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Temperature Variability in Illinois: 1895-2002

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ABSTRACT

This paper focuses on climate change and variability in Illinois, describing the behavior of annual, seasonal, and monthly temperatures since 1895 for use by climate-sensitive decision-makers. By examining the historical records we can better understand the climate we have experienced and better prepare us for any future changes in climate. The annual temperature pattern in Illinois is similar but larger in magnitude than the U.S. changes for the periods of 1895-1939 and 1940-1970. The warming since 1970 was less in Illinois than in the U.S. An examination of the monthly and seasonal data for Illinois suggests that most of the changes in temperature over the last 108 years have occurred in winter with February showing the largest changes over time, followed closely by January. For February, the period before 1940 showed a rapid warming of 1°C per decade, followed by a 0.5°C per decade cooling through 1970. Finally, the last 32 years have seen a warming of 1.2°C per decade. These changes in winter, and especially in January and February, were supported in the snowfall records as well. The climate processes behind the large changes that centers on February are not clear at this time.

INTRODUCTION

The climate has always been changing on various time scales, from decades to centuries, and in varying magnitudes. Previous studies have examined various aspects of past climate change in Illinois, including Changnon (1980), Changnon et al. (1997), and Changnon and Winstanley (1999).

The subject of future climate change, especially the effect of global warming due to greenhouse gasses, has been widely debated over the last few decades. Recent developments such as the Kyoto Treaty and the national assessment of the impacts of climate change on the U.S. (National Assessment Synthesis Team, 2000) have ensured that the topic remains in the forefront of environmental issues in Illinois and elsewhere. Most of the discussion of evidence and potential impacts has focused on global, national, or regional scales when addressing climate change. However, what has happened in Illinois with regards to climate variability and change in the last century? Has Illinois become warmer or cooler? Has the warming or cooling been uniform through the year? This

paper focuses on those questions using annual and monthly temperature data for Illinois and the U.S. for the last 108 years. Some of the possible mechanisms for U.S. climate variability and change, in general, will be discussed. However, it is beyond the scope of this paper to determine all the mechanisms operating on Illinois temperatures or the proportion of their contributions.

It is important to identify two key concepts in describing the temporal aspects in describing the temporal aspects of climate: climate change and climate variability. Climate variability is defined as the variation of the climate around the long-term mean state of the atmosphere. Climate change, on the other hand, relates to long-term change sustained over several decades, or longer (American Meteorological Society, 1999).

Activities sensitive to climate variability and change include various aspects of agriculture, energy usage, water resources, and transportation. Historical temperature records can be used to understand previous impacts to these sectors such as the cold winters of the late 1970s or the hot summers of the 1930s. Past temperature records are useful for planning purposes of those activities that are sensitive to the behavior of annual and seasonal temperatures. For example, research by Lamb and Changnon (1981) and Angel et al. (1993) suggest that the most recent 5-20 years are the best estimate of the average temperature of the next year. This paper does not attempt to "forecast" the Illinois climate for the next 10, 30, or 100 years. Still, by examining the historical records we can better understand the climate we have experienced and better prepare us for any future changes in climate.

DATA AND METHODOLOGY

The primary data sources used were the temperature records archived by the National Climatic Data Center (NCDC). For the period 1895 to 2000, stations belonging to the U.S. Historical Climate Network (USHCN) were used in the analysis (Figure 1). These temperature records have been adjusted by NCDC to account for biases caused by the time of observation (Karl et al., 1986), station moves, and urbanization. Between 26 and 36 USHCN stations in Illinois were used, with the number of available stations increasing with time. Most sites are located in rural areas or small towns, minimizing the effects of urbanization.

The update of the USHCN stations lags behind the present by 2 to 3 years due to the amount of processing done by NCDC. Therefore, an alternate NCDC dataset of statewide monthly temperatures were used for 2001-2003. This alternate NCDC dataset used all available cooperative observer data in the state while only adjusting for the time of observation bias. A comparison with the USHCN data reveals no significant differences between the two (less than 0.1°C). At the time of this writing, final quality-controlled data was available through February 2003. For comparative purposes, all regression trend analyses were performed on the period 1895-2002. The early 2003 data was included in figures, when appropriate, for illustrative purposes. Additional information on changes in maximum and minimum daily temperatures and snowfall was obtained directly from selected long-term daily cooperative observer records.

