MEAN ANNUAL TEMPERATURE AND TOTAL ANNUAL PRECIPITATION TRENDS AT CANADIAN BIOSPHERE RESERVES

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Abstract. This article examines instrumental climate records from a variety of stations associated with the following Biosphere Reserves across Canada: (i) Waterton Lakes, (ii) Riding Mountain, (iii) Niagara Escarpment, (iv) Long Point, and (v) Kejimkujik (Candidate Biosphere Reserve). Annual series are generated from daily temperature and precipitation values. In addition, homogeneous data are used from other stations and regional records to supplement the records from the local biosphere stations. Long term trends are identified over the period of the instrumental record. In general, data from the interval 1900 to 1998 show cooler temperatures in the 1920's, warming from the early 1940's into the early 1950's, cooling into the 1970's, and subsequent warming. At many stations, 1998 is the warmest in the instrumental record. Comparisons with the regional data sets show good agreements between the temperature series. The 20th century warming is approximately 1.0 °C in the Riding Mountain area and 0.6 °C in the Long Point, Niagara Escarpment, and Waterton Lakes areas. There has been slight cooling in the Kejimkujik area over the past half century. Precipitation data show increasing trends in the Kejimkujik, Long Point, Niagara Escarpment, and Waterton Lakes areas with no long term trend in the Riding Mountain area. This work is part of the Canadian Biosphere Reserves Association (CBRA) Climate Change Initiative (CCI), designed to present climate change information to Biosphere Reserve communities to allow local organizations to understand climate change and adapt to potential impacts.

Keywords: biosphere reserves, climate trend, ecosystems, precipitation and temperature

1. Introduction

This article is an examination of climate records from stations representing several biosphere reserves across Canada. Commissioned by the Canadian Biosphere Reserves Association (CBRA), the goal is to provide information on climate variations to Biosphere Reserve communities interested in addressing the climate issue from a local perspective.

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1.1. Biosphere Reserves and Climate Change

Biosphere Reserves are terrestrial and coastal ecosystems that are internationally recognized within the framework of the United Nations Educational Scientific and Cultural Organization's (UNESCO) Man and the Biosphere Reserve Programme. More than 350 Biosphere Reserves are recognized by UNESCO, including ten in Canada. The CBRA has identified climate change as a key area of interest, based primarily on potential impacts to ecological function and economic development. The CBRA Climate Change Initiative (CCI) has the following objectives.

1) Provide information on climate change impacts, trends, and scenarios to biosphere reserve communities across Canada.
2) Develop Community Climate Change Strategies through community-based workshops.
3) Initiate community action to deal with climate change, focussing on adaptation.

The CCI meets several goals set out for Biosphere Reserves in the Seville Strategy. This strategy is widely accepted as the global vision for Biosphere Reserves and includes research, testing models of sustainable development, and education, monitoring and training. The CCI provides information on climate change, the workshop process will involve the design, use and testing of a community-based approach to adapt to climate change, and communities will address an environmental problem at the local level.

1.2. Study Objectives

This study has the following objectives.

1) Compile data from climate stations nearby and in biosphere reserves. Examine variations in mean annual temperature and total annual precipitation over the period of the instrumental records. Describe long term trends.
2) Compare results with published regional data sets.
3) Identify problems with the instrumental records and make recommendations for further analysis.

2. Twentieth Century Climate Trends

2.1. Global and Northern Hemisphere Climate Trends

Compilations of data from climate stations distributed around the globe show warming of up to 0.6 °C over the last century (Jones, 1988; IPCC, 1990, 1992; Jones, 1994a, b; IPCC, 1996; Hansen *et al*., 1999; Peterson *et al*., 1999; Quayle *et al*., 1999). Global and northern hemisphere mean annual temperature departures, relative to 1951–1980, are shown on Figure 1(a,b) from 1880 to 1999. These data are from the Goddard Institute for Space Studies (Hansen *et al*., 1999). Mean annual temperatures increased from approximately 1910 to 1940, with a warm interval peaking in the late 1930's and early 1940's. Temperatures cooled slightly over the subsequent 25 to 30 years. Temperatures began increasing by the mid 1970's and have warmed since, with the exception of a short term cooling following the eruption of Mount Pinatubo in 1991 (Hansen *et al*., 1996). Trends have not been uniform around the globe. The warming is most marked in the mid and high latitudes of continental interiors (IPCC, 1996). Some areas have shown stable temperatures or cooling in recent decades, such as the north Atlantic (Jones, 1988; Morgan *et al*., 1993; Pocklington, 1998).

Total annual precipitation shows a gradual increase from 1900 to the late 1950's, this was followed by a decrease to 1970, higher amounts of precipitation in the 1970's and a decrease since 1980 (Jones and Hulme, 1996; IPCC, 1996). Precipitation amounts have increased in high northern latitudes but have decreased slightly in the subtopics of the southern and northern hemispheres, and have shown marked decreases in areas such as the Sahel of Africa (Jones and Hulme, 1996; IPCC, 1996). Overall, between 55°S and 85°N the amount of the 20th century increase in precipitation is only 1–2% (IPCC, 1996).

2.2. Canadian Climate Trends

The pattern of temperature change shown at the hemispheric scale has been recognized in examinations of records across Canada (Gullett and Skinner, 1992; Skinner and Gullet, 1993; Findlay *et al*., 1994a; Vincent *et al*., 1999; Zhang *et al*., in press). Mean annual temperature departures, relative to 1951–1980, are shown on Figure 1c. Data over the period 1895 to 1992 are from Findlay *et al*. (1994a) and for 1993 to 1999 from the Climate Trends and Variations Bulletin (Whitewood, 2000). Note that in the early portion of the record, there are relatively few data from northern Canada. Mean annual temperatures warmed from the 1890's to the 1940's, cooled from the 1940's to the 1970's and have warmed since the late 1970's (Figure 1c). All regions of Canada, with exception of the northeastern Arctic, have shown some 20th century warming. The rates of increase are highest in western Canada, particularily in the Mackenzie District, the northwestern boreal forest and the Prairies.

In North America, total annual precipitation amounts increased by 4 to 5% in the United States and 13% in southern Canada over the period 1890 to 1990 (Groisman and Easterling, 1995). Increases in precipitation are highest in south-central and southeastern Canada and adjacent areas of the United States (Groisman and Easterling, 1994). Findlay *et al*. (1994b) and Zhang *et al*. (in press) also describe increasing trends in Atlantic Canada, the Great Lakes region, and southern British Columbia but note a slight decreasing trend in the Prairies.

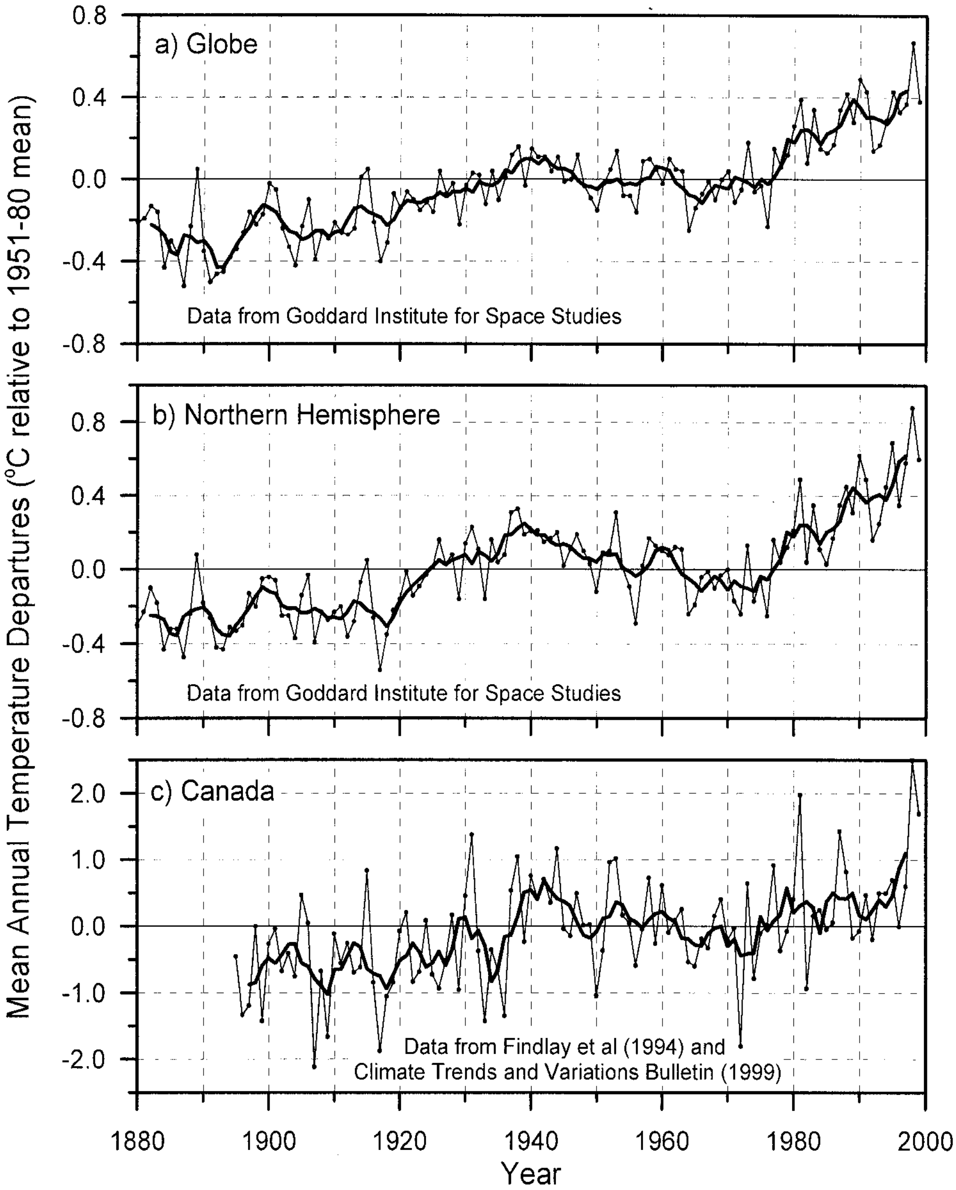

Figure 1. Mean annual temperature departures for the: a) Globe, b) Northern Hemisphere, and c) Canada. A five year running mean is passed through each series.

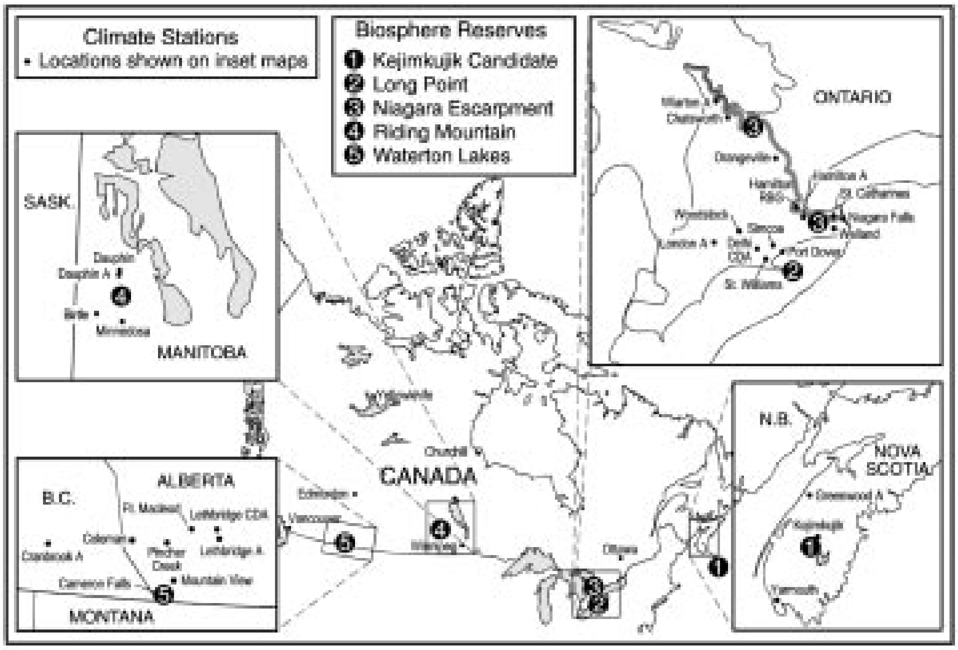

Figure 2. Location map of Biosphere Reserves and climate stations.

