A SEVERE THUNDERSTORM CLIMATOLOGY FOR ALBERTA

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Abstract

A continuing demand exists for severe thunderstorm climatologies. As with common meteorological parameters such as temperature and wind, a requirement exists for information on hail, strong wind gusts, heavy rain, and tornadoes. Severe thunderstorm climatologies have a much lower reliability than the more common parameters because of a number of factors, nearly all related to the relatively small size and localized nature of these events. Nonetheless, over the past ten years, an ever increasing effort has been brought to bear on the prediction and detection of severe thunderstorms in Alberta. The data base of severe weather events is now large enough to allow an analysis and interpretation.

The frequency distribution of the over 800 severe events recorded in Alberta over the years 1982 to 1991 has been developed in the traditional fashion. As well, the distribution has been corrected to take into account the population distribution of the province, as demographics, specifically public education and awareness, seem to be one of the factors affecting the reporting of severe thunderstorm events. When corrected, the climatology shows substantial differences between the raw and the final distributions, and suggests that some 300 events (34%) go unnoticed or unreported in the province each year.

Using the corrected climatology, users can assess risk in various sections of the province, and more importantly, gain an appreciation for the problems involved with determining a true frequency and distribution of severe events. Caution must be exercised in drawing conclusions from the correction because of the large uncertainties involved, but some encouragement can be gained from the knowledge that the patterns obtained seem similar to meteorologists' subjective impressions of Alberta thunderstorm behavior.

1. Introduction

The climatology of severe thunderstorm events is unlike that of other meteorological parameters. For standard weather parameters, such as temperature, precipitation, and wind, there is often up to 100 years of data with which to calculate spatial distributions and averages, and extreme values are generally well known. Evidence of this is the gradual decrease seen in the number of records set. This is not the case with severe thunderstorms. Every year reports of severe events have become more comprehensive, but the actual reports are still known to be well below the true number of events which occur. Mainly because of their predominantly small-scale and short-duration, severe thunderstorm events often affect few people or properties. Also, reports of two nearly identical events could be reported in widely different ways depending on where the events took place: one might be reported as a major event because it affected a city or town while the other might go completely unnoticed across open rangeland. These types of difficulties make a reliable determination of the frequency and distribution of severe thunderstorms a very difficult, if not impossible, task.

Since the late 1970's, the Alberta Weather Centre has operated an intensive summer program to detect and forecast severe thunderstorms. In addition to the meteorological advancements in the program, public awareness activities have increased, and improvements have been continuing in the number and spatial distribution of a volunteer spotter network. In 1987, an F4 intensity tornado in the city of Edmonton claimed 27 lives and caused property damage in excess of $250 million (Bullas and Wallace 1988). As a result, public awareness, concern, and sensitivity have been at heightened levels ever since. In recent years, many economic sectors have taken an expanded interest in severe weather. Utilities and the construction industry are more concerned than ever with the frequency and distribution of severe weather. Costly hailstorms in urban areas have prompted the insurance industry to demand climatological information in order to assess risk.

The climatology of tornado events has been reasonably well documented for some years. McKay and Hage, in the sixties, did extensive but largely unpublished work that covered the first half of the century. More recently, Newark (1984) compiled maps indicating annual tornado incidence and probability of tornado damage. To this date, however, very little published material is available on Canadian non-tornadic thunderstorms. Severe thunderstorm climatologies for the United States have been described in various references and summarized in Kelly et al. (1985), but these make no use of Canadian data.

As will be seen, limitations in the quality of data lead to a major challenge in determining a reliable severe weather climatology. Despite this, the goal of this study is to use the Alberta Weather Centre's severe weather database to determine as accurate a climatology for Alberta as the data will permit.

2. Limitations of Severe Weather Data

Thunderstorm severity is difficult to quantify. In some cases, depending on location or time of year, conditions need not be extreme to cause damage or public concern. Indeed, copious small hail during late July or early August may be of more concern to a wheat farmer than a few very large stones in early June. Many individuals have suggested various criteria based on damage with a view that any storm that causes damage is severe. Nonetheless, for many practical as well as abstract, ideological reasons, the Alberta Weather Centre has adopted a set of quantitative definitions for severe thunderstorm conditions (Table 1). These criteria have been in place since the 1988 severe weather season. Previous to that, three threshold values were different: heavy rain was previously defined as 25 mm in one hour, and severe winds were defined as at least 100 km per hour and, prior to 1986, severe hail was defined as 15 mm or greater. Since the vast majority of severe weather reports are qualitative in nature, we assume that the changes in definition have had minimal effect on the numbers or types of events reported.

Convective season summaries have been prepared by the Alberta Weather Centre annually for the past ten years. The prime purpose for these has been to publish all known events

Table 1. Definitions of severe thunderstorm events as applied in the province of Alberta.