ANALYSIS

Annual Variability and Changes – U.S. and Illinois

Figure 2 shows the contiguous U.S. and Illinois annual mean temperature since 1895, expressed as a departure from their respective 1971-2000 averages for the period 1895-2002. Using simple linear regression, the U.S. temperatures have warmed by about 0.7°C from 1895 to 1939, cooled by some 0.4°C from 1940 to 1970, before warming 0.9°C from 1971 to 2002. Applying simple linear regression to the period of record gives an overall upward trend of about 0.4°C in the last 108 years for the U.S. The slope of the linear regression for the periods 1895-1939, 1971-2002, and 1895-2002 were statistically significant at α=0.05. The slope of the linear regression for the period 1940-1970 was slightly less significant with a p-value of 0.058.

The temporal pattern for Illinois shows some similarities and some differences. In fact, the correlation between the U.S. and Illinois temperature pattern is +0.8. One significant difference is that the magnitudes of the temperature changes were larger for Illinois during the two distinct periods of 1895-1939 and 1940-1970 periods. The early warming was 0.9°C for Illinois, compared to 0.7°C for the U.S. The cooling was 0.8°C in Illinois, compared to 0.4°C for the U.S. The most recent period of warming in Illinois was 0.8°C, compared to 0.9°C for the U.S. The slopes of the linear regression for the periods 1895-1939 and 1940-1970 were statistically significant at α=0.05. The slope for the period 1971-2002 was slightly less significant with a p-value of 0.067. Linear regression over the period of record for Illinois indicates a 0.15°C warming over the last 108 years (not statistically significant). This was less than the 0.4°C warming for the U.S. because the warming since 1970 was not been as strong as at the national level.

In addition, the Illinois annual mean temperature departures of the past 20 years are still only comparable to the warm period from the 1930s to the 1950s and not in the category of unprecedented climate change for the state. In fact, the mean temperature for the 1981-2002 period was not statistically different from the 1930-1960 period using a t-test.

Monthly/Seasonal Variability and Changes – Illinois

Many climate-related activities are more sensitive to changes in temperature during certain times of the year rather than the year as a whole. For example, corn and soybean crops could be harmed by warmer summers while consumers might benefit from warmer winter temperatures due to less heating demand.

Before examining changes in monthly temperatures in Illinois, it is important to note an important feature of Illinois temperatures. While temperatures are lowest in winter and highest in summer (Table 1), the variability about the mean is about twice as large in winter as it is in summer. In other words, it is more common for a January of a particular year to be 2°C above or below average than it is for July to be 2°C above or below average. This higher cold-season variability applies to a variety of time scales from year-to-year variability to decadal changes. As will be shown, the temperature variability and trends in colder months tend to be much larger than in the warmer months.

Table 2 summarizes the Illinois monthly temperature trends, determined from linear regression, for the three periods originally found in the annual time series for Illinois in

Figure 2. In the 1895-1939 period, the warming occurred in nine of the 12 months. No change occurred in November while the spring months of April and May showed a slight cooling. The strongest warming occurred in February. A statistically significant increase also occurred in July. In the period of annual cooling across Illinois, 1940-1970, a majority of months showed cooling except for slight warming in the spring months of April and May and the autumn month of November. The cooling in January was statistically significant. In general, the pattern was consistent between these two periods with winter, summer, and autumn mostly reflecting the changes in the annual average temperatures. Spring showed a reverse pattern to the annual average temperatures. However, the warming of the last period, 1971-2002, showed a warming during the periods of November to February and April to August. In all three periods since 1895, the changes in February were some of the largest of any month.

Figure 3 shows the seasonal temperature departure since 1895. Winter (defined as December, January, and February) shows interannual temperature variations that are the largest of all four seasons. In addition, the pattern of long-term change is similar in direction to the annual temperature time series for Illinois: a 2.2°C warming trend for 1895-1939, a cooling trend of 1.8°C for 1940-1970, and a warming trend of 2.4°C for 1971-2002. Smaller year-to-year variability is evident in spring (March-May) with no discernable long-term changes. In summer (June-August), a small warming of 0.8°C occurred for 1895-1939, a 0.9°C cooling for 1940-1970, and a warming of 0.4°C for 1971-2002. These were much smaller than in winter and resulted in no linear trend over the 1895-2002 period. The 1930s and 1950s stand out as being the warmest decades in the record. Another noteworthy feature is the much reduced variability in summer temperatures during the 1960s and 1970s. Fall (September-November), similar to spring, showed no long-term changes.

The findings identified by Figure 3 reveal that most of the temporal pattern in the annual average temperature for Illinois (Figure 2b) comes from winter with lesser contributions from summer and virtually none from spring and fall.

