Tornado Frequency and its Large-Scale Environments Over Ontario, Canada

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Abstract: Over the last two decades, there exist ever-increasing changes in tornado frequency over Ontario, Canada. It is shown through a composite analysis that the tornado events occur more frequently over Ontario with stronger low-level cyclonic circulations and stronger baroclinicity under conditions of warmer atmospheric temperature.

1. INTRODUCTION

Tornado has high impacts on Canadian society in terms of loss of life and damage of property. In Canada, during an average year about 80 tornadoes have been reported that result in, on average, 2 deaths, 20 injuries, and tens of millions of dollars in property damage. Because of its small-scale nature, tornado is a localized short-lived phenomenon and it is therefore difficult to detect and predict. Up to date, the detection and prediction of tornado almost solely rely on observations and related analyses. Using proximity soundings and analysis data to examine mesoscale environments for severe storms and tornadoes have been extensively documented in previous studies (e.g., [1-3]). Different from these researches, in this work we attempt to diagnose relationships between tornado frequency and its large scale environments from climatological point of view and to examine the large scale environments associated with large and small frequency of tornado occurrence. Our goal is therefore to anticipate large scale environments that are favorable for more tornadogenesis rather than to forecast an individual tornado. In this study, we examine Ontario tornado frequency variability and its relationship with large scale atmospheric conditions using a composite analysis technique. To our knowledge, this technique is the first time being employed in tornado frequency analysis.

2. DATA

The quality-controlled data for tornado events and days over Ontario are obtained from the Ontario Storm Prediction Center (OSPC) of Environment Canada. The data set contains numbers of tornado events (i.e., one event is for one tornado) and days over 24 years (1979-2002), and this data set is currently officially available till year 2002. Ontario is geographically located between Hudson Bay and the Great Lakes. To the north of 46^{o}N, Ontario's west-east area extent is from 96^{o}W to 79^{o}W, and to the south of 46^{o}N, its eastern boundary is extended to approximately 74^{o}W. Since 1979, tornado sightings were routinely archived by Environment Canada. Therefore, the frequency data may be reasonably representative of the actual numbers of tornado events [4, 5] although caution must be exercised when one deals with the tornado dataset [6, 7]. In this work, we are interested in all F-scale tornadoes because there is only few F2 or stronger tornado occurred every year in Ontario. The reanalysis data are obtained from the National Centers for Environmental Prediction (NCEP). The NCEP data are available from year 1948 to 2008. These analyses are archived with a horizontal resolution of 2.5^{o} latitude × 2.5^{o} longitude, and 17 constant pressure levels at 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, and 10 hPa [8]. The period of 1979-2002 is examined for details.

3. TORNADO FREQUENCY VARIABILITY

As shown in Fig. (**1a**), there are substantial decadal variabilities in Ontario tornado frequency over the last two decades. These variabilities in numbers of tornado events are similar to those in numbers of tornado days. The correlation between the numbers of tornado events and the numbers of tornado days is 0.90 with statistically significant level greater than 99%. To better visualize the tornado event frequency, we sort the original numbers of tornado events in an ascending order and present them in a form of the anomaly with a mean of 17.6 (Fig. **1b**). As observed from Fig. (**1b**), there are a number of years with positive and negative anomaly of tornado events. The ten strongest positive anomaly years appear in 1980, 1981, 1982, 1983, 1984, 1985, 1987, 1998, 1999, and 2001, referred to as high-event years, whereas the ten strongest negative anomaly years appear in 1986, 1988, 1989, 1990, 1991, 1992, 1993, 1996, 2000, and 2002, referred to as low-event years. The statistical difference between two means of tornado numbers during two ten-year periods can be determined using a t test through computation of statistic t [9, 10]:

$$t = \frac{\bar{y}_2 - \bar{y}_1}{s\sqrt{\frac{1}{n_2} + \frac{1}{n_1}}} \tag{1}$$

where n_2 and n_1 ($n_2 = n_1 = 10$) indicate the size of the y_2 and y_1, $\bar{y}_2$ and $\bar{y}_1$ are the sample means of 10 high-event and 10