Severe Thunderstorm Event	Criteria
Hail	Greater than 20 mm diameter ("grape sized")
Wind	Gusts above 90 km h^{-1}
Heavy Rain	More than 30 mm accumulation in any one hour period[1]
Tornado	Any tornado or waterspout

[1]Various emergency response agencies throughout Alberta were consulted in order to determine their criteria for a severe event: a 100-year-return-period rainstorm for rural areas and a 50-year-return-period rainstorm for urban areas. The Alberta Weather Centre would prefer to have issued a warning prior to an occurrence of such a storm, so warning criteria was set at the 25-year-return-period rainstorm level. Averaged across the province from south to north this level is 30 mm per hour (southern areas see this type of storm much more often than northern ones).

and to monitor the performance of the severe weather warning program. Events are counted when separated by more than 30 kilometres or 30 minutes from an event of similar type. Also, concurrent, yet different phenomena, such as large hail combined with damaging winds, are counted as separate events. These methods are by no means perfect, but they provide the only practical way of establishing a consistent data set and are typical of methods used elsewhere.

Kelly et al. (1985) provide the best description of the problems involved in compiling a comprehensive data set of severe weather events: "*... in order to take its proper place in the climatological record, a severe event must be observed, properly perceived as a severe event, and must stimulate the observer to report it for the record.*" Each of these steps introduces an added degree of uncertainty and complication into the process.

There are two ways to determine that an event has occurred. About two thirds of the total number of reports are received through a network of volunteers, which had grown to some 1300 strong across the province by 1992. These individuals contact the severe weather forecast team on a toll-free number, or are called by the forecast staff when a storm is known to be in their area (from radar, satellite, or lightning data). The remainder of the reports are uncovered through research of some 150 weekly newspapers published across the province. Of course, both of these methods lead to inherent errors. Spotters vary in their availability and enthusiasm, and they are not distributed uniformly. Efforts in recent years have been to increase the rural distribution, but spotters still tend to be concentrated in towns and cities. Media reporting is often affected by the weather sensitivity of the local economy. For example, farming areas are much more likely to report events than suburban regions, or a marginal event may go unreported because of a more significant one several days before. Overall, the data set of events compiled since 1982 is considered to be representative, yet not comprehensive, of typical Alberta summer convective weather.

Apart from reporting biases, there are a wide range of demographic influences on severe weather data. Factors such as population density, degree of urbanization, transportation routes, public awareness and concern, local range of visibility (due to terrain), media activity, and so on, all contribute in some fashion to the degree to which events are reported. To further complicate matters, they all vary not only spatially, but over the time period of the data as well. The net result is undoubtedly complex and non-linear. Fortunately, since population density intuitively has the strongest influence on the data, it is the one factor for which a correlation can be most easily determined. Several authors (e.g., Kelly et al. 1985; and Doswell 1985) have recommended against attempting to apply corrections to the data for these parameters, mainly because of possible large non-linear effects.

3. Severe Thunderstorm Event Data

The annual distribution of severe weather events over the ten year period from 1982 to 1991 is shown in Fig. 1. The apparent increase in the number of events from 1987 onward may be a result of increased awareness and, as a result, increased reporting of events, triggered by the Edmonton Tornado.

The monthly distribution of severe weather events is shown in Fig. 2. As might have been expected the most active month is July.

The monthly distributions of hail, rain, and wind follow the same pattern as the total number of events. The pattern for tornadoes is a bit different and is shown in Fig. 3.

The probability of severe events is not uniform throughout the day. Convective cells tend to reach their most vigorous development during the late afternoon and evening. Similarly, severe events show a propensity to occur during the latter part of the afternoon or evening (Fig. 4).

Most of the observed severe weather events follow this general pattern. Severe winds do tend, however, to occur later in the day than large hail events, heavy rains, or tornadoes (Fig. 5).

Severe weather event counts were determined for each of Alberta's 75 counties, municipal districts, improvement districts, and special areas. In addition, data for the two largest cities (Edmonton and Calgary) were included, because their areal sizes are comparable to some of the smaller county or district sizes. Normalizing each of these to annual occurrences per unit area provides an uncorrected climatological map (Fig. 6). Because of the wide range in size of the various sub-areas, a contoured map such as this automatically yields the desired variation in resolution inherent in the data.

The distribution of reported events has several characteristics. Frequency is higher in the south and lower (though not zero) in the north. The frequency is also lower in the foothill areas along the southwest border of the province. Maxima are centered on Edmonton (22 events per year per 10,000 km^2), Calgary (16 events per year per 10,000 km^2), Lethbridge (7 events per year per 10,000 km^2), and Peace River (11 events per year per 10,000 km^2). The first three of these four locations are the largest cities in Alberta, with populations of 617,000, 711,000, and 61,000 respectively. On the other hand, Peace River is not a heavily populated area. In central Alberta, there are axes of high event frequency between Edmonton and Calgary (a heavily-populated, high-traffic corridor), from Edmonton towards the southeast (a well known storm track amongst regional forecasters), and from the eastern border with Saskatchewan extending west towards Edmonton (another transportation corridor with a high population base). In summary, the patterns associated with the reported event frequencies show a high correlation with population distribution in the province (Fig. 7), with some hints of known thunderstorm tracks embedded.