Because most of the temperature changes occurred in the winter months, a closer examination of each winter month is warranted. Figure 4 shows the monthly temperature departures in Illinois for December, January, and February. December temperatures showed small changes over time (Table 2). However, the last 40 years in December have seen four of the sharpest departures on the cold side of average since 1895.

For January, the period from 1900 to the mid-1950s were warmer than average, cooling to near-average conditions until the cold January's of the late 1970s. Linear regression gives a warming of 1.3 °C for 1895-1939 and a 2.2°C cooling for 1940-1970. The temperature warmed again in the last 32 years of the record, yielding a warming of 3.5°C for 1971-2002. All the years of above-average temperature early in the record resulted in a net cooling of 1.3°C over 1895-2002 for January.

February showed the most remarkable changes of any month in Illinois. The period before 1940 showed a rapid warming of about 1°C per decade (a 4.6°C increase for 1895-1939). This was followed by a 0.5°C per decade cooling through 1970 (a 1.7°C cooling for 1940-1970). Finally, the last 32 years of the record have seen a warming of 1.2°C per

decade (a 3.8°C warming for 1971-2002). However, February 2003 was below-average for the first time since 1994. Overall, February experienced a linear trend of 2.2°C over the 1895 to 2002 period.

The conditions leading to changes in winter temperature appear to have impacted snowfall in Illinois as well. Figure 5 shows the statewide average snowfall from the winter of 1901-02 to 2002-2003, based on cooperative weather sites with reliable snowfall records, ranging from an average of 50 sites before 1948 and 125 sites after 1948. The lower snow amounts from 1920 to 1960 generally correspond to warmer-than-average winter temperatures in Figure 3. The higher snowfall amounts from 1960 to 1985 occurred during a period of below-average winter temperatures. The period since 1985 is marked by lower snowfall amounts, similar in magnitude to the earlier 1920-1960 period. This recent downturn in snowfall matches the rapid increase in winter temperatures, particularly in February. State-wide February snowfall dropped in half from the 1980s to the 1990s (15 cm to 7.5 cm).

Not only does snowfall respond to winter temperatures but it is possible that snowfall acts as a feedback mechanism because snow cover can result in cooler night-time temperatures. An analysis of historical data for Champaign/Urbana, Illinois, show that night-time temperatures are 5.4 times more likely to drop below -18°C (0°F) with snow cover than without. Daytime temperatures can be lower as well with snow cover due to the high albedo of snow.

DISCUSSION

There is general agreement within the scientific community that significant increase in annual mean temperature occurred in the U.S. prior to 1940, that significant cooling occurred from the 1940s to the 1970s, and that the annual mean temperature increased further in the last 20-30 years of the record. In a recent report, the National Research Council (2001) states that the reasons for this pattern of United States temperature change are not clear. It is possible that the warming through 1940 and subsequent cooling through the 1970s were of natural origin. Possible mechanisms include changes in ocean circulation or variations in either solar luminosity or the frequency of major volcanic emissions. Considering that the core of the cooling in the mid-20th century occurred in the eastern U.S., a possible explanation was the high level of sulfate aerosols due to the burning of high sulfur coal during this time. They state that "a casual linkage between the buildup of greenhouse gasses in the atmosphere and the observed climate changes in the 20th century cannot be unequivocally established." The issue remains unresolved because of the level of natural variability in the climate system, the relatively short record of climate change, and the difficulty of climate models to simulate the climate of the past century.

Most of the changes in temperature since 1895 in Illinois are the result of very large changes in February, followed by similar changes in January. However, it is unusual for known climate mechanisms to operate so intensely and consistently on such a short time scale (one to two months) even in winter. For example, El Niño impacts in the Midwest include a moderation of winter-time temperatures. Nevertheless, their frequency and intensity in the 20th century show no discernible changes that would match the patterns

found in Illinois. In any event, the recent warming in January and February has moderated the winter season in Illinois in recent years.

CONCLUSIONS

The purpose of this paper is to identify changes in annual, seasonal, and monthly temperatures since 1895, exclusively for Illinois, for use by climate-sensitive decision-makers. By examining the historical records we can better understand the climate we have experienced and better prepare us for any future changes in climate.

The annual temperature in Illinois generally reflects the annual temperature for the U.S. with warming through 1940, cooling through the 1970s, and a return to warming afterwards. However, the magnitudes are different. The early warming was 0.9°C for Illinois, compared to 0.7°C for the U.S. The cooling was 0.8°C in Illinois, compared to 0.4°C for the U.S. The period of recent warming in Illinois was 0.8°C, smaller than the 0.9°C warming for the U.S. As a result of alternating periods of warming and cooling, the linear trend over the last 108 years for Illinois was 0.15°C.