3. Methods

The five biosphere reserve sites selected by the CBRA for this project are:

1) Kejimkujik Candidate Biosphere Reserve,
2) Long Point Biosphere Reserve,
3) Niagara Escarpment Biosphere Reserve,
4) Riding Mountain Biosphere Reserve, and
5) Waterton Lakes Biosphere Reserve.

3.1. Station Selection and Data Manipulation

Personnel from each biosphere reserve, in consultation with Environment Canada, selected climate stations to represent each area. Stations were located nearby or within the biosphere reserves and are free of urban heat island effects (Figure 2). Table I presents the period of record for each climate station.

Daily values of mean temperature and total precipitation were acquired for each station from Environment Canada. Mean monthly temperature and total monthly precipitation were generated from the daily data. Mean annual temperature (MAT) and total annual precipitation (TAP) were calculated using the monthly values for each calendar year. A missing value was assigned to monthly temperature if more than five days of data were absent in that month. For monthly precipitation,

TABLE I

Climate stations locations, period of record, and data sources

Station[a]	Prov	ID[b]	Elev. (m)	Location		Data source[c]	Data type[d]	Record
Kejimkujik Candidate Biosphere Reserve								
Greenwood A	N.S.	8202000	28	44°59′N	64°55′W	1	T,P	1942–1998
Greenwood A (adj)	N.S.	8202000	28	44°59′N	64°55′W	2,3	T,P	1942–1998
Kejimkujik Park	N.S.	8202590	127	44°26′N	65°12′W	1	T,P	1966–1994
Kejimkujik 1 (Auto)	N.S.	8202592	127	44°26′N	65°12′W	1	T,P	1993–1998
Yarmouth (adj)	N.S.	8206500	43	43°50′N	66°05′W	2,3	T^1,P^1	1895–1998
Long Point Biosphere Reserve								
Delhi CDA	Ont.	6131982	232	42°52′N	80°33′W	1	T,P	1934–1998
London A (adj)	Ont.	6144475	278	43°02′N	81°09′W	2	T^1	1895–1998
Port Dover	Ont.	6136643	186	42°47′N	80°13′W	1	T,P	1895–1983
Simcoe	Ont.	6137735	223	42°52′N	80°20′W	1	T,P	1895–1961
St. Williams	Ont.	6137399	213	42°42′N	80°27′W	1	T,P	1954–1990
St. Williams Auto	Ont.	6137401	213	42°42′N	80°27′W	1	T,P	1989–1997
Woodstock (adj)	Ont.	6149625	282	43°08′N	80°46′W	3	P	1895–1998
Niagara Escarpment Biosphere Reserve								
Chatsworth	Ont.	6111467	305	49°24′N	80°54′W	1	T	1964–1998
Hamilton A	Ont.	6153194	238	43°10′N	79°56′W	1	T	1959–1998
Hamilton RBG (adj)	Ont.	6153300	102	43°17′N	79°53′W	3	P^1	1943–1998
Niagara Falls	Ont.	6135638	183	43°08′N	79°05′W	1	T	1902–1995
Orangeville	Ont.	6155788	405	43°55′N	80°03′W	1	T,P	1949–1967
Orangeville MOE	Ont.	6155790	412	43°55′N	80°05′W	1	T,P	1961–1998
St. Catharines (adj)	Ont.	6137287	98	43°12′N	79°10′W	2	T^1	1902–1996
Welland (adj)	Ont.	6139445	175	43°00′N	79°16′W	3	P	1895–1998
Wiarton A (adj)	Ont.	6119500	222	44°45′N	81°06′W	2	T^1	1895–1998
Wiarton A	Ont.	6119500	222	44°45′N	81°06′W	1	P	1948–1998
Riding Mountain Biosphere Reserve								
Birtle (adj)	Man.	5010240	522	50°26′N	101°03′W	2,3	T,P	1905–1995
Dauphin	Man.	5040675	292	51°09′N	100°02′W	1	T,P	1903–1947
Dauphin (adj)	Man.	5040675	292	51°09′N	100°02′W	3	P^1	1933–1996
Dauphin A	Man.	5040680	305	51°06′N	100°03′W	1	T,P	1942–1998
Dauphin A (adj)	Man.	5040580	305	51°06′N	100°03′W	2,3	T,P	1904–1998
Minnedosa	Man.	5011760	521	50°16′N	99°50′W	1	T,P	1895–1998
Minnedosa (adj)	Man.	5011760	521	50°16′N	99°50′W	1	P	1895–1998

TABLE I
(continued)

Station[a]	Prov	ID[b]	Elev. (m)	Location	Data source[c]	Data type[d]	Record
Waterton Lakes Biosphere Reserve							
Cameron Falls	Alb.	3051165	1311	49°03′N 113°55′W	1	T,P	1975–1995
Coleman (adj)	Alb.	3051720	1341	49°38′N 114°35′W	3	P	1913–1996
Cranbrook A (adj)	B.C.	1152102	939	49°36′N 115°47′W	1	T^1	1910–1998
Ft. Macleod (adj)	Alb.	3032680	950	49°43′N 113°24′W	3	P	1896–1987
Lethbridge A (adj)	Alb.	3033880	929	49°38′N 112°48′W	2	T	1938–1998
Lethbridge CDA (adj)	Alb.	3033890	921	49°42′N 112°47′W	2,3	T^1,P	1902–1998
Mountain View (adj)	Alb.	3034720	1318	49°08′N 113°38′W	3	P	1913–1997
Pincher Creek (adj)	Alb.	3035202	1190	49°31′N 114°00′W	2	T^1	1895–1993

[a] Station: (adj) Indicates homogeneity adjusted data.
[b] ID: Environment Canada code.
[c] Data source: 1: Monthly data calculated from daily values supplied by Environment Canada; 2: Canadian historical temperature database (http://ccrp.tor.ec.gc.ca/HCCD2/); 3: Rehabilitated Canadian monthly precipitation database (http://ccrp.tor.ec.gc.ca/HCCD2/).
[d] Data type: T: Mean Annual Temperature; P: Total Annual Precipitation. Superscript 1 indicates joined record.

a missing value was assigned if more than three days of data were absent in a month. The latter differs from the method used by Environment Canada which assigns a missing value to any month that lacks one or more daily precipitation measures. Our method was used to limit the number of missing values in the annual precipitation series.

The records from some stations span only a few decades or have substantial amounts of missing data and/or long data gaps. No attempts were made to estimate missing monthly temperature or precipitation values. In recent years, some stations have been automated. The automated stations may not yield data that are entirely consistent with the previous manual operations particularly for winter precipitation.

3.2. Homogeneous Station Data

Changes in station location, site exposure, observers, observation program, and instrumentation can produce non-climatic variations in a temperature or precipitation time series. These non-homogeneous records are not ideal for climate change trend analyses. To assess the importance of homogeneity to this study, the local climate records presented in this article are compared to long term, homogeneous temperature and precipitation records. The homogeneous data are drawn from stations in the Canadian Historical Temperature Database (CHTD) (Vincent and

Gullett, 1999) and the Canadian Monthly Precipitation Database (CMPD) (Mekis and Hogg, 1999).

The CHTD contains monthly temperature records from 210 locations. The data have been adjusted for homogeneity and extend back as early as 1895. Some records have been derived by joining adjacent stations. Missing monthly values were estimated and gaps filled by using correlations with nearby stations. Regression techniques were employed to identify non-climatic steps in annual series and monthly correction factors used to generate the adjusted homogeneous data (Vincent, 1998; Vincent and Gullett, 1999). Historical station records were used to confirm the non-climatic variations.

The CMPD contains monthly precipitation records from 490 locations, many dating to 1920 or earlier. For each station, daily records of rainfall and snowfall were adjusted to remove variations attributed to gauge type. Corrections applied to rainfall address wind undercatch, evaporation, wetting loss, and trace amounts. Ruler measures were used for snowfall and density corrections applied. Monthly data were derived from daily corrected values. When data from adjacent stations were joined, records were adjusted based on ratios of observations during overlapping periods. Missing monthly values and data gaps of up to two years have been estimated for some stations (Mekis and Hogg, 1999).

3.3. Regional climate records

The station data presented in this article are compared with temperature and precipitation records from several Canadian climate regions (Gullett and Skinner, 1992). Regional data are drawn from Trends '93 (Findlay *et al*., 1994a, b) and the Climate Trends and Variations Bulletin for Canada (CTVB) (Whitewood *et al*., 1999; Whitewood, 2000). Regional records are produced from the Historical Canadian Climate Database (HCCD) in a manner that accounts for the uneven spatial distribution of stations. In the HCCD, temperature records have been adjusted to ensure homogeneity, stations joined to increase record lengths, and missing data estimated. Precipitation data have been homogeneity assessed but not adjusted nor missing values estimated.

Regional temperatures are given as departures from the 1951–1980 mean. Variations in precipitation are presented as standardized departures in Trends '93 and as percentage departures in the CTVB, both using 1951–1980 as the base period. Trends '93 is used for temperature departures for 1895 to 1992, and CTVB for 1993 to 1999. Standardized departures of precipitation are taken from Trends '93 for 1895 to 1992 and converted to percentage departures. The CTVB is used for precipitation percentage departures for 1993 to 1999. The data from Trends '93 and CTVB were derived with the same methodology and are compatible (Whitewood, personal communication, 2000).

3.4. Presentation of Results

The warmest and coolest five year periods, and the five warmest and five coolest individual years for the regional and longer station records are presented in Table II. MAT and TAP for climate stations and regions representing each biosphere reserve are shown in Figures 3 to 12. Homogeneous station records are denoted by the term 'adjusted'. A five year running mean is plotted (thick line) through each series. Regression was used to examine the correlation between pairs of stations and between stations and the regional series for each biosphere reserve (Tables III to VII).

3.5. Trend Calculation and Significance

The standard approach used to fit a trend to a climate time series is least squares regression with a *t*-test employed for significance (e.g. Skinner and Gullett, 1993; Findlay *et al*., 1994a). The model assumes a climate record is comprised of a long term linear trend with white noise superimposed. However, most climate records have serial correlation, which can influence the trend magnitude and lead to overestimation of the statistical significance (von Storch, 1999). This problem can be largely ignored when the autocorrelation coefficient is small (e.g. 0.1). Using data from 11 of the time series in this study the lag-1, lag-2, and lag-3 autocorrelation coefficients averaged 0.18, 0.12 and 0.11. Two methods were used to assess the trend magnitude and significance. The first method is the standard approach described above. The second assumes a component of the noise is due to serial correlation and it must be removed from the data set before the trend magnitude is determined. The method followed was based in part on Zhang *et al*. (in press). The lag-1 coefficient is calculated and used to remove the autocorrelation (pre-whiten) from the time series (van Storch, 1999). An estimate of the trend is derived from the resulting pre-whitened series using least squares. This trend estimate is then removed from the original time series and the residuals used to produce a second estimate of the lag-1 coefficient. This coefficient is used to pre-whiten the original data and a second estimate of the trend is derived also using least squares. The procedure is repeated until estimates of the lag-1 autocorrelation coefficient and the trend magnitude converge in consecutive iterations. Significance is assessed with a *t*-test.