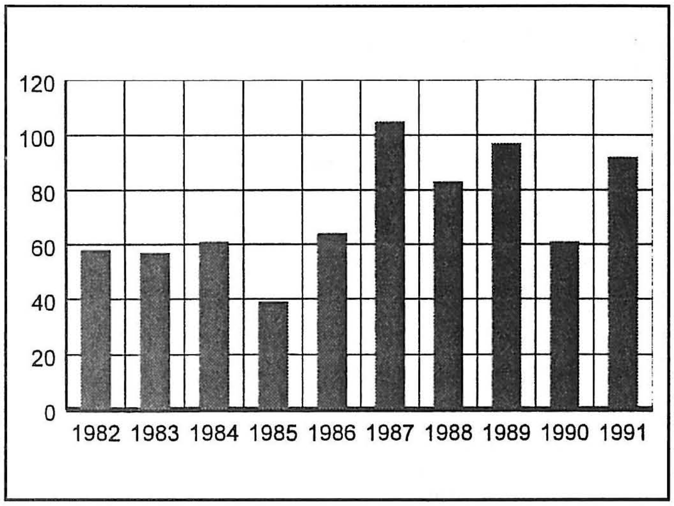

Fig. 1. Annual distribution of severe weather events, 1982–1991.

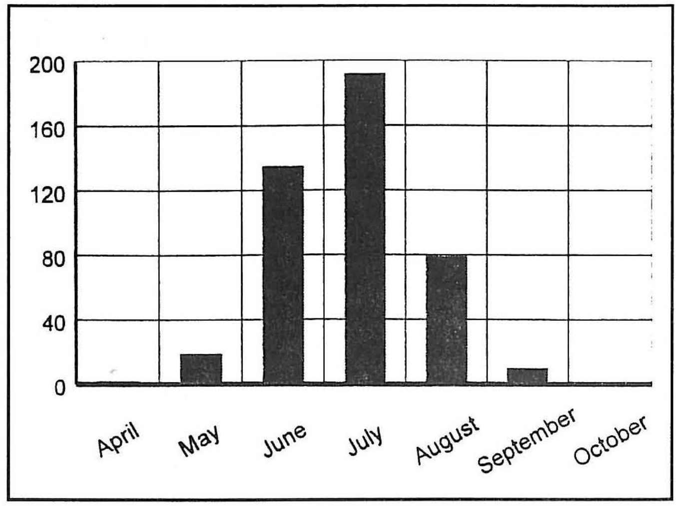

Fig. 2. Monthly distribution of severe weather events, 1987–1991.

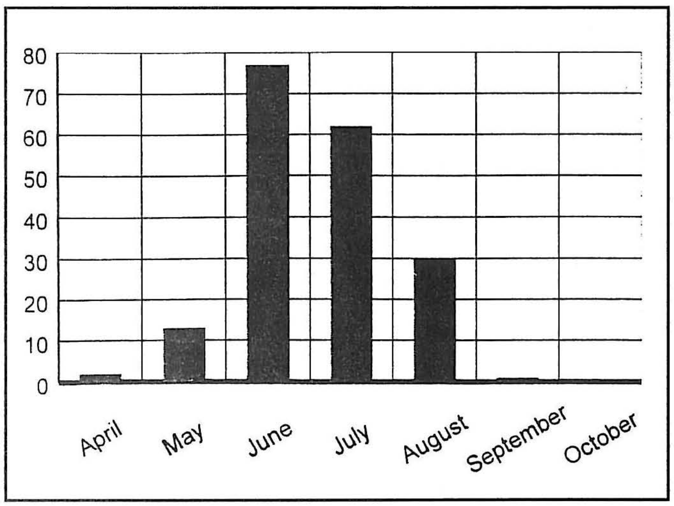

Fig. 3. Distribution of tornadoes by month, 1982–1991.

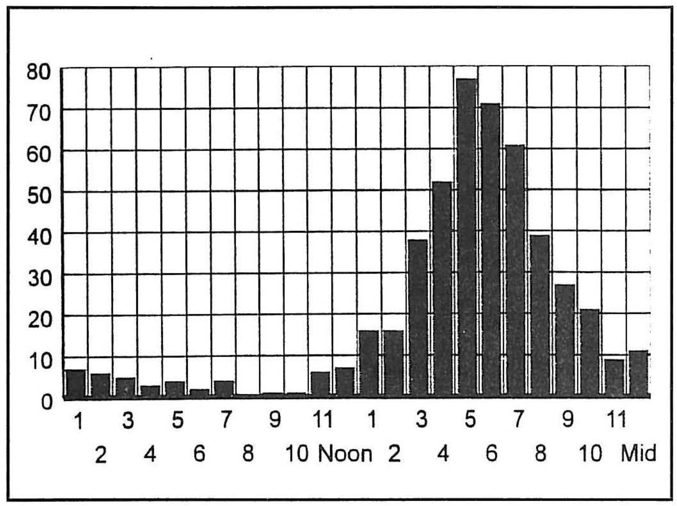

Fig. 4. Occurrence time of severe weather events, 1982–1991.