An examination of monthly and seasonal trends reveals that most of the changes found in the annual temperature in Illinois are driven by changes in winter temperature. In turn, most of changes in winter temperature are the result of very large changes in January and February temperatures. For February, the period before 1940 showed a rapid warming of 1°C per decade, followed by a 0.5°C per decade cooling through 1970. Finally, the last 32 years of the record have seen a warming of 1.2°C per decade. The results for winter, and especially for January and February, are supported in the snowfall records as well.

The results show that temperatures have changed on a decadal time scale in recent Illinois history. As defined in the introduction, the changes of the 20th century mean temperature record behaved more like climate variability than climate change because the temperatures shifts were not sustained over “several decades or longer” as defined by the American Meteorological Society. Meanwhile, efforts are currently underway at the Illinois State Water Survey to examine temperature changes in the 19th century. Using the older records will help in determining how unusual the changes of the 20th century really are.

ACKNOWLEDGMENTS

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Table 1. Mean and standard deviations of monthly temperatures in Illinois for the period 1895-2001.

Month	Mean	Standard Deviation
January	-3.3°C (26.0°F)	3.0°C (5.4°F)
February	-1.4°C (29.4°F)	3.0°C (5.4°F)
March	4.4°C (39.9°F)	2.6°C (4.7°F)
April	10.9°C (51.6°F)	1.7°C (3.1°F)
May	16.8°C (62.3°F)	1.8°C (3.3°F)
June	22.0°C (71.6°F)	1.4°C (2.6°F)
July	24.3°C (75.8°F)	1.2°C (2.2°F)
August	23.2°C (73.8°F)	1.4°C (2.5°F)
September	19.2°C (66.5°F)	1.5°C (2.7°F)
October	12.8°C (55.0°F)	1.8°C (3.3°F)
November	5.2°C (41.3°F)	1.9°C (3.5°F)
December	-1.1°C (30.0°F)	2.7°C (4.9°F)

Table 2. Trends in degrees Celsius per decade of monthly temperatures for Illinois, as determined by linear regression. Values underlined are statistically significant at α=0.05. Shaded cells indicate a warming while unshaded cells indicate no change or a cooling.

Month	1895-1939 °C per decade	1940-1970 °C per decade	1971-2002 °C per decade
January	0.3	<u>0.7</u>	1.1
February	<u>1.0</u>	0.5	<u>1.2</u>
March	0.3	0.4	0.1
April	0.1	0.1	0.1
May	0.1	0.2	0.2
June	0.1	0.2	0.1
July	<u>0.3</u>	0.2	0.1
August	0.1	0.4	0.2
September	0.1	0.0	0.0
October	0.1	0.5	0.1
November	0.0	0.1	0.2
December	0.3	0.3	0.2
Annual	<u>0.2</u>	<u>0.3</u>	0.3

Figure 1. Stations from the U.S. Historical Climate Network (USHCN) used in this study.

