A Study Comparing the Long-term Climate near NIGEC Sponsored AmeriFlux Sites to the Recent Period of CO_2 Flux Measurements

By

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TABLE OF CONTENTS

* Respective AmeriFlux site

DESCRIPTION OF PARAMETERS

1) START OF THE GROWING SEASON (Measured as days after Jan. 1)

   Defined by one of two criterions:

   a) The first of three consecutive days during the transition between the cool period and the warm period when the mean temperature is 47° F or higher, or
   b) The first of two consecutive days during the transition between the cool period and the warm period when the mean temperature is 50° F or higher.

2) END OF THE GROWING SEASON (Measured as days after Jan. 1)

   Defined by one of two criterions:

   a) The first of three consecutive days during the transition from the warm period to the cool period when the mean temperature is 49° F or lower, or
   b) The first of two consecutive days during the transition from the warm period to the cool period when the mean temperature is 46° F or lower.

3) LENGTH OF THE GROWING SEASON (Measured in days)

   The difference between the end of the growing season and the start of the growing season for a given year.

4) LAST FREEZE (Measured as days after Jan. 1)

   The last day during the transition between the cool period and the warm period when the minimum temperature is 31° F or lower.

5) FIRST FREEZE (Measured as days after Jan. 1)

   The first day during the transition between the warm period and the cool period when the minimum temperature is 31° F or lower.

6) FREEZE FREE PERIOD (Measured in days)

   The difference between the first freeze and the last freeze for a given year.

7) END OF SNOW COVER (Measured as days after Jan. 1)

   The last day of ten or more consecutive days during the transition between the cool period and the warm period when there is at least 1 inch of snow on the ground.

8) SNOW COVER PERIOD (Measured in days)

The total number of consecutive days from the end of snow cover date back to the start of that snow cover. It must be at least ten days in length to be considered significant.

9) TOTAL COOL PERIOD PRECIPITATION (Measured in inches)

The total precipitation from November 1 of the previous year through April 30 of the current year. (e.g. Total cool period precipitation for 1957 includes precipitation from November 1, 1956 through April 30, 1957)

10) TOTAL WARM PERIOD PRECIPITATION (Measured in inches)

The total precipitation from May 1 through October 31 of the current year. (e.g. Total warm period precipitation for 1957 includes precipitation from May 1, 1957 through October 31, 1957)

11) COOL PERIOD MAXIMUMS (Measured in °F)

The average maximum temperature for the cool period as defined above in the total cool period precipitation description.

12) COOL PERIOD MEANS (Measured in °F)

The average mean temperature for the cool period as defined above.

13) COOL PERIOD MINIMUMS (Measured in °F)

The average minimum temperature for the cool period as defined above.

14) WARM PERIOD MAXIMUMS (Measured in °F)

The average maximum temperature for the warm period as defined above in the total warm period precipitation description.

15) WARM PERIOD MEANS (Measured in °F)

The average mean temperature for the warm period as defined above.

16) WARM PERIOD MINIMUMS (Measured in °F)

The average minimum temperature for the warm period as defined above.

APPENDIX DESCRIPTION

Figure		Page

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I. Abstract. This paper examines the long-term climate near six NIGEC sponsored CO_2 flux towers in the AmeriFlux Network. It compares the long-term climate to the climate during the more recent CO_2 flux study period at the sites. Tendencies in sixteen climate parameters that affect CO_2 exchange are studied to determine any changes over the longer period. Statistics are then used to analyze the long-term data in order to find where the recent CO_2 flux study period climate data ranks in terms of normalcy. This is done in order to gauge how representative this recent climate data is compared to the long-term data. Each parameter for each year at each station is classified as either normal, anomalous, very anomalous, or extreme. These classifications are then quantified to produce a normalcy index rating for each year at each station. This normalcy index rating is used to compare years within individual stations and between stations. The information is used to assess the overall relationship between the stations studied. Potential synoptic trends and CO_2 exchange trends are discussed based on the overall climate trends at the stations studied.

II. INTRODUCTION

Debates over the environment and the consequences of environmental change have been increasing in recent years. Industry and environmentalists have clashed in their views and priorities concerning the role of environmental issues. With this, it becomes important to establish some understanding of the role of the changing environment. With the Energy and Water Development Appropriations Act of 1990, the National Institute for Global Environmental Change (NIGEC) was started by the Department of Energy (DOE). The purpose of NIGEC is to plan and execute regional programs of research in global environmental change. NIGEC supports research to understand the mechanisms responsible for global change and it focuses on identifying the most important forcing factors. The research is intended to guide the United States in its response to natural and anthropogenic global environmental change (13).

The top priorities in NIGEC research concern exchange of carbon by U.S. ecosystems, the ecological effects of climate change, and the regional impacts and consequences of climate change. The exchange of carbon by U.S. ecosystems is studied through the AmeriFlux CO_2 Network. AmeriFlux is a network of sites across North America that has provided the first set of detailed observations of ecosystem level exchanges of CO_2, water, energy, and momentum on multiple temporal scales (13). These data have provided an abundance of information concerning the interdependence between ecosystems and their environments. In recent years, NIGEC has put some research focus on studying the response of CO_2 exchange by ecosystems to climate change. It has sponsored thirteen AmeriFlux sites in the U.S. and has started to investigate this relationship. Through its research, NIGEC has been able to identify significant interannual variability in carbon storage by ecosystems due to climate variability. Therefore, it implies that changes in the convective layer can evoke changes in the boundary layer. Since it is possible that trends in climatic parameters can lead to trends in CO_2 exchange at the ecosystem level, it becomes important to investigate the behavior of the long-term climate at these stations. In this study, National Climatic Data Center (NCDC) weather stations near six of the thirteen NIGEC sponsored AmeriFlux sites are used to investigate the long-term changes in climatic parameters that may affect CO_2 exchange by ecosystems. It is assumed that these NCDC stations represent the AmeriFlux stations in terms of overall climate.

III. BACKGROUND RESEARCH

NIGEC research into the relationship between climate variability and carbon dioxide exchange variability has yielded some important findings. The various findings have shown that interannual variability in certain climatic parameters is related to interannual variability in carbon dioxide exchange at the ecosystem level. Variability in parameters like temperature, precipitation, snow cover, growing season start and end dates, and first and last freezes are shown to be related to carbon exchange variability.

In terms of CO_2 respiration, Goulden et al find that shifts are associated with anomalies in soil temperature, deep snow in winter, and drought in summer (6). More specifically, they find that climatic changes that promote soil thaw are likely to cause a net efflux of CO_2 from a site (7). In terms of CO_2 sequestration, or uptake, Barford et al find that weather and seasonal climate (variations in growing season-length or cloudiness) regulate seasonal and interannual fluctuations of carbon uptake (2). Schimel et al find that CO_2 uptake varies by about 100% from year to year as a result of climate variability (16). In terms of overall carbon exchange, Tian et al have found that there is a substantial year-to-year variation in net carbon exchange due to climate variability and that since the 1960's, terrestrial ecosystems in the U.S. have acted as a sink of atmospheric CO_2 as a result of wetter weather and higher CO_2 concentrations in the atmosphere (19).

In general, an increase in temperature is apparently associated with a net flux of CO_2 away from a site. Houghton et al find that higher temperatures cause a release of CO_2 in the long term (9), and Saleska et al find that warming may cause a net carbon loss from some terrestrial ecosystems (14). However, this net flux of CO_2 away from a site may not be due to warming directly. Saleska et al find that changes in soil moisture caused by warming may be as important in driving ecosystem response as the direct effects of soil temperature (14). Also, Davidson et al find that plant primary production declines with increasing mean annual temperature, and it is this decline, not an increase in soil-carbon decomposition rate that explains decreasing soil-carbon content with increasing temperature (4).

The relationship between temperature and soil moisture is noted by Saleska et al with their 'drought stress hypothesis.' It posits that the effect of moisture in reducing plant photosynthetic inputs is larger than the temperature effect predicted to increase soil respiration. They also relate decreased CO_2 uptake with decreased soil moisture (14). Davidson et al support this soil moisture relationship with CO_2 flux as they find that soil water content can influence respiration of soil (3). Shaver et al find that if increased evapotranspiration decreases soil moisture, and species changes result in better stomatal control of water loss, the result will be increased sensible heat flux to the atmosphere (17). This increased sensible heat flux to the atmosphere combined with the net loss of carbon from ecosystems due to warming could result in a positive feedback enhancing anthropogenic global warming (14). However, any increases in precipitation and in atmospheric CO_2 could moderate this effect with an increase in ecosystem sequestration of carbon (19).

In terms of the transition seasons, Savage and Davidson find that springtime variation accounts for 1/3 to 2/3 of interannual variation in soil respiration (15). Saleska et al find that heating causes photosynthetic uptake to start earlier in the spring and that earlier snow melt may change the timing of the shift between net respiration and net uptake of CO_2 in the spring (14). Related to this, Hollinger et al find that significant ecosystem uptake of carbon begins with thawing of the soil in early April and that it is abruptly reduced with the first frost in autumn (8). Saleska et al find that the period of time from the end of the growing season to snow cover, when the ecosystem is a net source of carbon to the atmosphere, could last longer under warmer conditions (14). This last finding could result in a positive warming feedback as more CO_2 is in the atmosphere and the soil is drier due to less snow cover in early winter. Reck states that the growing season length accounts for 80% of the variance in net CO_2 uptake, indicating that each additional day in the growing season contributes to about 6 gCm^{-2} day^{-1} (13). This combined with the other findings show that the transition seasons can be very significant in determining the behavior of carbon exchanges between the atmosphere and different ecosystems.

One place to investigate these findings and extend them to the longer record is at the NIGEC sponsored AmeriFlux sites. Shifts in some of these parameters could lead to major changes in the carbon exchange at the sites. Therefore, the relationship between the short flux record and the longer climate record needs to be studied. The current period of CO_2 flux measurements at the sites may not be climatically representative of the longer time period and it is important to see whether or not this is true. An anomalous period climatically could result in an anomalous period of CO_2 flux measurements.

IV. PROCEDURE AND SITE DESCRIPTIONS

Climatic parameters that affect CO_2 fluxes are studied over the long term and compared to the more recent CO_2 flux study periods at specific NIGEC sponsored AmeriFlux sites. These climatic parameters are derived based on NIGEC research concerning the interaction between CO_2 flux from ecosystems and climate. Sixteen climatic parameters are derived for six out of the thirteen NIGEC sponsored sites. These data are taken from the National Climatic Data Center (NCDC) website for six stations that are geographically similar to the NIGEC sponsored AmeriFlux sites. Each NCDC station is assumed to represent the climate of one of the AmeriFlux sites.

For each station, the long term tendencies of each parameter are analyzed. Also, statistics are produced for each parameter to analyze the means of the long term data (Table 4.1) and to analyze the deviation from the means for the recent data during the period of CO_2 flux studies at each station. Student t-tests for paired data are administered for each parameter to determine the t-probability for the recent data compared to the long term data. A probability level of less than 0.1 is considered significant. All recent data that scores less than 0.1 passes the test and is considered significantly different from the long term data. The deviations from the means are then classified into a rating system in terms of their relative normalcy. Each parameter for each year of the CO_2 study at each station is classified as either normal, anomalous, very anomalous, or extreme, depending on the relative normalcy of the data. Normal data is defined as data within one standard deviation of the mean of the parameter analyzed. Anomalous data are data outside one standard deviation of the mean but inside the tenth and ninetieth percentiles. Very anomalous data is data outside the tenth and the ninetieth percentiles but inside two standard deviations of the mean. Finally, extreme data are data outside two standard deviations of the mean. These classifications are then quantified to determine a normalcy index rating for each study year at each station (Table 6.1). Normal data for a parameter at a given station receives a 1.00 while anomalous data receives a 0.67, very anomalous data receives a 0.33, and extreme data receives a 0.00. An average is then taken for each year at each station to determine the normalcy index rating.

Table 4.1 Mean values for each parameter for each station over the study period

	Birch Hill Dam, MA	Chapel Hill, NC	Cheboygen, MI	Manhattan, KS	Martinsville, IN	Willow Reservoir, WI
Start of the growing season	Day 101	Day 20	Day 110	Day 55	Day 58	Day 111
End of the growing season	Day 273	Day 306	Day 275	Day 297	Day 289	Day 266
Length of the growing season	172 Days	285 Days	166 Days	242 Days	231 Days	155 Days
Last freeze	Day 141	Day 101	Day 132	Day 109	Day 112	Day 143
First freeze	Day 263	Day 301	Day 287	Day 289	Day 284	Day 263
Freeze free period	122 Days	200 Days	155 Days	181 Days	172 Days	119 Days
End of snow cover	Day 76	---------	Day 84	Day 44	Day 32	Day 103
Snow cover period	80 Days	----------	108 Days	25 Days	23 Days	138 Days
Cool period precipitation	20.7 in. (526mm)	21.4 in. (544mm)	11.1 in. (282mm)	9.5 in. (241mm)	19.3 in. (490mm)	8.5 in. (216mm)
Warm period precipitation	21.2 in. (538mm)	24.2 in. (615mm)	17.7 in. (450mm)	24.5 in. (622mm)	22.7 in. (577mm)	21.7 in. (551mm)
Cool period max. temp.	41.7° F (5.41°C)	58.9° F (14.9°C)	36.6° F (2.56° C)	50.9° F (10.5° C)	47.7° F (8.72° C)	32.6° F (0.33° C)
Cool period mean temp.	30.9° F (-0.6°C)	46.9° F (8.28°C)	28.4° F (-2.0° C)	39.6° F (4.22° C)	37.8° F (3.22° C)	22.4° F (-5.33° C)
Cool period	19.7° F	34.5° F	19.8° F	27.8° F	27.5° F	11.7° F

min. temp	(-6.8°C)	(1.39°C)	(-6.78° C)	(-2.33° C)	(-2.5° C)	(-11.3° C)
Warm period max. temp.	73.2° F (22.9°C)	82.5° F (28.1°C)	69.5° F (20.8° C)	82.9° F (28.3° C)	78.6° F (25.9° C)	69.1° F (20.6° C)
Warm period mean temp.	60.1° F (15.6°C)	70.9° F (21.6°C)	59.5° F (15.3° C)	71.0° F (21.7° C)	66.7° F (19.3° C)	57.7° F (14.3° C)
Warm period min. temp.	46.6° F (8.11°C)	58.9° F (14.9°C)	49.0° F (9.44° C)	58.6° F (14.8° C)	54.2° F (12.3° C)	45.8° F (7.67° C)

The parameters analyzed for the six stations are derived from temperature, precipitation, and snow on the ground. Parameters studied include the start, end, and length of the growing season which are based on mean temperature. The start of the growing season is defined as the first day of three consecutive days during the transition between the cool period and the warm period when the mean temperature at the station is 47° F or higher or as the first day of two consecutive days during the transition between the cool period and the warm period when the mean temperature at the station is 50° F or higher. If either criterion is met, the day is considered the start of the growing season and is represented as days after January 1. The end of the growing season is defined as the first day of three consecutive days during the transition between the warm period and the cool period when the mean temperature at the station is 49° F or lower or as the first day of two consecutive days during the transition between the warm period and the cool period when the mean temperature at the station is 46° F or lower. If either criterion is met, the day is considered the end of the growing season and is represented as days after January 1. The length of the growing season is defined as the difference between the end of the growing season and the beginning of the growing season for a given year and is measured in days.

Other parameters studied include the last freeze, the first freeze, and the freeze free period. The last freeze is defined as the last day during the transition between the cool period and the warm period when the minimum temperature at the station is 31° F or lower. It is represented as days after January 1. The first freeze is defined as the first day during the transition between the warm period and the cool period when the minimum temperature at the station is 31° F or lower and it is also represented as days after January 1. The freeze free period is defined as the difference between the first freeze and the last freeze for a given year and is measured in days.

Parameters studied also include the end of snow cover date and the snow cover period. The end of snow cover date is defined as the last day when there is at least one inch of snow on the ground at the site after ten or more consecutive days of at least one inch of snow on the ground. If no consecutive periods of ten days or more exist then there is no significant snow cover for the station for that year. This end of snow cover date is represented as days after January 1. The snow cover period is defined as the number of consecutive days from the end of snow cover date until the beginning of that particular snow cover period. It must be at least ten days long to be considered significant and it is represented in days.

Precipitation parameters are also included in the data. The calendar year is broken into two six month periods. The cool period is from November 1 of the previous year through April 30 of the study year. The warm period is from May 1 through October 31 of the study year. Total precipitation for the cool and warm periods is calculated for each study year. For example, the 1949 cool period includes total precipitation from November 1, 1948 through April 30, 1949 and the 1949 warm period includes total precipitation from May 1, 1949 through October 31, 1949. Total precipitation for both periods is measured in inches.

Finally, temperature data for the cool and warm periods is also included as climatic parameters. The calendar year is split into cool and warm periods identical to those for precipitation. The overall average maximums, means, and minimums for each period are calculated for each study year. Temperatures are measured in degrees Fahrenheit.

These parameters are analyzed for all NCDC stations which are assumed to represent the six NIGEC sponsored AmeriFlux sites used in this study. The AmeriFlux sites are described briefly along with their respective NCDC stations.

Harvard Forest, MA

The Harvard Forest flux tower is situated at 42° 32' N and 72° 10' W at a mean elevation of 340m above sea level. The terrain is hilly with gentle slopes and the vegetation type is a temperate deciduous forest. This site is represented by the climate data from **Birch Hill Dam, MA**. Birch Hill Dam is situated at 42° 38' N and 72° 07' W at an elevation of 263m above sea level. This station was at an elevation of 262m above sea level from 1948 until 1985 and has been at its current elevation since that time* (21, 22).

Duke Forest, NC

The Duke Forest flux tower is situated at 35° 58’ N and 79° 06’ W and has a hardwood deciduous forest type of vegetation. This site is represented by the climate data at **Chapel Hill, NC**. Chapel Hill is situated at 35° 55’ N and 79° 05’ W at an elevation of 152m above sea level. Since 1948, Chapel Hill has ranged in location from 152m to 153m above sea level and between 79° 04’ W and 79° 06’ W* (21, 22).

University of Michigan Biological Station, MI

The University of Michigan Biological Station flux tower is situated at 45° 33’ N and 84° 42’ W at an elevation of 234m above sea level. It is near Lake Michigan and the terrain is hilly with a gentle slope and the vegetation is mostly deciduous forest with some coniferous. This site is represented by the climate data at **Cheboygen, MI**. Cheboygen is situated at 45° 39’ N and 84° 28’ W at an elevation of 179m above sea level and it is near Lake Huron. The station has ranged from 179m to 180m in elevation throughout the study period* (21, 22).

Konza Prairie, KS

The Konza Prairie flux tower is situated at 39° 04’ N and 96° 33’ W at a mean elevation of 324m above sea level. The vegetation type is C4 tall grass prairie. This site is represented by the climate data at **Manhattan, KS**. Manhattan is situated at 39° 12’ N and 96° 35’ W at an elevation of 325m above sea level. The station has ranged in location between 39° 11’ and 39° 13’ N and between 96° 34’ and 96° 36’ W since the start of the study period. It has also ranged in elevation between 317m and 326m since the start of the study period* (21, 22).

Morgan Monroe State Forest, IN

The Morgan Monroe State Forest flux tower is situated at 39° 19’ N and 86° 24’ W at an elevation of 275m above sea level. The vegetation type is mixed hardwood deciduous forest. This site is represented by the climate data at **Martinsville, IN**. Martinsville is situated at 39° 24’ N and 86° 27’ W at an elevation of 186m above sea level. The station has ranged in location between 39° 24’ and 39° 26’ N and between 86° 25’ and 86° 27’ W since the start of the study period. It has also ranged in elevation from 183m to 186m since the start of the study period* (21, 22).