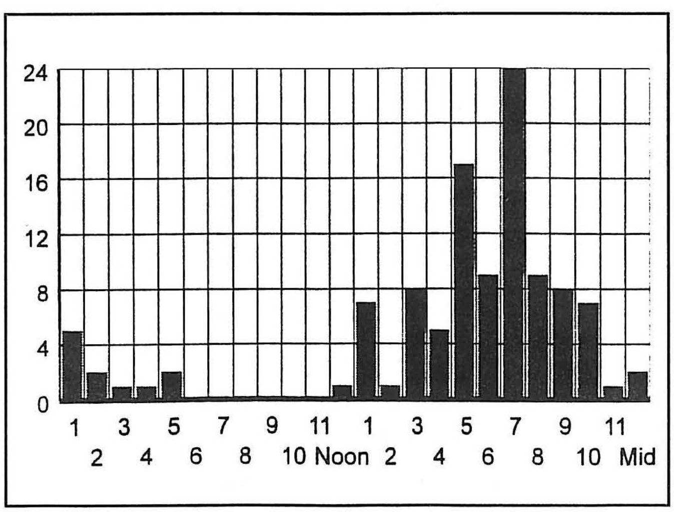

Fig. 5. Occurrence time of severe wind events, 1982–1991.

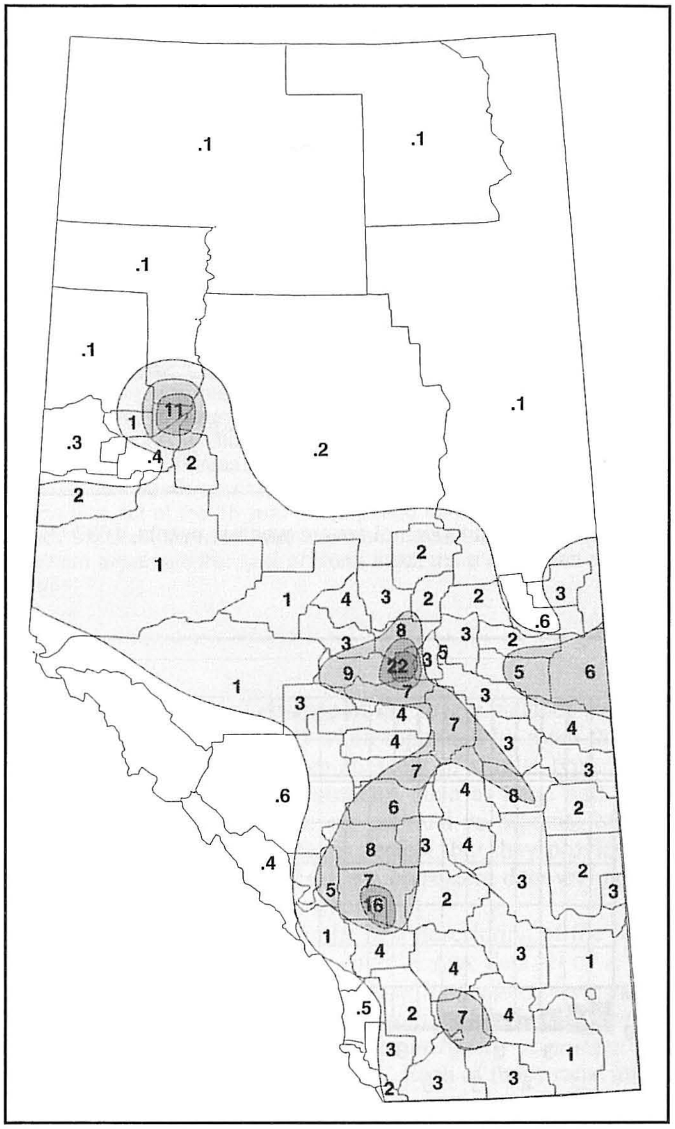

Fig. 6. Severe thunderstorm events reported in each Alberta county or district per 10,000 km² for the period 1982–1991. Contours are analyzed for values 1, 5, 10 and 20.