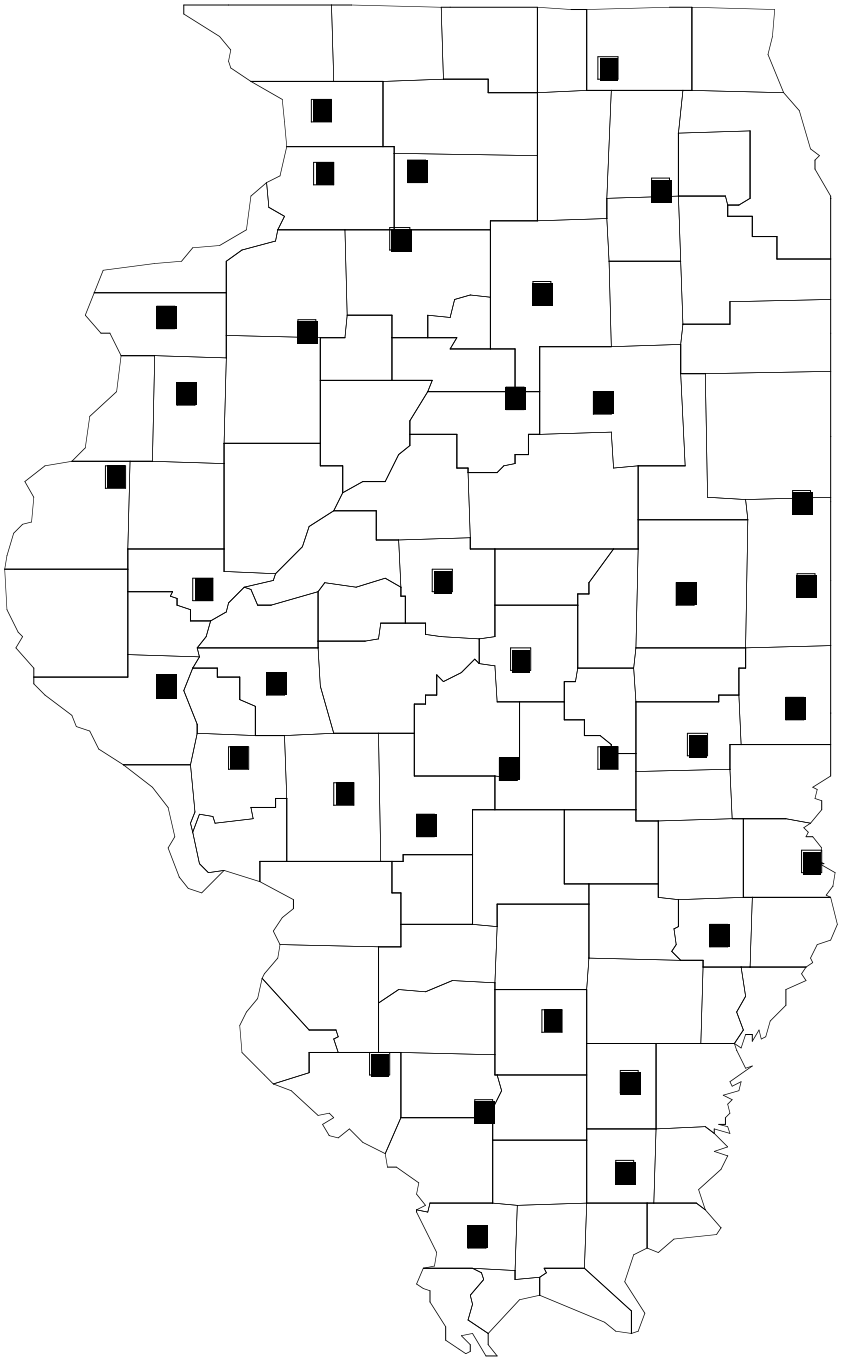


Figure 2. Annual mean temperature over time for the a) contiguous US and b) Illinois. Temperatures are expressed as departures from the 1971-2000 average. The darker line is a five-year moving average centered on the year to filter out the smaller-scale variability in the observations.