Willow Creek, WI

The Willow Creek flux tower is situated at 45° 48’ N and 90° 04’ W at an elevation of 520m above sea level. The terrain is essentially flat and the vegetation type is a temperate/boreal forest. This site is represented by the climate data at **Willow Reservoir, WI**. Willow Reservoir is situated at 45° 43’ N and 89° 51’ W at an elevation of 476m above sea level. The station has remained essentially stationary for the study period (21, 22).

* Shift is likely due to the datum shift resulting from the conversion of geographic coordinates from the NAD 27 system to the NAD 83 system during the study period (23)

V. STATION ANALYSES AND RESULTS

Birch Hill Dam, MA- (representing Harvard Forest, MA)

The Birch Hill Dam data set includes climate records starting from November 1, 1948 through October 31, 2002, totaling 54 years of data for each parameter. The data consists of sixteen climatic parameters derived from records of temperature, precipitation, and snowfall on the ground at the site. Tendencies in these parameters are analyzed to determine changes over the period. Additionally, correlations amongst the parameters are attempted to investigate links between them. Finally, the data for the recent years during the NIGEC sponsored AmeriFlux CO_2 flux project at Harvard Forest, MA (1991-2002) is compared to the entire length of the study period to determine the statistical significance of these recent data (Table 5.1). An index is then used to quantify and compare years within the CO_2 flux study period to determine relative normality and abnormality of the data (Table 6.1).

Table 5.1 Value and Normalcy Index Classification for each parameter for each year

	1991	1992	1993	1994	1995	1996
Start of the growing season	Day 95 (N) 40th%	Day 112 (N) 83rd%	Day 110 (N) 75th%	Day 106 (N) 59th%	---------	Day 111 (N) 79th%
End of the growing season	Day 273 (N) 59th%	Day 268 (N) 36th%	Day 263 (A) 12th%	Day 276 (N) 64th%	----------	Day 268 (N) 36th%
Length of the growing season	178 Days (N) 66th%	156 Days (A) 17th%	153 Days (A) 11th%	170 Days (N) 44th%	----------	157 Days (A) 19th%
Last freeze	Day 116 (VA®) 2nd%	Day 147 (N) 65th%	Day 120 (VA) 4th%	Day 131 (N) 25th%	Day 129 (N) 20th%	Day 137 (N) 45th%
First freeze	Day 265 (N) 57th%	Day 268 (N) 69th%	Day 263 (N) 49th%	Day 276 (A) 89th%	Day 254 (N) 22nd%	Day 269 (N) 76th%

Freeze free period	149 Days (VA) 94th%	121 Days (N) 54th%	143 Days (A) 83rd%	145 Days (A) 87th%	125 Days (N) 58th%	132 Days (N) 70th%
End of snow cover	Day 35 (VA) 4th%	Day 3 (E®) 2nd%	Day 94 (N) 79th%	Day 86 (N) 64th%	----------	Day 92 (N) 78th%
Snow cover period	25 Days (VA) 6th%	31 Days (A) 15th%	120 Days (VA) 94th%	97 Days (N) 60th%	----------	28 Days (A) 12th%
Cool period precipitation	22.0 in. (559mm) (N) 58th%	20.6 in. (523mm) (N) 45th%	22.3 in. (566mm) (N) 63rd%	25.6 in. (650mm) (A) 89th%	----------	29.1 in. (739mm) (E®) 100th%
Warm period precipitation	34.3 in. (871mm) (E) 98th%	21.5 in. (546mm) (N) 59th%	18.2 in. (462mm) (N) 26th%	22.9 in. (582mm) (N) 72nd%	27.0 in. (686mm) (A) 85th%	29.3 in. (744mm) (VA) 93rd%
Cool period max. temp.	47.1° F (8.39° C) (E®) 100th%	42.2° F (5.67° C) (N) 68th%	41.8° F (5.44° C) (N) 62nd%	41.7° F (5.39° C) (N) 57th%	----------	40.2° F (4.56° C) (N) 23rd%
Cool period mean temp.	35.0° F (1.67° C) (VA) 98th%	30.5° F (-0.83° C) (N) 47th%	30.5° F (-0.83° C) (N) 45th%	29.3° F (-1.5° C) (N) 23rd%	----------	28.5° F (-1.94° C) (A) 11th%
Cool period min. temp.	22.3° F (-5.39° C) (A) 81st%	18.2° F (-7.67° C) (N) 34th%	18.5° F (-7.5° C) (N) 36th%	16.3° F (-8.72° C) (A) 11th%	----------	16.2° F (-8.78° C) (VA) 9th%
Warm period max. temp.	74.8° F (23.8° C) (A) 80th%	71.9° F (22.2° C) (N) 22nd%	74.6° F (23.7° C) (N) 78th%	74.5° F (23.6° C) (N) 76th%	75.8° F (24.3° C) (VA) 96th%	73.0° F (22.8° C) (N) 52nd%
Warm period mean temp.	60.9° F (16.1° C) (N) 72nd%	58.3° F (14.6° C) (VA) 9th%	61.0° F (16.1° C) (N) 74th%	61.9° F (16.6° C) (A) 89th%	61.5° F (16.4° C) (A) 87th%	60.2° F (15.7° C) (N) 57th%
Warm period min. temp.	46.9° F (8.28° C) (N) 67th%	44.0° F (6.67° C) (VA®) 2nd%	46.7° F (8.17° C) (N) 59th%	48.4° F (9.11° C) (A) 87th%	46.8° F (8.22° C) (N) 63rd%	46.9° F (8.28° C) (N) 65th%
	1997	**1998**	**1999**	**2000**	**2001**	**2002**
Start of the growing season	Day 120 (VA) 96th%	Day 87 (A) 13th%	Day 112 (N) 83rd%	Day 94 (N) 34th%	Day 113 (N) 86th%	Day 103 (N) 47th%
End of the growing season	Day 266 (N) 21st%	Day 278 (N) 70th%	Day 278 (N) 70th%	Day 273 (N) 59th%	Day 273 (N) 59th%	Day 282 (A) 87th%
Length of the growing season	146 Days (VA) 4th%	191Days (VA) 92nd%	166 Days (N) 34th%	179 Days (N) 69th%	160 Days (N) 26th%	179 Days (N) 69th%
Last freeze	Day 147 (N) 65th%	Day 134 (N) 34th%	Day 134 (N) 34th%	Day 137 (N) 45th%	Day 134 (N) 34th%	Day 134 (N) 34th%

First freeze	Day 265 (N) 57th%	Day 267 (N) 63rd%	Day 280 (VA) 95th%	Day 272 (N) 82nd%	Day 281 (VA®) 100th%	Day 281 (VA®) 100th%
Freeze free period	118 Days (N) 44th%	133 Days (N) 73rd%	146 Days (A) 89th%	135 Days (N) 76th%	147 Days (VA) 92nd%	147 Days (VA) 92nd%
End of snow cover	Day 95 (N) 85th%	Day 43 (VA) 9th%	Day 77 (N) 43rd%	Day 60 (N) 19th%	Day 101 (VA) 96th%	Day 39 (VA) 6th%
Snow cover period	26 Days (VA) 8th%	27 Days (VA) 9th%	10 Days (E®) 2nd%	46 Days (N) 23rd%	117 Days (VA) 92nd%	32 Days (A) 17th%
Cool period precipitation	28.6 in. (726mm) (VA) 98th%	25.6 in. (650mm) (A) 87th%	19.7 in. (500mm) (N) 42nd%	23.7 in. (602mm) (N) 81st%	21.3 in. (541mm) (N) 57th%	16.4 in. (417mm) (A) 17th%
Warm period precipitation	15.9 in. (404mm) (N) 19th%	22.2 in. (564mm) (N) 67th%	27.2 in. (691mm) (A) 89th%	28.5 in. (724mm) (VA) 91st%	19.7 in. (500mm) (N) 41st%	21.1 in. (536mm) (N) 56th%
Cool period max. temp.	43.2° F (6.22° C) (N) 83rd%	45.4° F (7.44° C) (VA) 94th%	46.2° F (7.89° C) (E) 98th%	45.3° F (7.39° C) (VA) 92nd%	43.7° F (6.5° C) (N) 87th%	45.8° F (7.67° C) (VA) 96th%
Cool period mean temp.	32.3° F (0.17° C) (N) 74th%	33.8° F (1.0° C) (VA) 91st%	33.6° F (0.89° C) (A) 89th%	33.3° F (0.72° C) (A) 83rd%	30.0° F (-1.11° C) (N) 40th%	35.0° F (1.67° C) (VA®) 100th%
Cool period min. temp.	20.9° F (-6.17° C) (N) 72nd%	21.6° F (-5.78° C) (N) 79th%	20.3° F (-6.5° C) (N) 57th%	21.4° F (-5.89° C) (N) 77th%	16.5° F (-8.61° C) (A) 15th%	23.8° F (-4.56° C) (VA) 96th%
Warm period max. temp.	72.2° F (22.3° C) (N) 30th%	75.1° F (23.9° C) (A) 87th%	76.0° F (24.4° C) (VA®) 100th%	72.8° F (22.7° C) (N) 46th%	74.4° F (23.6° C) (N) 72nd%	73.2° F (22.9° C) (N) 54th%
Warm period mean temp.	58.6° F (14.8° C) (A) 19th%	62.0° F (16.7° C) (VA) 91st%	62.1° F (16.7° C) (VA) 93rd%	59.1° F (15.1° C) (N) 26th%	60.6° F (15.9° C) (N) 67th%	60.5° F (15.8° C) (N) 61st%
Warm period min. temp.	44.5° F (6.94° C) (VA) 6th%	48.5° F (9.17° C) (A) 89th%	47.9° F (8.83° C) (N) 81st%	45.2° F (7.33° C) (N) 20th%	46.4° F (8.0° C) (N) 50th%	47.1° F (8.39° C) (N) 72nd%

(N) = normal,

(A) = anomalous

(VA) = very anomalous

(E) = extreme

® denotes the record for the period

Tendencies

Tendencies are analyzed for all sixteen parameters as well as for running averages of mean temperature and precipitation for both the cool period and the warm period. The running averages consist of 10, 20, and 30 year analyses.

The running averages for the cool period mean temperature and total precipitation are analyzed (Fig. 1a, 2a, and 3a). All cool period mean temperature running averages exhibit decreasing slopes from the start of the period until about the mid1970’s with increasing slopes from that point until the end of the period. This compensation creates little evidence of overall change over the period. The overall changes are -0.61° F (-0.34° C), -0.40° F (-0.22° C), and -0.36° F (-0.2° C) for the 10, 20, and 30 year running averages, respectively. For all averages, total cool period precipitation has steadily increased throughout the period. The overall changes are +4.6 inches (117mm), +4.0 inches (102mm), and +2.8 inches (71.1mm) for the 10, 20, and 30 year running averages, respectively.

The running averages for warm period mean temperature and total precipitation are also analyzed (Fig. 4a, 5a, and 6a). All warm period mean temperatures show overall decreasing tendencies over the period. However, the 10 and the 20 year running averages exhibit slight increases since about 1980. The overall changes are -1.4° F (-0.78° C), -1.5°F (-0.83° C), and -0.86° F (-0.48° C) for the 10, 20, and 30 year running averages, respectively. For all averages, total warm period precipitation has steadily increased as in the case of total cool period precipitation. The overall changes are +8.0 inches (203mm),

+6.9 inches (175mm), and +4.7 inches (119mm) for the 10, 20, 30 year running averages, respectively.

The cool period maximum, mean, and minimum temperatures as well as total cool period precipitation are analyzed over the period (Fig. 7a). The cool period maximum temperatures demonstrate an overall change of around +1.8° F (+1.0° C) (Fig. 7a). Although these maximums decrease from the start of the period until the mid1970's the increase from that point until the end of the period is more than enough to compensate and create an overall increase. In fact, maximum temperatures during the twelve year CO_2 flux study period average 2.14° F (1.19° C) warmer than the average maximums for the whole period. Also, this difference between the means of the two periods is greater than one standard deviation of the mean for the whole period. These maximums passed the student t-test for significance with a 0.09 t-probability of occurrence and are therefore, significantly different. For the study period, cool period maximums are available for every year except 1995 (Table 5.1). Of the available eleven years of data, six years exhibit normal data while the other five years show at least anomalous data. From 1991 through 1997, the data is for the most part normal with the exception of 1991 which is the record warmest cool period maximums experienced for the period. However, from 1998 through 2002, all data is very anomalous or extreme with the exception of 2001 which is normal. For cool period maximums, the earlier portion of the study period is relatively normal while the more recent portion is very anomalous. In fact, all years from 1997 through 2002 are ranked in the top ten for the warmest for the period.

In terms of cool period mean temperatures, a similar decrease occurs from the start of the period until about the mid1970's with an increase since then (Fig. 7a).

However, the overall change for the mean temperatures of the period is -0.78° F (-0.43° C). Still, despite this overall decrease, average mean temperatures for the CO_2 flux study period are 1.05° F (0.58° C) warmer than the averages for the whole period. These means failed the student t-test for significance with a 0.69 t-probability of occurrence. But as with the cool period maximums, eleven years of data for cool period mean temperatures are available for the study period. Similarly to the maximums, the means show relatively normal data in the earlier portion of the study period and relatively anomalous data for the later portion of the study period (Table 5.1). In the data, five years are considered normal while six years are considered at least anomalous. This includes the record warmest and the second warmest cool period means for the period in 2002 and 1991, respectively. Along with the first and second warmest data there are three other years that are ranked in the top ten for warmth (1998, 1999, and 2000). Also, 1996 is the sixth coolest for the period.

In terms of cool period minimum temperatures, there has been an overall decrease since the start of the period (Fig. 7a). The change over the period is about -3.3° F (-1.83° C) with a small difference (< 1/100th° F) between average minimums during the CO_2 study period and the overall period. So, there has been a drastic decrease in cool period minimum temperatures overall, however, the recent period shows little difference from the whole period. Despite the small difference, these minimums passed the student t-test for significance with a 0.02 t-probability of occurrence. Unlike with the other cool period temperatures, minimum temperatures show no preference for normalcy in the earlier portion of the study period (Table 5.1). Overall, six years are considered normal while five years are considered at least anomalous. Also, three years (1994, 1996, and 2001) are ranked in the top ten for the coolest data while 2002 is the third warmest for the period.

In terms of total cool period precipitation, there is a decrease until the mid 1960's with an increase since then and an overall change of +3.7 inches (94.0mm) over the whole period (Fig. 8a). This is roughly the equivalent of one average month of precipitation for the area. Also, the average total cool period precipitation is 2.5 inches (63.5mm) higher during the CO_2 study period than during the whole period. These recent cool period precipitation years were close but failed slightly in the student t-test for significance with a 0.11 t-probability of occurrence. For cool period precipitation, six years are considered normal while five years are considered at least anomalous (Table 5.1). In this case, the middle portion of the study period is the most anomalous while the earlier and later portions are more normal. The study period consists of four years ranked in the top ten for the wettest including the wettest and the second wettest in 1996 and 1997, respectively. The study period also includes the ninth driest in 2002.

Cool period maximum temperatures have increased while cool period minimum temperatures have decreased creating an overall decrease in cool period mean temperatures while cool period precipitation has increased over the period. The maximums and minimums passed the student t-tests for significance and so are considered significantly different from the longer period. The diurnal temperature range during the cool period months has then increased over the period which would lead one to speculate that cloud cover has decreased and therefore precipitation has decreased as well. However, in this case, the opposite scenario exists. One possible explanation is that precipitation events are becoming less frequent yet more intense creating more opportunities for large diurnal temperature ranges yet still allowing an increase in total precipitation. Temperatures are slightly more anomalous toward the later portion of the study period while precipitation is more anomalous in the middle of the period. In terms of both cool period parameters, the beginning of the study period is relatively normal then becomes cooler and wetter toward the middle followed by warmer and drier toward the end.

Warm period maximum, mean, and minimum temperatures as well as warm period total precipitation are also analyzed over the period (Fig. 9a). Warm period maximum temperatures demonstrate a decrease until about 1980 with an increase since and an overall change of -0.67° F (-0.37° C) over the period. Warm period mean temperatures show the same pattern of decreasing until 1980 and increasing since with a similar overall change of -0.70° F (-0.39° C) for the period. Warm period minimum temperatures have demonstrated an overall decrease throughout the period with an overall change of -1.1° F (-0.61° C). Despite the decrease for all warm period temperatures over the period, the averages for the CO_2 study period are warmer than for the whole period by 0.85° F (0.47° C), 0.46° F (0.26° C), and 0.03° F (0.02° C) for the maximum, mean, and minimum temperatures, respectively. So, warm period temperatures are slightly warmer than average during the recent period when compared to the whole showing that the recent increase since about 1980 has roughly compensated for the overall decrease since the beginning of the period. All three warm period temperatures failed their student t-tests for significance with t-probabilities of 0.80, 0.96, 0.54 for the maximums, means, and minimums, respectively. According to this test, warm period temperatures during the recent period are similar to those of the longer period.

The warm period maximum, mean, and minimum temperatures each have twelve years of data for the study period (Table 5.1). Of the twelve years, eight are considered normal for warm period maximums. Of the other four years, three are ranked in the top ten for the warmest (1995, 1998, and 1999) in the period including the warmest for the period in 1999. Warm period mean temperatures include six normal years and six years that are at least anomalous. This includes four years ranked in the top ten warmest (1994, 1995, 1998, and 1999) and two years ranked in the top ten coolest (1992 and 1997). For swarm period minimum temperatures, eight out of the twelve years in the study period are considered normal. The other four years consist of two years ranked in the top ten warmest (1994 and 1998) and two years ranked in the top ten coolest (1992 and 1997) with 1992 holding the record for the coolest year in the period. For all warm period temperatures, 2000 through 2002 is considered normal.

In terms of total warm period precipitation, there has been a steady and overall increase over the period with a change of +7.3 inches (185mm) (Fig. 10a). The average warm period precipitation total during the CO_2 study period is 2.8 inches (71.1mm) higher than the average for the whole period. This increase in warm period total precipitation is the equivalent of about two average summer months of precipitation for the area. This is approximately a 30% increase in summer precipitation over the period. Despite this, warm period precipitation failed the student t-test for significance with a 0.17 t-probability of occurrence. In terms of the study period, seven out of the twelve study years are considered normal (Table 5.1). All of the remaining five years are ranked in the top ten wettest years for the whole period. This includes 1991, 1995, 1996, 1999, and 2000. Tropical systems late in the warm period are responsible for some of these abnormally wet years. This is true for 1991, 1996, and 1999.

For at least the last twenty years, there has been an increase in warm period temperatures and in total warm period precipitation. The temperature changes are much less significant than the precipitation change, however. One scenario that may be occurring is one in which warmer temperatures are allowing more evaporation and therefore more convective activity. This could create increases in precipitation while keeping temperatures more moderate with the increased cloud cover resulting from the extra convection.

The start, end, and length of the growing season are also analyzed over the period (Fig. 11a, 12a, and 13a). The growing season tendencies are much more variable than those of temperature and precipitation. The start of the growing season has changed by -1.1 days since the start of the period (Fig. 11a). This means that the start of the growing season has shifted by about one day earlier. However, the average day during the CO_2 flux study period is 4.7 days later than that of the whole period. This means that during the recent period, the start occurs about one half of a week later than the average for the whole despite a trend toward slightly earlier starts over the period. Along with this, the start of the growing season during the recent period failed the student t-test for significance with a 0.59 t-probability of occurrence. These recent start dates are considered similar to those of the longer period. Only two out of the eleven available study year data are not considered normal for the start of the growing season (Table 5.1).

In 1997, the third latest start occurs on April 30 of that year and in 1998, the seventh earliest start occurs on March 28 of that year.

The end of the growing season shows a tendency toward earlier dates until about the mid1970's and a tendency toward later dates since then (Fig. 12a). The overall change is about -4.9 days, or almost five days earlier over the period. The difference between the average date during the recent period compared to the whole period is small (<8/100ths of a day). Along with this, the end of the growing season failed the student t-test for significance with a 0.47 t-probability of occurrence. Similar to the start of the growing season, the end consists of only two out of the eleven available years that are considered at least anomalous (Table 5.1). In 1993, the sixth earliest ending occurs on September 20 of that year and in 2002, the sixth latest ending occurs on October 9 of that year.

