NOTES AND CORRESPONDENCE

Seasonal and Spatial Patterns of Rainfall Trends on the Canadian Prairies*

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ABSTRACT

Regression analysis was used to establish linear trends of rainfall amounts and number of events at 140 stations with 40 years of record across the Canadian prairies. Annual rainfall was further split into three 4-month seasonal groups of amounts and events, and similar analysis was performed on these variables. There has been a significant increase in the amounts and number of rainfall events during the most recent 40-yr period (1956–95). Increase in annual rainfall was 51 mm, or about 16% of the 40-yr mean, while the number of rainfall events increased by 17, or about 29%. Spring (January–April) experienced proportionately the largest increase, with amount and number increasing by 46% and 64%, respectively, during the 40-yr period. This result may be related to the conversion of snow to rain as a result of warming during this period. The increases in rainfall amount and number of events during summer (May–August) were similar to the annual patterns. There was no significant increase in amount and number of rainfall events during the autumn season (September–December). The increases in rainfall amount and number of events were not uniform across the prairies, with the least increase in number and amounts of rainfall in southern Manitoba, Canada, and the largest increase in Alberta and Saskatchewan, Canada. Little or no change in amounts was obtained in the northern portion of the prairie provinces. The results confirmed that the prairies are not getting drier; however, there are seasonal and spatial differences in rainfall trends on the prairie.

1. Introduction

Scientific evidence is beginning to crystalize regarding the impact of an enhanced greenhouse effect on global temperature and precipitation. The consensus of opinion is that, on average, global temperature will rise with increases in atmospheric concentration of greenhouse gases (Vinnikov et al. 1990; Karl et al. 1997). For precipitation on a global scale, it is believed that, as temperature increases, more evaporation takes place, leading to more precipitation (Karl et al. 1997). However, spatial and temporal nonuniformity is expected to accompany both temperature and precipitation changes around the globe.

Some of the results on precipitation suggest that spatial and temporal nonuniformity in trends exist, which confound generalities over large areas. Idso and Balling (1991) examined the precipitation trend over the conterminous United States and concluded that there was no significant changes in precipitation between 1901 and 1954. From 1955 to 1987, however, precipitation across the United States increased by 8.6% while it rose by 16% in the central United States. Using historical weather data from the three Canadian prairie provinces, Akinremi et al. (1999) reported that precipitation increased by 0.62 mm yr^{-1} or about 10%, between 1921 and 1995. On the other hand, Ripley (1986) examined the annual and seasonal trends of precipitation at three stations in Saskatchewan, Canada, and noted that the recent decrease in summer precipitation and increase in winter and spring precipitation agree with ‘‘greenhouse predictions’’ but the decrease in annual precipitation in the southern prairie did not.

The Canadian prairie may be unique in its response to climate change because of the influence of the large-

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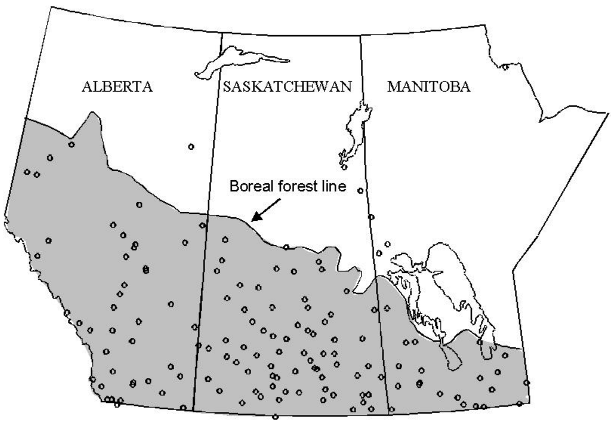

FIG. 1. Locations of 140 climatological stations on the Canadian prairies.

scale anthropogenic changes in land use. This is exemplified by the conversion of about 60% of the area of native mixed perennial grasses to annual crop, primarily wheat by the early part of this century (Raddatz 1998). This author demonstrated that the frequency of thunderstorms during the early and late portions of the growing season has likely declined because of a change from perennial grasses to annual cereals. Conversely, the potential for deep convection has been enhanced during periods of rapid foliage expansion and seed production for spring wheat and similar annual crops (Raddatz 1998).