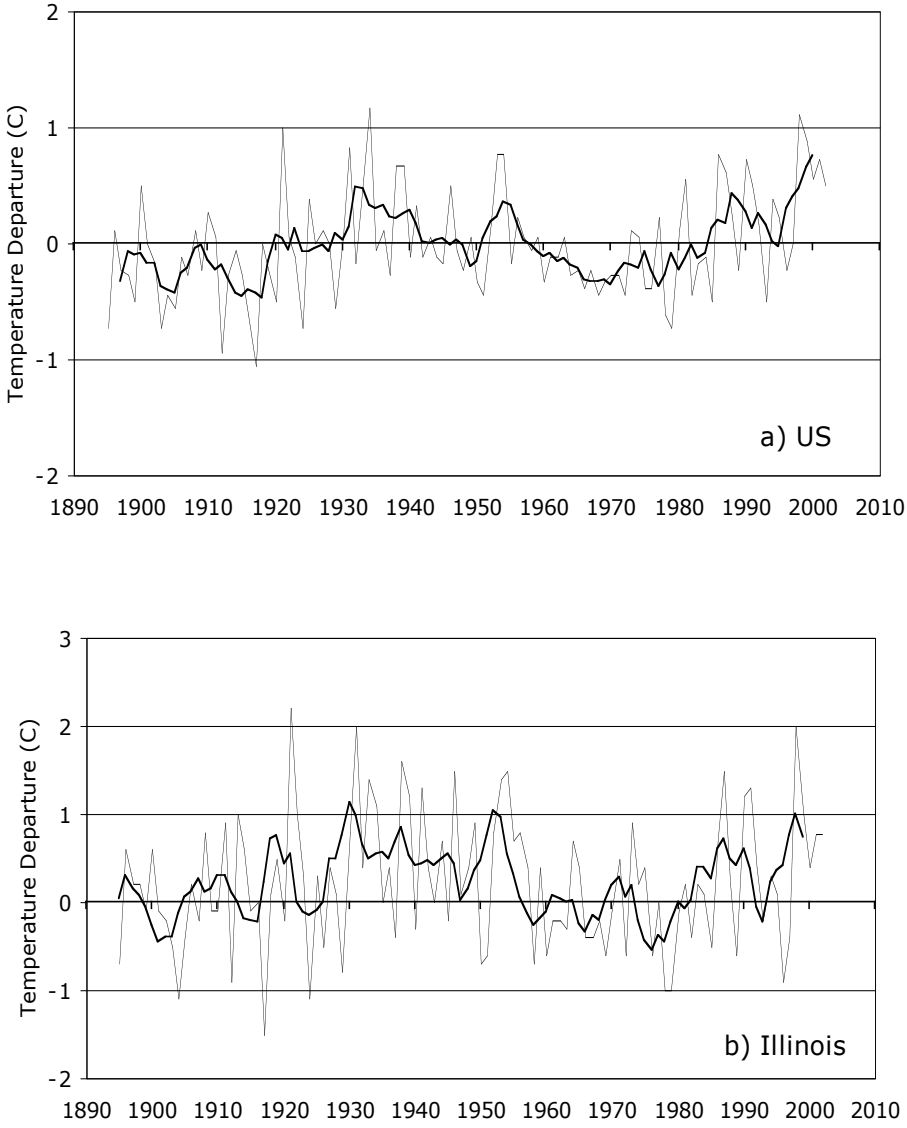
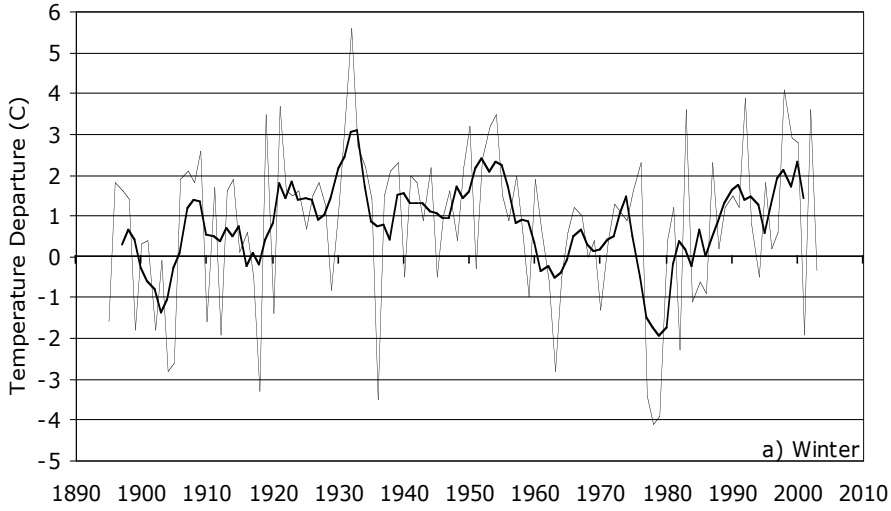


Figure 3. Mean temperatures over time for Illinois for a) winter, b) spring, c) summer, and d) fall. Temperatures are expressed as departures from the 1971-2000 average. The darker line is a five-year moving average centered on the year to filter out the smaller-scale variability in the observations. The winter graph includes data for the 2002-2003 season.



