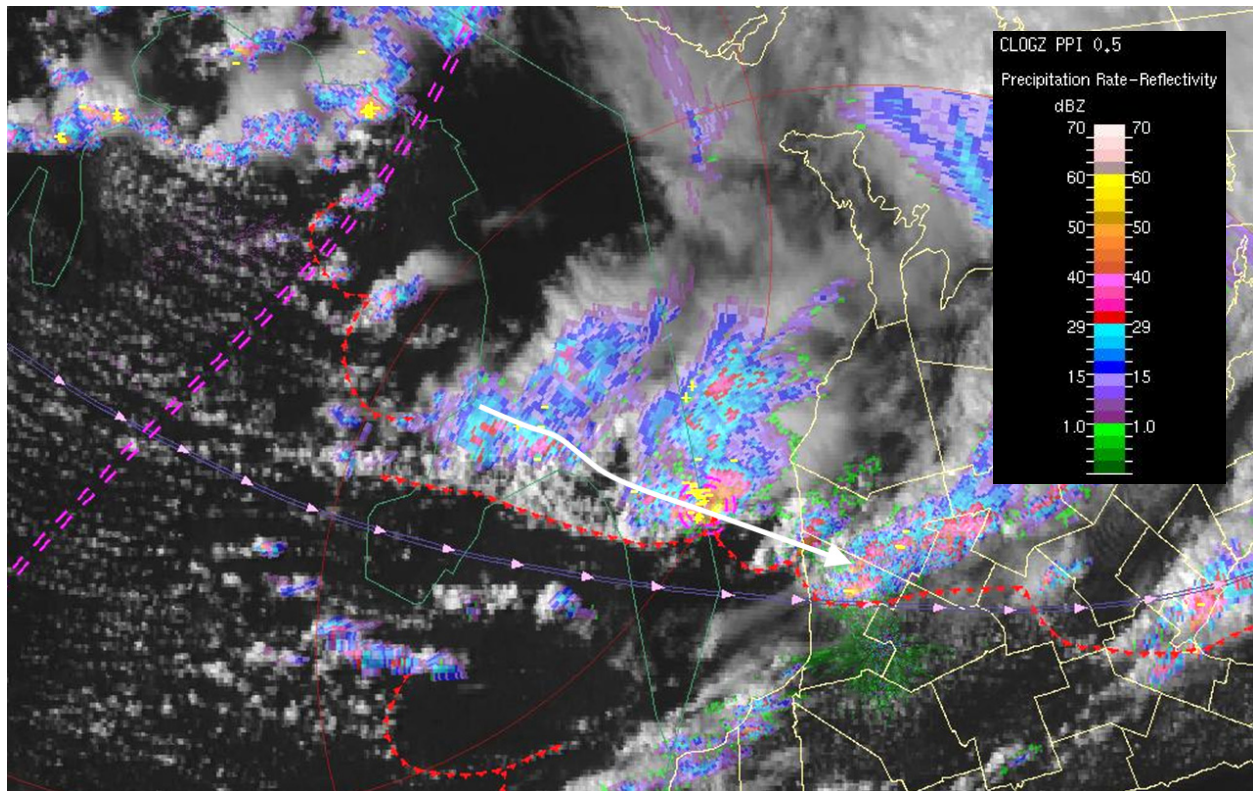


Figure 11. 0.5° radar reflectivity from the APX (Alpena, MI) and WSO (Exeter, ON) radars showing the Goderich supercell at 1520 LT with outflow boundaries in red and the complete storm track in white. Lightning is shown as yellow crosses. The broken magenta circle indicates that a mid-level mesocyclone is present. The magenta line over Michigan indicates an upper trough, while the pink line stretching from Michigan east-southeast to Ontario indicates the position of the upper-level jet. The radar reflectivity colour legend is shown inset.