Results from the trend analyses are presented in Table VIII. Trends are expressed as a change in temperature or precipitation per hundred years. In general, removal of the autocorrelation produced trends that were smaller in magnitude and in some cases not significant relative to the standard linear approach. In the following text, the temperature trends discussed were those measured after removal of autocorrelation. The precipitation trends described were those fit by the linear approach due to data gaps in these series.

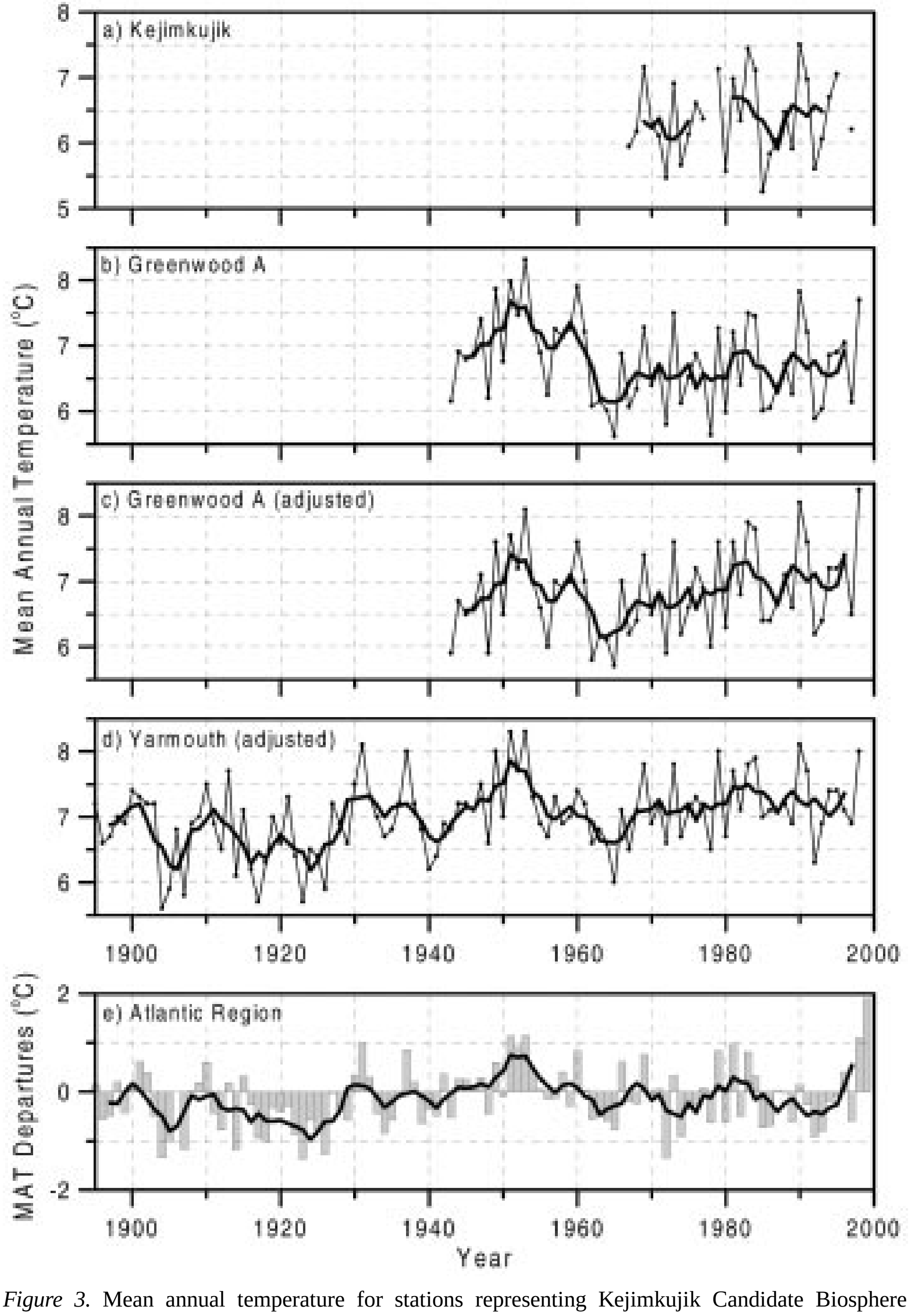

Figure 3. Mean annual temperature for stations representing Kejimkujik Candidate Biosphere Reserve, and departures for the Atlantic Region.

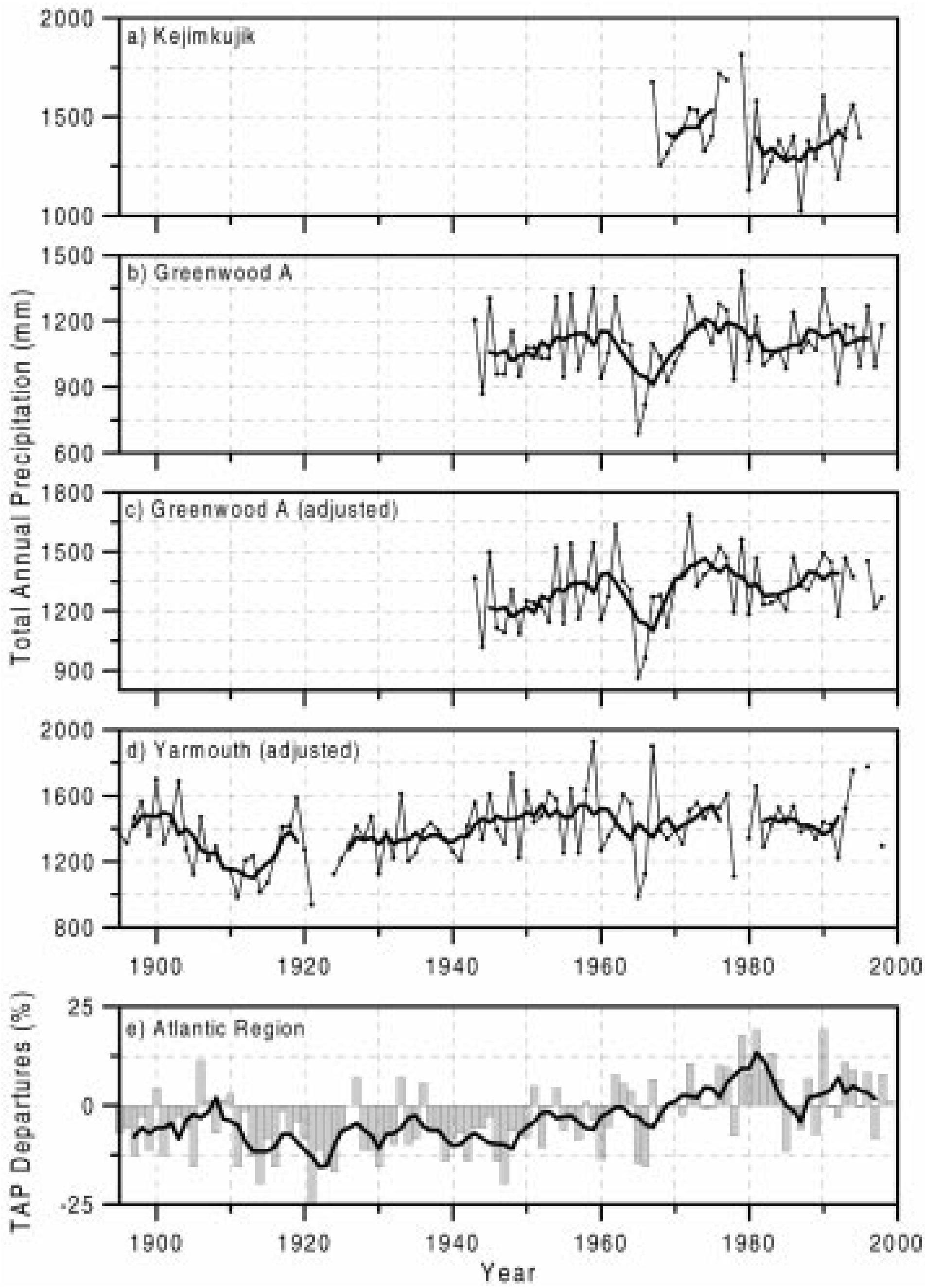

Figure 4. Total annual precipitation for stations representing Kejimkujik Candidate Biosphere Reserve, and departures for the Atlantic Region.

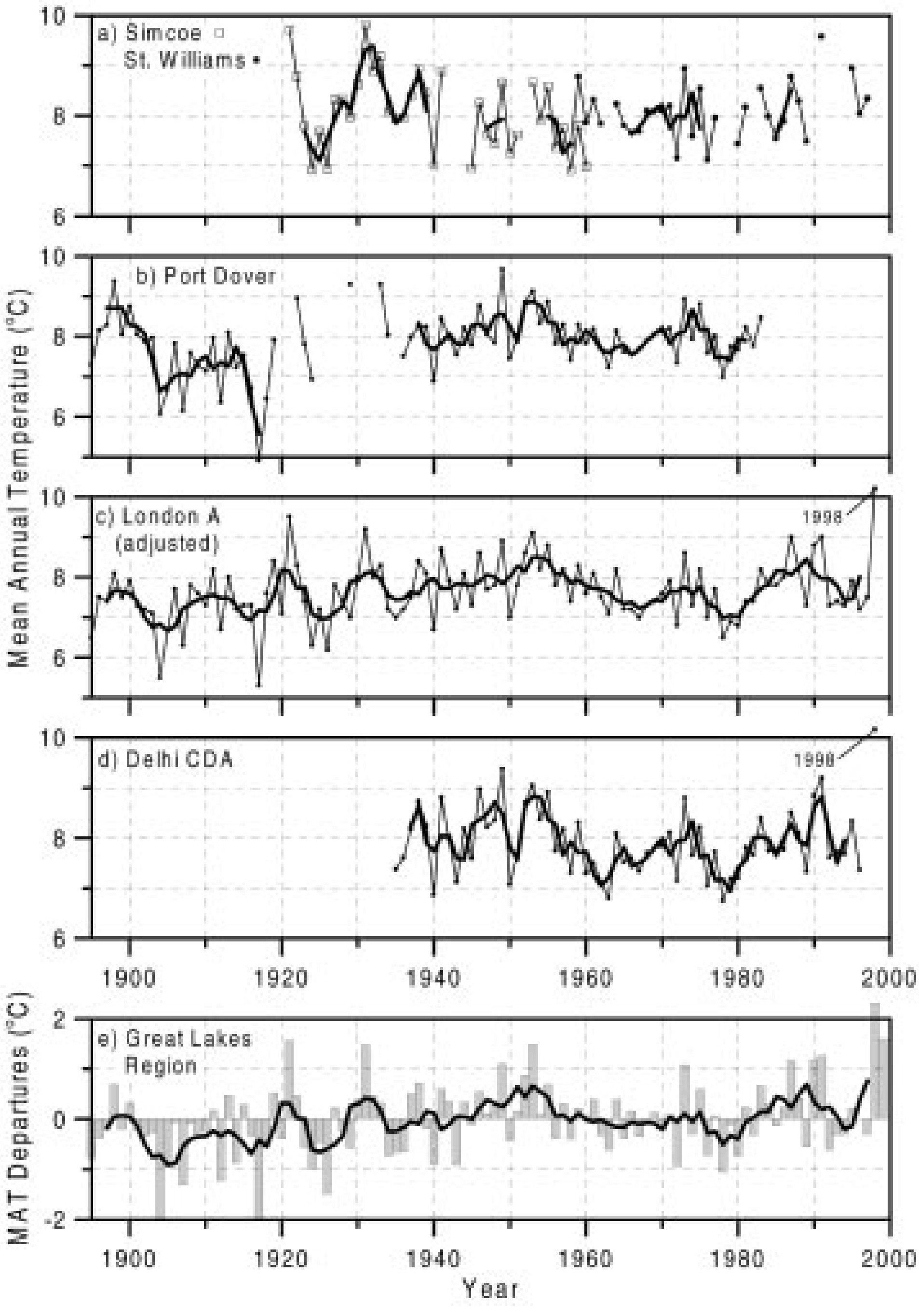

Figure 5. Mean annual temperature for stations representing Long Point Biosphere Reserve, and departures for the Great Lakes Region.