The combination of these start and end dates of the growing season create a tendency toward shorter lengths of the growing season by 3.8 days (Fig.13a). Also, the average length during the CO_2 flux study is 4.8 days shorter than the average length for the whole period. In accordance to the start and the end of the growing season, the length also fails the student t-test for significance with a 0.46 t-probability of occurrence. In this case, however, five of the available eleven years of data are considered at least anomalous (Table 5.1). Four out of the five years are ranked in the top ten shortest periods (1992, 1993, 1996, and 1997) while 1998 is the fifth longest growing season for the period.

The last freeze, first freeze, and freeze free period between the two have also been analyzed over the period (Fig. 14a, 15a, and 16a). The last freeze in the spring shows a tendency toward later dates until about 1980 and toward earlier dates since then (Fig.

14a). The overall change is -7.6 days, for a shift of more than a week toward earlier last freezes. The average for the CO^2 study period is also 7.9 days earlier than the average for the whole. Despite this change, only two of the available twelve years of data are considered at least anomalous (Table 5.1) and this data fails the significance test with a 0.16 t-probability of occurrence. In 1991, the last freeze occurs on April 26 of that year and is the earliest for the period. Then in 1993, the second earliest last freeze occurs on April 30 of that year.

In terms of the first freeze in the fall, an overall tendency toward later dates is observed with a change of +8.1 days over the period (Fig. 15a). The difference between the averages of the recent period when compared to the overall average is 7.0 days later. This is validated since these data passed the significance test with a 0.09 t-probability of occurrence. In this case, only four out of the twelve available years of data are considered at least anomalous (Table 5.1). However, this does include the latest three first freezes as well as the sixth latest first freeze. In fact, in 1999 a forty five year old record is tied when the first freeze occurs on October 7. Then in 2001, this record is broken again and the new record is tied the following year in 2002 when the first freeze does not occur until October 8 in both years.

These tendencies create an overall change in the freeze free period of +15.7 days (Fig. 16a). This means that the period of time between freezes has increased by more than two weeks. Also, the average time between freezes during the recent study period is 14.9 days longer than the average of the whole period. This is a large change in the freeze free period with almost equal influence from both the last freeze and the first freeze dates. The combination yields a freeze free period that passes the significance test with a 0.03 t-probability of occurrence. These recent data are significantly different from that of the longer period. Unlike with the first and last freezes, the freeze free period consists of six out of twelve available years of data which are considered to be at least anomalous (Table 5.1). All six years are ranked in the top ten for the longest freeze free periods and include 1991, 1993, 1994, 1999, 2001, and 2002.

This data shows that the freeze free period and the growing season length are not well linked. This is especially true in autumn, where first freezes are occurring later but the growing seasons are ending earlier. Cold air may be moving in earlier but may not cold enough to freeze until later. Perhaps the volatility of the atmosphere has increased causing more powerful fronts that keep weather patterns in motion. These powerful fronts may bring in colder air earlier in the season but air movement may keep the area from experiencing sufficiently calm conditions to produce the radiative cooling needed to allow the minimum temperatures to drop below freezing at night. The same can be said about the spring season in terms of the recent period where freezes end earlier yet cold air continues later in the season.

The ending dates of the snow cover periods as well as the length of these snow cover periods are also analyzed (Fig. 17a and 18a). Both parameters show significant change over the period. The last day with snow on the ground has changed by -18.0 days and the average end of snow cover date for the recent period is 9.9 days earlier than the average for the whole period (Fig. 17a). Despite the drastic change, these data fail the significance test with a 0.30 t-probability of occurrence. In terms of the available study years, five of the eleven years are considered to be at least anomalous (Table 5.1). These consist of four out of the top five earliest endings of the snow cover period including the top three earliest in 1992, 1991, and 2002, respectively. Also, the third latest ending occurred in 2001 when the snow was on the ground until April 11 of that year.

The period of snow cover on the ground has changed by -40.0 days and the average snow cover period during the recent study period is 28.9 days shorter than the average for the whole period (Fig, 18a). This large change is validated by the significance test in which the recent period passes with a 0.02 t-probability of occurrence. For the eleven available study years, the snow cover period is considered to be at least anomalous for nine of them (Table 5.1). Of these nine years, seven are ranked in the top ten shortest periods while two are ranked in the top ten longest periods. These two longer periods occurred in 1993 and 2001 and the only two normal periods occurred in 1994 and 2000. All other years are very short including the record for the period in 1999 with only 10 days of significant snow cover which is the minimum allowed. The study period is variable in terms of snow cover period with definite preference toward shorter periods when compared to the whole period.

Based on this data, snow is melting off much earlier and the length of time that the snow is on the ground has decreased significantly. However, this does not mean that winter precipitation has decreased since it has been shown that quite the opposite is true. Winter precipitation is increasing while snow on the ground is melting off earlier leading to the assumption that more precipitation events, at least in late winter and early spring, are in the form of rain rather than snow. It is also interesting to note that there is a tendency toward extremes in the case of snow on the ground. The recent years have exhibited either feast or famine for the most part with most data falling in the at least anomalous category.

Correlations amongst parameters

Many correlations amongst parameters were attempted, however, few significant correlations were found. Despite this, there are a few comparisons of interest. First, the length of the growing season is compared with the start and the end of the growing season (Fig. 19a). It shows that the start of the growing season has a higher correlation to the length than does the end of the growing season (0.79 for the start compared to 0.45 for the end). The same type of comparison is done for the first and last freeze compared to the freeze free period (Fig. 20a). It shows that the last freeze in the spring has a higher correlation to the freeze free period than does the first freeze in autumn (.86 for the last compared to .71 for the first). Due to their higher variability, the start of the growing season and the last freeze date control the length of the growing and freeze free seasons more readily than the end of the growing season and the first freeze date. Therefore, the timing of the onset of spring is more important than the onset of autumn in determining the length of the growing and freeze free periods.

Other correlations were attempted but did not produce any definitive links between parameters. It is intuitive to assume that earlier melting of snow in the spring leads to earlier last freezes and earlier starts to the growing season since the air can more easily warm without the snow on the ground. These comparisons do lead to the expected trends, however, and the correlations are poor. A comparison between the lengths of the growing season and freeze free periods does not produce a strong correlation as expected based on the previous results where it is shown that the growing season has truncated while the freeze free period has expanded over the period (Fig. 21a). Any attempts to correlate temperature to precipitation within seasons in addition to temperature or precipitation to growing season, freezing data, or snow produce poor results as well.

<u>Chapel Hill, NC</u>- (representing Duke Forest, NC)

The Chapel Hill data set includes climate records starting from November 1, 1948 through October 31, 2002, totaling 54 years of data for each parameter. The data consists of fourteen climatic parameters derived from records of temperature and precipitation at the site. Tendencies in these parameters are analyzed to determine changes over the period. Additionally, correlations amongst the parameters are attempted to investigate links between them. Finally, the data for the recent years during the NIGEC sponsored AmeriFlux CO_2 flux project at Duke Forest, NC (1997-2002) is compared to the entire length of the study period to determine the statistical significance of these recent data (Table 5.2). An index is then used to quantify and compare years within the CO_2 flux study period to determine relative normality and abnormality of the data (Table 6.1).

Table 5.2 Value and Normalcy Index Classification for each parameter for each year

	1997	1998	1999	2000	2001	2002
Start of the growing season	Day -3 (VA®) 3rd%	Day 4 (N) 27th%	Day 13 (N) 51st%	Day 0 (A) 15th%	Day 31 (N) 76th%	Day 28 (N) 69th%
End of the growing season	Day 310 (N) 71st%	Day 308 (N) 53rd%	Day 297 (N) 18th%	Day 283 (E) 4th%	Day 301 (N) 31st%	Day 303 (N) 35th%
Length of the growing season	313 Days (VA) 94th%	304 Days (N) 78th%	284 Days (N) 44th%	283 Days (N) 42nd%	270 Days (N) 27th%	275 Days (N) 35th%
Last freeze	Day 100 (N) 46th%	Day 82 (A) 12th%	Day 76 (VA) 6th%	Day 75 (VA) 4th%	Day 110 (N) 76th%	Day 98 (N) 40th%

First freeze	Day 321 (VA) 98th%	Day 311 (N) 87th%	Day 308 (N) 71st%	Day 320 (VA) 96th%	Day 302 (N) 52nd%	Day 323 (E®) 100th%
Freeze free period	221 Days (A) 86th%	229 Days (VA) 93rd%	232 Days (VA) 94th%	245 Days (E®) 100th%	192 Days (N) 37th%	225 Days (VA) 91st%
Cool period precipitation	22.3 in. (566mm) (N) 61st%	----------	25.0 in. (635mm) (N) 75th%	20.1 in. (511mm) (N) 41st%	17.8 in. (452mm) (N) 25th%	13.6 in. (345mm) (VA) 8th%
Warm period precipitation	18.6 in. (472mm) (VA) 9th%	17.7 in. (450mm) (VA) 6th%	38.9 in. (988mm) (E®) 100th%	22.9 in. (582mm) (N) 46th%	23.7 in. (602mm) (N) 52nd%	26.7 in. (678mm) (N) 72nd%
Cool period max. temp.	58.4° F (14.7° C) (N) 47th%	----------	61.1° F (16.2° C) (N) 81st%	60.8° F (16.0° C) (N) 76th%	57.1° F (13.9° C) (N) 27th%	63.1° F (17.3° C) (VA) 98th%
Cool period mean temp.	47.6° F (8.67° C) (N) 65th%	----------	49.0° F (9.44° C) (N) 84th%	48.6° F (9.22° C) (N) 76th%	45.6° F (7.56° C) (N) 29th%	50.5° F (10.3° C) (VA) 94th%
Cool period min. temp.	36.3° F (2.39° C) (N) 75th%	----------	36.4° F (2.44° C) (N) 76th%	36.0° F (2.22° C) (N) 69th%	33.7° F (0.94° C) (N) 39th%	37.6° F (3.11° C) (VA) 92nd%
Warm period max. temp.	81.4° F (27.4° C) (N) 24th%	84.5° F (29.2° C) (A) 88th%	81.5° F (27.5° C) (N) 31st%	82.1° F (27.8° C) (N) 51st%	81.5° F (27.5° C) (N) 27th%	83.6° F (28.7° C) (N) 75th%
Warm period mean temp.	70.5° F (23.4° C) (N) 36th%	73.3° F (22.9° C) (VA) 96th%	71.1° F (21.7° C) (N) 54th%	71.3° F (21.8° C) (N) 62nd%	70.4° F (21.3° C) (N) 34th%	73.0° F (22.8° C) (VA) 92nd%
Warm period min. temp.	59.1° F (15.1° C) (N) 51st%	61.5° F (16.4° C) (VA) 90th%	60.3° F (15.7° C) (N) 78th%	60.0° F (15.6° C) (N) 70th%	58.9° F (14.9° C) (N) 44th%	61.8° F (16.6° C) (VA) 96th%

(N) = normal

(A) = anomalous

(VA) = very anomalous

(E) = extreme

® denotes the record for the period

Tendencies

Tendencies are analyzed for all fourteen parameters and for 10, 20, and 30 year running averages of mean temperature and precipitation for the cool and warm periods.

Running averages for cool period mean temperature and total precipitation are analyzed (Fig. 1b, 2b, and 3b). The 10 year running average yields a decrease in cool period mean temperature until around 1980 with an increase since that time. The 20 and 30 year running averages yield a decrease until the early 1970's with an increase since that time. The overall changes for the period are small as a result of the increases and decreases. The changes are + 0.56° F (+0.31° C), +0.40° F (+0.22° C), and + 0.41° F (+0.23° C) for the 10, 20, and 30 year running averages, respectively. For total cool period precipitation, the 10 and 20 year averages yield decreases until the early 1970's with increases since that time, while the 30 year average yields a decrease until about 1980 with an increase since. The overall changes, as a result, are +0.4 inches (10.2mm), +1.2 inches (30.5mm), and +0.3 inches (7.62mm) for the 10, 20, ands 30 year running averages, respectively. The changes in precipitation are small because of almost equal increases and decreases over the period.

Running averages for warm period mean temperature and total precipitation are also analyzed (Fig. 4b, 5b, and 6b). The 10 year running average for warm period mean temperature yields a decrease until about 1980 with an increase since that time while the 20 and 30 year averages yield a decrease until the mid 1970's with an increase since. The overall changes are very small, as a result, at just +0.06° F (+0.03° C), -0.35° F (-0.19° C), and +0.12° F (+0.07° C) for the 10, 20, and 30 year running averages, respectively. Total warm period precipitation has steadily increased over the period for all running averages by +1.7 inches (43.2mm), +1.5 inches (38.1mm), and +1.1 inches (27.9mm) for the 10, 20, and 30 year running averages, respectively.

Cool period maximum, mean, and minimum temperatures along with total cool period precipitation are analyzed for the period (Fig. 7b). Cool period temperatures reveal a decrease until the late 1970's with a slight increase since that time. The overall changes are decreases in temperature by -0.90° F (-0.50° C), -0.75° F (-0.42° C), and -0.60° F (-0.33° C) for the maximum, mean, and minimum cool period temperatures, respectively. However, the averages for temperatures during the recent study period are warmer than the averages for the whole period. The temperatures during the study period are warmer by +1.19° F (+0.66° C), +1.33° F (+0.74° C), and +1.49° F (+0.83° C) for the maximum, means, and minimums, respectively. The temperatures during the six year study period are abnormally warm enough to create an increasing tendency. Despite any differences, all three recent temperatures for the cool period failed the significance tests with 0.20, 0.26, and 0.35 t-probabilities of occurrence for the maximums, means, and minimums, respectively. For cool period temperatures, data is missing for 1998. For the five available years of data, only 2002 is considered at least anomalous for all three temperatures (Table 5.2). This year yields the second warmest maximums, the fourth warmest means, and the fifth warmest minimums for the period, respectively.

Total cool period precipitation, on the other hand, has decreased slightly overall during the period by -0.5 inches (12.7mm) (Fig. 8b). The average precipitation during the study period is 1.6 inches (40.6mm) less than the average for the whole period. The recent period has been slightly drier than the whole period and the overall tendency demonstrates at least a slight decrease. The small difference between the recent period and the longer period is validated by the significance test in which this parameter failed with a 0.31 t-probability of occurrence. There are five years available from the study period with 1998 missing. Of the five years available, only 2002 is considered abnormal (Table 5.2). This year is the fourth driest for the period.

The cool periods have been warming slightly for the last twenty five years and have been drying slightly since the beginning of the period. During the study period, the cool periods have been warmer and drier than average, as a whole.

Warm period maximum, mean, and minimum temperatures along with total warm period precipitation are also analyzed over the period (Fig. 9b). Warm period maximums and means yield an overall slight decrease while the minimums yield a decrease until the late 1970's with an increase since for an overall slight increase. The changes over the period are -0.87° F (-0.48° C), -0.29° F (-0.16° C), and +0.24° F (+0.13° C) for the maximums, means, and minimums, respectively. The average temperatures during the study period are slightly warmer than the average for the whole period for means and minimums while they are nearly unchanged for maximums. Averages over the study period are different than averages for the whole period by -0.03° F (-0.02° C), +0.69° F (+0.38° C), and +1.41° F (+0.78° C) for the maximums, means, and minimums, respectively. Of these temperatures, only the recent maximums passed the significance test. These temperatures scored t-probabilities of 0.05, 0.26, and 0.59 for the maximums, means, and minimums, respectively. Of the six study years, only 1998 is considered at least anomalous for all three temperatures (Table 5.2). This includes the seventh warmest maximums, the third warmest means, and the sixth warmest minimums for the period. Also, in 2002, the third warmest minimums occur which create the fifth warmest means while the maximums are considered normal.

Total warm period precipitation has increased overall for the period by +2.5 inches (63.5mm) and the average precipitation for the six year study period is 0.6 inches (15.2mm) higher than the average for the whole period (Fig. 10b). The study period on average is very similar to the whole period in terms of warm period precipitation but the tendency over the whole period is increasing. This small difference is validated by this parameter's failure in the significance test with a 0.61 t-probability of occurrence. With this data, three out of the six available study years are considered at least anomalous (Table 5.2). This includes the wettest warm period in 1999 and the third and fifth driest warm periods in 1998 and 1997, respectively.

The warm periods have changed very little in the way of temperatures but have become slightly wetter since the start of the period. The study period is slightly warmer in terms of minimum temperatures and slightly wetter. Possibly the increase in precipitation is associated with an increase in cloudiness that may be keeping minimum temperatures higher while slightly decreasing maximum temperatures. Also, tropical systems such as Hurricane Floyd in 1999 are a large influence on warm period precipitation.

The start, end, and length of the growing season are also analyzed over the period (Fig. 11b, 12b, and 13b). The start of the growing season yields a tendency toward later dates until the late 1970's with a tendency toward earlier dates since that time (Fig. 11b). The overall change is toward later dates by +4.5 days. However, the average start date during the study period is 8.2 days earlier than that of the whole period. The tendency toward earlier dates since the late 1970's is represented by the much earlier dates found in the study period even though the entire period yields later dates. These earlier dates failed the significance test with a 0.16 t-probability of occurrence. Just two out of the six years from the 1997-2002 study period are considered to be at least anomalous (Table 5.2). In 1997, the start date is the earliest for the period and occurs on December 28, 1996 while in 2000, the start date is the seventh earliest start and occurs on December 31, 1999.

The end of the growing season yields an overall tendency toward earlier dates by -8.1 days for the whole period (Fig. 12b). The average date during the study period is 5.5 days earlier than that of the whole period so the earlier dates during the study period are represented by the overall tendency toward earlier dates. These earlier dates passed the significance test with a 0.01 t-probability of occurrence. Despite this passing of the test, the ending dates in the study period are all considered normal with the exception of 2000 when the second earliest ending date occurred on October 9 (Table 5.2).

In terms of the overall length of the growing season, there is a tendency toward shorter periods until the late 1970's with a tendency toward longer periods since that time (Fig. 13b). The overall tendency is toward shorter periods by -12.7 days while the average length of the growing season is 2.8 days longer during the study period when compared to the whole period. Despite the above average lengths during the study period and the increase since the late 1970's the overall change is a shortening by almost two weeks. These above average lengths passed the significance test with a 0.01 t-probability of occurrence. Despite this, the growing season lengths during the study period are normal for the most part with the exception of 1997 when the fourth longest season occurred (Table 5.2).

The last freeze, first freeze, and the freeze free period between them are analyzed as well (Fig. 14b, 15b, and 16b). The last freeze in the spring yields a strong overall tendency toward earlier dates by -9.3 days while the average date during the study period is earlier by 10.4 days in comparison to the average date of the whole period (Fig. 14b). The average date during the study period is well represented by the overall tendency. Also, the recent last freeze dates passed the significance test with a 0.09 t-probability of occurrence. Of the six last freezes during the study period, three are considered abnormal (Table 5.2). In 1998, the sixth earliest last freeze occurred on March 23. In 1999, the third earliest last freeze occurred on March 17 and in 2000, the second earliest last freeze occurred on March 15. Three of the top six earliest last freezes occur during the study period.

The first freeze in autumn yields a tendency toward earlier dates until the late 1970's with a tendency toward much later dates since that time (Fig. 15b). The overall change is toward later dates by +4.7 days while the average date during the study period is 13.7 days later than that of the whole period. This 13.7 day difference in the average is greater than one standard deviation from the average for the whole period. The first freeze dates are much later during the study period than they are during the whole period. Despite this, the parameter failed the significance test with a 0.19 t-probability of occurrence. Like with the last freezes, three out of the six study years are considered abnormal (Table 5.2). These are, in fact, the top three latest first freezes for the period. In 1997, the second latest date is set and occurs on November 17 of that year. In 2000, the third latest date is set and occurs on November 15. Then in 2002, the latest first freeze for the period occurs on November 19 of that year.