A major portion of prairie agricultural land is classified as semiarid to arid; as such, precipitation is rarely sufficient to meet crop demand. Knowing the current precipitation trend and its spatial and temporal pattern is of value to agricultural producers in this region. The current study extends the earlier analysis performed by Akinremi et al. (1999) by reducing the study period to include a larger number of recording stations, which permits the spatial projection of current rainfall trend on the prairie. The objective of our study was to determine the trend in rainfall during the most recent 40-yr period (1956–95) and to assess the spatial and seasonal pattern of these trends.

2. Methods

a. Historical weather data

The weather data used in this study are a subset of that used by Akinremi et al. (1999) and were obtained from the Environment Canada archive for the three prairie provinces (Alberta, Saskatchewan, and Manitoba, Canada). These data are part of the Nat Christie database used in a climate change study (McGinn et al. 1999) and were recently updated to include data up to 1995. A total of 140 stations (Fig. 1) that had complete daily precipitation records within the last 40 years (1956–95) were used across the prairie.

TABLE 1. Annual and seasonal distribution of rainfall amounts and events, means of a 40-yr time series (1956–95) on the Canadian prairie.

	Time interval	Amounts (mm)	Std dev (mm)	No. of events	Std dev
Yearly mean	Jan–Dec	318.4	38.4	59.8	7.1
Period 1	Jan–Apr	19.1	7.7	5.6	2
Period 2	May–Aug	239.5	35.4	40.1	5.1
Period 3	Sep–Dec	59.8	17	14.1	3

b. Addressing the problem of inhomogeneity

The implication of the changes in the measurement techniques is that historical precipitation data cannot be used for rigorous trend analysis until the inhomogeneities are identified and adjustments are made to the data to remove them. Our study focused mainly on rainfall (snowfall was not considered), which constitutes about 70% of total precipitation on the prairie, because any significant variations in the amount or timing of rainfall during the growing season can have severe effects on agricultural productivity on the prairie (Bonsal et al. 1999). We corrected the historical rainfall data for inhomogeneity using the approach of Akinremi et al. (1999). We defined a precipitation event as any day with a measurable amount of precipitation.

c. Seasonal designation and statistical analysis

Beginning with data from 1956, the daily rainfall amount and number of events at each station were accumulated for the entire year, and this set was designated as the annual rainfall. In addition, the year was split into three equal periods. Period 1 was from January to April and seasonally represented a combination of late winter and spring on the prairies. Period 2 was from May to August, which coincided with summer and the prairie growing season. Period 3 was from September to December, a combination of the autumn and early winter seasons.

Rainfall amount and number of events were generated for the three periods at each station. The rainfall trends during these periods were examined in the light of findings that snowfall has decreased on the prairie within the last 35 years (Akinremi et al. 1999), presumably falling as rain as the climate warmed.

Mean annual rainfall amount and number of events were calculated for the entire prairie using the 140 stations, as was the mean during the three periods of the year. Regression analysis was used to establish linear trends of rainfall amounts and number of rainfall events at each station. We used the t test to determine if the linear trends were significantly different from zero at the 5% probability level.

Table 2. Linear trends of rainfall amounts and number of events across the prairies in the most recent 40 years across 140 stations. Numbers in boldface type are significantly different from zero at the 0.05 level.

Parameters	Linear trend (yr^{-1})	Linear trend [% (40 $yr)^{-1}$]	Stations with positive trend	Stations with negative trend
Rainfall amount				
Annual	**1.28**	16	121	19
Period 1*	**0.22**	46	119	21
Period 2	**0.98**	16	124	16
Period 3	0.08	5	93	47
No. of rainfall events				
Annual	**0.43**	29	128	12
Period 1	**0.09**	64	128	12
Period 2	**0.28**	28	128	12
Period 3	0.06	17	106	34

* Period 1 is from Jan to Apr, period 2 is from May to Aug, and period 3 is from Sep to Dec.

3. Results and discussion

a. Statistical characteristics of annual rainfall

On the Canadian prairie, the annual mean rainfall was 318.4 mm from a mean annual total of 60 rainfall events during the last 40 years (Table 1). Six percent of the annual rainfall amount falls in period 1, 75% in period 2, and 19% in period 3. Of the 60 rainfall events recorded in a year, 67% (40) occur in period 2, 9% in period 1, and 24% in period 3. Hence, period 2 has the most amount of rainfall, the highest number of rainfall events, and the highest relative rainfall intensity when compared with the other two periods of the year (6 millimeters per event in period 2 as compared with 3.4 and 4.2 millimeters per event in periods 1 and 3, respectively).

b. Linear trends in rainfall amounts

The slopes of the regression analysis (linear trend) for the amount of rainfall and the number of rainfall events, averaged across the prairies, are shown in Table 2. Of the 140 stations examined, the trend of annual rainfall was positive at 121 and negative at 19 stations. A positive trend of 1.28 mm yr^{-1} was obtained for annual prairie rainfall, which was significantly greater than zero (significance level $P \leq 0.05$). On average, rainfall has increased by 51.2 mm or about 16% across the prairie during the 40-yr study period.