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low-event years, respectively, and s is the estimated standard deviation defined as:

$$s = \sqrt{\frac{\sum_{i=1}^{n_2}(y_{i2} - \overline{y_2})^2 + \sum_{i=1}^{n_1}(y_{i1} - \overline{y_1})^2}{n_2 + n_1 - 2}} \quad (2)$$

Under the null hypothesis H_o, Eq. (1) has a t distribution with $n_2 + n_1 - 2$ (=18) degree of freedom. According to our calculation, the statistic t is equal to 9.0 ($> t_{0.01} = 2.9$) with the statistically significant level of 99%. If the six strongest positive and negative anomaly years (with $n_2 + n_1 - 2 = 10$ degree of freedom) are considered, the statistic t is equal to 3.1 ($> t_{0.05} = 2.2$) with the statistically significant level at least 95%.

To understand how the tornado frequency is linked with large scale atmospheric conditions, we consider a simple composite of anomalies for geopotential height (1000-hPa) and thickness (1000-500 hPa) during the high-event and low-event years [10]. These anomalies are computed based on the NCEP suggested climatological mean from 1968 to 1996. Since tornadoes in Ontario mostly occur from March to September [4], composite analyses are performed over these 7 months using monthly mean NCEP data. As displayed in Fig. (**2**), geopotential height (1000-hPa) anomalies over Ontario during the high-event years are negative with values from -2 to -3 m whereas the anomalies over the low-event years appear mainly positive with values from 0 to 4 m. This indicates that the high-event years are associated with more anomalous cyclonic circulations than the low-event years.

Fig. (**3a**, **b**) show thickness (1000-500 hPa) anomalies during the high-event and low-event years, respectively. The magnitude of the positive anomaly in the high-event years ranges from 4 to 15 m while the magnitude in the low-event years varies from 1 to 4 m. It is interesting to note that the north-south thickness difference across the whole Ontario is 11 m in the high-event years whereas only 3 m in low-event years. Based on the thermal wind relationship, the thickness (1000-500 hPa) is proportional to the mean temperature of the layer between 500 and 1000 hPa. This indicates that the high-event years are linked to the warmer temperature whereas the low-event years are associated with the cooler temperature over Ontario. Since the north-south thickness

