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Time varying properties of convective systems in the Great Lakes region of North America

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Abstract. Convective cell characteristics were deduced from radar data using an object oriented approach. Composite plots of the locations of the storm cells revealed the mesoscale character of the convection. Cell occurrence was analyzed on times scales ranging from daily to interannual. A semi-diurnal signal in cell properties was recognized and was related to the lake breeze-land breeze mechanism at work in the area. On an annual basis, the cell frequency exhibited a bimodal nature with a large year-to-year variability.

1 Introduction

Summertime convection in the Great Lakes region of southern Canada encompasses a wide variety of meteorological circumstances. The main local influences on the convective systems are the presence of the Great Lakes, some mild topographic features related to the Niagara escarpment, and the urban effect of the greater Toronto area.

The purpose of this study is to demonstrate that the analysis of an extended time series of data from a single radar can provide quantitative information on the characteristics of convective weather systems. The approach complements both case study and numerical modeling approaches to the improved understanding of mesoscale aspects of convection as well as its seasonal and interannual behaviour.

2 Data Collection and Analysis

Volume scan data taken on a scanning cycle of 10 min with the C-band radar at King City, Canada, during the period May to August from 1990 to 2003 were used in the analysis. Details of the methodology are contained in Boodoo et al. (2003). Briefly, an object oriented approach similar to Potts et al. (2000) was employed using the Canadian radar Decision Support System (CaRDS) to identify convective cells. The basis of the cell identification scheme was that the reflectivity be greater than 40 dBZ to a height above 8.5 km. This object oriented approach with a relatively high reflectivity threshold minimizes the problems associated range biases of a pixel based approach as noted in Bellon and Zawadzki (2003). Cell identification with this approach suffers no range dependency until beyond a range of 200 km.

Significant properties for each cell were then determined. Derived cell properties used in this analysis include the maximum reflectivity (Z_{max}), echo top (ET), vertically integrated liquid above 1.5 km (VIL15) and above 5.0 km (VIL50). VIL50 was corrected for range bias following Bellon and Zawadzki (2003).

The dataset is comprised of 33 330 convective cells encompassing 695 days of significant convection over 14 years.

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3 Results

3.1 Spatial distribution

There is a general decrease in cell occurrence going from south to north and west to east (Fig. 1). This is similar to the results of Burrows et al. (2002) based on data from the Canadian lightning detection network. Five maxima in cell frequency are apparent over southern Ontario (Fig. 1). The characterization of the area surrounding these maxima (indicated by the numbers 1 to 5 in Fig. 1) is as follows. Region 1 is the Niagara escarpment, an area of higher terrain where topographic influences would be significant. [See Fig. 7 in Boodoo et al. (2003) for a view of the topographic features of the area.] Region 2, at the southwest edge of the radar coverage, is an agricultural area in which the convergence of lake breezes has a strong effect on convection (King et al., 2003). Region 3 is the most rural area with many smaller lakes and large forested areas. Region 4 is part of a large urban area that is influenced both by being at the western edge of Lake Ontario and to the lee of the escarpment. Region 5 is the area around Niagara Falls that has the addition effect

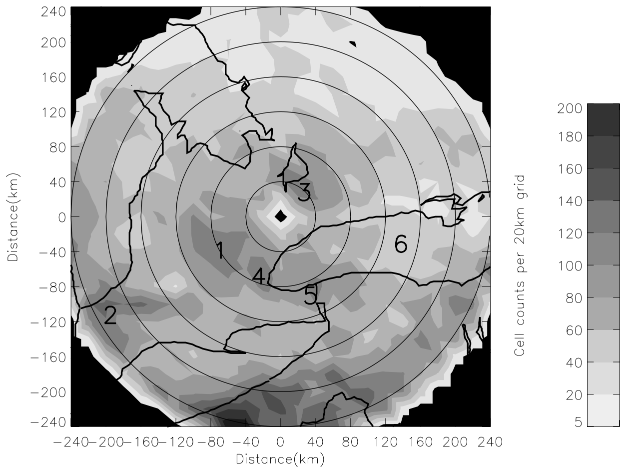

Fig. 1. The spatial frequency distribution of cell occurrence. Range rings are 40 km apart. Numbers 1 to 5 highlight specific local maxima (see text). Number 6 refers to the area over Lake Ontario.

of the presence of a persistent moisture source from spray off the falls. A sixth region defined in Fig. 1, the area over Lake Ontario that is influenced by the cool lake waters, was included to serve as a contrast of the convective behaviour between land and water.

The general mean properties of the cells in this study are Z_{max} at 50.4 dBZ, ET 11.2 km, VIL15 12.3 kg m^{-2}, and VIL50 4.3 kg m^{-2}. When range biases are removed, there were two significant regional positive anomalies. In region 5, the VIL15 was 14.8 kg m^{-2}, an indication of the effect of the enhanced low level moisture in the area. In region 2, the VIL50 was 5.0 kg m^{-2}. This is in keeping with the results of King et al. (2003) that suggested this region was responsible for the genesis of intense convection.