The rainfall trend obtained during the first four months of the year, January–February–March–April (JFMA), was positive at 119 stations and negative at 21, a pattern similar to the annual rainfall (Table 2). A trend of 0.22 mm yr^{-1} was obtained for this period, which was significantly different from zero ($P \leq 0.05$). This increase, however, represents about 46% of the 40-yr mean rainfall during JFMA. Although the amount of rainfall during period 1 was small, 19 mm on average (Table 1), it has experienced proportionately the largest increase. The increase in rainfall during this period may be due to the conversion of snow to rainfall with the warming trend on the prairie (Saunders and Byrne 1994; Cutforth et al. 1999). Akinremi et al. (1999) reported a significant decrease in the annual amount of snow on the prairies during the most recent 35 years (1961–95). Because low winter temperatures are responsible for precipitation in the form of snow on the prairie, a warmer climate, especially during the spring and autumn seasons, will cause more of the precipitation to fall as rain with a concomitant decrease in the amount of snowfall.

The trend of rainfall during the summer months, May–June–July–August (MJJA), parallels the annual trend (Table 2), which was expected because the summer rainfall constitutes 75% of annual rainfall (Table 1). A significant trend of 0.98 mm yr^{-1}, or about 16% of the 40-yr mean, was obtained during MJJA. This positive trend, during the period of the year that is most critical to agriculture, suggests that summer months are not getting drier on the prairies. The increase in summer rainfall may be due to an increase in convective activities associated with increased soil surface evaporation and evapotranspiration from plants (Raddatz 1998; Strong 1997; Clark and Arritt 1995). This increased evapotranspiration could result from a combination of a warming trend and an increase in cropped acreage following a reduction of area in fallow on the prairie. Although surface moisture loss may only make a small contribution to total precipitation (McDonald 1962), the enhanced evapotranspiration may be more important in the thermodynamics of cloud formation and frequency of rainfall during summer (Goldman 1968).

Unlike the first eight months of the year, the increase in rainfall during September–October–November–December (SOND) was small (0.08 mm yr^{-1}) and was not significantly different from zero. As well, more stations (47) had negative trends during this period when compared with the other two periods of the year.

c. Linear trends in number of rainfall events

Results obtained for the number of rainfall events are similar to those of rainfall amounts (Table 2). An increase of 0.43 events per year was obtained for the annual number of rainfall events, and this increase was significantly different from zero ($P \leq 0.05$). Thus, rain is falling more frequently on the prairie than was the case 40 years ago. The trends of rainfall events during periods 1 and 2 are positive (0.09 and 0.28 events per year, respectively) and are significantly different from zero ($P \leq 0.05$). The trend in the number of rainfall events during period 3 was small (0.06 yr^{-1}) and was not significantly different from zero.

The similarity between the trends in amount and number of rainfall events suggests that the two are related. Previously, we found that the increase in amount of

