P59 # USING TORNADO, LIGHTNING AND POPULATION DATA TO IDENTIFY TORNADO PRONE AREAS IN CANADA

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1. INTRODUCTION

Tornado resilience measures written into the National Building Code of Canada in 1995 were based on a forensic study of the Barrie / Grand Valley F4 tornadoes of 31 May 1985 (Allen 1986). The measures include anchors in manufactured and permanent structures, and masonry ties in permanent structures (schools, hospitals, auditoriums) – all relatively inexpensive for new buildings. However, Environment Canada was asked to clearly define 'tornado prone' regions in Canada in order for these design recommendations to become binding.

To define such regions, an updated Canadian tornado climatology was needed. The first 30-year Canadian tornado database was published by Michael Newark of Environment Canada in 1984, and covered the years 1950-1979 (Newark, 1984). A new 30-year Canadian tornado database covering the years 1980-2009 has now been developed. Tornado data were assembled from each region of Canada over the 30-year period and refined using a consistent methodology, extending the work of Sills et al. (2004). Based on this new tornado data set, plotted in Fig. 1, approx. 70 tornadoes are reported across Canada each year.

There are several very large yet relatively remote areas of Canada (e.g. northern Ontario and Quebec, parts of the Prairies) where severe weather is believed to occur but is rarely reported, creating significant gaps in the tornado climatology. In order to fill those gaps, and better define 'tornado-prone' regions of Canada, a novel approach combining tornado, lightning and population data was used.

2. DATA AND METHODOLOGY

To fill data gaps and define tornado prone regions, we generated synthesized tornado density values on a 50-km grid using tornado occurrence, lightning flash density and population density.

The new 30-year tornado data were gridded so that tornado occurrence values represented any parts of tornado paths through each grid cell, including tornadoes originating in the United States. The resulting gridded data are shown in Fig. 2.

Newark (1984) used a correction factor to reduce the bias in tornado reports resulting from variations in population density. This approach, however, could not address meteorologically based variations in tornado incidence. Since that time, a new robust observation platform has been established that does provide a meteorological parameter – lightning – continuously across Canada: the Canadian Lightning Detection Network. A 10-year lightning climatology has been established based on millions of lightning flashes (Burrows and Kochtubajda 2010). While it is not currently possible to distinguish between tornadic and

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non-tornadic thunderstorms using lightning data, the lightning climatology identifies areas of Canada prone to thunderstorms, some of which will produce tornadoes. Therefore, lightning density values from this climatology were interpolated to the 50-km grid as shown in Fig. 3.

A ‘probability of detection’ (POD) weighting mask was created based on population density values derived from the 2001 Canadian census and interpolated to the 50-km grid (Fig. 4). The weighting increases based on an exponential function from population density near 0 persons km^{-1} to 6 persons km^{-1}, above which a tornado POD of 1 can be assumed (King, 1997).

Where POD was 1 or greater, the observed tornado count was used. Otherwise, the synthesized tornado count was modeled as a Poisson regression with lightning flash density as predictor, weighted by population density.

3. RESULTS

Brooks and Doswell (2001) observed that the distribution of 1920-1998 United States tornadoes by F-scale ranking was approaching log-linear, consistent with the standard statistical distribution of rare events. They also observed that the log-linear slope for F2-F4 tornadoes in the U.S. database has been relatively constant since 1950 and may be an indicator of “true” tornado distribution. We used this apparent relationship in two different ways for this study.

First, an F2-F4 slope is obtained using the new 30-yr tornado database for Ontario (Fig. 5, 1990s United States tornadoes are also plotted for comparison). It is assumed that all regions across Canada should have a similar slope to that from Ontario since they all experience a similar mix of supercell and non-supercell tornadogenesis processes. Ontario is used because there is a large sample size and the database has a relatively high quality. While the Prairies region also has a large sample size, many tornadoes there are assigned an F0 rating due to lack of damage indicators, and therefore the Prairie database is expected to have a low F-scale bias. In Quebec, British Columbia and the Maritime provinces, the sample sizes are relatively small and a robust F2-F4 slope cannot yet be established.