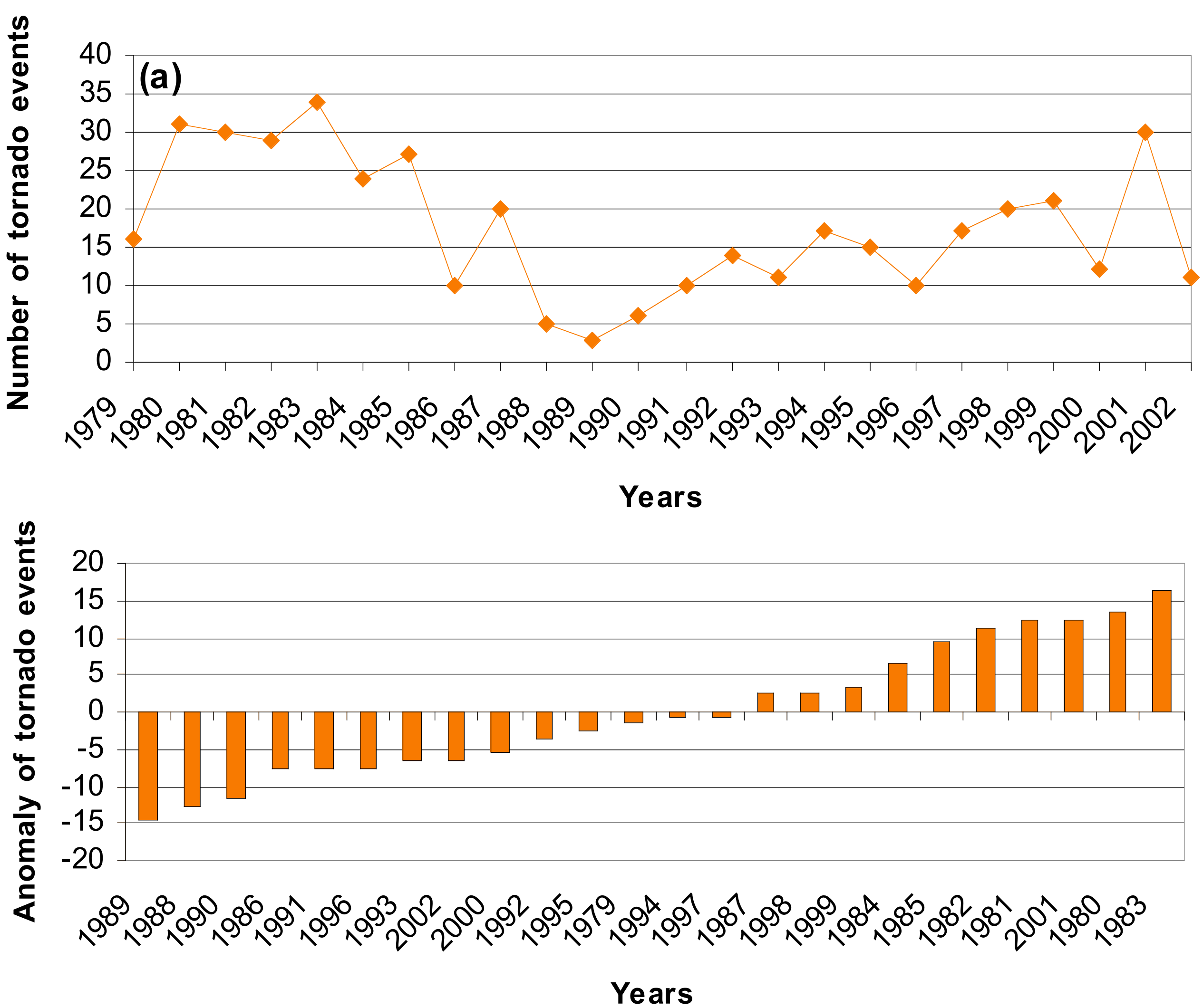

Fig. (1). (**a**) Time series of tornado event number (1979-2002) over Ontario; (**b**) Same as (**a**) except the anomaly of tornado event number being sorted in an ascending order.