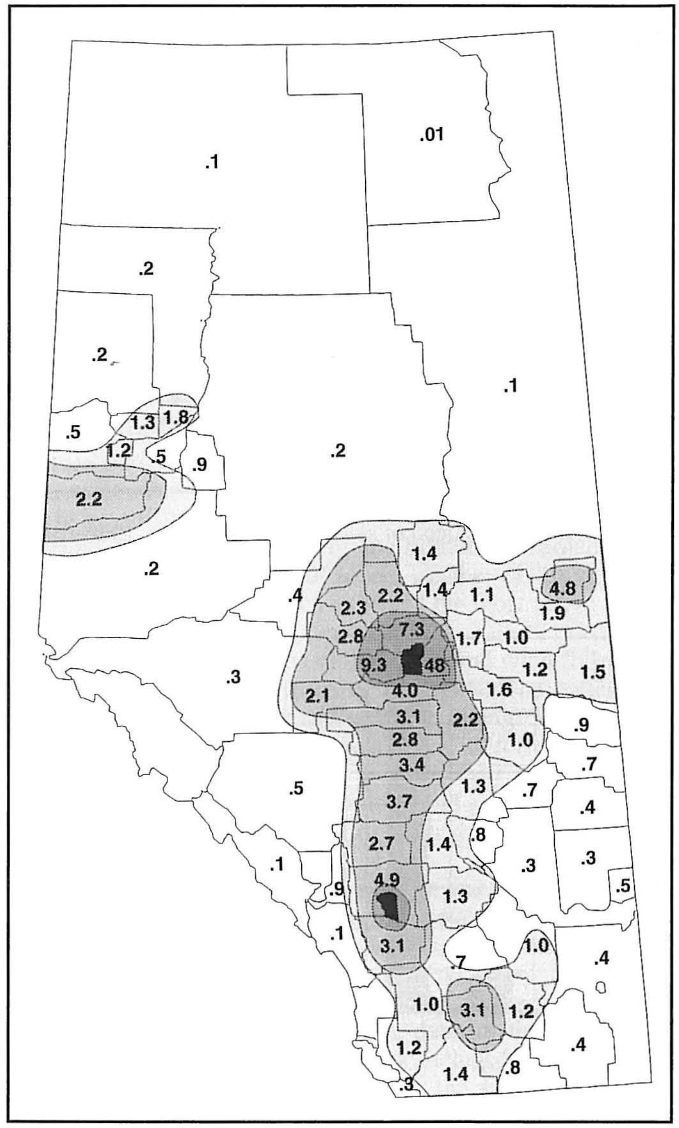

Fig. 7. Population density in persons per km² from 1991 census. Contours are analyzed for values 1, 2 and 5.

4. Correcting for Population Density

In order to try to determine the degree of correlation between reports and population densities, the values shown in Figs. 6 and 7 were plotted against each other as shown in Fig. 8. Note that the values used for population density were rural values (Statistics Canada 1991), excluding the residents of cities, towns, and villages from the numbers in each county or district. We felt this would be a closer measure of the general population density for each area, and more representative of event observing and reporting tendencies.

The degree to which population density affects reported events is evident from Fig. 8. The data would seem to indicate that reporting is ineffective for population densities below 0.3 persons per square kilometre. A least-squares regression fit to the remaining points (with the exception of two small districts which were wildly anomalous) yields the relationship

$$\textbf{Reported events} = 2.87 + 4.63\log(\text{Pop. Dens.}) \quad (1)$$

This is the curve (a) in Fig. 8. At first glance the solution seems heavily biased by the Edmonton and Calgary data points. And, indeed, dropping those two points results in a slightly smaller sloped curve (b). To further investigate the sensitivity of the data, half of the counties and districts were randomly removed and the regressions recalculated. In the several tries we made, the regression curves centered about curve (a) and none exceeded the difference displayed by curve (b). Thus, curve (b) represents a measure of data sensitivity.

In principle then, by applying a correction factor dependent on population density to the data, the only remaining causes for the scatter from curve (a) in Fig. 8 are climatology and unaccountable demographic influences. The correction factor can be determined from the regression equation (1) and by assuming that the regression value 16.76 at a population density of 1000 per square kilometre is a reasonable average event frequency for the province as a whole. Each of the values in Fig. 6 was therefore multiplied by

$$16.76/(2.87 + 4.63\log(\text{Pop. Dens.})) \quad (2)$$

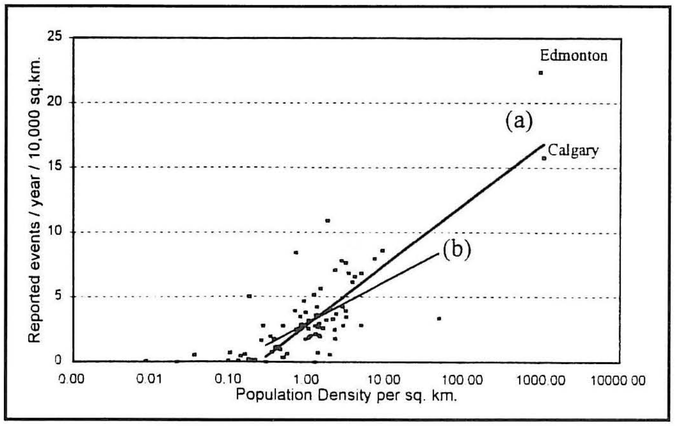

Fig. 8. Severe thunderstorm events versus population density per km². Graphs (a) and (b) are explained in the text.

(The factor 16.76 has been obtained by assuming that all the events that occur within the city boundaries of both Edmonton and Calgary are reported. In both cities, the population densities are sufficient to guarantee that severe events are recorded but, even in the large cities, it is possible that events will not be reported—although this would seem much less likely since the Edmonton Tornado of 1987.)

When applied to total events, the correction alters the frequency map significantly (Fig. 9). It is encouraging to note that the event frequencies in the major cities are now similar to the frequencies in surrounding counties. As a result, maxima have been shifted away from population centres. This smoothing around the population centres is a desired effect of the correction. (Choosing regression curve (b), for example, results in singular points or hills in the contour patterns near Edmonton and Calgary. But the countryside surrounding these two cities should display a climatology similar to the cities themselves. Thus, the regression solution that includes the two city data points has been used.)