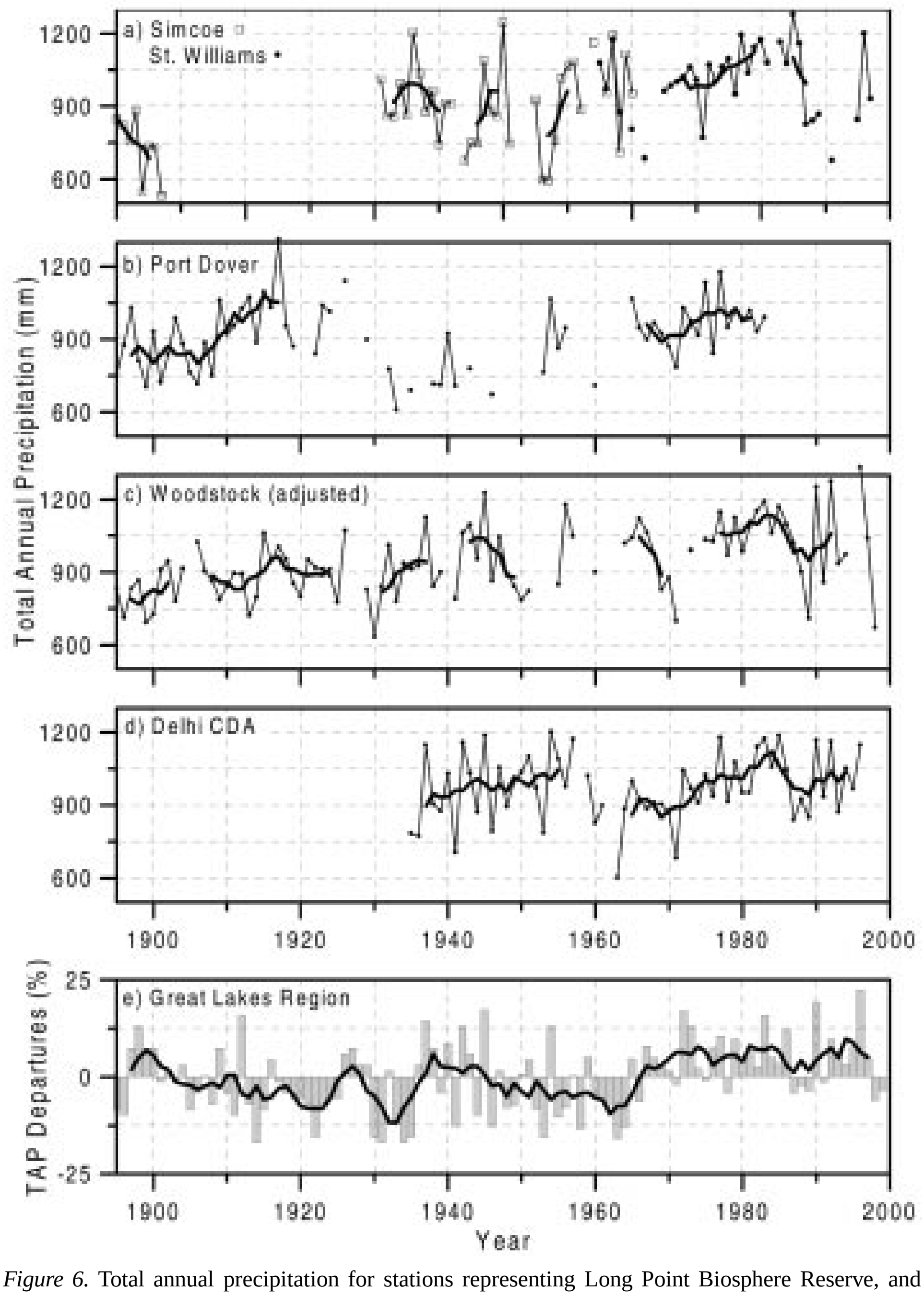

Figure 6. Total annual precipitation for stations representing Long Point Biosphere Reserve, and departures for the Great Lakes Region.

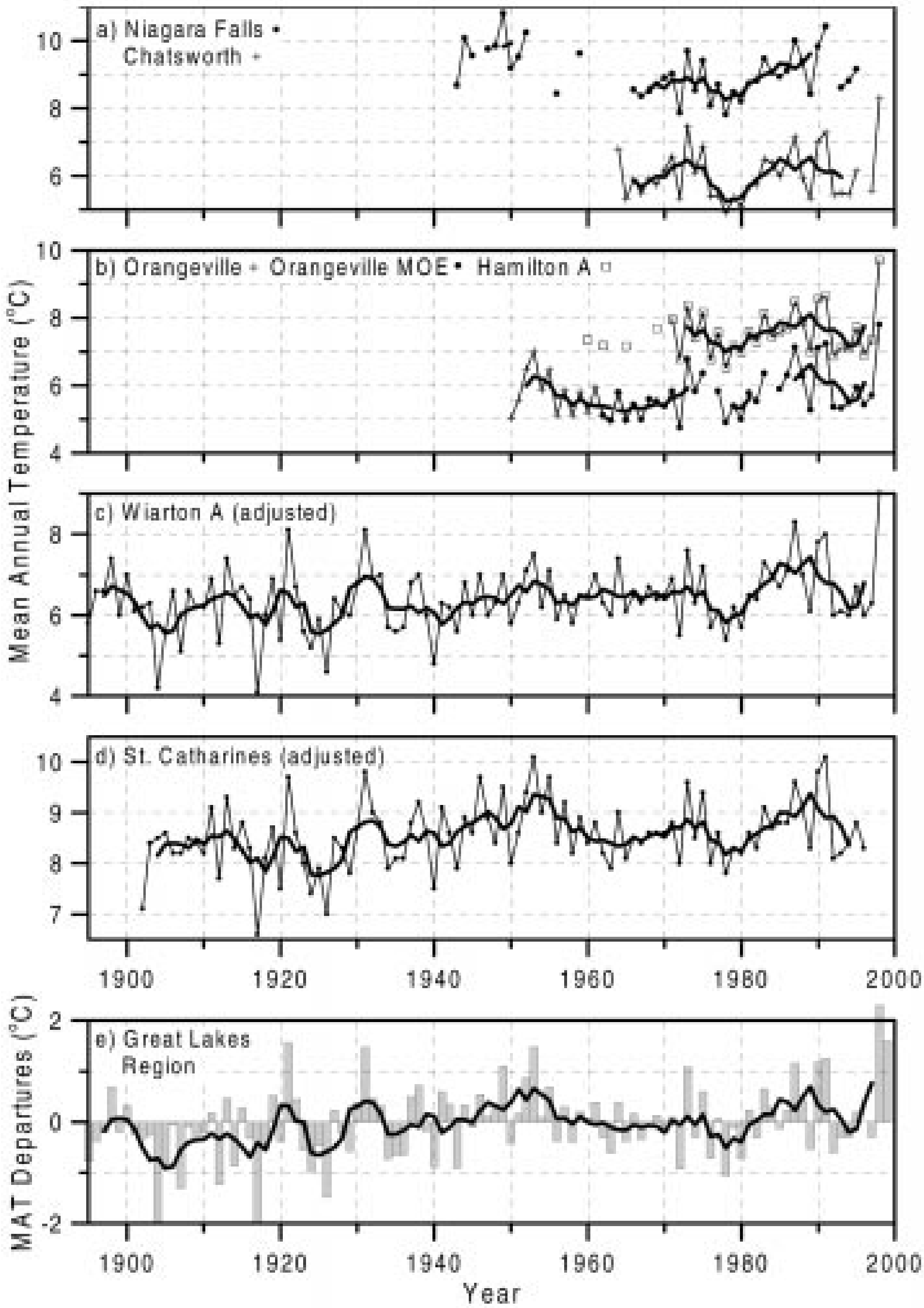

Figure 7. Mean annual temperature for stations representing Niagara Escarpment Biosphere Reserve, and departures for the Great Lakes Region.

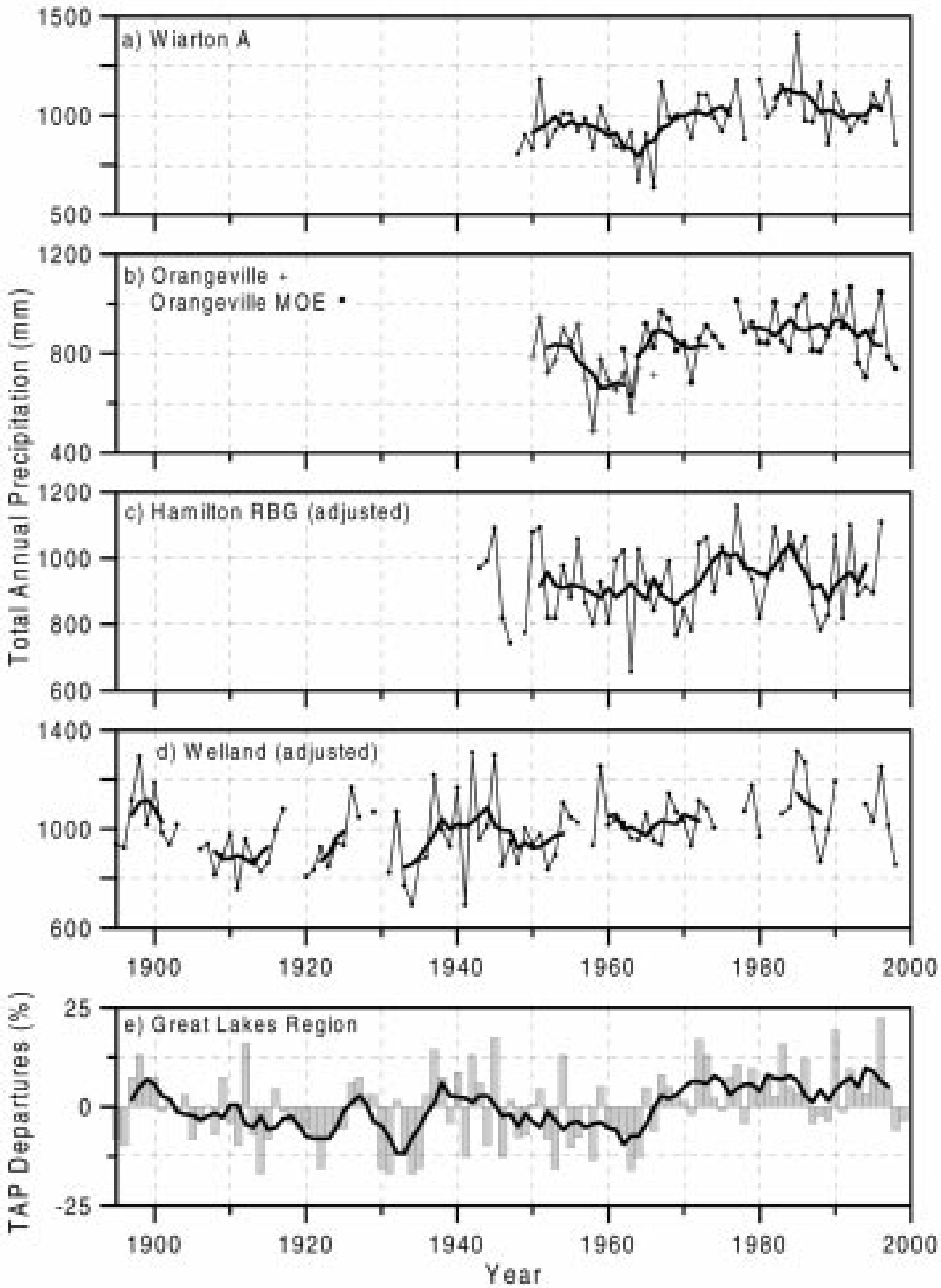

Figure 8. Total annual precipitation for stations representing Niagara Escarpment Biosphere Reserve, and departures for the Great Lakes Region.