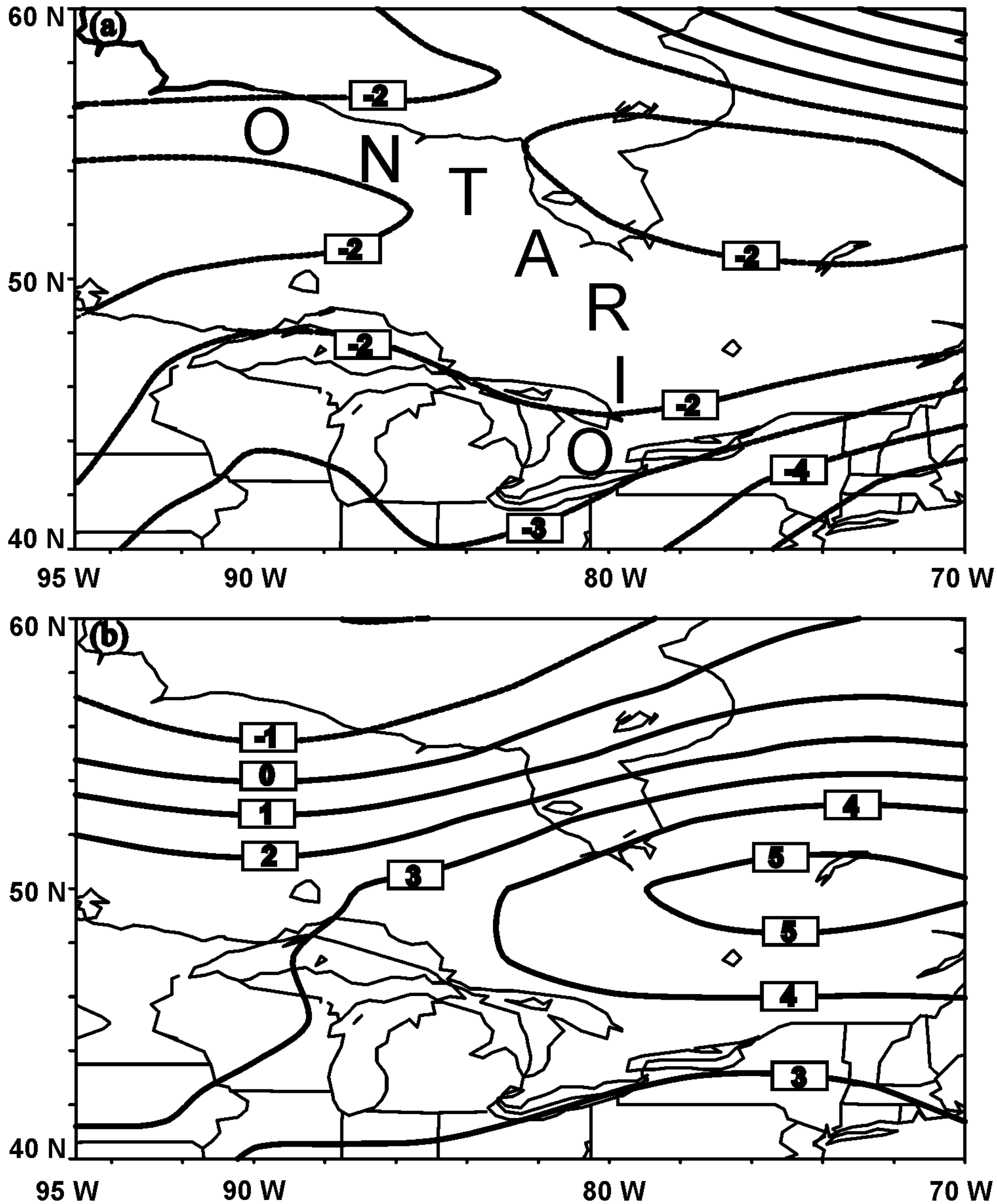

Fig. (2). Spatial distribution of geopotential height (1000 hPa) anomaly (m) in (**a**) ten high-event years, and (**b**) ten low-event years.

difference in the high-event years is three times more than that in the low-event years, it is suggested that over the Ontario region, much stronger baroclinicity is associated with the high-event years than that in the low-event years. Hence, the large scale atmospheric conditions associated with warmer air temperature and stronger low-level baroclinicity are favorable for more tornadogenesis.

4. CONCLUSIONS

In this study, we have examined Ontario tornado frequency changes over the last two decades. It is found that Ontario tornado frequency has substantial variabilities during the past 24 years. The connection of decadal variability of Ontario tornado frequency to large scale atmospheric conditions is investigated. It is shown through a composite analysis that the stronger low-level cyclonic circulations, stronger baroclinicity, and warmer atmospheric temperature are favourable for more frequent tornado occurrence over Ontario, Canada. Further researches will be carried out in the future to understand how these conditions favourable for tornadogenesis are modulated by low-frequency modes of climate change.