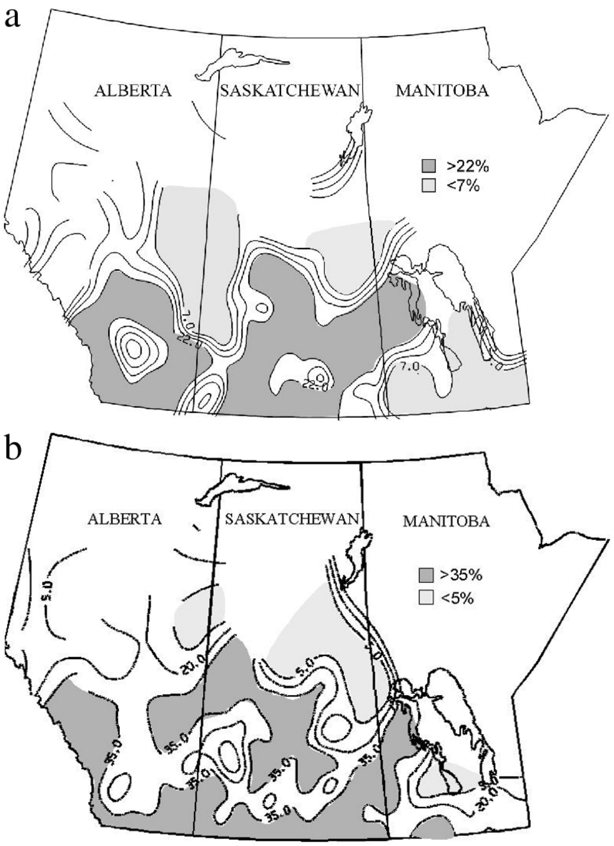

FIG. 2. Spatial distribution of linear trends in (a) annual amount of rainfall at contour intervals of 5% and (b) annual number of rainfall events at contour intervals of 15% across the prairie during the period of 1956–95. Percentages are relative to the 40-yr mean at each station.

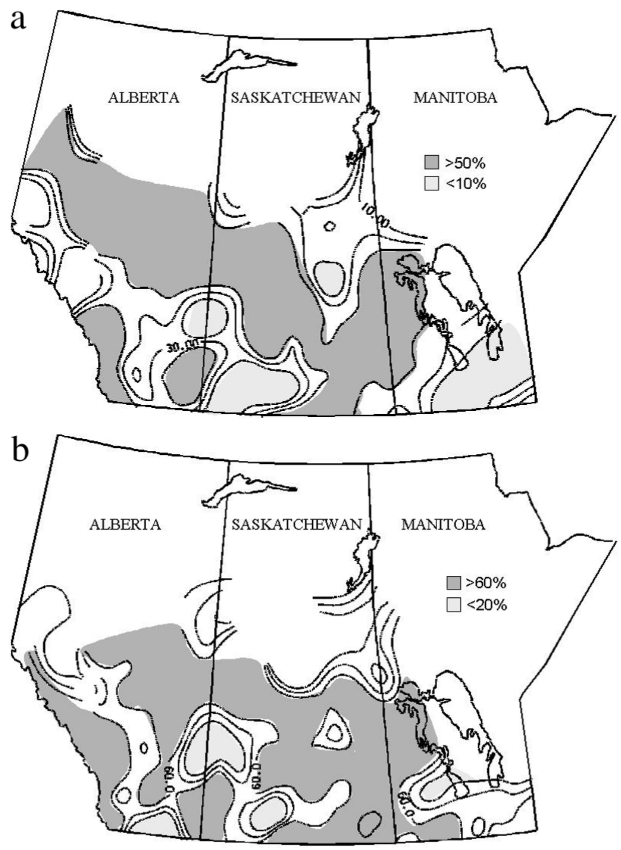

FIG. 3. Spatial distribution of linear trends in (a) amount of rainfall at contour intervals of 20% and (b) number of rainfall events at contour intervals of 20% during spring (JFMA) across the prairie from 1956 to 1995.

precipitation on the prairie was not accompanied by an increase in intensity, but by a significant increase in the frequency of low-intensity events (Akinremi et al. 1999). The increase in rainfall on the prairie may be due, in large part, to an increase in the number of rainfall events.

d. Spatial pattern of trends in amount and number of rainfall events

The spatial pattern of the trends in rainfall amount and number of events on the prairies is shown as contoured maps prepared from the trend at each of the 140 stations (Fig. 1) and expressed as a percentage of the 40-yr mean at each station (Fig. 2). The spatially coherent regions of trends in rainfall amount across the prairie is shown in Fig. 2a. The least increase (less the 7%) was found in southern Manitoba and in the northern prairie region, and a large area of southern Saskatchewan and Alberta showed increases in excess of 22%. The reason for this spatial pattern is unknown. However, the pattern resembles the distribution of soil moisture as simulated by the Canadian Climate Centre's Global Circulation Model (for $2 \times CO_2$ concentration) showing dry conditions in southern Manitoba and wetter soils in Alberta and Saskatchewan (Laprise et al. 1998).