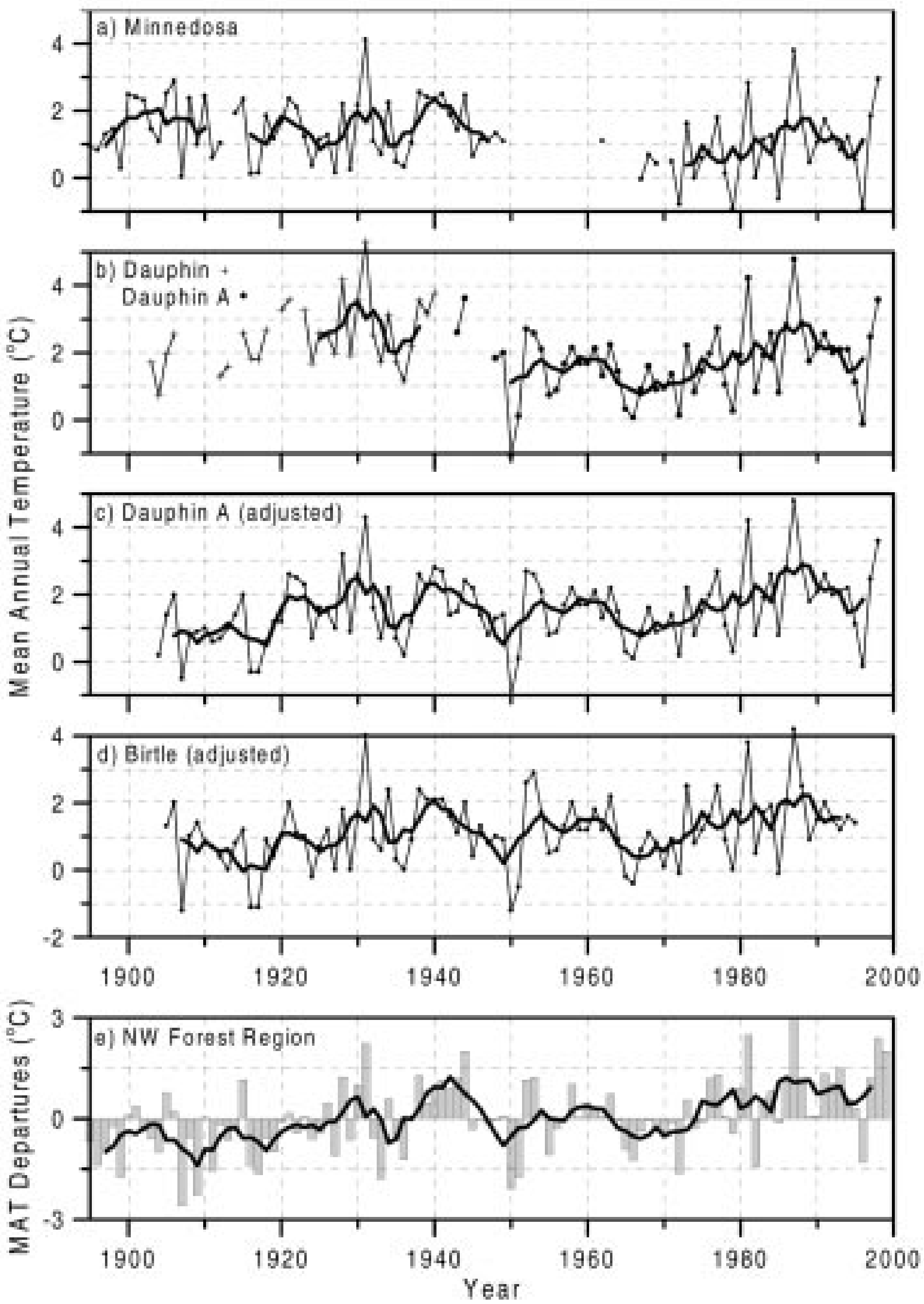

Figure 9. Mean annual temperature for stations representing Riding Mountain Biosphere Reserve, and departures for the NW Forest Region.

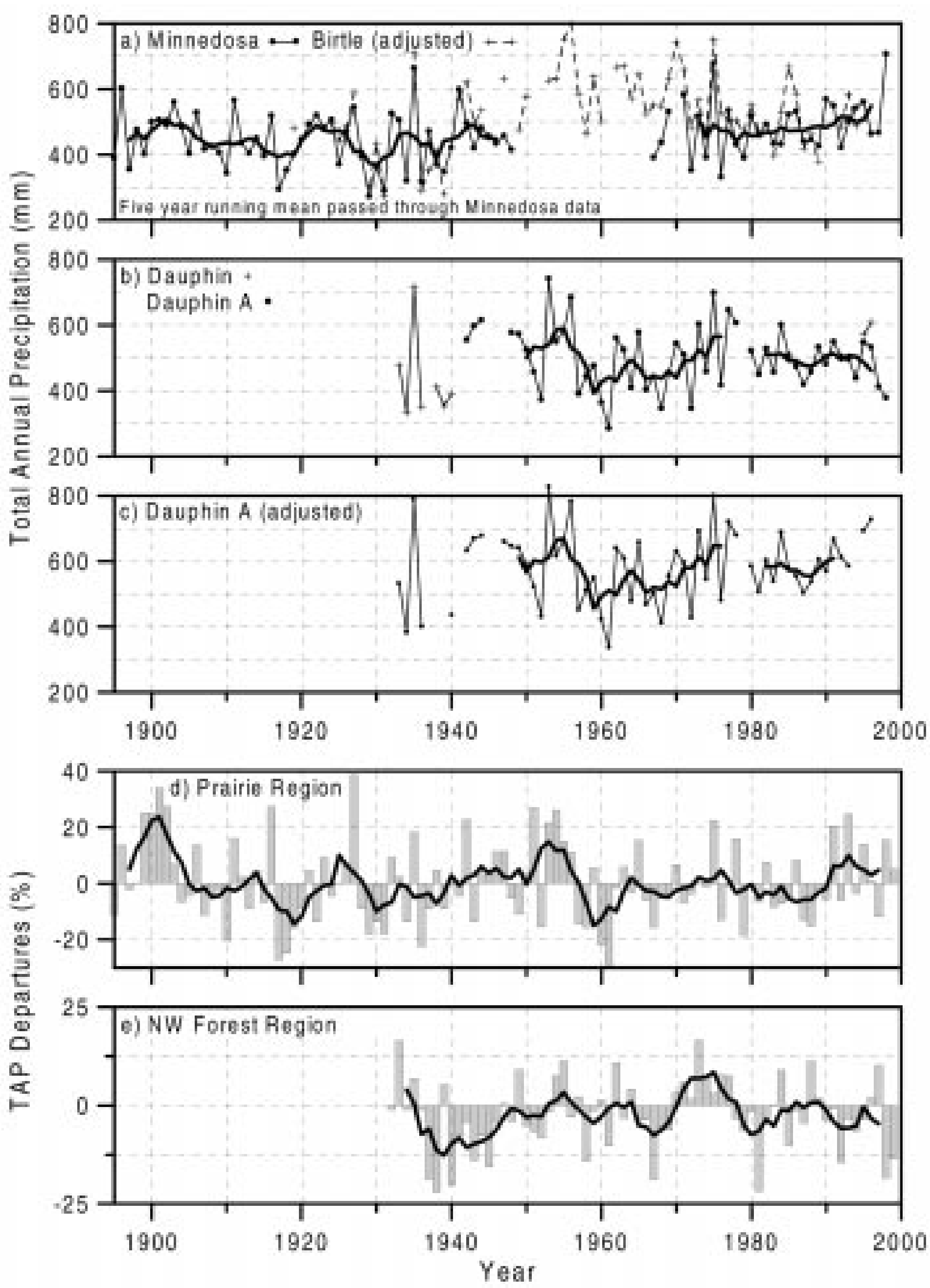

Figure 10. Total annual precipitation for stations representing Riding Mountain Biosphere Reserve, and departures for the NW Forest Region.

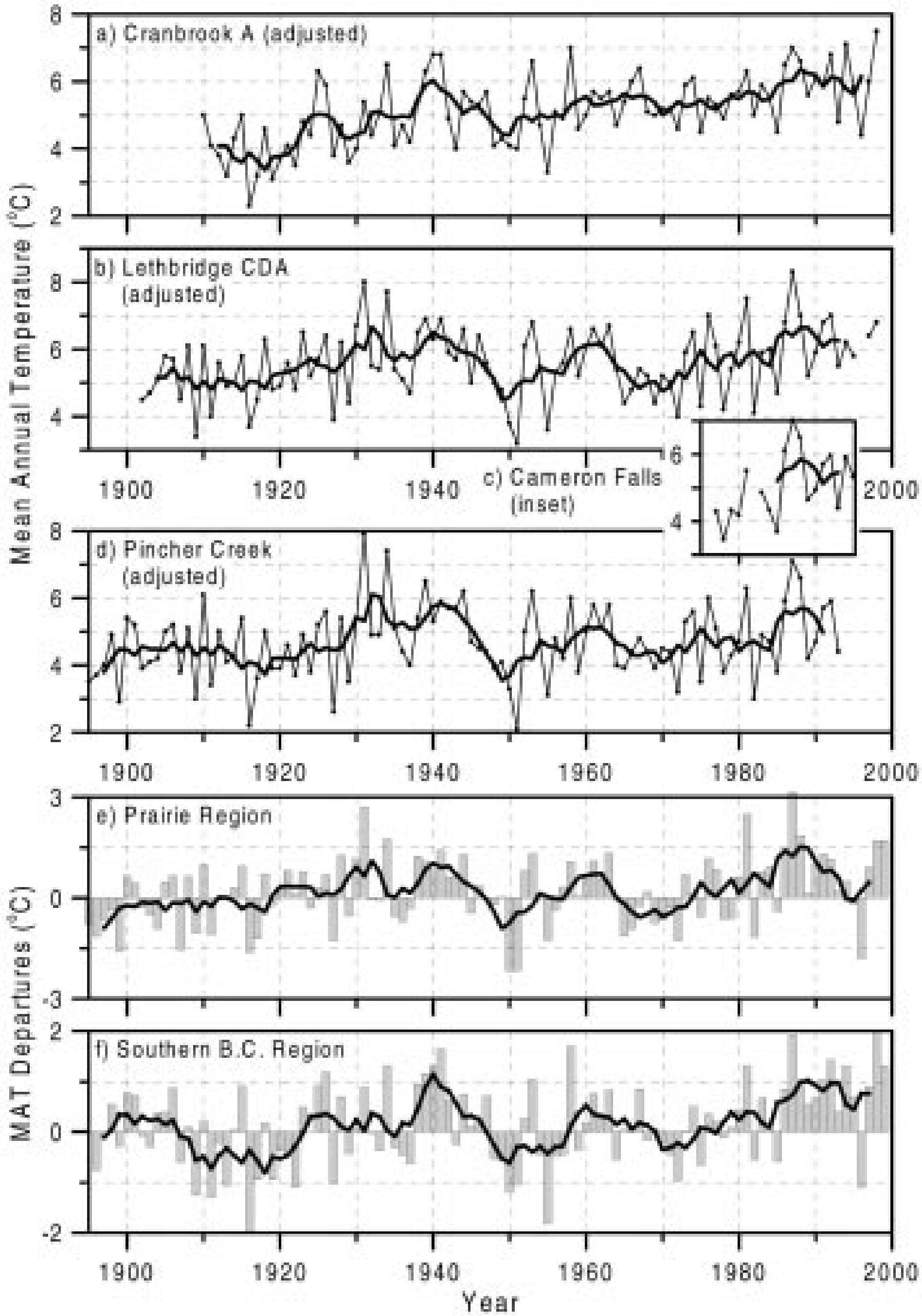

Figure 11. Mean annual temperature for stations representing Waterton Lakes Biosphere Reserve, and departures for the Prairie and Southern B.C. Regions.