The total freeze free period yields similar tendencies to the first freeze dates with shorter periods until the late 1970's and longer periods since that time (Fig. 16b). The overall change over the period is +14.0 days while the average length during the study period is 24.1 days longer than the average for the whole period. This, as with the first freeze dates, is greater than one standard deviation from the average length of the whole period. The freeze free period is much longer during the study period than it is during the whole period. The significance test validates this as the recent period passed the test with a 0.06 t-probability of occurrence. In addition, five out of the top ten longest freeze free periods occur during this six year study period (Table 5.2). This includes the longest of the period occurring in 2000. Only 2001 is considered normal out of this data for freeze free period.

The data here shows that the freeze free period and the growing season length are not well linked. In terms of the overall tendencies, the growing season is shrinking while the freeze free period is expanding. This is similar to the data from Birch Hill Dam, MA. Since the growing season is based on mean temperature, this means that cold fronts are occurring later in the spring and earlier in the fall while low temperatures are staying above freezing earlier in the spring and later in the fall. Perhaps these two stations are experiencing higher volatility in the atmosphere where more powerful fronts are passing through bringing in colder air. However, without radiative cooling this air is not cold enough to freeze. The air motion may be inhibiting radiative freezes. The overall result could mean that there are fewer freezes during the transition seasons but more frontal passages.

Correlations amongst parameters

Many correlations are attempted to show relationships amongst the parameters. However, few of the comparisons yield favorable links. Though, similar to the Birch Hill Dam, MA data, this data shows favorable links between the start of the growing season and the last freeze date to the length of the growing season and the freeze free period, respectively. The start of the growing season yields a 0.87 correlation to the length of the growing season while the end of the growing season yields only a 0.43 correlation to the length of the growing season (Fig. 19b). Similarly, the last freeze date shows a 0.83 correlation to the freeze free period, but the first freeze date also shows a decent correlation to the freeze free period at 0.72 (Fig. 20b).

Other correlations are not very good though some are at least worth mentioning. Warmer winter mean temperatures are seen to be slightly correlated to earlier starts of the growing season with a correlation of 0.60 (Fig. 22a). This makes sense because the growing season is based on mean temperature and if warmer winter means eclipse the start of the growing season criteria then earlier starts can occur. Also, warmer summer minimums yield a 0.61 correlation to longer freeze free periods (Fig. 23a). This also makes sense because freezes are based on minimums and if minimums at the beginning and the end of the summer period are warmer there is less chance of a freeze. It is also interesting to note that a poor correlation is found between the length of the growing season and the freeze free period (Fig. 21b). This is expected since it is already mentioned that these two parameters can not be linked very well. Any other attempts to link temperature to precipitation within seasons in addition to temperature or precipitation to growing season or freeze data produce poor results.

<u>Cheboygen, MI</u>- (representing Univ. of Michigan Biological Station, MI)

The Cheboygen data set includes climate records starting from November 1, 1950 through October 31, 2002, totaling 52 years of data for each parameter. The data consists of sixteen climatic parameters derived from records of temperature, precipitation, and snowfall on the ground at the site. Tendencies in these parameters are analyzed to determine changes over the period. Additionally, correlations amongst the parameters are attempted to investigate links between them. Finally, the data for the recent years during the NIGEC sponsored AmeriFlux CO_2 flux project at the University of Michigan Biological Station, MI (1998-2002) is compared to the entire length of the study period to determine the statistical significance of these recent data (Table 5.3). An index is then used to quantify and compare years within the CO_2 flux study period in order to determine relative normality and abnormality of the data (Table 6.1).

Table 5.3 Value and Normalcy Index Classification for each parameter for each year

	1998	1999	2000	2001	2002
Start of the growing season	Day 86 (VA) 6^{th}%	Day 90 (A) 12^{th}%	Day 68 (E®) 2^{nd}%	Day 111 (N) 53^{rd}%	Day 106 (N) 33^{rd}%
End of the growing season	Day 275 (N) 46^{th}%	Day 275 (N) 46^{th}%	Day 266 (A) 17^{th}%	Day 268 (N) 23^{rd}%	Day 281 (N) 77^{th}%
Length of the growing season	189 Days (VA) 92^{nd}%	185 Days (A) 88^{th}%	198 Days (E®) 100^{th}%	157 Days (N) 33^{rd}%	175 Days (N) 73^{rd}%
Last freeze	Day 118 (A) 12^{th}%	Day 147 (VA) 94^{th}%	Day 141 (N) 76^{th}%	Day 119 (A) 17^{th}%	Day 145 (A) 85^{th}%
First freeze	Day 277 (N) 23^{rd}%	Day 280 (N) 35^{th}%	Day 272 (A) 14^{th}%	Day 280 (N) 35^{th}%	Day 287 (N) 58^{th}%
Freeze free period	159 Days (N) 52^{nd}%	133 Days (A) 13^{th}%	131 Days (VA) 9^{th}%	161 Days (N) 64^{th}%	142 Days (N) 27^{th}%
End of snow cover	Day 87 (N)	Day 83 (N)	Day 58 (VA)	Day 93 (N)	Day 93 (N)

	45th%	39th%	8th%	75th%	75th%
Snow cover period	80 Days (A) 14th%	95 Days (N) 27th%	73 Days (A) 12th%	119 Days (N) 65th%	100 Days (N) 35th%
Cool period precipitation	11.6 in. (295mm) (N) 56th%	12.1 in. (307mm) (N) 67th%	8.6 in. (218mm) (N) 23rd%	11.2 in. (284mm) (N) 48th%	14.0 in. (356mm) (N) 89th%
Warm period precipitation	17.4 in. (442mm) (N) 47th%	16.8 in. (427mm) (N) 45th%	13.2 in. (335mm) (A) 12th%	26.0 in. (660mm) (VA) 98th%	26.4 in. (671mm) (E®) 100th%
Cool period max. temp.	39.1° F (3.94° C) (VA) 92nd%	39.6° F (4.22° C) (VA) 98th%	40.2° F (4.56° C) (VA®) 100th%	36.2° F (2.33° C) (N) 51st%	39.4° F (4.11° C) (VA) 94th%
Cool period mean temp.	32.4° F (0.22° C) (VA®) 100th%	30.5° F (-0.83° C) (N) 80th%	30.9° F (-0.61° C) (A) 88th%	28.9° F (-1.72° C) (N) 61st%	32.3° F (0.17° C) (VA) 98th%
Cool period min. temp.	25.3° F (-3.72° C) (E®) 100th%	20.8° F (-6.22° C) (N) 67th%	21.1° F (-6.06° C) (N) 78th%	21.0° F (-6.11° C) (N) 69th%	24.6° F (-4.11° C) (VA) 98th%
Warm period max. temp.	71.3° F (21.8° C) (A) 88th%	70.9° F (21.6° C) (N) 82nd%	68.9° F (20.5° C) (N) 38th%	69.5° F (20.8° C) (N) 50th%	67.8° F (19.9° C) (N) 22nd%
Warm period mean temp.	61.7° F (16.5° C) (VA) 96th%	59.9° F (15.5° C) (N) 60th%	59.1° F (15.1° C) (N) 46th%	60.3° F (15.7° C) (N) 70th%	59.1° F (15.1° C) (N) 44th%
Warm period min. temp.	51.5° F (10.8° C) (VA) 96th%	48.4° F (9.11° C) (N) 40th%	48.9° F (9.39° C) (N) 48th%	50.6° F (10.3° C) (VA) 92nd%	50.0° F (10.0° C) (N) 78th%

(N) = normal

(A) = anomalous

(VA) = very anomalous

(E) = extreme

® denotes the record for the period

Tendencies

Tendencies are analyzed for all sixteen parameters and for 10, 20, and 30 year running averages of mean temperature and precipitation for the cool and warm periods.

Running averages for cool period mean temperature and total precipitation are analyzed (Fig. 1c, 2c, and 3c). All three running averages exhibit the same pattern of changing temperature and precipitation. In terms of temperature, they each show a decrease till the mid 1980's with an increase since that time. The overall changes for the temperature running averages are decreases by -1.02° F (-0.57° C), -0.91° F (-0.51°C), and -0.53° F (-0.29° C) for the 10, 20, and 30 year running averages, respectively. These temperature data are relatively insignificant in comparison to the precipitation changes. All three running averages exhibit overall increases in precipitation over the period by +3.0 inches (76.2mm), +2.3 inches (58.4mm), and +1.7 inches (43.2mm) for the 10, 20, and 30 year running averages, respectively. These data seem to indicate that the cool periods are becoming wetter.

Warm period mean temperature and precipitation are also analyzed with 10, 20, and 30 year running averages (Fig. 4c, 5c, and 6c). All running averages show a steady decrease in mean warm period temperatures and a steady increase in total warm period precipitation. The decreases in temperature are -2.09° F (-1.16° C), -1.71° F (-0.95° C), and -1.09° F (-0.61° C) and the increases in precipitation are +1.8 inches (45.7mm), +2.0 inches (50.8mm), and +1.3 inches (33.0mm) for the 10, 20, and 30 year running averages, respectively. These data seem to indicate that the warm periods are becoming cooler and wetter.

Cool period maximum, mean, and minimum temperatures along with total cool period precipitation are analyzed for the period (Fig. 7c). Overall changes in cool period temperatures are not completely in sync. Maximum temperatures have been highly variable and essentially unchanged with a difference of just 7/100ths° F over the period.

Minimum temperatures have decreased slightly by -1.22° F (-0.68° C) creating an even smaller overall decrease in the means at -0.56° F (-0.31° C). Despite these very small changes in temperature over the period, the five years during the study period have yielded very warm temperatures. The averages of the maximums, means, and minimums during the study period are greater than the averages for the whole period by 2.31° F (1.28° C), 2.54° F (1.41° C), and 2.75° F (1.53° C), respectively. All three of these differences in the averages are greater than one standard deviation from the average of the whole period for their respective parameter. Despite this, all three temperatures failed the significance test with t-probabilities of 0.40, 0.54, and 0.76 for the maximums, means, and minimums, respectively. For the maximums, only 2001 is considered normal (Table 5.3). The years 1998, 1999, 2000, and 2002 are the fifth warmest, second warmest, the warmest, and the fourth warmest for the period, respectively. This is four out of the top five warmest winter maximums. For the minimums, only 1998 and 2002 are considered to be at least anomalous (Table 5.3). The years 1998 and 2002 are the warmest and the second warmest minimums of the period, respectively. For the means, 1998, 2000, and 2002 are the warmest, seventh warmest, and second warmest means of the period, respectively (Table 5.3). Both 1999 and 2001 are considered normal for the means.

Total cool period precipitation has revealed an overall increase over the period (Fig. 8c). The increase is by +2.6 inches (66.0mm) and the average cool period precipitation during the study period is greater than the average for the whole period by 0.4 inches (10.2mm). All cool period precipitation years are considered normal for this station (Table 5.3). These data are validated by the significance test in which they failed with an almost one to one t-probability at 0.96.

The cool periods at this station have been getting slightly wetter and minimum temperatures have cooled slightly. But temperatures have not changed much overall. However, the recent period of study has yielded some of the warmest readings for the period while precipitation is just slightly higher than it is for the whole period.

Warm period maximum, mean, and minimum temperatures along with total warm period precipitation are also analyzed over the period (Fig. 9c). All temperatures exhibit overall decreases with the most significant decreases associated with the maximums. The overall temperature changes for the period are -2.79° F (-1.55° C), -1.72° F (-0.96° C), and -0.70° F (-0.39° C) for the maximums, means, and minimums, respectively. The average temperatures are warmer for the study period than for the whole period but only slightly so. Averages for the study period are warmer than the whole period by 0.24° F (0.13° C), 0.56° F (0.31° C), and 0.87° F (0.48° C) for the maximums, means, and minimums, respectively. However, all the temperatures failed the significance test with t-probabilities of 0.44, 0.66, and 0.81 for the maximums, means, and minimums, respectively. For the maximums, only 1998 is considered at least anomalous (Table 5.3). It is the seventh warmest for the period. For the minimums, only 1998 and 2001 are considered at least anomalous (Table 5.3). The years 1998 and 2001 are the third warmest and the fifth warmest for the period, respectively. For the means, 1998 is the third warmest for the period and is the only year considered at least anomalous for the study period (Table 5.3).

Total warm period precipitation has steadily increased over time by +3.0 inches (76.2mm) while the average precipitation for the study period is greater than that of the whole period by 2.3 inches (58.4mm) (Fig. 10c). However, the change is not considered significant as the data failed the significance test with a 0.31 t-probability of occurrence. Only 1998 and 1999 are considered normal for this station. The year 2000 is the sixth driest warm period while 2001 and 2002 are the second wettest and the wettest warm periods for the period, respectively (Table 5.3).

Warm periods at this station are becoming cooler and wetter with more cooling during the daily maximums. This could be the result of more convective activity in the afternoons that keeps temperatures down and increases total precipitation with the increased threat of rainfall. This could also mean that more frontal passages are present during the summer which are cooling the area and creating more precipitation. However, the later is questionable since the nightly minimums have not exhibited the same decreases that would be associated with frontal cooling.

The start, end, and length of the growing season are also analyzed over the period (Fig. 11c, 12c, and 13c). The start of the growing season yields a very strong tendency toward earlier dates by -9.1 days (Fig. 11c). Also, the average start date during the study period is earlier than the average start of the whole period by 17.4 days. This average start date during the 5 year study period is greater than one standard deviation from the average start date for the whole period. The start dates have become earlier and the very early start dates during the study period represent this shift. However, the recent start dates are right on the border of failing the significance test with a 0.10 t-probability of occurrence. In this five year study period, only two years are considered normal (2001 and 2002). The years 1998, 1999, and 2000 are the third earliest, sixth earliest, and the earliest starts of the period, respectively (Table 5.3).

The end of the growing season exhibits a tendency toward earlier dates by -4.7 days (Fig. 12c). The average ending date during the study period is earlier than the average ending of the whole period by 2.4 days. This shift is not as significant as with the start of the growing season but it is in the same direction. For some reason the whole season is shifting toward earlier times. According to the significance test this shift in the end of the growing season is not significant as it failed the test with a 0.54 t-probability of occurrence. During the five year study period, only one year is considered at least anomalous (Table 5.3). In 2000, the end of the growing season is the ninth earliest for the period occurring on September 22 of that year.

The combination of the changing start and the end of the growing season yields a longer length of the growing season by +4.4 days over the period (Fig. 13c). Also, the average length during the study period is greater than the average length during the whole period by 14.9 days. Overall, the study period has very long growing seasons. Along with this, these growing seasons scored a 0.10 t-probability in the significance test which is borderline passing for significance. Similar to the start of the growing season, the length has only two normal years (2001 and 2002) during the five year study period (Table 5.3). The years 1998, 1999, and 2000 are the fifth longest, seventh longest, and the longest growing seasons for the period, respectively.

The last freeze, first freeze, and freeze free period between them are analyzed as well (Fig. 14c, 15c, and 16c). The last freeze in the spring yields a tendency toward later dates by +5.5 days (Fig. 14c). Also, the average last freeze during the study period is later than the average of the whole period by 2.5 days. However, this parameter failed the significance test with a 0.49 t-probability of occurrence. Only the year 2000 is considered normal for last freeze date (Table 5.3). The years 1998 and 2001 are the sixth earliest and the eighth earliest for the period, respectively. Also, the years 1999 and 2002 are the second latest and the ninth latest for the period, respectively.

The first freeze in autumn shows a strong tendency toward earlier dates by -7.6 days (Fig. 15c). In addition to this tendency, the average first freeze during the study period occurs 7.4 days earlier than the average date of the whole period. Despite this, the parameter failed the significance test with a 0.40 t-probability of occurrence. The only year considered to be at least anomalous is 2000 which has the sixth earliest first freeze date occurring on September 28 of that year (Table 5.3).

The combination of these later last freezes and earlier first freezes creates a large decrease in the freeze free period by -13.1 days over the period (Fig. 16c). Also, the average freeze free period during the study period is 9.9 days shorter than the average for the whole period. This difference is not considered significant, however, since this parameter failed the significance test with a 0.32 t-probability of occurrence. The years 1999 and 2000 are the only years considered to be at least anomalous (Table 5.3). The years 1999 and 2000 are the sixth shortest and the fifth shortest freeze free periods of the period.

These data show that, like with other stations that are analyzed, the growing season length and the freeze free period are not well linked. In this case, the growing season is expanding while the freeze free period is truncating by almost two weeks. This is the opposite scenario from what is found with the Birch Hill Dam, MA and the Chapel Hill, NC data where, in both cases, the growing season is shrinking while the freeze free period is expanding by around two weeks over the period. It seems baffling that in

Massachusetts and in North Carolina freeze free periods are expanding while in Michigan they are collapsing at a similar rate. In Cheboygen, it is possible that warm air is moving into the area earlier in the spring season and cold air is waiting until later in the fall creating the longer growing seasons. But perhaps there is also a consistent presence of high pressure during the transition seasons that is becoming more frequent and allowing for more radiational cooling that enables temperatures to fall below freezing at night. This persistent high pressure over the upper Midwest may be what is feeding volatile storms over the east coast during the transition seasons leading to their expanded freeze free periods.

The ending dates of snow cover as well as the length of these snow cover periods are also analyzed over the period (Fig. 17b and 18b). Both parameters show some large changes over the period. The tendency in the end of snow cover date is toward earlier dates until the early 1980's and toward later dates since that time (Fig. 17b). The last day with snow on the ground has tended toward earlier dates by -7.0 days, overall. The average date of last snow cover during the study period is just 1.7 days earlier than the average for the whole period. This small difference is validated by the failed significance test with this parameter at a 0.67 t-probability of occurrence. Only one year during the five year study is considered at least anomalous (Table 5.3). In 2000, the end of snow cover is the fourth earliest for the period occurring on February 27 of that year.

The period of snow cover on the ground has truncated -15.5 days over the period (Fig. 18b). This tendency is well represented by the difference between the average snow cover periods for the study period when compared to the average of the whole period. The average during the study period is 14.6 days shorter than the average for the whole period. Despite this, the parameter failed the significance test with a 0.31 t-probability of occurrence. Of the five years in the study, two are considered at least anomalous (Table 5.3). The years 1998 and 2000 are the seventh shortest and the sixth shortest snow cover periods for the period.

The changing snow situation is similar at Cheboygen to what is found at Birch Hill Dam, MA. Though the Cheybogen trends in snow cover are not as drastic as those of Birch Hill Dam, they are trending toward the same directions. In both cases, there are trends toward earlier melting of snow in the spring and shorter periods of snow on the ground. In this case, as with Birch Hill Dam, precipitation in the winter is increasing slightly leading to the assumption that precipitation events in the late winter and early spring are falling in the form of rain rather than snow.

Correlations amongst parameters

Many correlations are attempted to show relationships amongst the parameters. As with other station correlations, these yield poor results. The only decent correlations are between the start of the growing season and the length of the growing season and between the last freeze and the freeze free period. When compared to the length of the growing season, the start of the growing season shows a 0.80 correlation while the end of the growing season shows only a 0.46 correlation (Fig. 19c). As with other stations that are analyzed, the start of the growing season is more variable and therefore controls the length more readily than does the end of the growing season. The comparison between the last freeze and the freeze free period yields a better correlation than between the first freeze date and the freeze free period (0.73 for the last freeze and 0.67 for the first freeze). However, the difference between the correlations is not as significant (Fig. 20c). The last freeze in the spring is not as important in determining the length of the freeze free period as the start of the growing season is in determining the length of the growing season. It is also interesting to note that a poor correlation is found between the length of the growing season and the freeze free period as is expected based on the results (Fig. 21c). This is similar to other stations that are analyzed. There are no significant correlations found between any other parameters for this station.