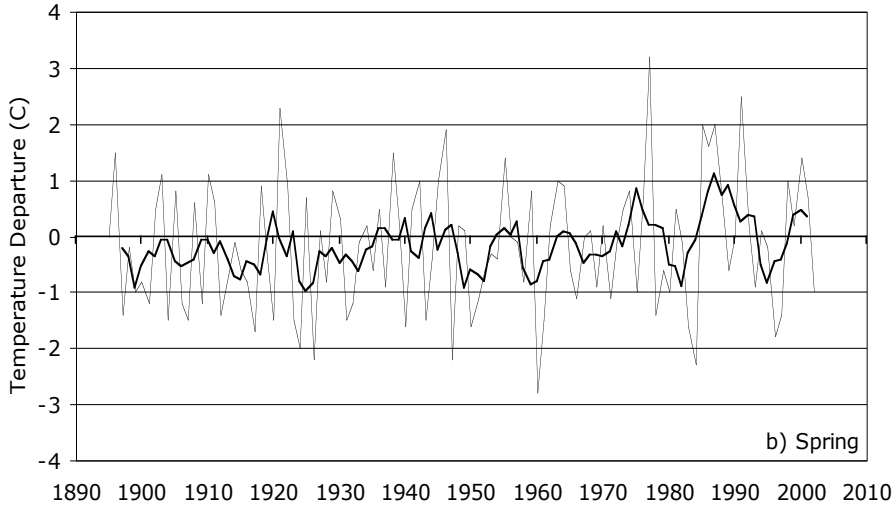
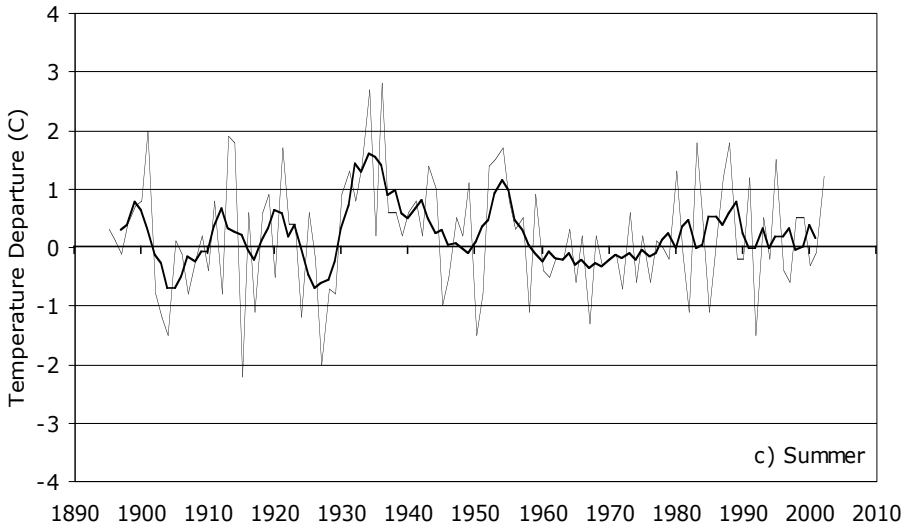


Figure 3. (continued)



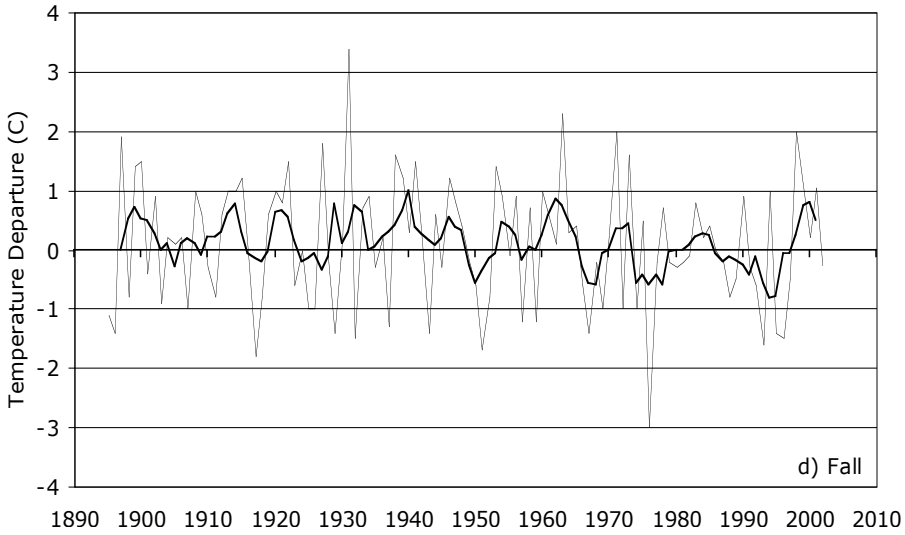
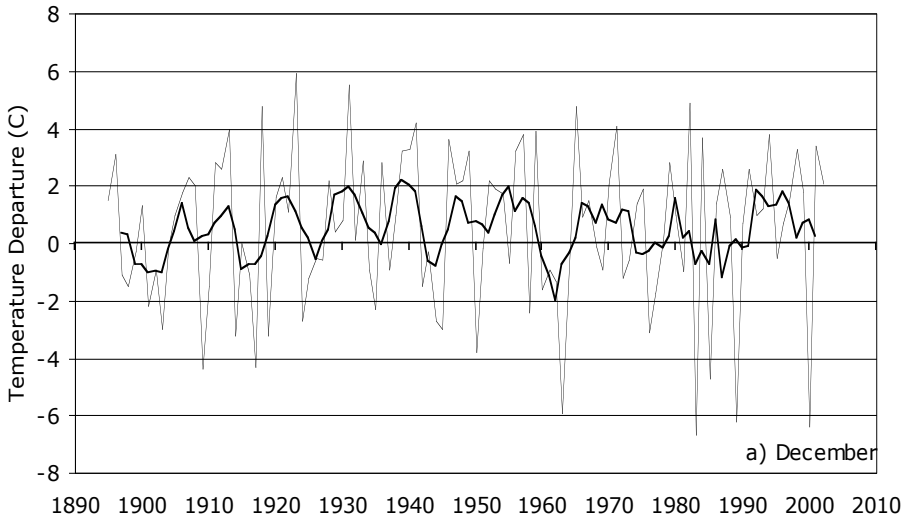
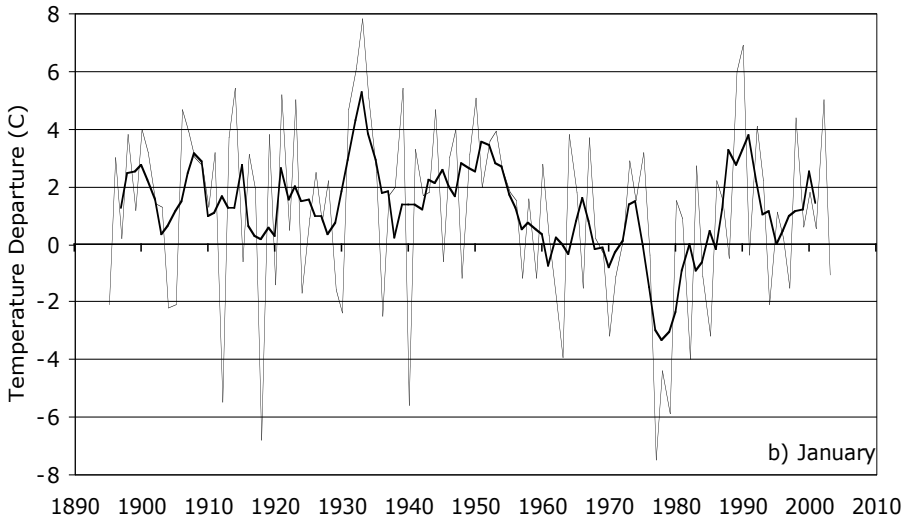