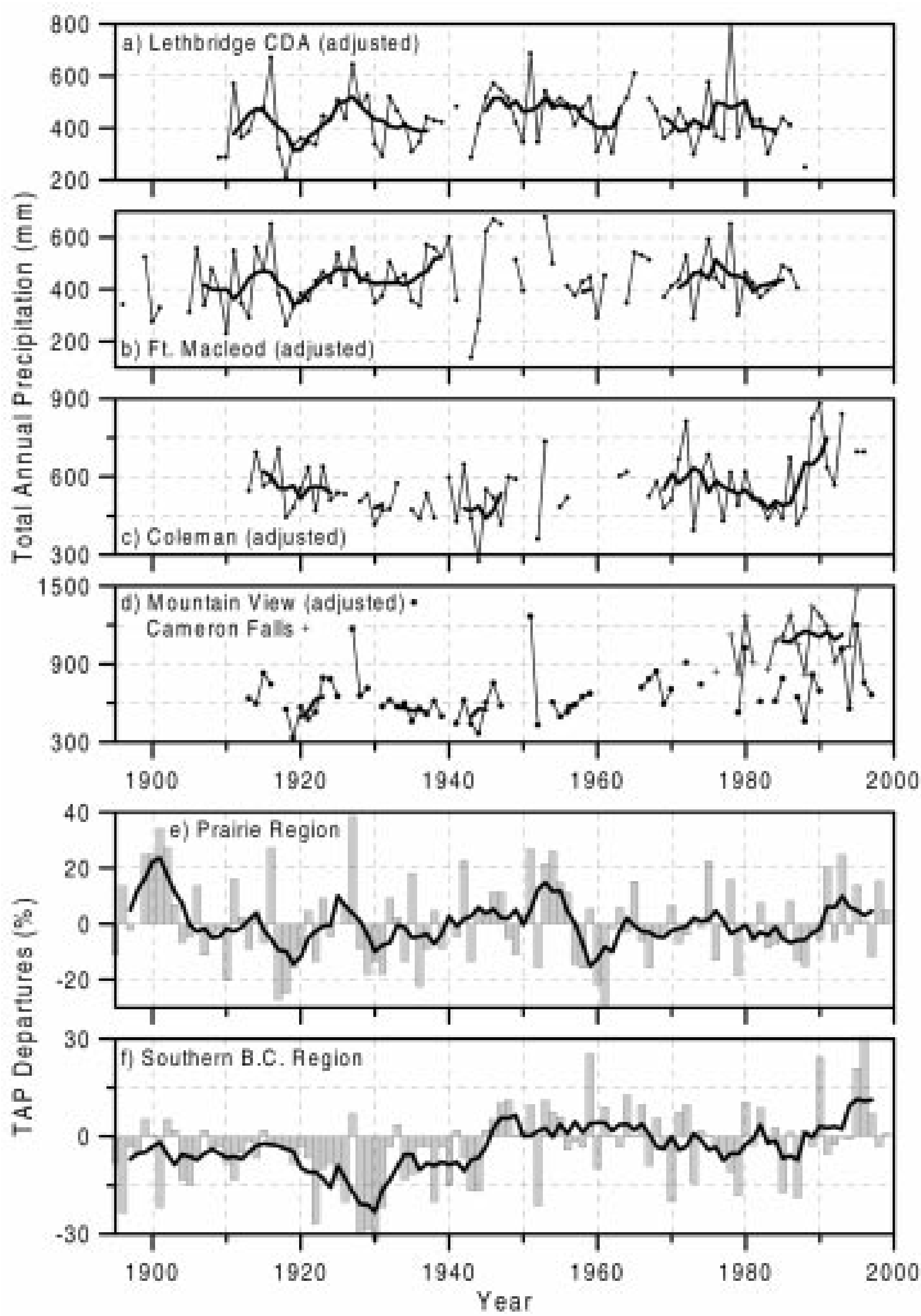

Figure 12. Total annual precipitation for stations representing Waterton Lakes Biosphere Reserve, and departures for the Prairie and Southern B.C. Regions.

TABLE II

Warmest five year period, warmest five individual years, coolest five year period, and coolest five individual years for selected stations and regions

Station	Warmest five year period	Five warmest years	Coolest five year period	Five coolest years
Kejimkujik Candidate Biosphere Reserve				
Greenwood A (adj)	1949–1953	1998, 1990, 1953, 1983, 1984	1962–1966	1965, 1962, 1943, 1948, 1972
Yarmouth (adj)	1949–1953	1953, 1951, 1990, 1931, 1998	1922–1926	1904, 1917, 1923, 1907, 1905
Atlantic Region[a]	1949–1953	1999, 1953, 1951, 1998, 1931	1922–1926	1923, 1972, 1904, 1926, 1914
Long Point Biosphere Reserve				
Delhi CDA	1951–1955	1998, 1949, 1991, 1953, 1946	1960–1964	1978, 1963, 1940, 1976, 1950
London A (adj)	1952–1956	1998, 1921, 1931, 1953, 1991	1903–1907	1917, 1904, 1926, 1924, 1907
Niagara Escarpment Biosphere Reserve				
Orangeville MOE[b]	1987–1991	1998, 1991, 1987, 1990, 1953	1963–1967	1972, 1978, 1963, 1965, 1967
St. Catharines (adj)[c]	1987–1991	1991, 1953, 1990, 1931, 1955	1923–1927	1917, 1926, 1902, 1924, 1940
Wiarton A (adj)	1987–1991	1998, 1987, 1991, 1949, 1952	1923–1927	1917, 1904, 1926, 1940, 1907
Great Lakes Region[d]	1995–1999	1998, 1999, 1921, 1953, 1931	1903–1907	1917, 1904, 1926, 1907, 1912

TABLE II
(continued)

Station	Warmest five year period	Five warmest years	Coolest five year period	Five coolest years
Riding Mountain Biosphere Reserve				
Dauphin A (adj)	1986–1990	1987, 1931, 1981, 1998, 1928	1916–1920	1950, 1907, 1916, 1917, 1996
Minnedosa	1938–1942	1931, 1987, 1998, 1986, 1981	1971–1975	1996, 1979, 1972, 1985, 1967
NW Forest Region	1940–1944	1987, 1981, 1998, 1931, 1999	1907–1911	1907, 1909, 1950, 1933, 1951
Waterton Lakes Biosphere Reserve				
Lethbridge A (adj)	1986–1990	1987, 1988, 1992, 1976, 1939	1947–1951	1951, 1955, 1996, 1950, 1982
Lethbridge CDA (adj)	1930–1934	1987, 1931, 1934, 1981, 1992	1947–1951	1951, 1909, 1955, 1916, 1950
Pincher Creek (adj)[c]	1930–1934	1931, 1934, 1987, 1988, 1935	1947–1951	1951, 1916, 1927, 1899, 1909
Prairie Region	1986–1990	1987, 1931, 1981, 1988, 1934	1947–1951	1950, 1951, 1996, 1916, 1899

[a] Regions use data from 1895-1999.
[b] Orangeville MOE record is composite of Orangeville and Orangeville MOE.
[c] Data do not extend to 1998.
[d] If 1999 is excluded the warmest five year period in Great Lakes Region is 1987–1991.

TABLE III

Correlations between stations and with regional records for mean annual temperature and total annual precipitation for the Kejimkujik Candidate Biosphere Reserve area

Mean annual	Kejimkujik MAT				Total annual	Kejimkujik TAP			
temperature	R^2	n	α	Period	precipitation	R^2	n	α	Period
Greenwood A	0.90	29	<0.001	1967–1997	Greenwood A	0.51	26	<0.001	1967–1997
Greenwood A (adj)	0.89	29	<0.001	1967–1997	Greenwood A (adj)	0.35	26	0.001	1967–1997
Yarmouth (adj)	0.81	29	<0.001	1967–1997	Yarmouth (adj)	0.53	26	<0.001	1967–1997
MAT departures from	Atlantic region MAT dep.				TAP departures from	Atlantic region TAP dep.			
1951–1980 mean	R^2	n	α	Period	1951–1980 mean	R^2	n	α	Period
Greenwood A	0.75	56	<0.001	1943–1998	Greenwood A	0.35	53	<0.001	1943–1998
Greenwood A (adj)	0.63	56	<0.001	1943–1998	Greenwood A (adj)	0.33	53	<0.001	1943–1998
Yarmouth (adj)	0.63	56	<0.001	1943–1998	Yarmouth (adj)	0.17	53	0.002	1943–1998

TABLE IV

Correlations between stations and with regional records for mean annual temperature and total annual precipitation for the Long Point Biosphere Reserve area

Mean annual	London A (adj) MAT				Total annual	Woodstock (adj) TAP			
temperature	R^2	n	α	Period	precipitation	R^2	n	α	Period
Delhi CDA	0.87	63	<0.001	1935–1998	Delhi CDA	0.48	50	<0.001	1935–1996
Port Dover	0.65	79	<0.001	1895–1983	Port Dover	0.14	57	0.005	1895–1983
St. Williams	0.70	33	<0.001	1956–1997	St. Williams	0.40	29	<0.001	1955–1997

MAT departures from	Great lakes region MAT dep.				TAP departures from	Great lakes region TAP dep.			
1951–1980 mean	R^2	n	α	Period	1951–1980 mean	R^2	n	α	Period
Delhi CDA	0.81	63	<0.001	1935–1998	Delhi CDA	0.47	60	<0.001	1935–1996
Port Dover	0.68	79	<0.001	1895–1983	Port Dover	0.15	63	0.002	1895–1983
St. Williams	0.73	33	<0.001	1956–1997	St. Williams	0.28	34	0.001	1955–1997
London A (adj)	0.89	104	<0.001	1895–1998	Woodstock (adj)	0.26	89	<0. 001	1895–1998

TABLE V

Correlations between stations and with regional records for mean annual temperature and total annual precipitation for the Niagara Escarpment Biosphere Reserve area

Mean annual	Wiarton A (adj) MAT				Total annual	Hamilton RBG (adj) TAP			
temperature	R^2	n	α	Period	precipitation	R^2	n	α	Period
Chatsworth	0.92	34	<0.001	1964–1998	Hamilton A	0.63	31	<0.001	1960–1996
Orangeville (joined)	0.87	47	<0.001	1950–1998	Orangeville MOE	0.46	34	<0.001	1962–1996
Wiarton A	0.86	49	<0.001	1948–1998	Wiarton A	0.05	47	0.150	1949–1996

Mean annual	St. Catharines (adj) MAT				Total annual	Welland (adj) TAP			
temperature	R^2	n	α	Period	precipitation	R^2	n	α	Period
Hamilton A	0.94	30	<0.001	1960–1996	Niagara Falls	0.63	42	<0.001	1934–1995
Niagara Falls	0.65	40	<0.001	1943–1995	Hamilton RBG (adj)	0.34	47	<0.001	1939–1996

MAT departures from	Great lakes region MAT dep.				TAP departures from	Great lakes region TAP dep.			
1951–1980 mean	R^2	n	α	Period	1951–1980 mean	R^2	n	α	Period
Orangeville (joined)	0.89	47	<0.001	1950–1998	Hamilton RBG (adj)	0.29	56	<0.001	1939–1996
St. Catharines (adj)	0.75	95	<0.001	1902–1996	Welland (adj)	0.53	89	<0.001	1895–1998
Wiarton A	0.91	49	<0.001	1948–1998	Wiarton A	0.35	50	<0.001	1948–1998
Wiarton A (adj)	0.87	104	<0.001	1895–1998					

TABLE VI

Correlations between stations and with regional records for mean annual temperature and total annual precipitation for the Riding Mountain Biosphere Reserve area