Correction for population density has resulted in substantial changes to the pattern of severe event frequencies. Instead of the axis lying along the Edmonton Calgary corridor, it is now shifted to run from east-central Alberta near the town of Oyen up towards the northwest to Edmonton. Secondary axes lie in extreme southern Alberta (Warner, Lethbridge, and Vulcan counties), and from the Bow Valley area west of Calgary up through Mountainview, Red Deer, and Stettler counties. A broad, less defined axis runs up to the northwest towards Peace Country, but the local maximum near the town of Peace River is likely anomalous.

The same correction applied to the counts of different types of events results in Figs. 10 through 13. The maps suggest differences in the distribution of the various types of events. For example, hail and wind events are more frequent in the foothills than tornadoes and heavy rain. Axes of tornado activity may be different from those for the other event types, possibly due to differences in associated storm dynamics. Rain events are more frequent in the east, possibly because storms in this area often form in the foothills, and are therefore more mature and likely to form into convective complexes, or heavy precipitation supercells, as they move eastward. Whatever the reasons, these figures show climatological frequencies more in line with perceived Alberta thunderstorm behavior, and with a lower dependency on population distribution.

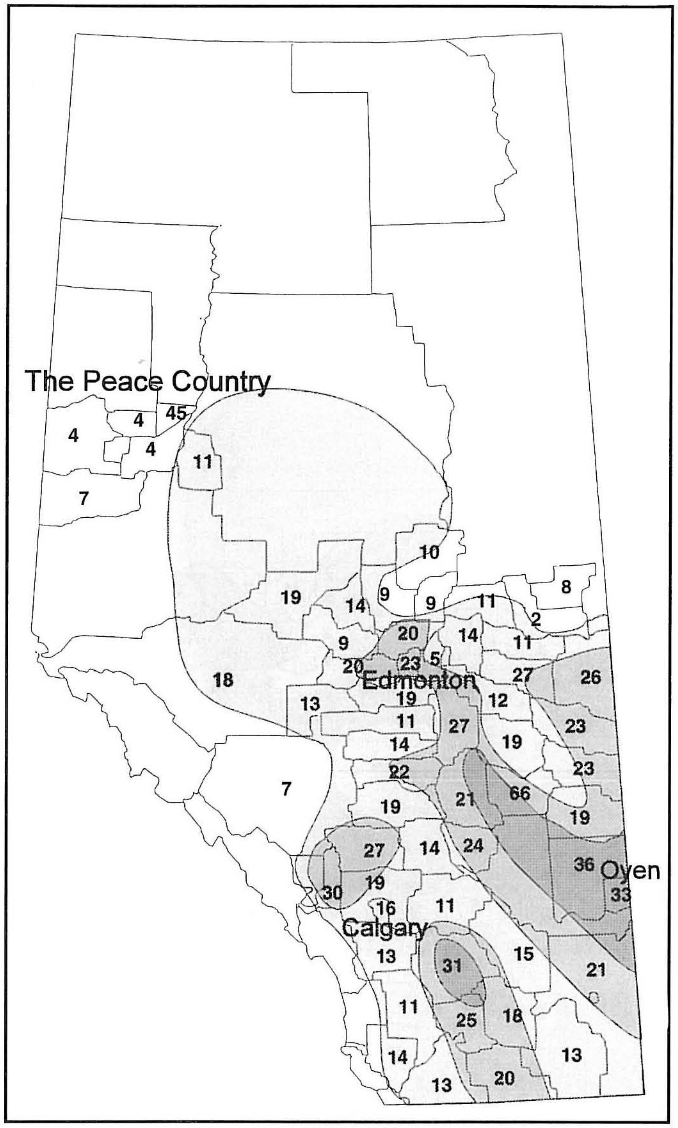

Fig. 9. Severe thunderstorm events per year per 10,000 km² adjusted for population density. Contours are analyzed for values 10, 20 and 30.

5. Discussion

The final word must be to caution those who may see fit to make decisions based on the data presented. The correction of incomplete data sets is a risky business. One cannot know for certain that the correction applied has led to an improvement or degradation in the data. In this particular case, population density is only one of many variables which affect severe thunderstorm event reporting. One could even wonder if there is an inverse relationship at work. That is, was the distribution of population in the province affected by storm climatology (in pioneer days) in any way? For certain, settlement (farming) is dependent on rainfall, most of which is convective in nature in most Alberta summers. This is only one of many unknown influences. Users must be aware of inaccuracies which can occur in a procedure such as the one which was applied here. Additionally, one must also bear in mind that the data base upon which this statement has been built is only ten years in length—rather short from a climatic perspective.