The slope determined using the Ontario data reveals that F0 tornadoes are significantly under-represented in the database. Therefore, an F0 ‘boost’ was applied to fit the slope, adding over 250 tornadoes to the total tornado count.

The resulting tornado density values, seen in Fig. 6, show that a number of gaps in tornado occurrence are filled, including the northern Prairies, northwestern Ontario and south-central Quebec. Interestingly, low density values remain between Lake Superior and Hudson Bay. Overall, the modelling suggests that approx. 250 tornadoes should occur in Canada on average each year. That is more than three times the reported annual occurrence rate of 70 tornadoes per year, giving an indication of the number of tornadoes that likely go unreported.

Second, the identified F2-F4 slope is applied to the F0-boosted model results to partition the total number of modelled tornadoes into F0-F5 categories. For this work, regions prone to just F0-F1 tornadoes, and regions prone to F2-F5 tornadoes (in addition to F0-F1 tornadoes), needed to be identified. The American Society of Civil Engineers building codes (ASCE, 2005) provide tornado-resilience design recommendations referencing a tornado density of 1.0×10^{-5} km^{-2} yr^{-1}. This threshold is thus a logical baseline for the definition of tornado prone regions of Canada.

Using this threshold, tornado prone areas for F0-F1 and F2-F5 were contoured subjectively based on the partitioned model results. Another area for ‘rare occurrence’ using the threshold 1.0×10^{-6} km^{-2} yr^{-1} was also contoured. Finally, all known Canadian tornadoes between 1792 and 2009 were superimposed for comparison (Fig. 7), showing that the tornado prone areas compare well with historical occurrences.

4. CONCLUSIONS

Tornado prone regions of Canada were identified using a novel methodology involving a new 30-yr Canadian tornado database, a 10-yr lightning flash density dataset and population density data, plus knowledge of the tornado occurrence values partitioned by F-scale using the F2-F4 log-linear slope relationship of Brooks and Doswell (2001). The tornado prone areas map has now been published in the National Building Code of Canada (NRCC, 2011).