Mean annual	Dauphin A (adj) MAT				Total annual	Dauphin A (adj) TAP			
temperature	R^2	n	α	Period	precipitation	R^2	n	α	Period
Birtle (adj)	0.85	91	<0.001	1905–1995	Birtle (adj)	0.29	44	<0.001	1935–1993
Dauphin	0.82	29	<0.001	1904–1940	Dauphin A	0.95	50	<0.001	1942–1996
Dauphin A	0.95	53	<0.001	1943–1998	Minnedosa	0.46	38	<0.001	1915–1996
Minnedosa	0.58	77	<0.001	1904–1998					
MAT departures from	NW forest region MAT dep.				TAP departures from	NW forest region MAT dep.			
1951–1980 mean	R^2	n	α	Period	1951–1980 mean	R^2	n	α	Period
Birtle (adj)	0.73	91	<0.001	1905–1995	Birtle (adj)	0.06	50	0.089	1935–1994
Dauphin A	0.89	53	<0.001	1943–1998	Dauphin A	0.06	53	0.072	1942–1998
Dauphin A (adj)	0.78	95	<0.001	1904–1998	Dauphin A (adj)	0.07	56	0.042	1933–1996
MAT departures from	Prairie region MAT dep.				TAP departures from	Prairie region			
1951–1980 mean	R^2	n	α	Period	1951–1980 mean	R^2	n	α	Period
Birtle (adj)	0.79	91	<0.001	1905–1995	Birtle (adj)	0.37	59	<0.001	1919–1994
Dauphin A	0.87	53	<0.001	1943–1998	Dauphin A	0.30	53	<0.001	1942–1998
Dauphin A (adj)	0.79	95	<0.001	1904–1998	Dauphin A (adj)	0.40	57	<0.001	1919–1994

4. Results

4.1. Kejimkujik Candidate Biosphere Reserve

4.1.1. *Mean Annual Temperature*

Data from Kejimkujik Park, Kejimkujik 1, Greenwood A, Greenwood A adjusted, Yarmouth adjusted, and the Atlantic Region are on Figure 3. The Kejimkujik stations are merged. Kejimkujik is strongly correlated with Greenwood A (R^2 = 0.90), Greenwood A adjusted (R^2 = 0.89), and Yarmouth adjusted (R^2 = 0.81) (Table III). Temperature change at Kejimkujik may be inferred from the other sites. Yarmouth shows cooler conditions in the early part of the century, with the coolest five year period in the 1920's (Table II). This was followed by warming to the early 1950's, cooling into the 1960's, and slight warming thereafter. This general pattern is also seen in the Atlantic Region (Figure 3e). There are strong correlations between the stations and the region (Table III). The regional and Yarmouth trends are 0.4 and 0.6 °C, the latter is significant. Greenwood A adjusted closely mirrors the Yarmouth record but there is a difference in the trends between the adjusted and the raw Greenwood data. The raw data series shows cooling and the adjusted series warming, although neither is significant.

4.1.2. *Total Annual Precipitation*

Data from the above stations are on Figure 4. Relations between the merged Kejimkujik record and Greenwood A, Greenwood A adjusted, and Yarmouth adjusted yield R^2 values of 0.51, 0.35, and 0.53. While these correlations are lower than those with temperature, they are all highly significant. Greenwood shows a gradual increase in precipitation from the early 1940's, with drier conditions in the mid 1960's and a wetter period into the 1970's. Similar variations are seen in the Yarmouth and Atlantic Region data, with the overall trends showing increases of 14%. The weaker relations between individual stations and the regional data (Table III) reflect greater spatial variance in precipitation relative to that seen with temperature.

4.2. Long Point Biosphere Reserve

4.2.1. *Mean Annual Temperature*

Data from Delhi CDA, Port Dover, Simcoe, St. Williams, St. Williams Auto, London A adjusted, and the Great Lakes Region are on Figure 5. The St. Williams stations are merged. The Simcoe and St. Williams records are fragmentary, Delhi CDA spans only six decades, and Port Dover does not extend beyond the 1980's. Relations between Delhi CDA, Port Dover, and St. Williams with London A adjusted are strong (R^2 = 0.87, 0.65, 0.70) as are relations with the Great Lakes Region (R^2 = 0.81, 0.68, 0.73; Table IV). Thus, temperature trends in the Long Point Biosphere area can be inferred from London A and Great Lakes data. The records show cooler conditions prevailing through much of the early part of the century

TABLE VII

Correlations between stations and with regional records for mean annual temperature and total annual precipitation for the Waterton Lakes Biosphere Reserve area

Mean annual temperature	Cameron Falls MAT				Total annual precipitation	Cameron Falls TAP			
	R^2	n	α	Period		R^2	n	α	Period
Cranbrook A (adj)	0.80	18	<0.001	1977–1995	Coleman (adj)	0.35	17	0.012	1976–1995
Lethbridge A (adj)	0.66	18	<0.001	1977–1995	Ft. Macleod (adj)	0.29	10	0.122	1976–1988
Lethbridge CDA (adj)	0.75	18	<0.001	1977–1995	Lethbridge CDA (adj)	0.27	10	0.109	1976–1987
Pincher Creek (adj)	0.89	16	<0.001	1977–1993	Mountain View (adj)	0.55	11	0.009	1979–1995
MAT departures from 1951–1980 mean	Prairie region MAT dep.				TAP departures from 1951–1980 mean	Prairie region TAP dep.			
	R^2	n	α	Period		R^2	n	α	Period
Cranbrook A (adj)	0.37	89	<0.001	1910–1998	Coleman (adj)	0.10	69	0.009	1913–1996
Cranbrook A (adj)	0.89	61	<0.001	1938–1998	Ft. Macleod (adj)	0.18	79	<0.001	1909–1988
Lethbridge CDA (adj)	0.87	96	<0.001	1902–1998	Lethbridge CDA (adj)	0.43	76	<0.001	1896–1987
Pincher Creek (adj)	0.79	99	<0.001	1895–1993	Mountain View (adj)	0.19	60	<0.001	1913–1997
MAT departures from 1951–1980 mean	Southern B.C. MAT dep.				TAP departures from 1951–1980 mean	Southern B.C. TAP dep.			
	R^2	n	α	Period		R^2	n	α	Period
Cranbrook A (adj)	0.78	89	<0.001	1910–1998	Coleman (adj)	0.28	69	<0.001	1913–1996
Lethbridge CDA (adj)	0.71	96	<0.001	1902–1998	Lethbridge CDA (adj)	0.08	76	0.013	1909–1988
Pincher Creek (adj)	0.67	99	<0.001	1895–1993	Mountain View (adj)	0.15	60	0.003	1913–1997

TABLE VIII

Mean annual temperature and total annual precipitation trends for stations and regions

Station/region	Period	MAT trend (°C 100 yr^{-1})		Period	TAP trend (% 100 yr^{-1})	
		Original[a]	Corrected[b]		Original[c]	Corrected[d]
Kejimkujik Candidate Biosphere Reserve						
Greenwood A	1944–1998	–0.9	–0.9	1944–1998	13	11
Greenwood A (adj)	1944–1998	0.7	0.7	1944–1994	26*	23
Yarmouth (adj)	1896–1998	0.6*	0.6*	1896–1998	14*	
Atlantic Region[e]	1896–1999	0.4*	0.4	1896–1999	14*	13*
Long Point Biosphere Reserve						
Delhi CDA	1936–1996	–0.4	–0.5	1936–1996	12	
London A (adj)	1896–1998	0.6*	0.5*			
Woodstock (adj)				1896–1998	22*	
Great Lakes Region	1896–1999	0.7*	0.6*	1896–1999	8*	7*
Niagara Escarpment Biosphere Reserve						
St. Catharines (adj)	1903–1996	0.6*	0.5*			
Wiarton A (adj)	1896–1998	0.7*	0.7*			
Wiarton A				1948–1998	35*	
Hamilton RBG (adj)				1950–1996	12	
Welland (adj)				1896–1998	13*	

TABLE VIII
(continued)

Station/region	Period	MAT trend (°C 100 yr^{-1})		Period	TAP trend (% 100 yr^{-1})	
		Original[a]	Corrected[b]		Original[c]	Corrected[d]
Riding Mountain Biosphere Reserve						
Birtle (adj)	1906–1995	1.1*	0.9*			
Dauphin A	1949–1998	2.3*	2.0*	1949–1996	2	
Dauphin A (adj)	1905–1998	1.0*	0.7*	1949–1996	21	
NW Forest Region	1896–1999	1.5*	1.3*	1933–1999	3	2
Waterton Lakes Biosphere Reserve						
Cranbrook A (adj)	1911–1998	2.3*	2.0*			
Lethbridge CDA (adj)	1903–1995	0.8*	0.8*	1909–1988	6	
Pincher Creek (adj)	1896–1993	0.6	0.6			
Ft. Macleod (adj)				1896–1987	13	
Mountain View (adj)				1913–1997	28*	
Prairie Region	1896–1999	0.8*	0.7*	1896–1999	–4	–3
Southern B.C. Region	1896–1999	0.8*	0.7*	1896–1999	13*	11*

* Significant at 0.05 level.
[a] Trend fit by least squares without autocorrelation correction to data series.
[b] Trend fit by least squares following autocorrelation correction to data series.
[c] Trend fit by least squares without autocorrelation correction, % 100 yr^{-1} is relative to 1951–1980 mean.
[d] Trend fit by least squares following autocorrelation correction, % 100 yr^{-1} is relative to 1951–1980 mean.
[e] MAT Trend is 0.3°C 100 yr^{-1} over the period 1896–1998 and is not significant.

and through much of the 1960’s and 1970’s. Warm intervals occurred in the early 1920’s and 1930’s, from the late 1940’s to mid 1950’s and since the late 1970’s. Variations at Delhi CDA and Port Dover are similar. Overall London A adjusted has a warming trend of 0.5 °C and the regional record is 0.6 °C (Table VIII). Delhi CDA shows cooling from the late 1930’s to 1996.

4.2.2. *Total Annual Precipitation*

Data from the Long Point Biosphere stations are shown on Figure 6. Woodstock adjusted and the Great Lakes Region show long term increases in total annual precipitation of 22 and 8% (Table VIII). Wetter periods occurred at the end of the 19th century, in the late 1930’s, and since the late 1960’s. Drier conditions were prevalent for much of the early 20th century and the 1950’s and 1960’s. The trend from Delhi CDA also shows increases in precipitation since 1940, although not statistically significant. Correlations between the local stations and the Woodstock and regional record are not as strong as with temperature (Table IV) and it is noted that during some periods the divergence in the records is substantial (e.g., Port Dover vs Region from 1900 to 1920).

4.3. Niagara Escarpment Biosphere Reserve

4.3.1. *Mean Annual Temperature*

The trends identified for Long Point are also noted from stations representing the Niagara Escarpment. Chatsworth, Hamilton A, Niagara Falls, Orangeville, Orangeville MOE and adjusted records from Wiarton A and St. Catharines are plotted on Figure 7. There are substantial north to south differences in mean annual temperature between stations but temporal variations in temperature along the Escarpment are similar. Correlations between the local stations and the adjusted and regional series are strong (Table V). Wiarton A adjusted, St. Catharines adjusted and the Great Lakes Region show long term warming of 0.7, 0.5 and 0.6 °C (Table VIII). The warmest periods are in the early 1930’s, early 1950’s, late 1980’s and 1990’s (Table II). Cooler temperatures are most marked in the early part of the century and in the late 1970’s.

4.3.2. *Total Annual Precipitation*

Data from Wiarton A, Orangeville, Orangeville MOE, Hamilton RBG adjusted, Welland adjusted and the Great Lakes Region are plotted on Figure 8. Long term increases in precipitation are recorded at Welland adjusted (13%) and in the region (8%) (Table VIII). The shorter records from Wiarton A and Hamilton RBG also show increasing trends from middle of the century to the late 1990’s. For stations in close proximity, the correlations between station records are strong (e.g., Orangeville MOE vs Hamilton RBG: $R^2 = 0.46$) but weak correlations are noted between distant stations, and between stations and the regional record (Table V).