3.2 Daily Time Scale

The diurnal variation of normalized cell counts is given in Fig. 2. Overall, there was a strong diurnal signal in cell occurrence with a late afternoon maximum at 20:40 UTC (16:40 EDT) and an early morning minimum at 14:10 UTC (10:10 EDT). Of the five subregions, region 2 had the earliest cell occurrence maximum at 19:50 UTC (15:50 EDT) and region 3 the latest cell maximum at 21:40 UTC (17:40 EDT). In region 6, there was a local minimum in cell frequency in the late afternoon and relative maxima in mid afternoon and early evening. In regions 4, 5 and 6 there is a semi diurnal component as well with a secondary maximum in cell frequency overnight and towards dawn. A similar semi-diurnal signal due to land-lake breeze interactions was also noted near Lake Michigan and along the Gulf of Mexico coast by Carbone et al. (2003) and Ahijevych et al. (2003).

Table 1 gives the regionally averaged cell properties during the afternoon maximum in cell frequency (18:00 to 23:50 UTC) and the time period corresponding to the secondary maximum in regions 4, 5 and 6 (07:00 to 11:00 UTC).

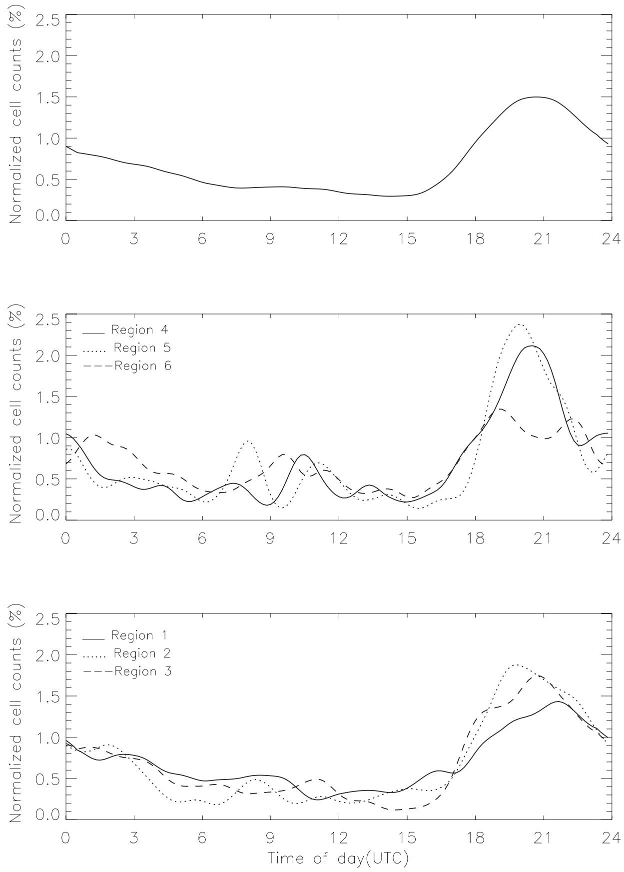

Fig. 2. The normalized diurnal variation of cell occurrence for the whole radar coverage (top), regions 4 to 6 (middle) and regions 1 to 3 (bottom).

There was no significant difference in Z_{max} among the regions in the afternoon vs. overnight. For echo top, region 2 was lower overnight while for regions 4, 5, and 6 echo tops were higher overnight. VIL15 were generally lower overnight except for region 6. VIL50 was less overnight in all regions except region 6 where it was the same overnight as during the afternoon. It is noteworthy that Z_{max} in region 6 was also higher overnight than in the afternoon. These results highlight and quantify differences in convective characteristics between regions adjacent to or over Lake Ontario and those further inland.

3.3 Monthly Time Scale

The normalized monthly average cell counts are shown in Fig. 3. About one-third of the convection occurs in both July and August. This was three times more than in May. However, the minimum and maximum percentages in seasonal activity are 0 to 34%, 4 to 45%, 6 to 66%, and 8 to 60% for the months of May through August respectively. This large year-to-year variability points out the complexity of the meteorological controls on the convection in this area.

The correlation coefficient between the monthly mean temperature at London, Ontario and the monthly cell counts

Table 1. Mean cell properties in the six regions during the late afternoon maximum in cell occurrence (18:00–23:30 UTC) and overnight secondary maximum (07:00–11:00 UTC). No overnight VIL15 was calculated for region 5 due to anomalous propagation contamination in that area at that time of day.