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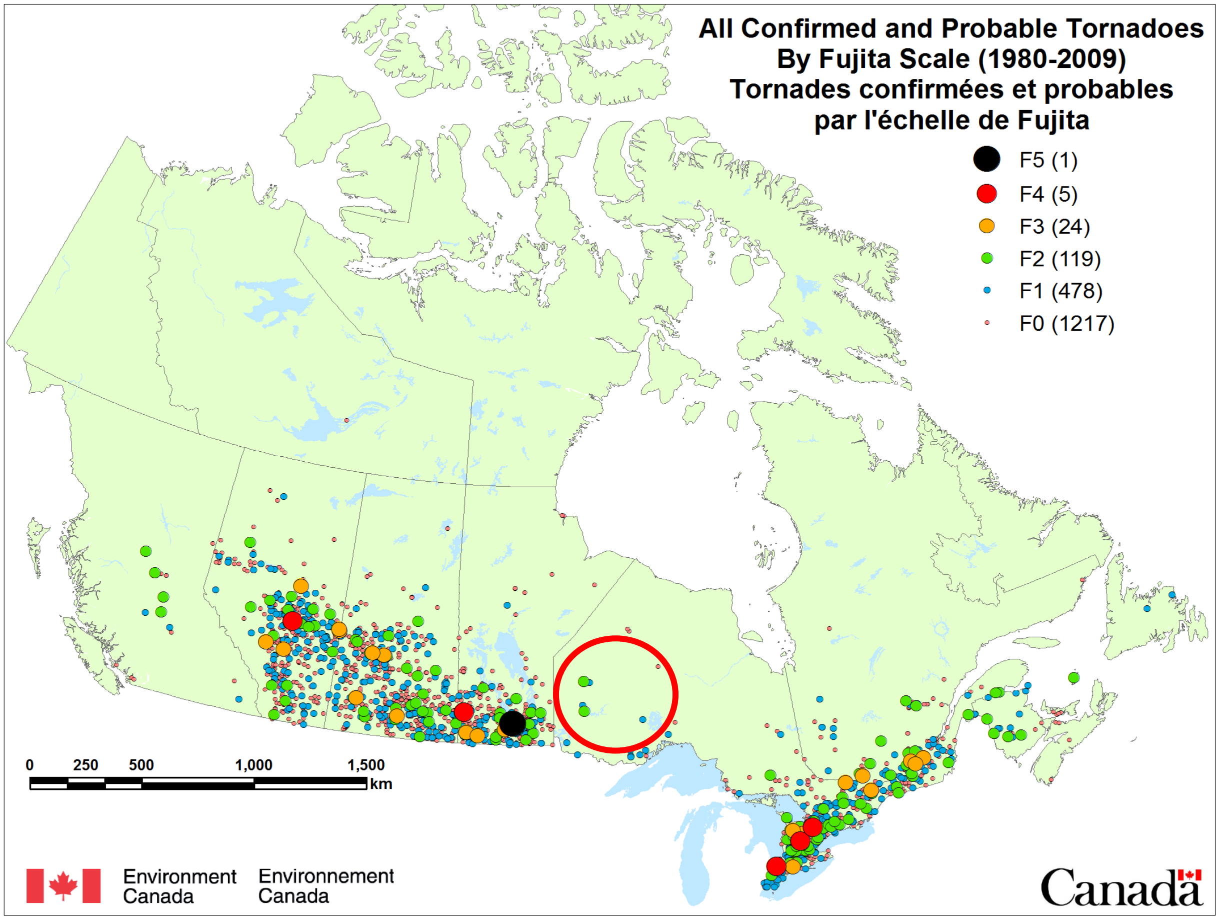

Figure 1. Updated 30-yr tornado database including all confirmed and probable tornadoes between 1980 and 2009. The red circle shows one area where under-reporting is expected to be significant due to very low population density.