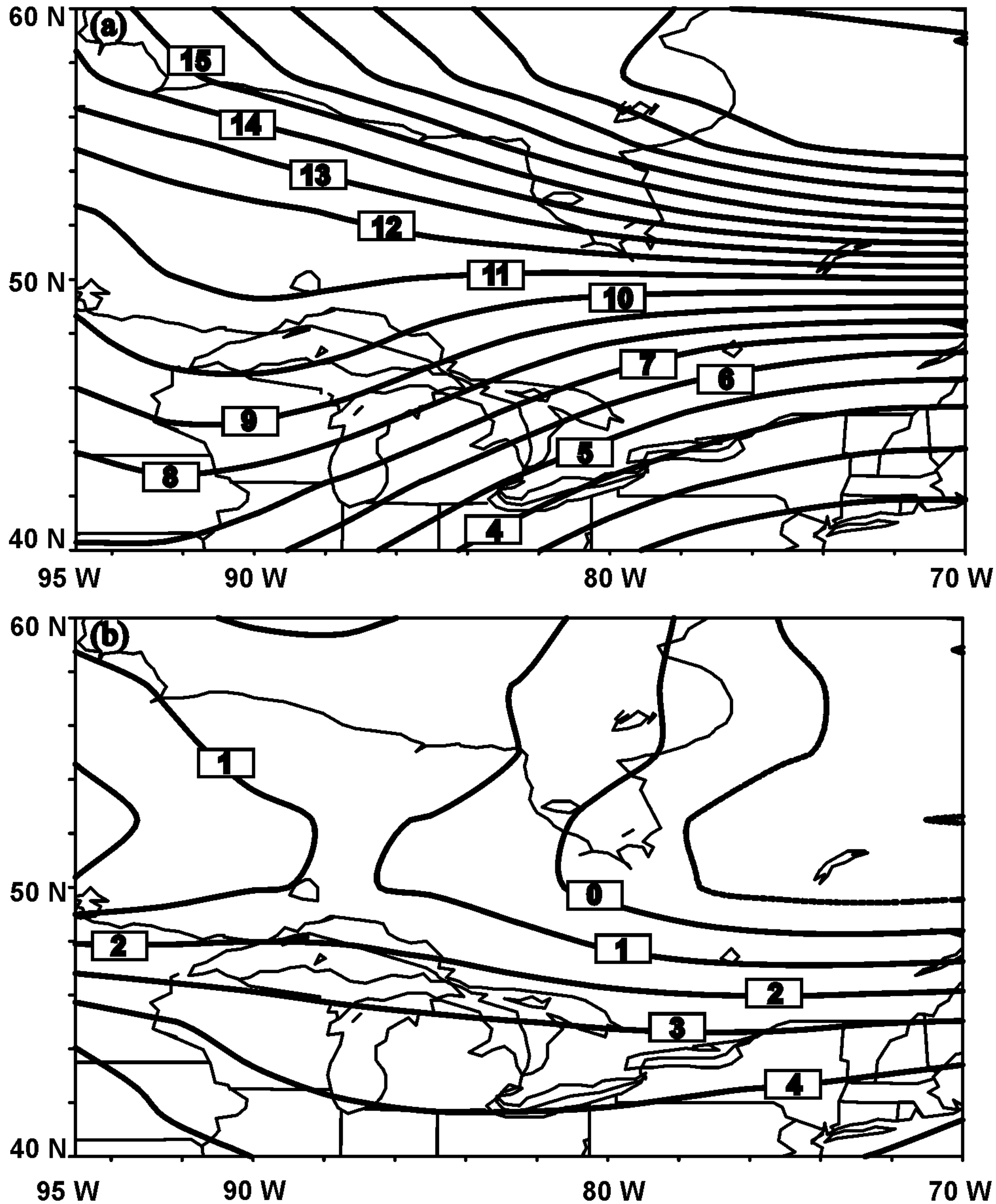

Fig. (3). Spatial distribution of thickness (1000-500 hPa) anomaly (m) in (**a**) ten high-event years, and (**b**) ten low-event years.

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