Manhattan, KS- (representing Konza Prairie, KS)

The Manhattan data set includes climate records starting from November 1, 1948 through October 31, 2002, totaling 54 years of data for each parameter. The data consists of sixteen climatic parameters derived from records of temperature, precipitation, and snow on the ground at the site. Tendencies in these parameters are analyzed to determine changes over the period. Additionally, correlations amongst the parameters are attempted to investigate links between them. Finally, the data for the recent years during the NIGEC sponsored AmeriFlux CO_2 flux project at Konza Prairie, KS (1996-2002) is compared to the entire length of the study period to determine the statistical significance of these recent data (Table 5.4). An index is then used to quantify and compare years within the CO_2 flux study period in order to determine relative normality and abnormality of the data (Table 6.1).

Table 5.4 Value and Normalcy Index Classification for each parameter for each year

	1996	1997	1998	1999	2000	2001	2002
Start of the growing season	Day 40 (N) 24th%	Day 1 (E®) 2nd%	Day 53 (N) 45th%	Day 36 (N) 19th%	Day 52 (N) 43rd%	Day 72 (N) 82nd%	Day 26 (VA) 8th%
End of the growing season	Day 304 (N) 68th%	Day 298 (N) 53rd%	Day 305 (N) 71st%	Day 290 (N) 29th%	Day 280 (A) 12th%	Day 298 (N) 53rd%	Day 288 (N) 24th%
Length of the growing season	264Days (N) 86th%	297Days (E) 98th%	252 Days (N) 70th%	254 Days (N) 72nd%	228Days (N) 26th%	226 Days (N) 23rd%	262Days (N) 83rd%
Last freeze	Day 99 (N) 20th%	Day 132 (E) 96th%	Day 108 (N) 49th%	Day 108 (N) 49th%	Day 103 (N) 32nd%	Day 108 (N) 49th%	Day 115 (N) 74th%
First freeze	Day 292 (N) 57th%	Day 299 (N) 82nd%	Day 315 (E®) 100th%	Day 277 (A) 15th%	Day 280 (N) 26th%	Day 279 (N) 21st%	Day 286 (N) 40th%
Freeze free period	193 Days (N) 77th%	167Days (N) 22nd%	207Days (VA) 96th%	169 Days (N) 26th%	177Days (N) 38th%	171 Days (N) 30th%	171Days (N) 30th%
End of snow cover	----------	----------	----------	----------	----------	Day 62 (N) 89th%	Day 39 (N) 39th%
Snow cover period	----------	----------	----------	----------	----------	22 Days (N) 48th%	10 Days (VA®) 6th%
Cool period precipitation	4.5 in. (114mm) (VA) 4th%	9.9 in. (251mm) (N) 65th%	9.0 in. (229mm) (N) 54th%	19.9 in. (505mm) (E®) 100th%	----------	9.8 in. (249mm) (N) 62nd%	----------
Warm period precipitation	26.3 in. (668mm) (N) 67th%	18.5 in. (470mm) (N) 24th%	26.4 in. (671mm) (N) 69th%	20.9 in. (531mm) (N) 31st%	----------	29.9 in. (759mm) (N) 82nd%	21.5 in. (546mm) (N) 39th%
Cool period max. temp.	51.6° F (10.9° C) (N) 58th%	50.4° F (10.2°C) (N) 42nd%	49.9° F (9.94° C) (N) 37th%	53.9° F (12.2° C) (A) 85th%	----------	48.7° F (9.28° C) (N) 21st%	----------
Cool period mean temp.	38.4° F (3.56° C) (N) 27th%	38.8° F (3.78°C) (N) 40th%	39.9° F (4.39° C) (N) 54th%	42.9° F (6.06° C) (VA) 94th%	----------	36.3° F (2.39° C) (VA) 9th%	----------
Cool period min. temp.	24.8° F (-4.0° C) (VA) 8th%	26.8° F (-2.9°C) (N) 35th%	29.3° F (-1.5° C) (N) 75th%	31.3° F (-0.39° C) (VA) 96th%	----------	23.3° F (-4.83° C) (E®) 2nd%	----------
Warm period max. temp.	82.1° F (27.8° C) (N) 37th%	83.1° F (28.4°C) (N) 63rd%	83.7° F (28.7° C) (N) 73rd%	82.9° F (28.3° C) (N) 62nd%	----------	84.6° F (29.2° C) (N) 83rd%	84.0° F (28.9°C) (N) 75th%
Warm period mean temp.	70.7° F (21.5° C) (N)	71.3° F (21.8°C) (N)	72.2° F (22.3° C) (N)	70.1° F (21.2°C) (N)	----------	71.1° F (21.7° C) (N)	71.0° F (21.7°C) (N)

	46th%	63rd%	83rd%	25th%		56th%	54th%
Warm period min. temp.	58.7° F (14.8° C) (N) 50th%	59.0° F (15.0°C) (N) 60th%	60.3° F (15.7° C) (VA) 90th%	56.8° F (13.8° C) (A) 17th%	----------	57.1° F (13.9° C) (N) 19th%	57.4° F (14.1°C) (N) 21st%

(N) = normal

(A) = anomalous

(VA) = very anomalous

(E) = extreme

® denotes the record for the period

Tendencies

Tendencies are analyzed for all sixteen parameters and for 10, 20, and 30 year running averages of mean temperature and precipitation for the cool and warm periods.

Running averages for cool period mean temperature and total cool period precipitation are analyzed (Fig. 1d, 2d, and 3d). All running averages exhibit steady increases in cool period mean temperature and steady increases in total cool period precipitation over the period. The overall increases in temperature are +1.42° F (+0.79° C), +0.95° F (+0.53° C), and +0.84° F (+0.47° C) for the 10, 20, and 30 year averages, respectively. The overall increases in precipitation are more significant at +3.3 inches (83.8mm), +3.0 inches (76.2mm), and +2.0 inches (50.8mm) for the 10, 20, and 30 year averages, respectively. This data is indicating that cool periods have become warmer and wetter at this station.

Warm period mean temperature and total precipitation are also analyzed with 10, 20, and 30 year running averages (Fig. 4d, 5d, and 6d). All running averages exhibit slight decreases in temperature with steady increases in precipitation. The decreases in mean temperature are -0.50° F (-0.28° C), -0.08° F (-0.04° C), and -0.22° F (-0.12° C) for the 10, 20, and 30 year running averages, respectively. The increases in total precipitation are +2.3 inches (58.4mm), +1.7 inches (43.2mm), and +1.4 inches (35.6mm) for the 10, 20, and 30 year running averages, respectively. This data indicates that warm period mean temperatures are generally unchanged but the warm period has become slightly wetter over the study period.

Cool period maximum, mean, and minimum temperatures along with total cool period precipitation are analyzed for the period (Fig. 7d). Overall, cool period temperatures have increased slightly over the period. The increases are +1.32° F (+0.73° C), +1.46° F (+0.81° C), and +1.63° F (+0.91° C) for the maximums, means, and minimums, respectively. However, the average temperatures during the study period are mostly cooler than the average temperatures for the whole period. The only exception is with the maximums which are almost identical to the average for the whole period with <3/100ths° F difference in temperature. The study period averages for the means and the minimums are cooler than the whole period by 0.31° F (0.17° C) and 0.70° F (0.39° C), respectively. All of these temperatures failed the significance tests with t-probabilities of 1.00, 0.83, and 0.73 for the maximums, means, and minimums, respectively. The recent period is very similar to the overall period in terms of cool period temperatures. The years 2000 and 2002 are missing for cool period temperatures at this station. Of the remaining five study years, only 1999 is considered at least anomalous for all temperatures (Table 5.4). It has the ninth warmest maximums, the third warmest minimums, and the fourth warmest mean temperatures for the period. The year 2001 is also considered anomalous for the minimums and the means as they are the coolest minimums and the fifth coolest means for the period.

Total cool period precipitation has increased by +4.1 inches (104mm) over the period (Fig. 8d). The average precipitation for the study period is 1.1 inches (27.9mm) higher than the average for the whole period which supports that the recent years have been wetter. This is a small difference which failed the significance test with a 0.38 t-probability of occurrence. The years 2000 and 2002 are missing for cool period precipitation at this station. Of the five study years remaining, 1996 and 1999 are considered at least anomalous (Table 5.4). They are the second driest and the wettest cool periods for the period, respectively.

The cool periods at this station have been getting wetter over the period while temperatures have increased some. However, the study period was close to average or slightly cooler than the average for the whole period in terms of temperature and a little wetter than the average for the whole period in terms of precipitation.

Warm period maximum, mean, and minimum temperatures along with total warm period precipitation are also analyzed over the period (Fig. 9d). Warm period temperatures have barely changed with only slight decreases in all cases. The changes in temperature over the period are -0.46° F (-0.26° C), -0.19° F (-0.11° C), and -0.08° F (-0.04° C) for the maximums, means, and minimums, respectively. The average temperatures for the study period are not much different than the average temperatures for the whole period. The maximums and means are warmer during the study period by 0.54° F (0.3° C) and 0.09° F (0.05° C), respectively. The minimums are slightly cooler during the study period by 0.39° F (0.22° C). All temperatures failed the significance tests with t-probabilities of 0.99, 0.76, and 0.56 for the maximums, means, and minimums, respectively. The year 2000 is missing for warm period temperatures at this station. Of the remaining six study years, all warm period maximums and means are considered normal (Table 5.4). However, 1998 and 1999 are the sixth warmest and the ninth coolest warm period minimums for the period.

Total warm period precipitation has been variable but has increased by +1.2 inches (30.5mm) over the period (Fig. 10d). However, the average precipitation during the study period is essentially equal to the average for the whole period. The study period is just slightly drier than the whole period by 0.6 inches (15.2mm). All available study years are considered normal for warm period precipitation (Table 5.4). This is supported by the failure of the significance test with a 0.84 t-probability of occurrence.

Warm periods at this station have not changed significantly over the period. Temperatures have decreased slightly while precipitation has increased slightly. However, the study period exhibits warmer maximums and cooler minimums than the whole period as well as slightly drier summers. The slightly dryer summers during the study period have likely allowed for larger diurnal temperature ranges but the differences are minor.

The start, end, and length of the growing season are also analyzed over the period (Fig. 11d, 12d, and 13d). The start of the growing season yields a very strong tendency toward earlier dates by -22.6 days (Fig. 11d). Also, the average start date during the study period is earlier than the average start date for the whole period by 14.6 days. The tendency toward earlier start dates is supported by the early start dates during the study period. These start dates passed the significance test with a 0.07 t-probability of occurrence. The recent dates are significantly earlier than those of the whole period. During the study period, two out of the seven years studied are considered at least anomalous (Table 5.4). The years 1997 and 2002 are the earliest and the fourth earliest starts to the growing season for the period.

The end of the growing season also shows a strong shift toward earlier dates by -13.3 days (Fig. 12d). The average ending date during the study period is only 2.2 days earlier than the average date for the whole period, however. These recent ending dates failed the significance test with a 0.63 t-probability of occurrence. The only year during the study period that is considered at least anomalous is 2000 which is the sixth earliest end to the growing season for the period (Table 5.4).

The combination of the earlier start and end dates of the growing season creates an expanding growing season over the period by +9.3 days (Fig. 13d). The average length of the growing season during the study period supports this as it is 12.4 days longer than the average for the whole period. Despite this longer length, the recent period failed the significance test with a 0.13 t-probability of occurrence. All growing season lengths during the study period are considered normal with the exception of 1997 which is the second longest growing season for the period (Table 5.4).

The last freeze, first freeze, and freeze free period between them are also analyzed over the period (Fig.14d, 15d, and 16d). The last freeze in the spring exhibits a tendency toward earlier dates until around 1980 with a tendency toward later dates after that time (Fig. 14d). The overall trend is toward earlier dates by -6.7 days. However, the average last freeze during the study period is 1.7 days later than the average for the whole period. These recent last freezes failed the significance test with a 0.39 t-probability of occurrence. All data during the study period is considered normal with the exception of 1997 which is the third latest last freeze for the period (Table 5.4).

The first freeze in autumn also shows a tendency toward earlier dates by -4.9 days (Fig. 15d). In this case, the average first freeze during the study period is close to the average for the whole period at only 0.5 days later. This is validated by the failure of the significance test with a 0.61 t-probability of occurrence. The years 1998 and 1999 are the only years considered at least anomalous (Table 5.4). They are the latest first freeze and the eighth earliest last freeze for the period, respectively.

The overall change in the freeze free period as a result of these earlier first and last freezes is not very significant (Fig. 16d). Freeze free periods have been variable over the period and the overall tendency is toward longer periods but by only +1.8 days. The average freeze free period during the study period is just 1.2 days shorter than the average for the whole period. This also is validated by the failure of the significance test with a 0.34 t-probability of occurrence. All data is considered normal with the exception of 1998 which is the second longest freeze free period for the period (Table 5.4).

These data show that the length of the growing season and the freeze free period are shifting toward earlier times. Both parameters are experiencing earlier starts and ends to their seasons. The growing season data has changed more drastically while the changes in the freeze data are more moderate. The shifts in the seasons seem quite large. The growing season is shifted by about two and a half weeks towards an earlier time while the freeze free period is shifted by almost a week toward an earlier time. For some reason, warm air is coming into the area earlier in the spring while cold air is coming into the area earlier in the fall. Perhaps a higher frequency of low pressure systems which bring about weather changes is occurring in the area. During the transition seasons, more storminess could be pulling in more warm air in the spring and more cold air in the fall.

This could also be supported by the noted increases in precipitation in both the warm period and cool period for this station.

The snow cover data for this station is sporadic since not every year has experienced a significant snow cover. Only 23 of the 54 years for the period include a significant snow cover period. Neither snow cover parameter included sufficient data for a student t-test for significance. However, these ending dates of snow cover and snow cover periods are analyzed as well (Fig. 17c and 18c). The change in the ending date of snow cover has been variable with an overall tendency toward earlier dates by just -1.5 days (Fig. 17c). However, the average ending snow cover date for the two years that experience a significant snow cover during the study period is 6.9 days later than that of the whole period. The only study years with significant snow covers are 2001 and 2002 (Table 5.4). Both years are considered normal in terms of the end of snow cover date.

The period of snow cover on the ground, as with other stations, has tended towards shorter periods (Fig. 18c). The overall change for the period is a truncation by -12.4 days. The average snow cover period for the two years during the study period which experience a significant snow cover is 9.8 days shorter than that of the whole period. This represents the overall trend quite well. Of the two study years available with significant snow covers, 2002 is tied for the shortest snow cover period at only 10 days (Table 5.4). This is the shortest snow cover allowed by the criteria.

This station does not experience a significant snow cover on an annual basis. From the beginning of this period of study until the mid 1980's, a significant snow cover occurs about once every two years on average. Since then, however, only four years have a significant snow cover. These trends represent what is happening when there is a snow cover but it is important to note that snow covers themselves are becoming less frequent. The trends in the available data are similar to what is occurring at other stations with snowfall data.

Correlations amongst parameters

Many correlations are attempted to show relationships amongst parameters. As with other correlations for different stations, these attempts yield poor results. As with other stations, there is a stronger correlation between the start of the growing season and the length of the growing season than between the end of the growing season and the length of the growing season (0.83 to 0.53, respectively) (Fig. 19d). However, unlike most stations, the last freeze and the first freeze have similar correlations to the freeze free period (Fig. 20d). In fact, the first freeze actually has a better correlation to the freeze free period than does the last freeze (0.73 to 0.71). The beginning and the end of the freeze free period are equally as important in determining the length of the freeze free period. The length of the growing season, as is found at other stations, is determined more importantly by the start of the season than the end. Of the other correlations that are attempted, most yield poor results. However, there is one that is worth noting. When comparing the end of the snow cover to the start of the growing season there is a correlation of 0.68 (Fig. 24a). As the end of the snow cover occurs later so too does the start of the growing season. This correlation is not terrific, however, and with only 23 years of snow cover data to work with this correlation may be misleading. It does make sense though since one would expect the growing season to change as the date of snow cover melt off changes.

Martinsville, IN- (representing Morgan Monroe State Forest, IN)

The Martinsville data set includes climate records starting from November 1, 1950 through October 31, 2002, totaling 52 years of data for each parameter. The data consists of sixteen climatic parameters derived from records of temperature, precipitation, and snow on the ground at the site. Tendencies in these parameters are analyzed to determine changes over the period. Additionally, correlations amongst parameters are attempted to investigate links between them. Finally, the data for the recent years during the NIGEC sponsored AmeriFlux CO_2 flux project at Morgan Monroe State Forest, IN (1998-2002) is compared to the entire length of the study period to determine the statistical significance of these recent data (Table 5.5). An index is then used to quantify and compare years within the CO_2 flux study period in order to determine relative normality and abnormality of the data (Table 6.1).

Table 5.5 Value and Normalcy Index Classification for each parameter for each year

	1998	1999	2000	2001	2002
Start of the growing season	----------	Day 22 (A) 16th%	Day 54 (N) 34th%	Day 93 (VA) 96th%	Day 29 (A) 21st%
End of the growing season	----------	Day 291 (N) 63rd%	Day 281 (N) 30th%	Day 279 (N) 20th%	Day 293 (N) 72nd%
Length of the growing season	----------	269 Days (A) 88th%	227 Days (N) 46th%	186 Days (VA) 4th%	264 Days (A) 83rd%
Last freeze	----------	Day 90 (VA) 4th%	Day 104 (N) 30th%	Day 109 (N) 37th%	Day 139 (E®) 100th%
First freeze	----------	Day 291 (N) 74th%	Day 282 (N) 47th%	Day 280 (N) 38th%	Day 287 (N) 57th%
Freeze free period	----------	201Days (VA®) 100th%	178 Days (N) 68th%	171 Days (N) 47th%	148 Days (VA) 4th%
End of snow cover	----------	Day 15 (N)	Day 37 (N)	Day 12 (A®)	----------

		25th%	63rd%	13th%	
Snow cover period	----------	15 Days (N) 50th%	17 Days (N) 63rd%	29 Days (N) 75th%	----------
Cool period precipitation	17.2 in. (437mm) (N) 29th%	----------	17.3 in. (439mm) (N) 31st%	11.2 in. (284mm) (E®) 2nd%	25.0 in. (635mm) (VA) 96th%
Warm period precipitation	27.0 in. (686mm) (N) 85th%	14.8 in. (376mm) (VA) 8th%	33.3 in. (846mm) (VA) 98th%	26.9 in. (683mm) (N) 81st%	25.9 in. (658mm) (N) 77th%
Cool period max. temp.	48.7° F (9.28° C) (N) 71st%	48.9° F (9.39° C) (N) 78th%	51.1° F (10.6° C) (VA) 93rd%	45.7° F (7.61° C) (N) 22nd%	52.0° F (11.1° C) (E) 96th%
Cool period mean temp.	40.2° F (4.56° C) (A) 87th%	39.0° F (3.89° C) (N) 73rd%	40.3° F (4.61° C) (A) 89th%	36.2° F (2.33° C) (N) 22nd%	41.7° F (5.39° C) (VA) 98th%
Cool period min. temp.	31.3° F (-0.39° C) (VA®) 100th%	28.7° F (-1.83° C) (N) 71st%	28.9° F (-1.72° C) (N) 76th%	26.2° F (-3.22° C) (N) 31st%	30.8° F (-0.67° C) (VA) 98th%
Warm period max. temp.	----------	79.7° F (26.5° C) (N) 79th%	77.7° F (25.4° C) (N) 32nd%	77.6° F (25.3° C) (N) 30th%	78.8° F (26.0° C) (N) 51st%
Warm period mean temp.	----------	67.0° F (19.4° C) (N) 57th%	66.9° F (19.4° C) (N) 55th%	66.4° F (19.1° C) (N) 38th%	67.9° F (19.9° C) (N) 81st%
Warm period min. temp.	----------	53.7° F (12.1° C) (N) 34th%	55.6° F (13.1°C) (N) 81st%	54.6° F (12.6° C) (N) 55th%	56.5° F (13.6° C) (VA) 98th%

(N) = normal

(A) = anomalous

(VA) = very anomalous

(E) = extreme

® denotes the record for the period

Tendencies

Tendencies are analyzed for all sixteen parameters and for 10, 20, and 30 year running averages of mean temperature and precipitation for the cool and warm periods.