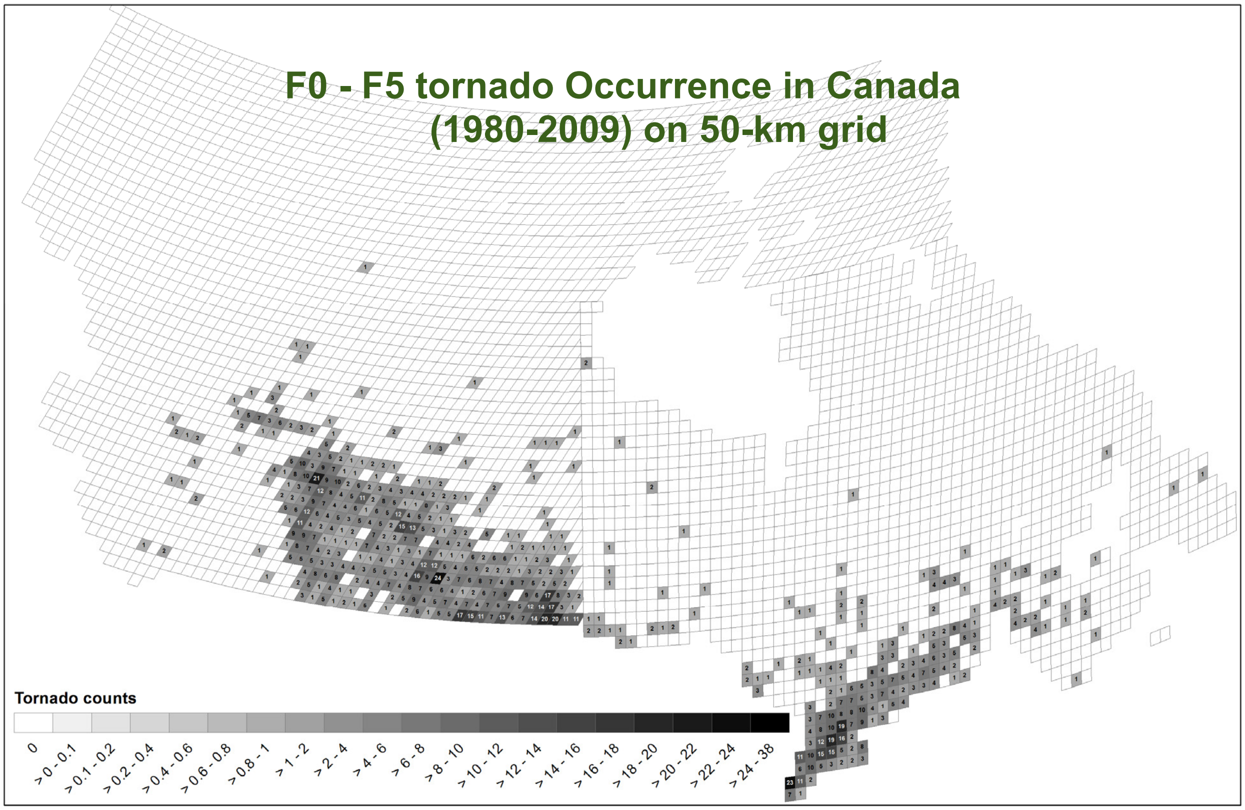

Figure 2. Map of tornado occurrence on a 50-km grid based on the updated 30-yr tornado database. The legend at bottom left shows the shading associated with tornado counts in each grid cell.