4.4. Riding Mountain Biosphere Reserve

4.4.1. *Mean Annual Temperature*

Data from Dauphin, Dauphin A, Dauphin A adjusted, Minnedosa, and Birtle adjusted are on Figure 9. Minnedosa shows warm temperatures early in the century, with the warmest period in the 1930's and early 1940's (Table II). The Dauphin record is similar with warmer conditions in the late 1920's, early 1930's, and early 1940's. Dauphin A shows cooler conditions for most of the 1960's to the mid 1970's, followed by an increase into the late 1980's. All stations show cooling between 1991 and 1996, and warming thereafter. The adjusted records from Dauphin A and Birtle show significant warming trends of 0.7 and 0.9 °C (Table VIII). The warmest periods at both stations were in the late 1980's. Correlations are strong between the adjusted Dauphin A record and the other stations, and with the regional data (Table VI). Riding Mountain Biosphere Reserve is situated in the transition between the Northwestern Forest and Prairie Regions. Data show warming of 1.3 °C in the Northwestern Forest Region (Figure 9, Table VIII) and 0.7 °C in the Prairie Region (Figure 11). Both regions show warm intervals in the late 1930's, early 1940's and following the late 1970's.

4.4.2. *Total annual precipitation*

Data from Minnedosa, Dauphin, Dauphin A, Dauphin A adjusted, Birtle adjusted, and the Northwestern Forest and Prairie Regions are shown on Figure 10. None of the records has a significant long term trend. Dauphin A shows a wet period in the early 1950's, and below average values in the late 1950's and 1960's. Birtle adjusted and Dauphin A adjusted are more strongly correlated with the Prairie regional data than with the Northwestern Forest Region (Table VI). The Prairie Region had wet intervals around 1900, in the early 1950's, and following 1990. Drier periods occur in the late 1910's, in the 1930's, early 1960's, and late 1980's.

4.5. Waterton Lakes Biosphere Reserve

4.5.1. *Mean Annual Temperature*

Data are plotted for Cameron Falls, Cranbrook A adjusted, Lethbridge CDA adjusted, Pincher Creek adjusted, and the Prairie and Southern B.C. Regions on Figure 11. Cameron Falls is the only station that falls within the biosphere reserve, it shows a general increase in temperature from 1976 to 1995. This record is highly correlated with nearby stations, with R^2 values as high as 0.89 (Pincher Creek, Table VII). Lethbridge CDA shows cooler conditions early in the century, from the late 1940's to early 1950's, and from the mid 1960's to mid 1970's. Warm intervals occur in the 1930's and 1940's, early 1960's, and following 1985. The record at Pincher Creek is similar. Lethbridge CDA has long term warming of 0.8 °C, Pincher Creek shows warming of 0.6 °C, though the latter is not significant. At Cranbrook A, the long term warming is 2.0 °C. Regional data show warming of

0.7 °C on the Prairies and in Southern B.C. The regional records are similar with exception of the period 1900 to 1922.

4.5.2. *Total Annual Precipitation*

Data from Cameron Falls, and adjusted records from Coleman, Ft. Macleod, Lethbridge CDA, and Mountain View are plotted on Figure 12. The Cameron Falls record is most highly correlated with Mountain View ($R^2 = 0.55$; Table VII). The latter shows a long term increase in annual precipitation of 28% (Table VIII). Trends from Ft. Macleod and Lethbridge CDA show insignificant changes of 13 and 6%. The Prairie Region shows no long term increase in precipitation (Figure 12e) while there is an increase of 13% in Southern B.C. (Figure 12f, Table VIII). Precipitation amounts in southern B.C. were below the 1951–1980 mean for much of the period of 1895 to 1945, with the 1920's and early 1930's having the lowest values. Relatively wet conditions occurred from the mid 1940's to the mid 1960's, and in the mid 1990's. The Prairie Region shows high amounts of precipitation around 1900, in the early 1950's, and in the 1990's. Drier periods occurred in the late 1910's, early 1930's, and early 1960's. The Lethbridge CDA record more closely matches the Prairie Region, Coleman is more highly correlated with Southern B.C. and Mountain View has similar correlations to both regions (Table VII). From these relations it is difficult to infer whether the Cameron Falls and Waterton Lakes Biosphere Reserve precipitation record more closely matches the Prairie or Southern B.C. records.

4.5.3. *Spatial Patterns in Temperature and Precipitation*

4.5.3.1. *Temparature:* Using a standard linear model, Findlay *et al*. (1994a) found annual temperatures across Canada increased by 1.0 °C from 1895 to 1992. Application of the same method to the data of Figure 1c (1896 to 1999) yields a value of 1.2 °C 100 yr^{-1}. The estimate drops to 1.1 °C if the data are adjusted for autocorrelation. Zhang *et al*. (in press) have calculated an increase of 0.9 °C over the period 1900 to 1995 for southern Canada. The 20th century warming is not spatially uniform across Canada (Table VIII). In the Atlantic Region, the warming is least substantial, only 0.4 °C from 1896 to 1999, with cooling of 0.5 °C from 1950 to 1999. The pattern seen from Kejimkujik and Greenwood A has been noted in several studies of stations from Atlantic Canada (Morgan, 1992; Gullett and Skinner, 1992; Morgan *et al*., 1993; Findlay *et al*., 1994; Morgan and Pocklington, 1995; Zhang *et al*., in press). At Long Point Biosphere Reserve, there was no net warming from 1935 to 1998 as indicated by the Delhi CDA and London A records (London A warming is <0.1 °C 100 yr^{-1} over the interval 1935 to 1998). However, when taken from 1896, London A and the regional data show warming of 0.5 and 0.6°C. Stations of the Niagara Escarpment Biosphere Reserve show a similar pattern, with cooling after the mid 1950's and marked warming after the late 1970's. Warming is greatest at stations representing Riding Mountain Biosphere Reserve (0.9 and 0.7 °C at Birtle and Dauphin A adjusted) and Waterton Lakes

Biosphere Reserve (0.8 °C at Lethbridge CDA). Similar temporal patterns have been described by Zhang *et al*. (in press) for the regions of interest.

Overall, the warmest five year intervals tend to be in the late 1980's, the early 1950's, or the early 1930's (Table II). The coolest periods are in the late 1910's, early 1920's, late 1940's, and early 1960's. The warmest individual years are 1998, 1999, and 1953 at the eastern sites, while in the west they are 1987, 1931, 1934, and 1998.

4.5.3.2. *Precipitation:* Significant long term increases in precipitation are seen at Wiarton A (35%), and from adjusted records at Greenwood A (26%), Yarmouth (14%), Woodstock (22%), Welland (13%), and Mountain View (28%). Regional data show significant trends in the Atlantic (14%), Great Lakes (8%), and Southern B.C. (13%) areas but not in the Prairie or Northwestern Forest Regions (Table VIII). We may infer that total annual precipitation increased through the period of record at Kejimkujik, Long Point and the Niagara Escarpment Biosphere Reserves and likely at Waterton Lakes Biosphere Reserve. The results are consistent with Groisman and Easterling (1994, 1995) who note increases in precipitation in south-central (12%) and southeastern Canada (11%) and adjacent areas of the United States over the period 1890 to 1990. Zhang *et al*. (in press) calculate an 11% increase in annual precipitation for southern Canada over the period 1900 to 1995 with significant increases in eastern Canada and southern B.C. but not in the Prairies.

5. Discussion

In the following sections, we will discuss some of the limitations of the instrumental data and suggest possible alternatives for biosphere reserve climate studies.

5.1. LOCAL VS REGIONAL DATA

Structurally, biosphere reserves consist of a protected core surrounded by a zone of restricted development and an area of co-operative planning and management. They are not specifically designed to be representative of a single ecological community or climatic subregion. A biosphere reserve may span hundreds of kilometers and possess a variety of climatic conditions. To establish climate trends from a reserve, data should be acquired from long standing stations located within the reserve that represent its full range of climates. In our study, most of the climate stations located within or very close to the biosphere reserves had short and fragmentary records. In addition, these records were developed from raw daily data and no homogeneity adjustments were made to the series. The influence of homogeneity adjustments on trends can be illustrated with data from Greenwood A. The annual series developed from raw data (Greenwood A) show cooling through the record (Figure 3b) while Greenwood A adjusted shows the opposite trend (Figure 3c). Other records show evidence of non-climatic steps in their records. For example, the temperature series at Minnedosa shows a marked cooling after a data gap in the 1950's and 1960's. Temperature magnitudes are not consistent with data from nearby stations. The Minnedosa station was relocated in 1966 to a lower elevation site. The cooling is likely related to cold air drainage from the adjacent uplands and does not reflect conditions in the wider area.

Given the distribution of the local stations and possible homogeneity problems it was necessary to incorporate data from nearby areas. It has been demonstrated that in most cases the correlations between the local biosphere stations and the longer term records were very strong for mean annual temperature. In turn, the long term stations were highly correlated with the regional data. The long term station and regional data can, therefore, be used to supplement the climate trend information for the temperature parameter.

Correlations between the local biosphere stations and the longer term records for total annual precipitation were generally statistically significant. However, only 20 to 50% of the variance in the biosphere station precipitation data were typically explained by the longer term series. In some cases, the correlations between the longer term records and the regional data were poor. The use of regional and long term records to infer precipitation trends at some biosphere reserves cannot always be done with high confidence.

5.2. Proxy data

When the instrumental data are inadequate it may be possible to access proxy information. For example, tree-ring chronologies developed from Limber Pine in the Crowsnest Pass area of Alberta (near Coleman) have been used to produce a record of total annual precipitation for the period 1505 to 1992 (Case and MacDonald, 1995). This record characterizes the frequency of drought in the region. Similar data are available from other biosphere areas. Use of paleoclimatic information is recommended to establish context for the 20th century climate trends shown from the instrumental record. In addition, other proxy data may be useful to support the instrumental record. For example, plant phenology records from central Alberta show a trend towards earlier flowering over the last 45 yr, reflecting a warming trend in winter and spring (Beaubien, 1999).

5.3. Temperature trends in context

Paleoclimatic data suggest that the magnitude of the temperature changes identified in this article are significant. Over the last millennium, the northern hemisphere experienced a long term cooling trend. From 1000 AD to 1850 AD mean temperatures declined at an average rate of –0.02°C per century but with considerable variance (Mann *et al*., 1999). Within this context, a 20th century warming of 0.5 °C is substantial. Station data from across the hemisphere show that the past decade

(1989–1998) and the year 1998 are the warmest in the instrumental record (Mann *et al.*, 1999). It is probable that these recent years are the warmest since at least 1400 AD (IPCC, 1996; Mann *et al.*, 1998) and perhaps the last 1000 yr (Mann *et al.*, 1999).

6. Conclusion

Biosphere reserves function to conserve biodiversity, demonstrate sustainable development, undertake research and monitoring, and educate and train at the local level. Reserves across Canada are instituting monitoring programs that primarily address changes in biological systems. Impacts on these systems are driven by natural processes, such as climate change, and by human development. Analyses of the instrumental record represents the best available means to document recent climate change. Results presented in this article show significant climate warming in all biosphere areas examined, with exception of Kejimkujik.

The purpose of the CBRA Climate Change Initiative is to design and test an approach that local communities may use to better understand climate change so they may respond and adapt to potential impacts. A component of this initiative is the presentation of instrumental climate data. The instrumental data presented in this article will be used in conjunction with information on potential impacts, paleoclimatic and proxy-climate data, and climate scenarios for use in community based workshops to be held in each biosphere reserve. These workshops will focus on the development of adaptation strategies to assist in planning and management.

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