Property		Subregion 1	2	3	4	5	6
Z_{max} (dBZ)	Afternoon	50.4	50.3	50.7	50.7	51.2	50.4
	Overnight	49.8	50.5	50.6	49.1	50.2	50.7
ET (km)	Afternoon	11.3.	11.8	10.8	10.8	10.9	11.4
	Overnight	11.3	11.0	10.8	11.0	11.5	11.4
VIL15 (kg m^{-2})	Afternoon	12.6	11.5	13.2	13.5	14.6	12.2
	Overnight	11.3	10.5	13.0	12.2	–	14.0
VIL50 (kg m^{-2})	Afternoon	4.5	5.6	4.5	4.4	4.4	4.6
	Overnight	4.1	4.2	4.0	3.6	2.5	4.6

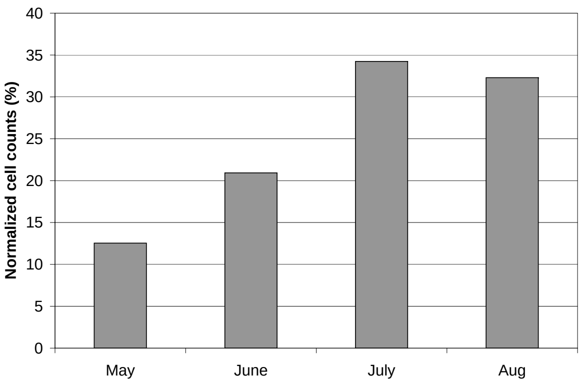

Fig. 3. The normalized distribution of cell frequency by month.

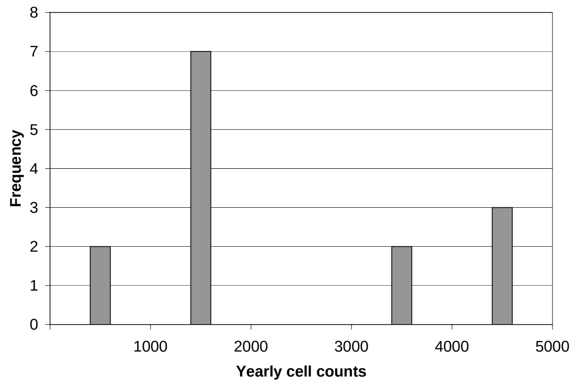

Fig. 4. The distribution of annual cell counts.

was 0.51. This suggests that although temperature is a significant factor, there are other synoptic scale factors that influence convection. These factors could include the phase and intensity of the North American monsoon circulation and the location and the strength of both the Bermuda high and the mid-latitude jet stream. An examination of continental scale (or larger) meteorological conditions could be used to relate large scale circulation anomalies to active convective days in southern Ontario by a methodology similar to Gyakum and Danielson (2000). Further downscaling is also possible that could relate the synoptic conditions to convective cell properties (e.g. Brimlow et al., 2004). Both approaches would provide insight to aid short and medium term weather forecasting.

3.4 Annual Time Scale

The frequency distribution of annual cell counts for the 14 years of the study is given in Fig. 4. The distribution is bimodal with yearly counts either less than 2000 or greater than 3000. The time trend is towards an increase in annual cell counts in the second seven years of this time series (+75%) as well as an increase in year to year cell count variability (+84%) as compared to the first seven years. To explore the possibility that the information in this study could be used to as a tool in the statistical predictions of convective activity at the inter-annual scale, a comparison of the southern oscillation index (SOI) (Hanley et al., 2003) and annual cell counts from 1993 to 2003 was carried out (Fig. 5). There is a relationship in that higher annual cell counts were associated with higher values of SOI. Only one year, 1996, did not follow the trend. The correlation between SOI and annual cell count was 0.70. The SOI in all five years of the study in which annual cell counts were associated with the higher peak (Fig. 5) was always > -0.8. It is important to note that a much more rigourous statistical treatment is necessary before any climatic significance can be attributed to these findings. The point of this analysis is to demonstrate that it provides that type of quantitative information from which such a treatment can be carried out.

4 Concluding Remarks

The objective oriented approach to the analysis of 14 years of radar data has provided quantitative information on the nature of the convection in the Great Lakes region of southern Canada. The spatial distribution of convective cells and their

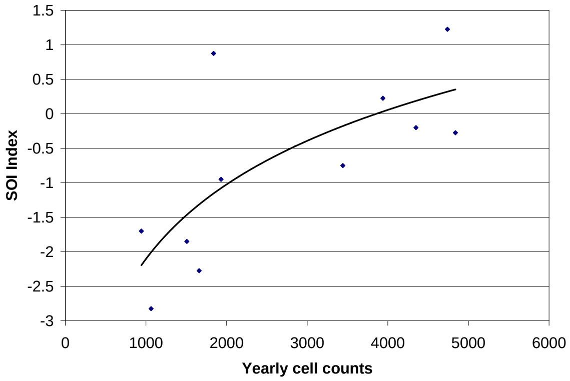

Fig. 5. A scatter plot of the southern oscillation index (SOI) and annual cell counts from 1993 to 2003.

diurnal properties were consistent with other studies in the area. However, due to the high spatial resolution, time sampling and sensitivity of the radar data, greater specificity to the analysis was evident.

As described in Carbone et al. (2002), this approach also holds promise to provide insight into the predictability of these coherent precipitation patterns at either a seasonal or interannual time scale. This information can also support numerical modeling activities. The spatial patterns and temporal behaviour of convective cells in this study provide validation data for model simulations over a wide range of applications.

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