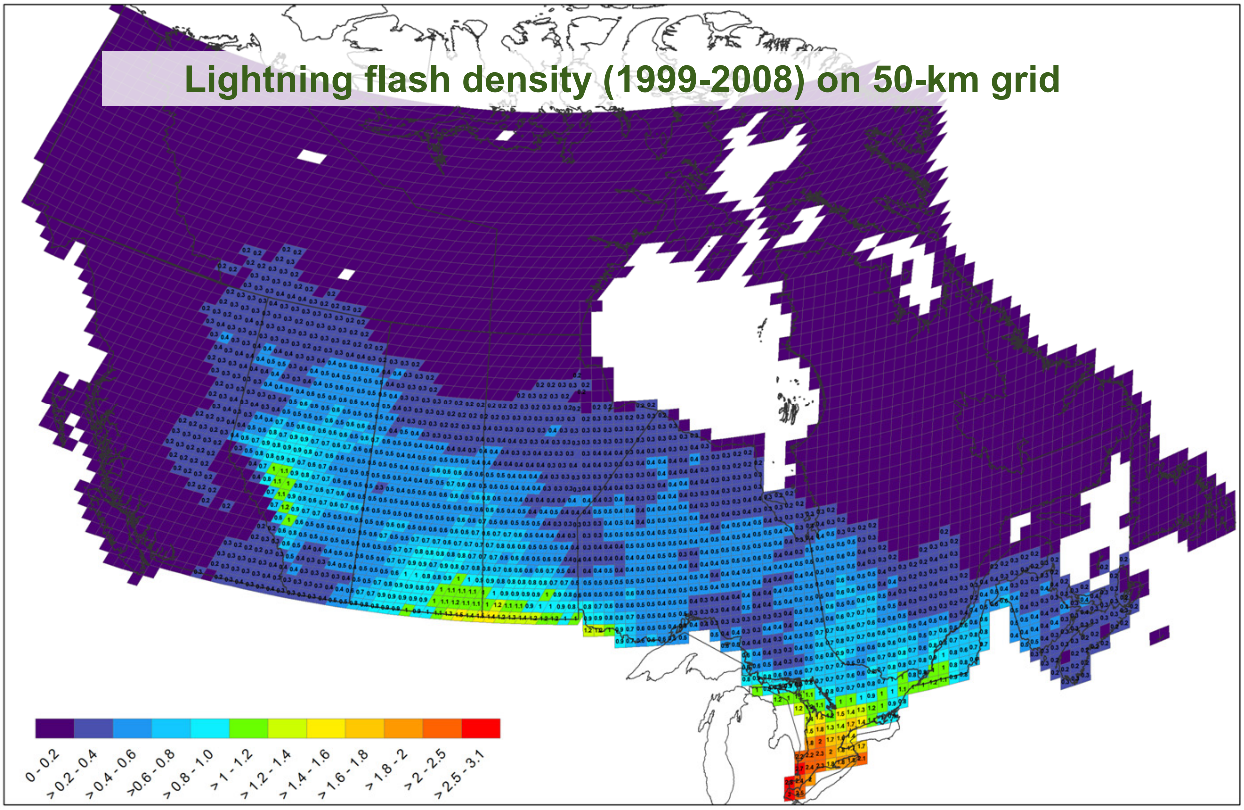

Figure 3. Map of 10-yr lightning flash density values from the Canadian Lightning Detection Network based on more than 23.5 million cloud-to-ground flashes (see Burrows and Kochtubajda, 2010). The legend at bottom left shows the colour associated with flash density in each grid cell.