Running averages for cool period mean temperature and total precipitation are analyzed (Fig. 1e, 2e, and 3e). All three running averages show slight overall increases in cool period mean temperature but with different patterns over the period. The 10 year average exhibits an increase until the mid 1970's with a decrease since that time for an overall increase of +0.27° F (+0.15° C). The 20 year average exhibits an increase until around 1980 with a decrease since for an overall increase of +0.25° F (+0.14° C). Finally, the 30 year average exhibits a decrease until the early 1970's with an increase since for an overall increase of +0.26° F (+0.14° C). The trends for precipitation are increases followed by decreases over the period. The 10 year average exhibits an increase in precipitation until the mid 1970's with a decrease since that time while the 20 and 30 year averages show an increase until around 1980 with a decrease since. The overall changes for all three averages are +2.6 inches (66.0mm), +2.0 inches (50.8mm), and +1.5 inches (38.1mm) for the 10, 20, and 30 year running averages, respectively. Cool period temperatures have not changed much while precipitation has increased over the period.

Warm period mean temperatures and total precipitation are also analyzed with 10, 20, and 30 year running averages (Fig. 4e, 5e, and 6e). Warm period temperatures exhibit steady tendencies toward cooling for all three running averages. The overall changes for the period are -1.83° F (-1.02° C), -1.26° F (-0.7° C), and -1.02° F (-0.57° C) for the 10, 20, and 30 year running averages, respectively. Warm period precipitation has shown an overall increase for all cases. The changes are +3.4 inches (86.4mm), +3.4 inches (86.4mm), and +2.2 inches (55.9mm) for the 10, 20, and 30 year running averages, respectively. Overall, warm periods have become steadily cooler and wetter over the period.

Cool period maximum, mean, and minimum temperatures along with total cool period precipitation are also analyzed for the period (Fig. 7e). Cool period temperatures exhibit much variability over the period with slight tendencies toward warming in all cases. The overall increases in temperature are +0.24° F (+0.13° C), +0.31° F (+0.17° C), and +0.40° F (+0.22° C) for the maximums, means, and minimums, respectively. Average temperatures during the five year study period are warmer than average temperatures for the whole period by 1.58° F (0.88° C), 1.64° F (0.91° C), and 1.73° F (0.96° C), for the maximums, means, and minimums, respectively. However, all temperatures failed the significance tests with t-probabilities of 0.83, 0.75, and 0.67 for the maximums, means, and minimums, respectively. For the maximums, 2000 and 2002 are considered at least anomalous (Table 5.5). They are the fourth and the third warmest for the period, respectively. For the minimums, 1998 and 2002 are considered at least anomalous (Table 5.5). The year 1998 is the warmest for the period while 2002 is the second warmest. For the means, 1998, 2000, and 2002 are considered at least anomalous (Table 5.5). They are the seventh, sixth, and second warmest for the period, respectively.

Total cool period precipitation has been highly variable over the period (Fig. 8e). The overall change for the period is an increase of +1.0 inch (25.4mm). Despite this overall increase for the period, average cool periods during the study period are drier than average cool periods during the whole period. The average cool period is 1.6 inches (40.6mm) drier during the study period. This is not considered significant as this parameter failed the t-test with a 0.79 t-probability of occurrence. For this parameter, 1999 is missing. The years 2001 and 2002 are considered at least anomalous while 1998 and 2000 are considered normal (Table 5.5). The year 2001 is the driest winter for the period while 2002 is the third wettest.

Cool periods at this station are becoming slightly warmer and wetter over the period. However, the recent period of study exhibits fairly significant warmth and drier conditions when compared to the whole period. The trends over the period are very subtle while the difference between the recent study period and the whole study period is more significant. Overall, the study years are warmer and drier than the rest of the period.

Warm period maximum, mean, and minimum temperatures along with total warm period precipitation are also analyzed over the period (Fig. 9e). All temperatures exhibit overall decreases over the period. The changes are -3.22° F (-1.79° C), -2.07° F (-1.15° C), and -0.92° F (-0.51° C) for the maximums, means, and minimums, respectively. Despite the large decreases in warm period temperatures over the period, the recent study period exhibits slightly warmer conditions for the means and the minimums which are warmer by 0.35° F (0.19° C) and 0.85° F (0.47° C), respectively. The maximums are slightly cooler during the study period by 0.14° F (0.08° C). The maximums and the means both passed the significance test with t-probabilities of 0.06 and 0.07, respectively. However, the minimums failed the test with a t-probability of 0.83. The maximums are very cool for the recent period while the minimums are relatively normal. For warm period temperatures, 1998 is missing. Of the remaining study years, only the minimums from 2002 are considered at least anomalous (Table 5.5). They are the second warmest for the period. All other warm period temperature data is considered normal.

Total warm period precipitation has increased over the period (Fig.10e). The increase in warm period precipitation is by +3.9 inches (99.1mm) over the period while the average study year is wetter than the whole period by 2.9 inches (73.7mm). This parameter failed the significance test with a t-probability of 0.22. Of the five study years available, 1999 and 2000 are considered at least anomalous (Table 5.5). The year 1999 is the fourth driest warm period for the study period while 2000 is the second wettest.

Warm periods at this station are becoming cooler and wetter with much of the cooling in the daily maximums. The temperatures during the study period are not good representatives of the changes over the period while the wetter than average conditions during the study period are a good representation of the overall changes. The study years are slightly warmer and much wetter than the rest of the period. The cloud cover associated with the increased precipitation in the summer is probably the reason for the cooler maximums over the period and likely the reason why maximums are cool during the study period while minimums are warm. This is probably the result of more convection during the warm period.

The start, end, and length of the growing season are also analyzed over the period (Fig. 11e, 12e, and 13e). The start of the growing season has been quite variable over the period. The overall change is slightly later by +2.3 days (Fig. 11e). Despite this small change toward later dates, the start of the growing season during the study period occurs 8.5 days earlier on average than it does for the whole period. However, the recent start dates failed the significance test with a 0.33 t-probability of occurrence. For the study period, 1998 is missing. Of the remaining four years, only 2000 is considered normal (Table 5.5). The years 1999 and 2002 are the seventh and the tenth earliest start dates for the period, respectively, while 2001 is the third latest start date for the period.

The end of the growing season exhibits high variability over the period (Fig. 12e). The overall change is toward later dates by +2.8 days. However, the end of the growing season occurs 3.3 days earlier during the study period than it does during the whole period, on average. These recent ending dates failed the significance test with a 0.57 t-probability of occurrence. Of the 4 years available, 1999-2002 are all considered normal in terms of end of the growing season (Table 5.5).

The variability of the start and the end of the growing season creates a highly variable length of the growing season as well (Fig. 13e). The length tends toward shorter periods until the mid 1970's and toward longer periods since that time. The overall change is a tendency toward longer periods by just +0.5 days. The average length during the study period is 5.2 days longer than the average for the whole period, however. These recent longer lengths are not considered significant since this parameter failed the significance test with a 0.23 t-probability of occurrence. Of the available years (1999-2002), only 2000 is considered normal (Table 5.5). The years 1999 and 2002 are the seventh and ninth longest, respectively, while 2001 is the second shortest of the period.

The last freeze, first freeze, and freeze free period between them are analyzed as well (Fig. 14e, 15e, and 16e). The last freeze in the spring yields a tendency toward later dates by +4.0 days (Fig. 14e). However, the average last freeze during the study period occurs 1.4 days earlier than the average for the whole period. This small change is validated since this parameter failed the significance test with a 0.95 t-probability of occurrence. Of the available years (1999-2002), 1999 and 2002 are considered at least anomalous (Table 5.5). While 1999 is the second earliest date of the period, 2002 is the latest date of the period.

The first freeze in autumn yields a tendency toward earlier dates by -9.3 days while the average first freeze occurs 0.9 days later during the study period than it does during the whole period (Fig. 15e). All of the available first freeze data is considered normal for the study period. This is validated by this parameter's failure of the t-test with a 0.74 t-probability of occurrence.

The combination of later last freezes and earlier first freezes yields a freeze free period that slopes toward shorter periods by -13.3 days (Fig. 16e). However, the average freeze free period during the study period is 2.2 days longer than that of the whole period. This small difference is shown in this parameter's failure of the t-test with a 0.95 t-probability of occurrence. Of the available study years (1999-2002), 1999 and 2002 are considered at least anomalous (Table 5.5). The year 1999 is the longest for the period while 2002 is the second shortest for the period.

In both the growing season and the freeze data, the recent study period data conflicts with the overall tendencies for the period. However, these data are not well linked to each other as is also seen with other stations. The overall growing season length has expanded slightly while the freeze free period had truncated significantly. The reason for the large truncation in the freeze free period may be similar to what is occurring at Cheboygen, MI. Perhaps there is a more persistent existence of high pressure during the transition seasons, especially in the fall. This would allow more radiational cooling and warming that could drop temperatures below freezing at night but still allow enough warming so that the mean temperatures are not affected greatly. This would allow the growing season data to seem relatively unchanged while the freeze free period truncates.

The ending dates of snow cover as well as the length of the snow cover periods are also analyzed over the period (Fig. 17d and 18d). Unfortunately, only eight years of snow data are available for the entire period. Six of the eight years occur after 1990 and three of these years occur during the study period. The tendencies in this case must be taken lightly as well as any analysis of this data. Neither parameter included sufficient data for a student t-test analysis. The end of the snow cover exhibits tendencies toward earlier dates by -31.9 days while the snow cover period exhibits tendencies toward shorter periods by -2.3 days. The three significant snow covers during the study period are 10.9 days earlier on average for the ending dates and 2.7 days shorter on average for the snow cover periods. The only study years available are 1999-2001. The only data considered at least anomalous for the snow data is the ending date in 2001 (Table 5.5). It is the earliest out of the eight recorded for the period. The rest of the snow data is considered normal. However, it is difficult to make any real assessment of the snow situation with all of the missing data.

Correlations amongst parameters

Many correlations are attempted to show relationships amongst parameters. These, for the most part, yield poor results. But like other stations, there are some decent results for the growing season and for the freeze free correlations. When compared to the length of the growing season, the start of the growing season shows a 0.92 correlation while the end of the growing season shows only a 0.37 correlation (Fig. 19e). When compared to the freeze free period, the last freeze shows a 0.73 correlation while the first freeze shows only a 0.59 correlation (Fig. 20e). Once again, what occurs in the spring is more important than what occurs in the fall in determining the length of the growing season and the freeze free period. There are so other significant correlations found amongst any of the parameters for this station. As with the other stations, the length of the growing season is poorly correlated to the freeze free period (Fig. 21e).

<u>Willow Reservoir, WI</u>- (representing Willow Creek, WI)

The Willow Reservoir data set includes climate records starting from November 1, 1949 through October 31, 2002, totaling 53 years of data for each parameter. The data consists of sixteen climatic parameters derived from records of temperature, precipitation, and snowfall on the ground at the site. Tendencies in these parameters are analyzed to determine changes over the period. Additionally, correlations amongst the parameters are attempted to investigate links between them. Finally, the data for the recent years during the NIGEC sponsored AmeriFlux CO_2 flux project at Willow Creek, WI (1998-2002) is compared to the entire length of the study period to determine the statistical significance of these recent data (Table 5.6). An index is then used to quantify and compare years within the CO_2 flux study period in order to determine relative normality and abnormality of the data (Table 6.1).

Table 5.6 Value and Normalcy Index Classification for each parameter for each year

	1998	1999	2000	2001	2002
Start of the growing season	Day 102 (N) 16^{th}%	Day 91 (VA) 8^{th}%	Day 115 (N) 67^{th}%	Day 110 (N) 48^{th}%	Day 104 (N) 27^{th}%
End of the growing season	Day 274 (A) 87^{th}%	Day 264 (N) 38^{th}%	Day 267 (N) 60^{th}%	Day 267 (N) 60^{th}%	Day 266 (N) 53^{rd}%

Length of the growing season	172 Days (A) 88^{th}%	173 Days (VA) 91^{st}%	152 Days (N) 45^{th}%	157 Days (N) 60^{th}%	162 Days (N) 69^{th}%
Last freeze	Day 117 (E) 6^{th}%	Day 115 (E®) 2^{nd}%	Day 140 (N) 40^{th}%	Day 115 (E®) 2^{nd}%	Day 141 (N) 43^{rd}%
First freeze	Day 275 (N) 79^{th}%	Day 264 (N) 49^{th}%	Day 280 (VA) 92^{nd}%	Day 279 (A) 89^{th}%	Day 281 (VA) 94^{th}%
Freeze free period	158 Days (VA) 98^{th}%	149 Days (VA) 91^{st}%	140 Days (N) 80^{th}%	164 Days (E®) 100^{th}%	140 Days (N) 80^{th}%
End of snow cover	----------	----------	----------	Day 97 (N) 25^{th}%	Day 103 (N) 50^{th}%
Snow cover period	----------	----------	----------	142 Days (N) 57^{th}%	110 Days (VA®) 4^{th}%
Cool period precipitation	5.7 in. (145mm) (A) 10^{th}%	8.2 in. (208mm) (N) 50^{th}%	7.9 in. (201mm) (N) 44^{th}%	10.4 in. (264mm) (N) 79^{th}%	14.6 in. (371mm) (E®) 100^{th}%
Warm period precipitation	13.7 in. (348mm) (VA) 4^{th}%	24.6 in. (625mm) (N) 75^{th}%	21.2 in. (538mm) (N) 51^{st}%	20.5 in. (521mm) (N) 41^{st}%	28.1 in. (714mm) (VA) 92^{nd}%
Cool period max. temp.	35.9° F (2.17° C) (A) 87^{th}%	35.9° F (2.17° C) (VA) 91^{st}%	37.2° F (2.89° C) (VA) 96^{th}%	31.8° F (-0.11°C) (N) 42^{nd}%	36.6° F (2.56° C) (VA) 94^{th}%
Cool period mean temp.	27.6° F (-2.44° C) (VA) 98^{th}%	25.9° F (-3.39° C) (VA) 91^{st}%	26.6° F (-3.0° C) (VA) 94^{th}%	21.7° F (-5.72° C) (N) 43^{rd}%	27.7° F (-2.39° C) (VA®) 100^{th}%
Cool period min. temp.	19.0° F (-7.22° C) (E®) 100^{th}%	15.5° F (-9.17° C) (VA) 91^{st}%	15.6° F (-9.11° C) (VA) 92^{nd}%	11.2° F (-11.6° C) (N) 49^{th}%	18.3° F (-7.61° C) (E) 98^{th}%
Warm period max. temp.	72.2° F (22.3° C) (VA) 94^{th}%	68.4° F (20.2° C) (N) 35^{th}%	68.9° F (20.5° C) (N) 46^{th}%	69.6° F (20.9° C) (N) 62^{nd}%	67.4° F (19.7° C) (N) 17^{th}%
Warm period mean temp.	60.8° F (16.0° C) (VA) 98^{th}%	58.5° F (14.7° C) (N) 67^{th}%	58.7° F (14.8° C) (N) 69^{th}%	59.2° F (15.1° C) (N) 88^{th}%	58.3° F (14.6° C) (N) 62^{nd}%
Warm period min. temp.	49.1° F (9.5° C) (VA®) 100^{th}%	48.1° F (8.94° C) (A) 85^{th}%	47.9° F (8.83° C) (A) 83^{rd}%	48.4° F (9.11° C) (VA) 90^{th}%	48.7° F (9.28° C) (VA) 96^{th}%

(N) = normal

(A) = anomalous

(VA) = very anomalous

(E) = extreme

® denotes the record for the period

Tendencies

Tendencies are analyzed for all sixteen parameters and for 10, 20, and 30 year running averages of mean temperature and precipitation for the cool and warm periods.

Running averages for winter mean temperature and total precipitation are analyzed (Fig. 1f, 2f, and 3f). In terms of temperature, the 10 year average exhibits a tendency toward cooling until the late 1970's with a tendency toward warming since that time for an overall tendency toward cooling by -1.52° F (-0.84° C). The 20 and 30 year averages show overall slopes toward cooling with cooling until the mid 1980's followed by warming since that time. The overall tendencies for the 20 and 30 year averages are cooling by -1.26° F (-0.7° C) and -0.73° F (-0.41° C), respectively. The precipitation is increasing until around 1970 and decreasing since that time for the 10 and 20 year averages. For the 30 year average, precipitation is increasing until the late 1970's and decreasing since. The overall changes for the averages are a slight drying over the period by -0.3 inches (7.62mm), -0.5 inches (12.7mm), and < $1/10^{th}$ inch for the 10, 20, and 30 year averages, respectively. These data seem to indicate that cool period conditions are becoming warmer and drier after becoming cooler and wetter early in the climate period.

Warm period mean temperature and total precipitation are also analyzed with 10, 20, and 30 year running averages (Fig. 4f, 5f, and 6f). In terms of temperature, the 10 and 20 year averages exhibit tendencies toward cooling until the mid to late 1980's with tendencies toward warming since that time. The 30 year average shows an overall tendency toward cooling over the period. The overall changes for the averages are decreases in temperature by -3.43° F (-1.91° C), -2.80° F (-1.56° C), and -1.78° F (-0.99° C) for the 10, 20, and 30 year averages, respectively. Warm period precipitation is sloping toward slightly drier conditions for all three running averages. The changes are by -0.8 inches (20.3mm), -0.7 inches (17.8mm), and -0.4 inches (10.2mm) for the 10, 20, and 30 year averages, respectively. These data seem to indicate that the station is sloping toward much cooler and slightly drier warm periods.

Cool period maximum, mean, and minimum temperatures along with total cool period precipitation are also analyzed for the period (Fig. 7f). Cool period temperatures all show tendencies toward cooling until the late 1970's with tendencies toward warming since that time. The overall change is cooling for the maximums and warming for the minimums by -1.05° F (-0.58° C), -0.48° F (-0.27° C), and +0.16° F (+0.09° C) for the maximums, means, and minimums, respectively. The average temperatures for all three temperature parameters during the five year study period are warmer than average temperatures for the whole period by greater than one standard deviation of these means for the whole period. The averages during the study period are warmer than the averages during the whole period by 2.86° F (1.59° C), 3.51° F (1.95° C), and 4.26° F (2.37° C) for the maximums, means, and minimums, respectively. The only normal study year is 2001 for all temperatures (Table 5.6). All other years exhibit temperatures that are at least anomalously warm. Despite this, all three temperatures failed the significance test with t-probabilities of 0.59, 0.37, and 0.25 for the maximums, means, and minimums, respectively. For the means, 1998, 1999, 2000, and 2002 are the second warmest, the sixth warmest, the fourth warmest, and the warmest for the period, respectively. For the maximums, 1998, 1999, 2000, and 2002 are the seventh, sixth, third, and the fourth warmest for the period, respectively. Finally, for the minimums, 1998, 1999, 2000, and 2002 are the warmest, the sixth warmest, the fifth warmest, and the second warmest for the period, respectively.

Total cool period precipitation has revealed an overall slight increase over the period by +0.6 inches (15.2mm) (Fig. 8f). The average precipitation during the study period is 0.9 inches (22.9mm) greater than the average precipitation during the whole period. This small difference is considered insignificant and failed the t-test with a t-probability of 0.84. For the study period, 1998 and 2002 are considered at least anomalous (Table 5.6). They are the fifth driest and the wettest winters for the period, respectively.

Cool periods at this station are sloping toward cooler and slightly wetter conditions. Despite the tendencies toward cooling, temperatures during the study period are much warmer than the rest of the period. These are some of the warmest temperatures for the entire period. Precipitation, on the other hand, is well represented during the study period by the tendency toward a slight increase.