Some coherent spatial patterns exist between the trends in number of rainfall events and the amount of rainfall (Figs. 2a,b). The Lake Winnipegosis–southeast Saskatchewan corridor had an increase of more than 35% in rainfall events and coincides roughly with the same region with more than 22% increase in rainfall amount. Also, northern Saskatchewan and Alberta experienced the least increase in the number of rainfall events—less than 5%; these regions also had the least increase in rainfall amount—less than 7%. Two regions with the largest increase in the number of rainfall events were in southern Alberta–Saskatchewan and central to northwestern Saskatchewan, extending slightly into portions of northeast Alberta. In these regions, rainfall events have increased by more than 35% in the period between 1956 and 1995.

The largest increase in rainfall during the spring period (JFMA) is along a northwest–southeast corridor through Alberta and Saskatchewan, and a southwest–northeast corridor through Saskatchewan and Manitoba (Fig. 3a). In this ''v''-shaped region, rainfall during period 1 has increased by more than 50%. Figure 3b shows

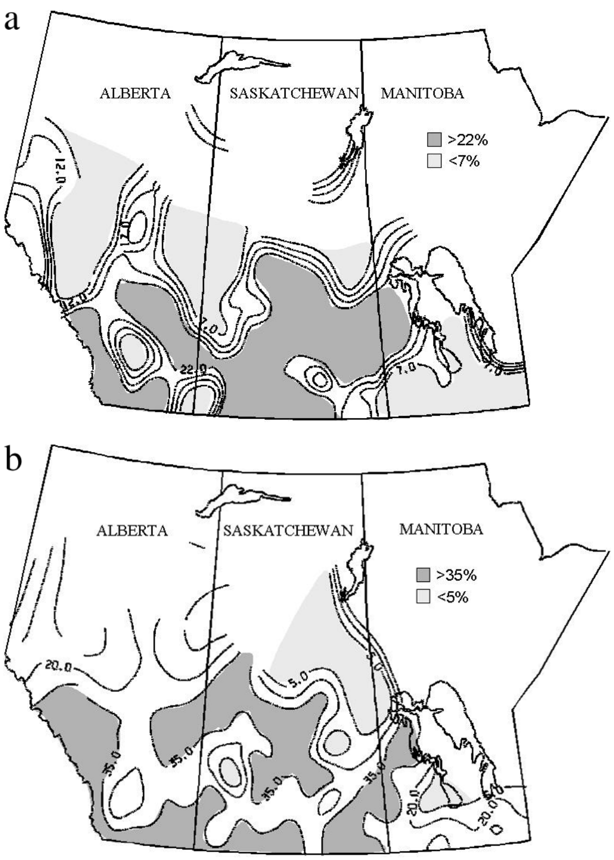

FIG. 4. Spatial distribution of linear trends in (a) amount of rainfall at contour intervals of 5% and (b) number of rainfall events at contour intervals of 15%, during summer (MJJA) across the prairie from 1956 to 1995.

the spatial pattern of the trend in the number of rainfall events during period 1. A considerable portion of the prairie has had an increase in the number of rainfall events during the first four months of the year, with increases in excess of 60% in most of Saskatchewan, central and northern Alberta, and southwestern Manitoba. Only a small portion of northern Saskatchewan and southern Alberta had increases in rainfall events that were less than 20% during JFMA. The best relationship in the spatial pattern of trends in rainfall amounts and number of events was obtained during period 1, with a significant correlation coefficient r of 0.54.

The spatial pattern of the trends in summer (MJJA) rainfall amounts and number of events (Figs. 4a,b) is similar to the annual trends (Figs. 2a,b). This result was not surprising, because rainfall during period 2 constitutes about 75% of the annual total (Table 1). Spatial coherence of trends in amount of rainfall is evident (Fig. 4a), given that a large portion of Saskatchewan and Alberta had experienced increases of more than 22%. Southern Manitoba and the northern portion of the prairie provinces had experienced the least increase (less than 7%), similar to that of the annual rainfall. The regions with the largest increase in number of summer rainfall events include southern Alberta and Saskatchewan and the central portion of Saskatchewan (Fig. 4b), with increases of more than 35%. The northern portions of Alberta and Saskatchewan had increases of less than 5%. The trends in amount and number of rainfall events during period 3 were not significant (Table 2).

e. Possible causes of trends in the number of events and amounts of rainfall

We speculate that the increase in rainfall amounts and number of events during the first 4 months of the year may not represent an overall increase in precipitation per se, but is due to a conversion of snow to rainfall as a result of warming during this period. Cutforth et al. (1999) reported that the percentage of precipitation in the form of snow has decreased as temperatures have warmed in southwestern Saskatchewan. The small amount of rainfall during this period exaggerates this conversion when increases are expressed relative to the mean. The increase in rainfall amounts and number of events during summer appears to be a real contribution to precipitation. The large-scale spatial coherence of these increases suggest that they may not be random, but are due to the influence of meso- to macroscale processes. These processes may include a prairie warming trend (Skinner and Gullet 1993), anthropogenic land use changes on the prairie (Raddatz 1998; Skinner and Majorowicz 1999), and changes in the surface or upper-air circulation patterns (Bonsal et al. 1999).