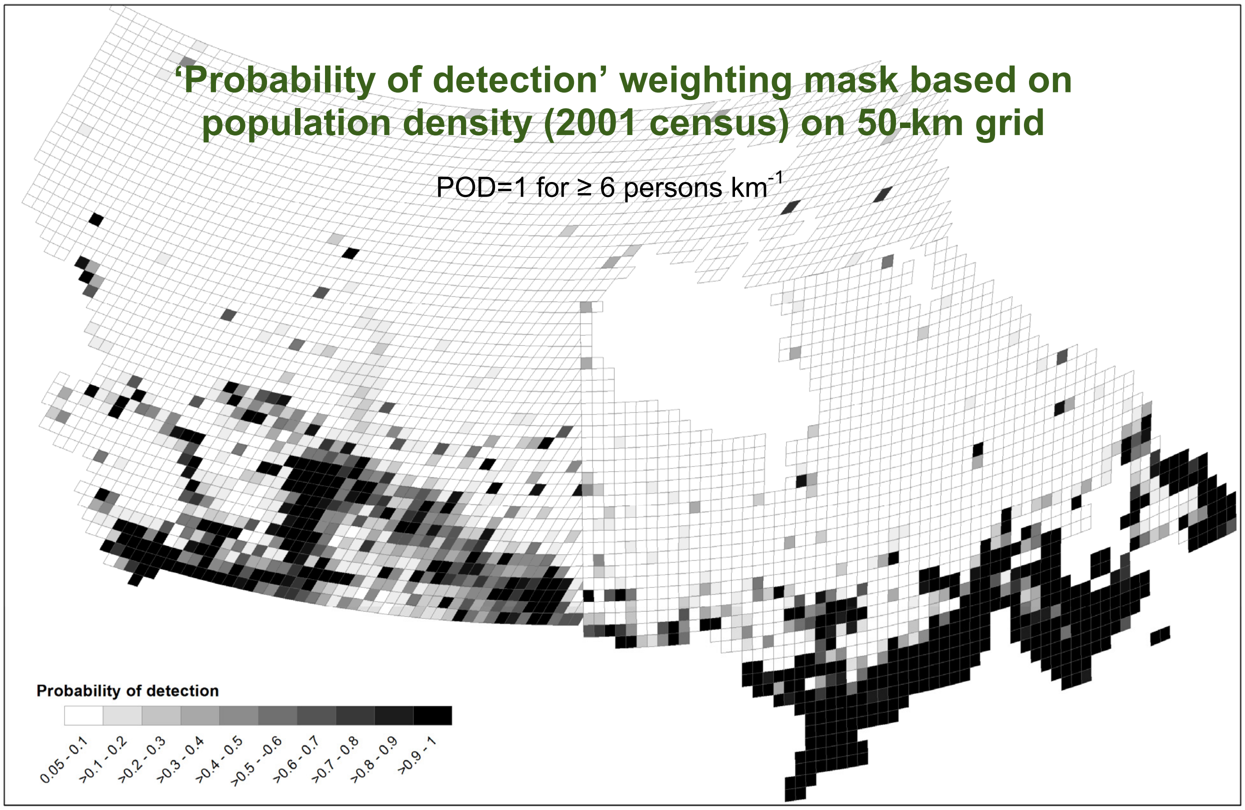

Figure 4. Map showing the weighting mask based on population density data from the 2001 Canadian census. The legend at bottom left shows the shading associated with probability of detection in each grid cell, with all values at or above 6 persons km^{-1} shaded black.

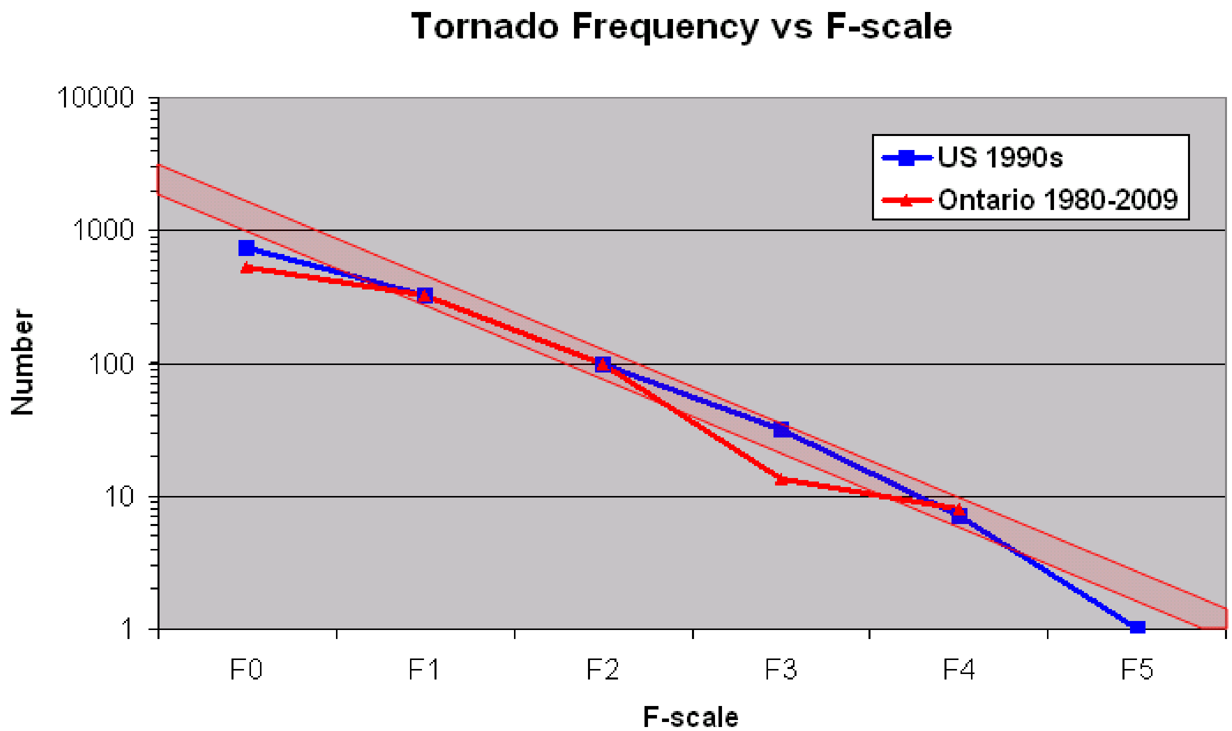

Figure 5. Log-linear graph of tornado frequency (normalized to 100 F2 tornadoes) vs. F-scale for Ontario for 1980-2009 (red) and for the United States for the 1990s (blue). The red box shows the F2-F4 slope for the Ontario data.