Figure 4. Monthly mean temperatures for a) December, b) January, and c) February over time for Illinois. Temperatures are expressed as departures from the 1971-2000 average. The darker line is a five-year moving average centered on the year to filter out the smaller-scale variability in the observations. The January and February graphs include data for 2003.





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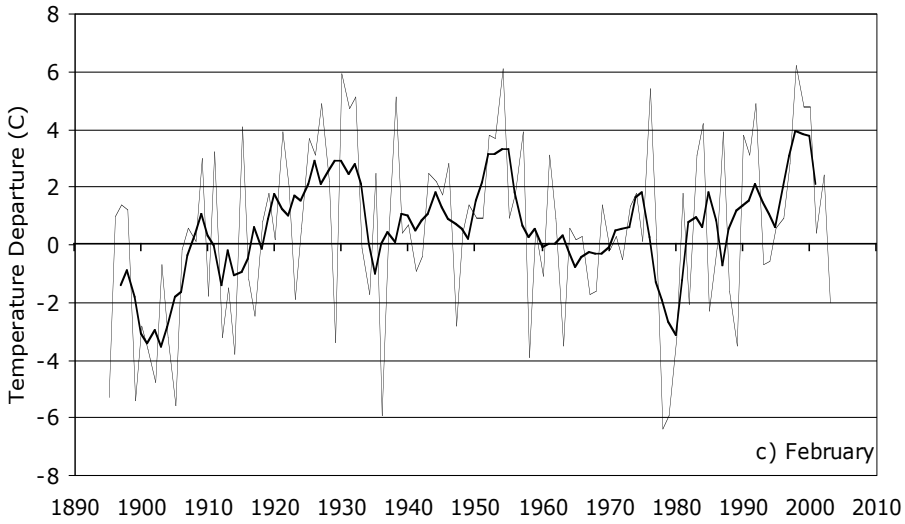

Figure 5. Annual total snowfall in Illinois from the winter of 1901-1902 to 2002-2003, as a departure of the 1971-2000 average. The darker line is a five-year moving average centered on the year to filter out the smaller-scale variability in the observations.