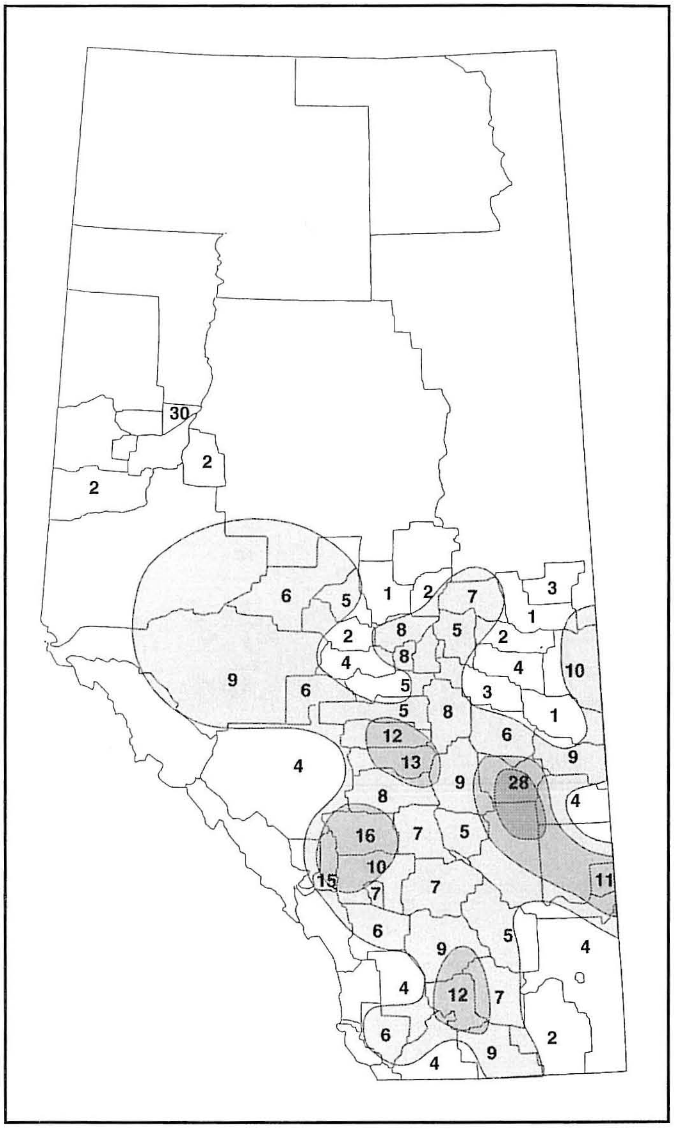

Fig. 10. Hail events per year per 10,000 km² adjusted for population density. Contours are analyzed for values 5, 10 and 20.

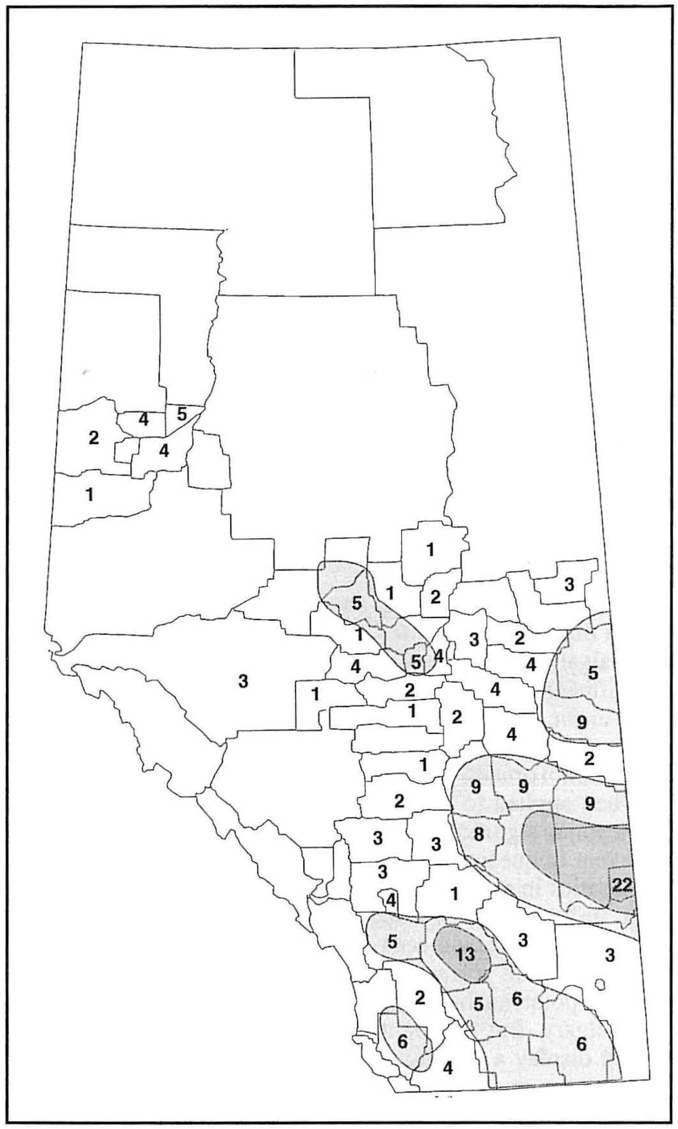

Fig. 11. Heavy rain events per year per 10,000 km² adjusted for population density. Contours are analyzed for values 5 and 10.