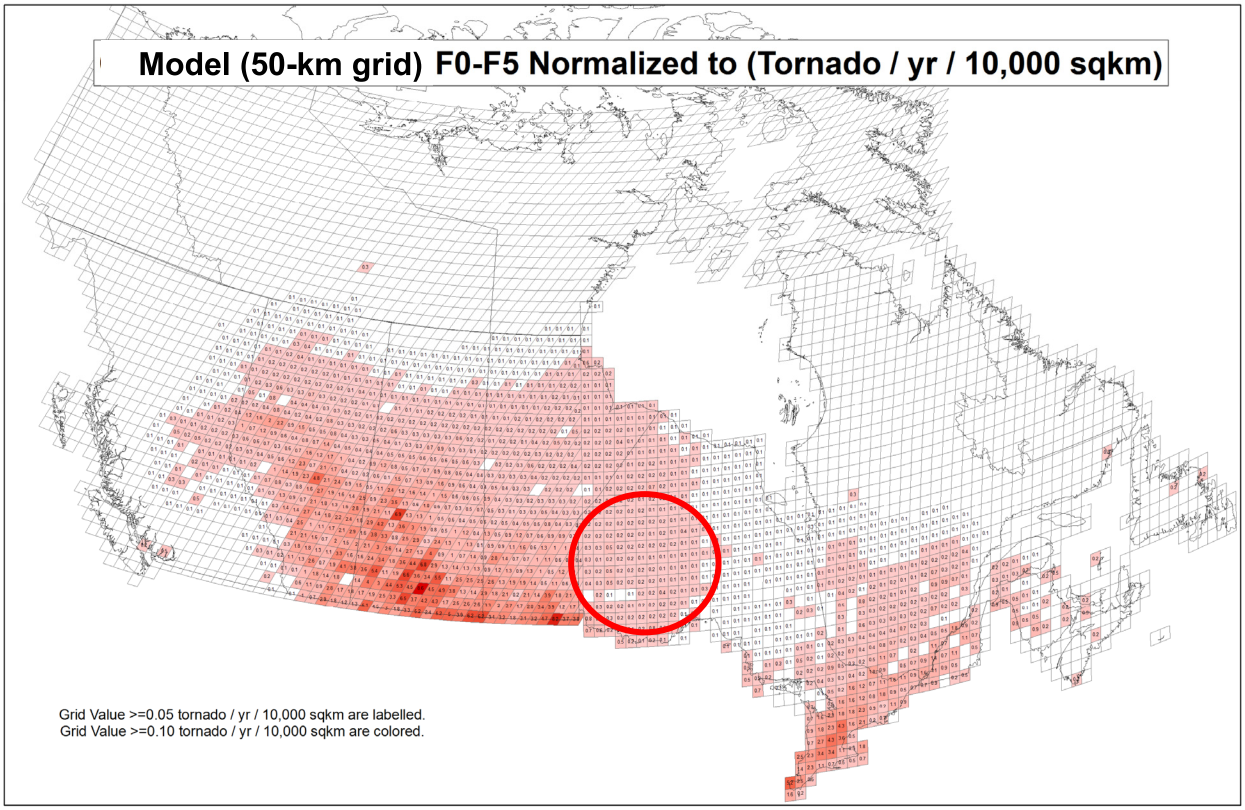

Figure 6. Map showing the F0-boosted tornado density values on the 50-km grid normalized to tornadoes yr^{--1} 10,000 sq km^{-1}. The red circle indicates the area in Fig. 1 thought to experience significant under-reporting of tornadoes.