4. Conclusions

There has been a significant increase in rainfall amount and number of events on the Canadian prairies within the 40-yr period from 1956 to 1995. Annual rainfall has increased by 51 mm or about 16% while number of rainfall events increased by 17 or about 29%. These increases were limited to the first 8 months of the year. The increases in rainfall amount and number of events were not uniform across the prairies, with the least increases occurring in southern Manitoba and the largest increases occurring in Alberta and Saskatchewan. Little or no change in amounts was obtained in the northern portion of the prairie provinces. In general, the results confirm that the prairie is not getting drier. However, there are seasonal and spatial differences in rainfall trends on the prairie.

REFERENCES

Akinremi, O. O., S. M. McGinn, and H. W. Cutforth, 1999: Precipitation trends on the Canadian prairies. *J. Climate,* **12,** 2996–3003.

Bonsal, B. R., X. Zhang, and W. D. Hogg, 1999: Canadian prairie growing season precipitation variability and associated atmospheric circulation. *Climate Res.,* **11,** 191–208.

Clark, C. A., and R. W. Arritt, 1995: Numerical simulation of the

effect of soil moisture and vegetation cover on the development of deep convection. *J. Appl. Meteor.*, **34,** 2029–2045.
Cutforth, H. W., B. G. McConkey, R. J. Woodvine, D. G. Smith, P. G. Jefferson, and O. O. Akinremi, 1999: Climate change in the semiarid prairie of southwestern Saskatchewan: Late winter–early spring. *Can. J. Plant Sci.,* **79,** 343–350.
Goldman, J. L., 1968: The high speed updraft—The key to the severe thunderstorm. *J. Atmos. Sci.,* **25,** 222–248.
Idso, S. B., and R. C. Balling Jr., 1991: Recent trends in United States precipitation. *Environ. Conserv.,* **18,** 71–73.
Karl, T. R., N. Nicholls, and J. Gregory, 1997: The coming climate. *Sci. Amer.,* **276,** 78–83.
Laprise, R., D. C. Caya, M. Giguere, G. Bergeron, H. Cote, J. P. Blanchet, G. Boer, and N. McFarlane, 1998: Climate and climate change in western Canada as simulated by the Canadian Regional Climate Model. *Atmos.–Ocean,* **36,** 119–167.
McDonald, J. E., 1962: The evaporation–precipitation fallacy. *Weather*, **May,** 168–177.
McGinn, S. M., A. Toure, O. O. Akinremi, D. J. Major, and A. G. Barr, 1999: Agroclimate and crop response to climate change in Alberta, Canada. *Outlook Agric.,* **28,** 19–28.
Raddatz, R. L., 1998: Anthropogenic vegetation transformation and the potential for deep convection on the Canadian prairies. *Can. J. Soil Sci.,* **78,** 657–666.
Ripley, E. A., 1986: Is the prairie becoming drier? *Drought: The impeding crisis? Proc. 16th Canadian Hydrology Symp.,* Ottawa, ON, Canada, National Research Council, 50–60.
Saunders, I. R., and J. M. Byrne, 1994: Annual and seasonal climatic changes in the Canadian prairies simulated by the CCC GCM. *Atmos.–Ocean,* **32,** 621–641.
Skinner, W. R., and D. W. Gullet, 1993: Trends of daily maximum and minimum temperature in Canada during the past century. *Climatol. Bull.,* **27,** 63–77.
——, and J. A. Majorowicz, 1999: Regional climatic warming and associated century land-cover changes in north-western North America. *Climate Res.,* **12,** 39–52.
Strong, G. S., 1997: Atmospheric moisture budget estimates of regional evapotranspiration from RES-91. *Atmos.–Ocean,* **35,** 29–63.
Vinnikov, K. Y., P. Y. Groisman, and K. M. Lugina, 1990: Empirical data on contemporary global climate changes (temperature and precipitation). *J. Climate,* **3,** 662–667.