Warm period maximum, mean, and minimum temperatures along with total warm period precipitation are also analyzed over the period (Fig. 9f). Warm period maximums and means show overall tendencies toward cooling by -3.37° F (-1.87° C) and -1.33° F (-0.74° C), respectively. Warm period minimums show a tendency toward cooling until the mid 1980’s with a tendency toward warming since that time for an overall tendency toward warming by +0.74° F (+0.41° C). The average temperatures during the study period are all warmer than the average temperatures for the whole period by 0.19° F (0.11° C), 1.43° F (0.79° C), and 2.66° F (1.48° C) for the maximums, means and minimums, respectively. The average minimums during the study period are warmer than the whole period by greater than one standard deviation of the mean for the whole period. This is validated by the t-test as the minimums passed with a 0.01 t-probability of occurrence. The maximums and means failed the t-test with t-probabilities of 0.60 and 0.32, respectively. During the study period, warm period maximums and means are considered normal with the exception of 1998 which has the fourth warmest maximums and the second warmest means for the period (Table 5.6). The minimums, however, are considered at least anomalously warm for all five years of the study period. For 1998 through 2002, the years are the warmest, the ninth warmest, the tenth warmest, the sixth warmest, and the third warmest for the period, in chronological order.

Total warm period precipitation has not changed much over the period (Fig. 10f). The tendency is toward slightly more precipitation by +0.4 inches (10.2mm). However, the average precipitation during the study period is 0.1 inches (2.54mm) less than the average for the whole period. This small difference failed the significance test with a 0.86 t-probability of occurrence. For the study period, only 1998 and 2002 are considered at least anomalous (Table 5.6). They are the second driest and the fifth wettest warm periods, respectively.

Warm periods at this station are sloping toward cooler and slightly wetter conditions. However, the study period is a time that is much warmer and slightly drier than the rest of the period. The warmth is especially true for the minimums. The overall diurnal temperature range during the warm period has sloped toward truncation. This seems to indicate more cloud cover during the summer. This may be true but precipitation has not shown a large increase to indicate it.

The start, end, and length of the growing season are also analyzed over the period (Fig. 11f, 12f, and 13f). The start of the growing season yields a tendency toward later dates by +5.4 days (Fig. 11f). Despite this, the average start date during the study period is 6.60 days earlier than the average start date for the whole period. These earlier dates failed the significance test with a 0.29 t-probability of occurrence. For the study period, only 1999 is considered at least anomalous and is the fourth earliest occurrence for the period (Table 5.6).

The end of the growing season exhibits a tendency toward earlier dates by -2.4 days (Fig. 12f). However, the average end date during the study period is 2.0 days later than the average end date for the whole period. These later dates failed the significance test with a 0.85 t-probability of occurrence. For the study period, only 1998 is considered at least anomalous and is the seventh latest occurrence for the period (Table 5.6).

The tendency toward later dates for the start and earlier dates for the end of the growing season yield a tendency in the length of the growing season toward truncation by -7.8 days (Fig. 13f). Despite this tendency, the study period exhibits average growing season lengths that are 8.62 days longer than those of the whole period. These longer growing seasons failed the significance test with a 0.34 t-probability of occurrence. For the study period, 1998 and 1999 are considered at least anomalous (Table 5.6). They are the seventh and sixth longest growing seasons for the period, respectively.

The last freeze, first freeze, and freeze free period between them are also analyzed over the period (Fig. 14f, 15f, and 16f). The last freeze in the spring exhibits a tendency toward earlier dates by -20.1 days (Fig. 14f). This tendency is well represented by the study period where the average last freeze dates are earlier than the average last freeze dates of the whole period by 17.8 days. The difference between the average dates of the study period and the average date of the whole period is greater than one standard deviation of the mean for the whole period. Last freeze dates during the study period are much earlier than the rest of the period on average. This is validated by the parameter's passing of the t-test with a 0.06 t-probability of occurrence. For the study period, 2000 and 2002 are considered normal while 1998, 1999, and 2001 are all considered extreme (Table 5.6). These are the top three earliest last freeze dates for the period, occurring in late April.

The first freeze in autumn exhibits a strong tendency toward later dates by +19.5 days (Fig. 15f). This tendency is well represented by the study period where the average first freeze dates are later then the average first freeze dates of the whole period by 13.1 days. This is also validated by the parameter's passing of the significance test with a 0.03 t-probability of occurrence. For the study period, only 1998 and 1999 are considered normal (Table 5.6). The years 2000, 2001, and 2002 are the fifth, sixth, and fourth latest first freeze dates of the period.

The tendencies toward much earlier last freezes and much later first freezes yield a tendency toward much longer freeze free periods (Fig 16f). The freeze free period exhibits an enormous expansion by +39.6 days over the period. This expansion is well represented by the study period where the average freeze free period is 30.8 days longer than the average freeze free period for the whole period. This difference in the averages is greater than one standard deviation of the mean for the whole period. The freeze free periods during the study period are much larger than those of the whole period on average. This is validated by this parameter's passing of the significance test with a 0.02

t-probability of occurrence. Only 2000 and 2002 are considered normal during the study period (Table 5.6). The years 1998, 1999, and 2001 are the second longest, sixth longest, and the longest freeze free periods of the period.

The growing season data and the freeze data are yielding trends in different directions. The growing season is truncating while the freeze free period is expanding drastically. This is similar to what is happening with the Birch Hill Dam, MA and the Chapel Hill, NC data. Similar to what is happening on the east coast, the upper Midwest is experiencing colder air later in the spring and earlier in the fall while freezes are being pushed to earlier times in the spring and later times in the fall. This could be the result of more active fronts during the transition seasons that are moving the air around more and bringing in cooler conditions as well as cloud cover. This moving air and cloud cover could be making it more difficult for freezes to occur during the transition seasons.

The snow cover data is relatively incomplete for this station (Fig. 17e and 18e). There is consistent data from the beginning of the period through 1976. From this point until the end of the period, only four years include snow cover data. Two of the years (2001 and 2002) occur during the study period. Neither parameter includes sufficient data for a student t-test analysis. The tendency for the end of snow cover is toward earlier dates by -10.1 days (Fig. 17e). The average end of snow cover date for the two available years in the study period is 3.0 days earlier than that of the whole period. The snow cover period yields a tendency toward shorter periods by -24.0 days (Fig. 18e). The average snow cover period for the two years available in the study period is 12.4 days shorter than that of the whole period. For the two available years, the snow cover data is considered normal with the exception of the snow cover period in 2002 (Table 5.6). This snow cover period is only 110 days and is the shortest snow cover period out of the twenty eight that are recorded.

The tendencies in the snow cover data are similar in direction to other stations with snow cover data. All stations show slopes toward earlier ending dates and toward shorter snow cover periods. Though the snow cover data is missing in a lot of cases, it is all sloping toward the same result.

Correlations amongst parameters

Many correlations are attempted to show relationships amongst parameters. This station yields poor results for most of the correlations that are attempted. This is similar to other stations that are analyzed. As with the other stations, the growing season and freeze data does yield some favorable comparisons. When compared to the length of the growing season, the start of the growing season shows a 0.86 correlation while the end of the growing season shows only a 0.68 correlation (Fig. 19f). Once again, the start of the growing season is more important in determining the length of the growing season than is the end of the growing season. When compared to the freeze free period, the last freeze in the spring shows a 0.84 correlation while the first freeze in the fall shows a 0.86 correlation (Fig. 20f). Manhattan, KS is the only other station that shows a slightly stronger correlation for the first freeze than for the last freeze. However, in both cases, the difference is small. There is also a poor correlation between the length of the growing season and the freeze free period (Fig 21f). This true for all stations analyzed and is expected with the results that are discovered in terms of the different trends for the parameters. All other correlations amongst the parameters that are attempted are considered poor as well.

VI. DISCUSSION

The six stations analyzed exhibit several similarities amongst them as well as some disparity in terms of the tendencies in the sixteen parameters used. In some cases, the change is more dramatic, while in others, there is less change. The information acquired from the data is valuable but also opens new doors and proposes new questions in terms of the causes of the changes in some cases. The six stations are discussed in terms of their similarities and differences in order to determine relative interdependence and to produce a broader picture of the influences from regional to synoptic scales. Tendencies, correlations amongst parameters, and individual study years are discussed.

First, the cool period is discussed in terms of tendencies in temperature and precipitation. For the running averages of mean temperature, all stations, with the exception of Martinsville, IN, exhibit slopes toward cooling until around the mid 1970's with slopes toward warming since (Figs. 1a-3f). The 30 year running average for winter mean temperature shows a similar slope at Martinsville, however, the 10 and 20 year averages show opposite tendencies. These opposite tendencies are weak in comparison and actually show slopes toward warming in the last decade as well. For changes in the actual maximums, means, and minimums, most stations show the same consensus (Figs. 7a-f). For the most part, stations exhibit an overall warming over the period or a cooling until around the mid 1970's followed by a warming. The overall tendency for most temperatures is toward warming. Some exceptions are the minimums at Birch Hill Dam, MA and at Cheboygen, MI as well as for the maximums at Willow Reservoir, WI which are cooling more significantly. All other slopes toward cooling are smaller. Chapel Hill, NC shows small slopes toward cooling in all three temperature parameters. Despite these slopes toward cooling, the study periods for the stations are much warmer than the rest of the period for the most part (Tables 5.1-5.6). The one exception is at Manhattan, KS where the study period is slightly cooler than the rest of the period on average. The other five stations, however, experience some of the warmest temperatures of the climate period during their study periods. These much warmer temperatures are responsible for the slopes toward warming in the later portions of the climate studies. Overall, the cool periods at the stations show warming at least in the last two decades and they show some of the warmest temperatures of the climate study occurring during the CO_2 flux study periods.

For the running averages, cool period precipitation exhibits slopes toward wetter conditions for all stations with the exception of Willow Reservoir, WI (Figs. 1a-3f). The slope toward drying at Willow Reservoir is very slight while the slopes toward higher precipitation are more significant for most of the stations studied. For changes in actual precipitation totals over the time period, all stations show tendencies toward wetter conditions with the exception of Chapel Hill, NC which shows a tendency toward slight drying (Figs. 8a-f). The study periods exhibit small differences from the whole period for most cases in terms of precipitation (Tables 5.1-5.6). Only Birch Hill Dam, MA and Manhattan, KS show a large difference in precipitation during the study period when compared to the rest of the period. Overall, cool period precipitation is increasing but the study periods, with the exception of a couple of stations, are not too different from average for the whole period.

The warm period is also discussed in terms of trends in temperature and precipitation. For all running averages of mean temperature, all stations exhibit slopes toward overall cooling for the most part (Figs. 4a-6f). Birch Hill Dam, MA, Chapel Hill, NC, and Willow Reservoir, WI show slight upward slopes toward warming during the last two decades, however, the overall tendencies are toward cooling. There seems to be more significant cooling across the Midwest than on the east coast. For changes in the actual maximums, means, and minimums, all stations show tendencies toward cooling with the exception of the minimums at Chapel Hill, NC and at Willow Reservoir, WI which show slight warming (Figs. 9a-f). The overall cooling is more significant at the three Midwestern stations than it is at the two east coast stations or at Manhattan, KS. Despite the overall tendencies toward cooling, all stations exhibit warmer than average temperatures during the study periods than compared to the whole periods (Tables 5.1-5.6). Some exceptions are cooler than average maximums at Chapel Hill, NC and Martinsville, IN and cooler than average minimums at Manhattan, KS. However, these cooler than average temperatures are less significant than the warmer than average temperatures that are present in the rest of the data. Overall, the warm periods are warmer during the study period than they are during the rest of the period.

For all running averages, warm period precipitation exhibits relatively dramatic increases in most cases (Figs. 4a-6f). Only Willow Reservoir, WI shows a very slight slope toward drying over the period. The rest of the stations show more significant slopes toward wetter conditions. For changes in actual precipitation totals over the time period, all stations show increases over the period (Figs. 10a-f). The increase at Willow Reservoir, WI is very slight but the rest of the stations show increases from one to as much as seven inches over the period. Willow Reservoir, WI and Manhattan, KS are just slightly drier during their study periods than the rest of the period (Tables 5.1-5.6). However, the other four stations experience very wet conditions during their study periods in comparison to the whole period. At least for the eastern four stations, the warm periods show tendencies toward wetter conditions and the study periods at these stations are wetter than the rest of the period.

The growing season at these stations is discussed in terms of its starts, ends, and lengths over the period. The growing season parameters show larger discrepancies between stations than do the temperature and precipitation parameters. The overall tendency in the start of the growing season is toward slightly later dates for three of the stations and toward, in some cases, much earlier dates for three of the stations (Figs. 11a-f). Willow Reservoir, WI, Martinsville, IN, and Chapel Hill, NC show slopes toward later dates by a few days while Manhattan, KS and Cheboygen, MI show tendencies of three weeks and one week toward earlier dates, respectively. Birch Hill Dam, MA shows a slight change toward earlier dates. In terms of the study periods, all of the stations, with the exception of Birch Hill Dam, MA, show earlier than average start dates (Tables 5.1-5.6). Birch Hill Dam, MA averages slightly later start dates during the study period. Even in stations with large overall tendencies toward later dates the averages during the study periods are earlier. For the most part, earlier spring warming is occurring during the flux study periods than during the rest of the period.

The overall tendency in the end of the growing season is toward earlier end dates for five out of the six stations (Figs. 12a-f). Only Martinsville, IN shows a slight slope toward later end dates over the period. Some of the end dates are occurring more significantly earlier as in Manhattan, KS where the end date is occurring two weeks earlier over the period. Despite the tendencies, the end dates during the study periods are quite close to the averages for the whole period (Tables 5.1-5.6). Willow Reservoir, WI shows slightly later than average end dates while Birch Hill Dam, MA shows little difference at all. The rest of the stations exhibit slightly earlier than average dates. None of the differences in the averages are significant with the exception of Chapel Hill, NC.

The overall tendencies in the length of the growing season are toward shorter periods for Birch Hill Dam, MA, Chapel Hill, NC, and Willow Reservoir, WI and toward longer periods for Cheboygen, MI, Manhattan, KS, and Martinsville, IN (Figs. 13a-f). The slopes toward shorter periods at Chapel Hill, NC and Willow Reservoir, WI and toward longer periods at Manhattan, KS are the most significant. During the study periods, the growing seasons are longer for most stations (Tables 5.1-5.6). Only Birch Hill Dam, MA has shorter than average growing seasons during its study period. Despite any strong tendencies toward shorter periods, the study periods exhibit longer than average growing seasons for the most part. Most of this is attributed to the overall earlier start dates of the growing season during the study periods.

The freeze free period at these stations is discussed and it exhibits variability amongst the stations much like the growing season. Many discrepancies are found amongst the stations. The overall tendencies in the last freeze dates in the spring are toward more significantly earlier dates at four of the stations and toward slightly later dates at two of the stations (Figs. 14a-f). Only Cheboygen, MI and Martinsville, IN show slopes toward slightly later dates. But for the other stations, freezes have sloped toward commencement earlier in the spring season. The average last freeze dates during the study periods are not much different from the overall averages for the whole period at Cheboygen, MI, Manhattan, KS, and Martinsville, IN (Tables 5.1-5.6). However, at the other three stations, average last freeze dates during the study periods are significantly earlier than the averages for the whole period.

The overall tendencies in the first freeze dates in autumn are toward later dates at Birch Hill Dam, MA, Chapel Hill, NC, and Willow Reservoir, WI and toward earlier dates at Cheboygen, MI, Manhattan, KS, and Martinsville, IN (Figs. 15a-f). The most significant tendencies are at Willow Reservoir, WI and Martinsville, IN. During the study periods, Birch Hill Dam, MA, Chapel Hill, NC, and Willow Reservoir, WI show much later than average first freezes than when compared to the whole period (Tables 5.1-5.6). The first freezes during the study period at Cheboygen, MI are much earlier than the average for the whole period. The other two stations show little difference between the averages.

The overall slopes in the freeze free period are toward much longer periods at Birch Hill Dam, MA, Chapel Hill, NC, and Willow Reservoir, WI and toward much shorter periods at Cheboygen, MI and Martinsville, IN (Figs. 16a-f). Manhattan, KS shows little change over the period. The average freeze free period during the study periods are much larger than the average for the whole period at Birch Hill Dam, MA, Chapel Hill, NC, and Willow Reservoir, WI (Tables 5.1-5.6). However, at Cheboygen, MI, the average freeze free period during the study period is shorter than the average for the whole period. The average freeze free periods at the other two stations show little difference from the averages of the whole period.

The snow cover data at these stations is discussed and the data is not consistent across all of the stations. Chapel Hill, NC experiences no significant snow covers over the period and is not discussed here. Manhattan, KS experiences a lower frequency of snow covers during later years in the period and also Martinsville, IN and Willow Reservoir, WI have some missing snow data over the period. Birch Hill Dam, MA and Cheboygen, MI are the only stations with consistent snow cover data over the period.

The overall slopes in the end of snow cover are toward earlier dates at four out of the five stations discussed (Figs. 17a-e). Manhattan, KS shows a less significant slope toward earlier dates than the other stations. The change in the end of snow cover date is from anywhere between one and four weeks at these stations. This is a more significant tendency toward an earlier melt off of snow in the spring season. The average end of snow cover date during the study periods is also earlier than the average for the whole period at four of the stations (Tables 5.1-5.6). At Manhattan, KS, the study period actually averages slightly later end of snow cover dates. However, this Manhattan, KS study period data only includes two years with a significant snow cover.

The overall slopes in the snow cover period are toward much shorter periods (Figs. 18a-e). At Martinsville, IN, the tendency is toward shorter periods but it is not nearly as significant as it is at the other four stations. At the other stations, the tendency is from anywhere between two and six weeks toward shorter periods. The same is true for the study periods where only Martinsville, IN shows slightly shorter periods on average and the rest of the stations show much shorter periods during the study periods than when compared to the whole period (Tables 5.1-5.6).

Correlations amongst parameters yield little in the way of favorable comparisons. However, there are some good correlations that involve the growing season and the freeze data that are common at all the stations. All stations exhibit a stronger correlation between the start of the growing season and the length of the growing season than between the end of the growing season and the length of the growing season (Figs. 19a-f). In all cases, the length of the growing season is determined more readily by the start of the growing season than by the end of the growing season. Therefore, variation in the spring will create variation in the whole growing season. This is supported by Savage and Davidson who find that variation in spring accounts for 1/3 to 2/3 of interannual variation of soil respiration (15). The interannual variation is mostly due to climatic factors.

A similar trend is found in correlations of the freeze data (Figs. 20a-f). In four of the six stations the last freeze in the spring shows a stronger correlation to the freeze free period than does the first freeze in the fall. At the other two stations, the last and first freezes are nearly equal in determining the length of the freeze free period. Once again, variation in the spring is more important in determining the length of the freeze free period than is the variation in autumn.

Each station has a slightly different length of the flux study period. Birch Hill Dam, MA includes the longest flux study period at twelve years while three stations are tied for the shortest flux study period at only five years. In Table 6.1, the normalcy index is used to rate each year at each station. It also includes the average rating for each year and the average rating for each station. From Table 6.1, the years can be ranked in order of normalcy and the stations can be ranked as well. Starting with 1998, so that all stations are included, the years ranked from most normal to least normal in terms of the parameters are 2001, 2000, 1999, 2002, and 1998. The stations ranked from most normal to least normal in terms of the CO2 flux study period climate data are Manhattan, KS, Martinsville, IN, Birch Hill Dam, MA, Chapel Hill, NC, Cheboygen, MI, and Willow Reservoir, WI. These rankings are based solely on the normalcy index which is derived from the statistical relationship of the data at each station as explained in chapter four.