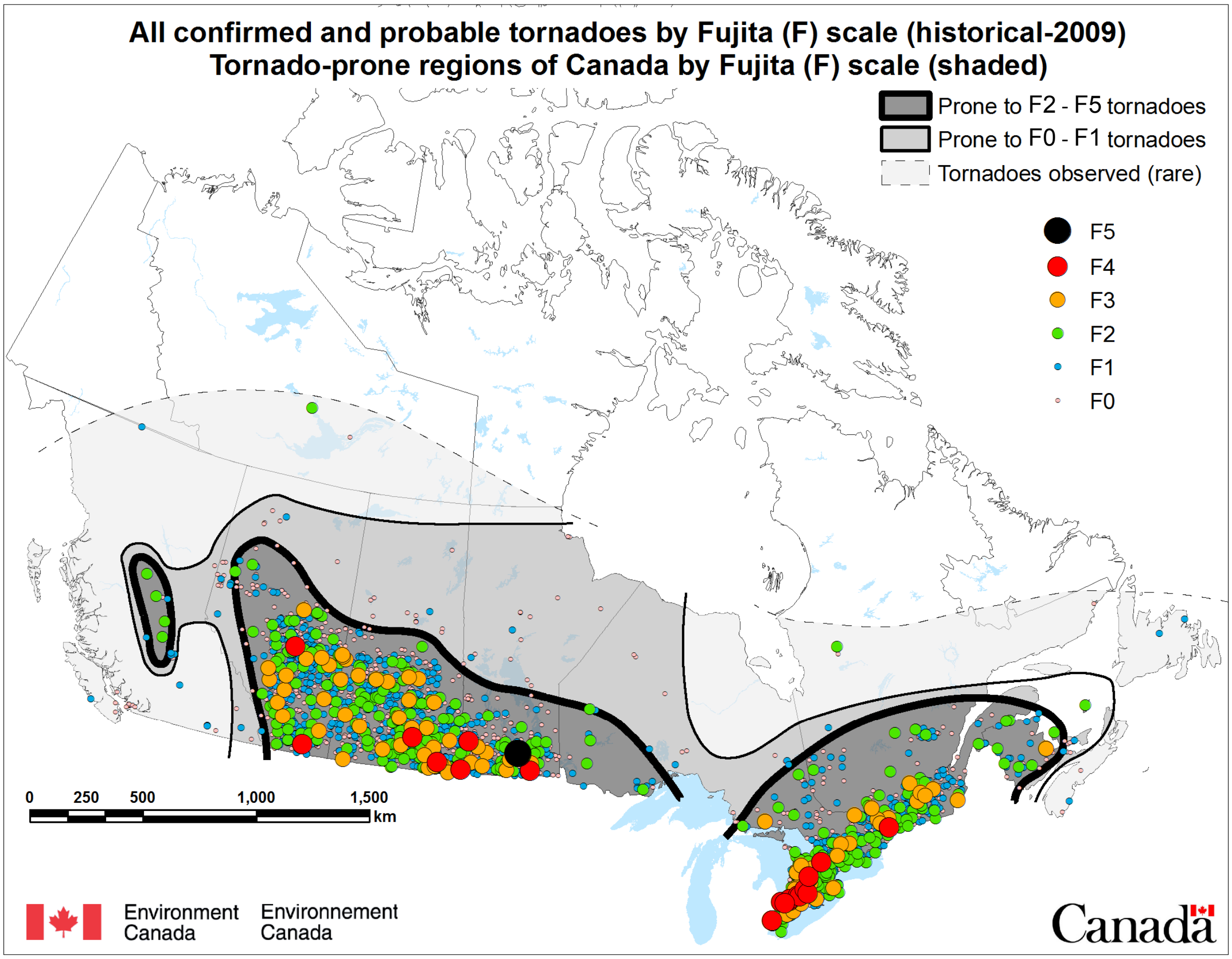

Figure 7. Map showing the F0-F1 and F2-F5 tornado prone areas as well as a ‘rare occurrence’ area, with all known Canadian tornadoes from 1792 to 2009 superimposed for comparison.