Authors

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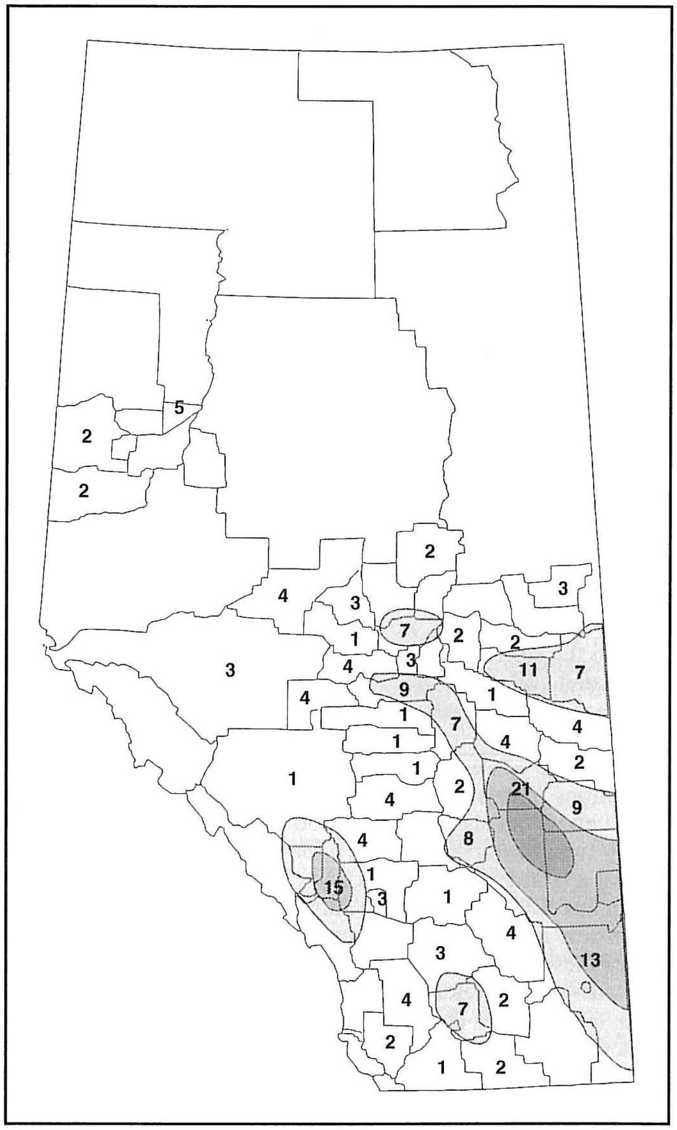

Fig. 12. Severe wind events per year per 10,000 km^2 adjusted for population density. Contours are analyzed for values 5, 10 and 20.

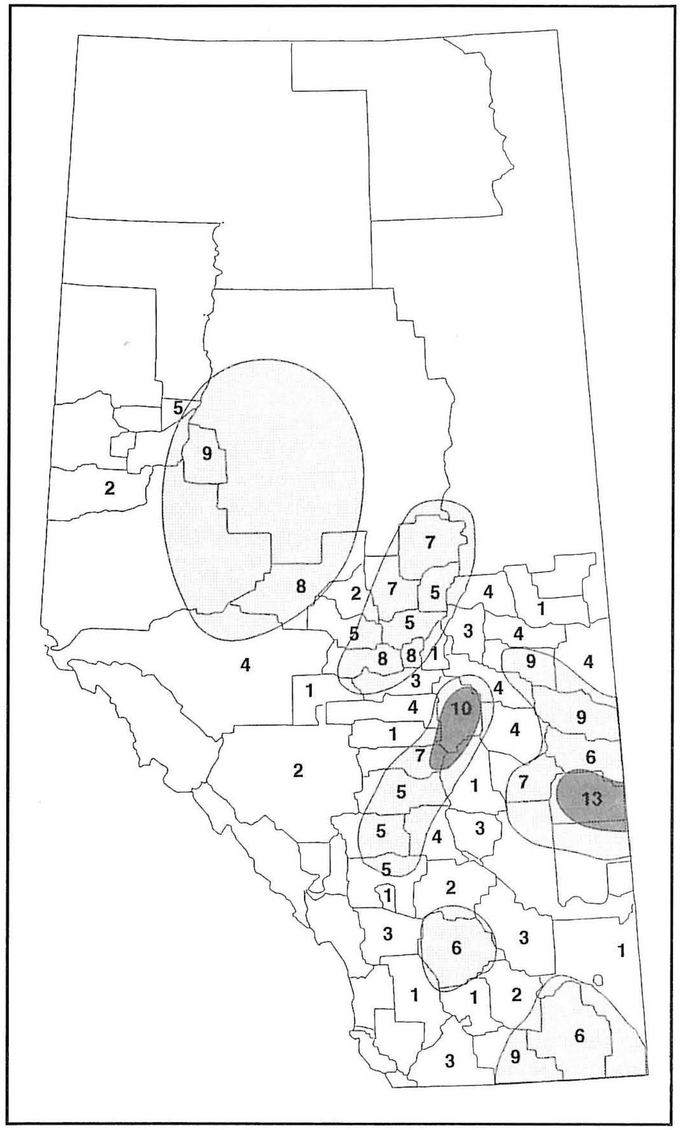

Fig. 13. Tornadoes per year per 10,000 km^2 adjusted for population density. Contours are analyzed for values 5 and 10.

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