Table 6.1 Normalcy Index Ratings for each year at each station

	Birch Hill Dam, MA	Chapel Hill, NC	Cheboygen, MI	Manhattan, KS	Martinsville, IN	Willow Reservoir, WI	Year averages
1991	0.62	----------	---------	----------	----------	----------	0.620
1992	0.81	----------	----------	----------	----------	----------	0.810
1993	0.85	----------	----------	----------	----------	----------	0.850
1994	0.88	----------	----------	----------	----------	----------	0.880
1995	0.81	----------	----------	----------	----------	----------	0.810
1996	0.79	----------	----------	0.90	----------	----------	0.845
1997	0.77	0.79	----------	0.79	----------	----------	0.783
1998	0.67	0.67	0.62	0.83	0.80	0.48	0.678
1999	0.69	0.83	0.85	0.76	0.82	0.62	0.762
2000	0.90	0.74	0.65	0.95	0.90	0.79	0.822
2001	0.81	1.00	0.90	0.90	0.83	0.81	0.875
2002	0.69	0.59	0.79	0.88	0.57	0.62	0.690
Station averages	0.774	0.770	0.762	0.859	0.784	0.664	0.785

VII. CONCLUSIONS

This climate study of the six NCDC stations has yielded some interesting results. In some cases, certain parameters have not changed much over time while some parameters show more significant change over the period for some stations. Also, the CO_2 study period is climatically anomalous for some parameters at certain stations. This could result in anomalous CO_2 flux data for these stations assuming that the NCDC stations are representative of the AmeriFlux stations. It is not possible to quantitatively measure the effect of the climate parameters on CO_2 flux with this study. However, some qualitative assessments can be discussed.

The average flux study period conditions at the stations are measured against the average conditions of the parameters for the whole period. In general, the cool period temperatures are very warm during the study period with exception of one station. The cool periods are wetter than average for the most part as well. Despite the wetter cool periods, snow has decreased in terms of its length of time on the ground for all stations. It is not known how the wetter conditions and less snow combine to contribute to net soil moisture. However, the cool period is a time of net flux of CO_2 to the atmosphere and the warmer conditions present during the study period may have enhanced this affect (9). CO_2 respiration to the atmosphere is increased with less snow on the ground which could also add to the affect of more CO_2 in the atmosphere during the cool periods (14). If the combination of wetter conditions and less snow on the ground yields higher soil moisture content then this may help moderate the affect by acting as a sink. However, plant productivity is low or none existent for the most part with these stations during the winter. Likely, the effects of these cool period climate parameters have combined to increase flux away from ecosystems during the cool periods for the stations as a whole.

The transition period between the cool period and the warm period is slightly anomalous for some stations as well. Spring variation accounts for a significant portion of overall interannual variability in soil respiration (15). Also, earlier warming and thawing can produce significant carbon uptake and earlier snow melt can change the timing of carbon fluxes (7, 8, and 14). During the study periods at these stations, the start of the growing season and snow melt have occurred earlier than average for the most part. Also, at three of the stations, the last freeze has occurred significantly earlier as well. The result of this earlier warming and thawing could result in significantly more uptake of CO_2 during the study periods. The absence of snow may moderate this affect slightly. But for the most part, these transitions between the cool periods and the warm periods during the study periods have probably contributed to more uptake of CO_2 based on these parameters.

Warm periods at these stations are warmer and wetter than average during the study periods for the most part. Also, the length of the growing season is significantly longer for five of the stations and the freeze free period is significantly longer for three of the stations. Each day that the growing season is changed has a large effect on overall carbon flux (13). The effects of a lengthened growing season and freeze free period could yield more CO_2 uptake. Also, the wetter conditions at these stations may have caused higher soil moisture that would also increase uptake during the study periods (14). However, the warmer temperatures at all of the stations may have dried out the soil causing increased respiration and decreased uptake due to lower plant primary productivity (4, 14, and 17). With this, it is difficult to say whether or not the warm periods have contributed to more respiration or to more sequestration during the study periods for these stations.

The transition between the warm period and the cool period yields conditions which are closer to normal than the other seasons. The ends of the growing seasons during the study periods are pretty close to normal. The first freezes, however, occur much later at three of the stations and much earlier at one of the stations. These differences amongst the stations probably cancel each other out for the most part. For the stations with later first freezes, perhaps CO_2 uptake continues until slightly later in the season and vice versa for the other stations. In the stations with earlier first freezes, a later start to the snow season could combine to produce more respiration (14). Since, first snow is not included in this study, it is not possible to make this assessment. It is difficult to discuss the CO_2 situation during the transition between the warm period and the cool period but the fluxes are probably close to normal during the study period.

The overall CO_2 flux conditions during the study periods are difficult to assess. The cool periods have probably contributed to more respiration while the transition between the cool period and the warm period has probably contributed to more uptake as a whole. However, the soil moisture situation during the warm period makes things more difficult. At some stations, the combination of warmer temperatures and wetter conditions may increase soil moisture while at others the opposite may be true. Since the transitions between the warm period and the cool period are fairly normal and the cool period and the transition between the cool period and the warm period may cancel each other out qualitatively, the soil moisture problem is likely the key to the overall CO_2 situation at the sites. The sites where soil moisture is increased during the warm period are probably a net sink for CO_2 while the sites where soil moisture is decreased during the warm period are probably a net producer of CO_2 during the study periods. However, this is a qualitative assessment.

It is also interesting to mention the potential synoptic implications that may be occurring which could be causing the changes in the parameters over the whole period. The individual parameters may combine to yield information in terms of the overall changing synoptic situation in the eastern half of the United States. For example, the end of the growing season is occurring earlier for five of the stations. This means that cold fronts that are synoptically driven are occurring earlier in the fall for the most part. Also, the first freeze dates for the east coast stations and for the Wisconsin station are occurring much later while the Michigan and the Indiana stations are freezing earlier during the transition between the warm period and the cool period. It may be true that a tendency toward high pressure centered in the eastern Midwest and a tendency toward low pressure along the east coast and the western Midwest is occurring.

Overall, the earlier ends to the growing seasons may indicate more active storm tracks during the transition between the warm period and the cool period. These storm tracks may be situated from southwest to northeast across the southeastern United States through New England and across the Great Plains through the upper Midwest and Wisconsin. In between these two storm tracks would lie general high pressure centered in the eastern Midwest. This would allow freezing temperatures to occur earlier in this region as a result of radiative cooling. The moving air in the path of the active storm tracks would reduce radiative cooling and create later first freezes at these stations. The Indiana station is actually the only station that has not experienced significantly earlier end of growing season dates. This supports this theory since cold fronts responsible for the earlier ending dates at the other stations would be the result of the active storm tracks and would not be present there. A similar situation may be present in the spring where the Michigan and Indiana stations are the only stations with later last freezes. Calm air due to high pressure could produce radiative conditions that are favorable for freezes later during the transition between the cool period and the warm period.

The cool periods and warm periods have been getting wetter for the most part over the time period. These could both be the result of either stronger or more frequent storms. The warm period increases may be due to increased convection though. This is supported by the fact that the four eastern most stations have experienced higher increases in warm period precipitation than the Wisconsin or the Kansas stations. This would be expected due to the higher humidity in the eastern part of the country. Increases in tropical systems may also be contributing to the warm period totals across these eastern stations. The wetter cool periods are likely due to increasingly active storm tracks or storm intensity, however.

It would be interesting to investigate whether any of these ideas are true or not. Perhaps a look at pressure tendencies during the transition seasons would yield some information regarding the synoptic trends over the eastern half of the U.S. If the east coast and the upper Midwest are trending toward lower average pressure and the eastern Midwest is trending toward higher average pressure during the spring and fall then this theory may have some validity. If these trends are true they may have some implications into trends in CO_2 fluxes. Also, cloud cover should be investigated at or near these stations over the time period especially during the warm period. The increased precipitation probably indicates increases in cloud cover that would hamper some plant photosynthetic production. Finally, an investigation into pressure frequencies may yield some important information pertaining to the intensity and the frequency of storms throughout the seasons. A higher wave number during the cool period and the transition periods may explain the increases in cool period precipitation and the cold fronts in the fall and warm fronts in the spring that effect the start and end of the growing season at the stations.

More active and frequent storms may have other implications as well. Thompson et al find that in the spring and early summer, deep convective venting of the boundary layer provides a net flux upward of CO and CO_2 to the free troposphere (18). They find that shallow cumulous and synoptic-scale weather systems make comparable contributions (18). So, an increase in storm activity or thunderstorm formation in late spring and early summer could help vent some CO_2 to the atmosphere. In terms of wave numbers, Reck finds that medium-scale waves in mid-latitudes contribute more to ozone variability than planetary scale waves (12). Therefore, higher wave number situations work more efficiently to mix air between the troposphere and the stratosphere as well as between the free troposphere and the boundary layer. This makes it imperative to investigate the frequency of wave numbers as well as other parameters in order to better determine the role of the free troposphere in CO_2 exchanges between ecosystems and the atmosphere.

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IX. APPENDIX

Figures 1-24

Figure 1a

Ten Year Running Average of Cool Period Mean Temperature and Precipitation

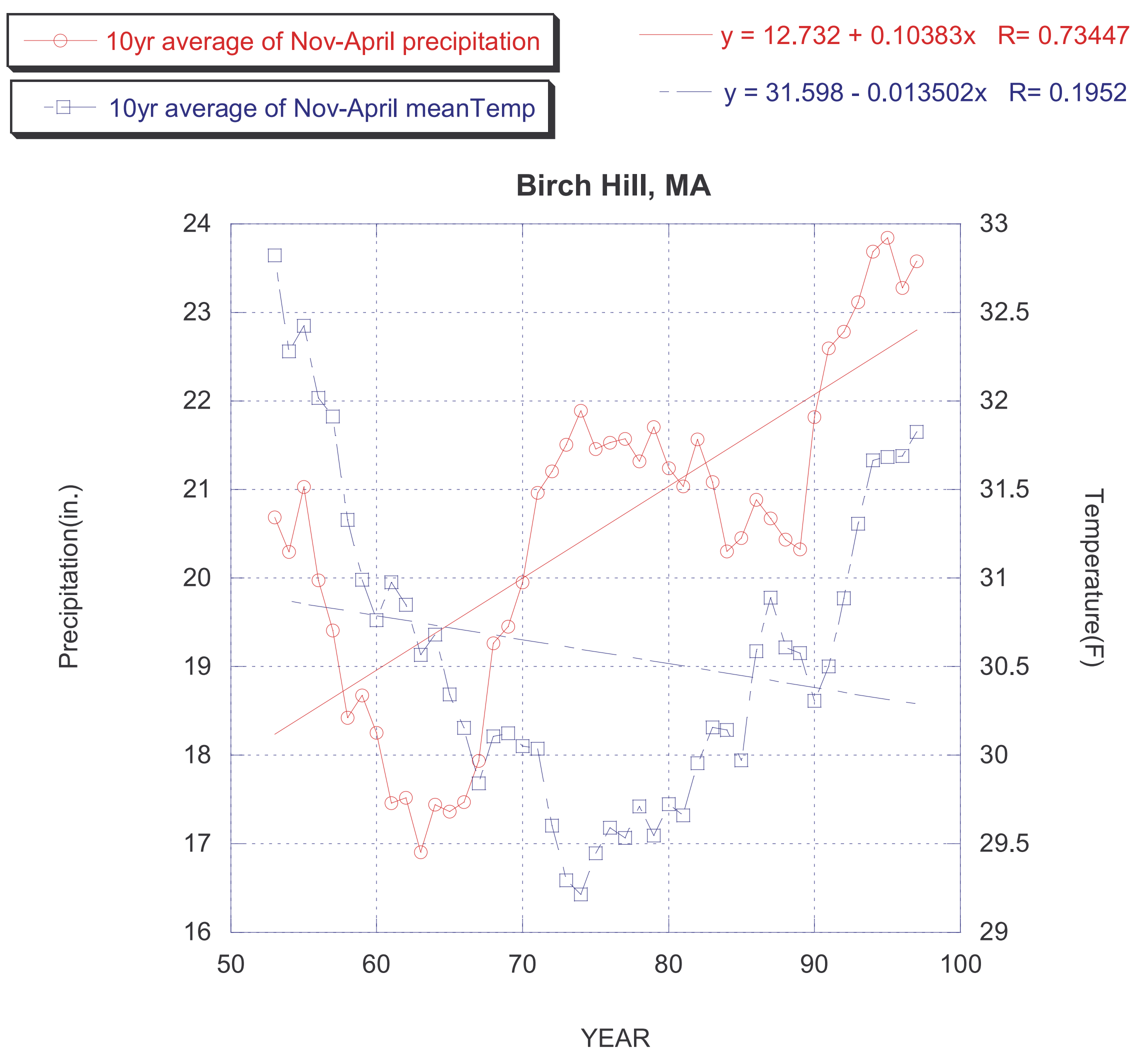


Figure 1b

Ten Year Running Average of Cool Period Mean Temperature and Precipitation

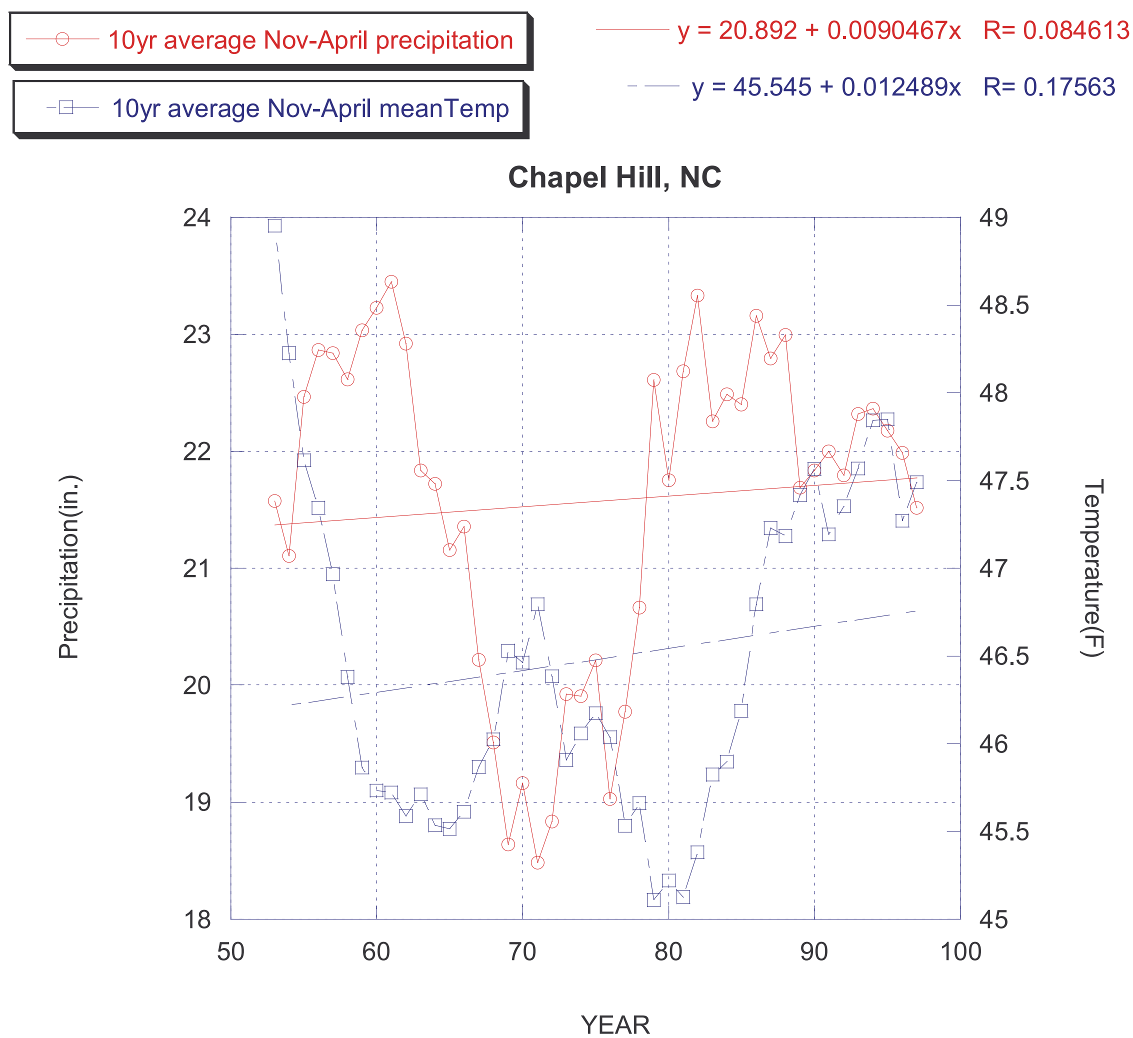


Figure 1c

Ten Year Running Average of Cool Period Mean Temperature and Precipitation

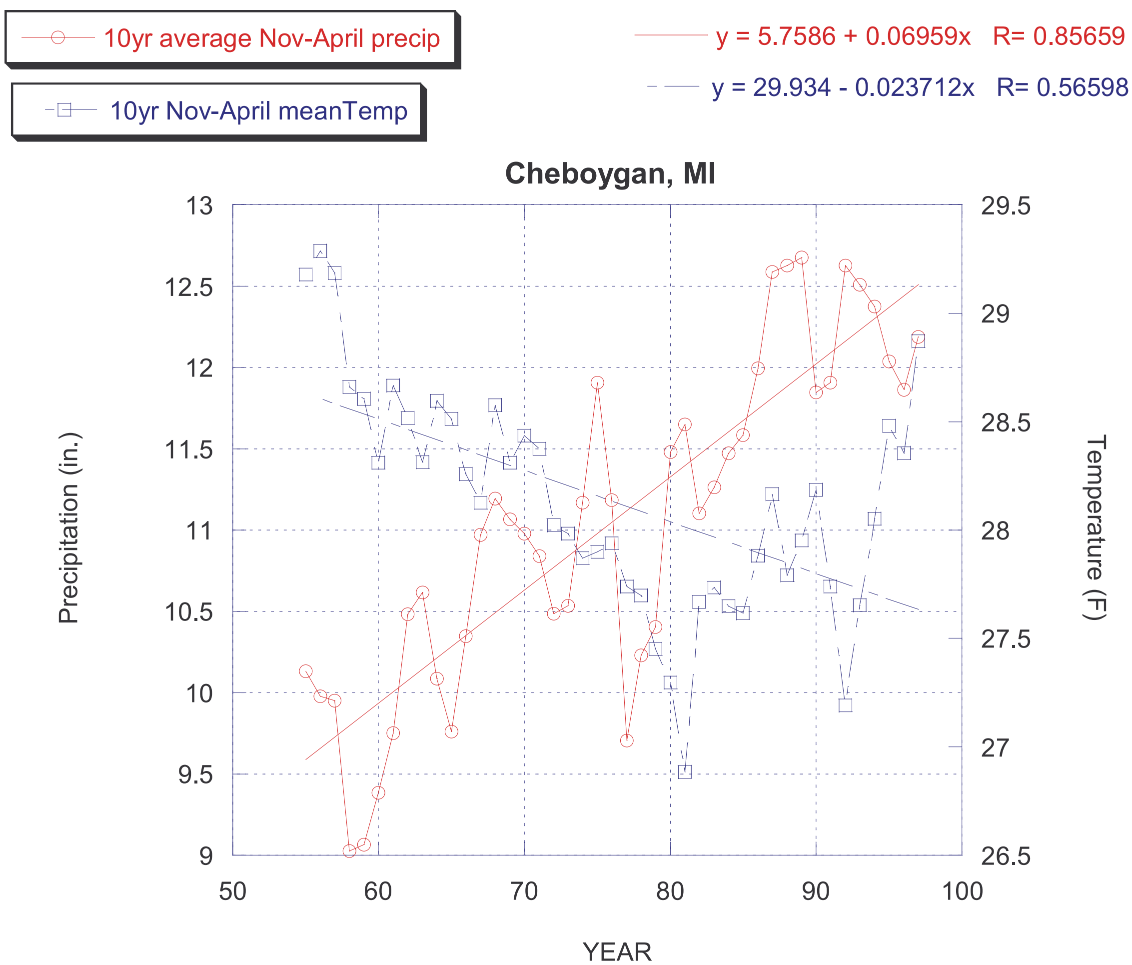


Figure 1d

Ten Year Running Average of Cool Period Mean Temperature and Precipitation

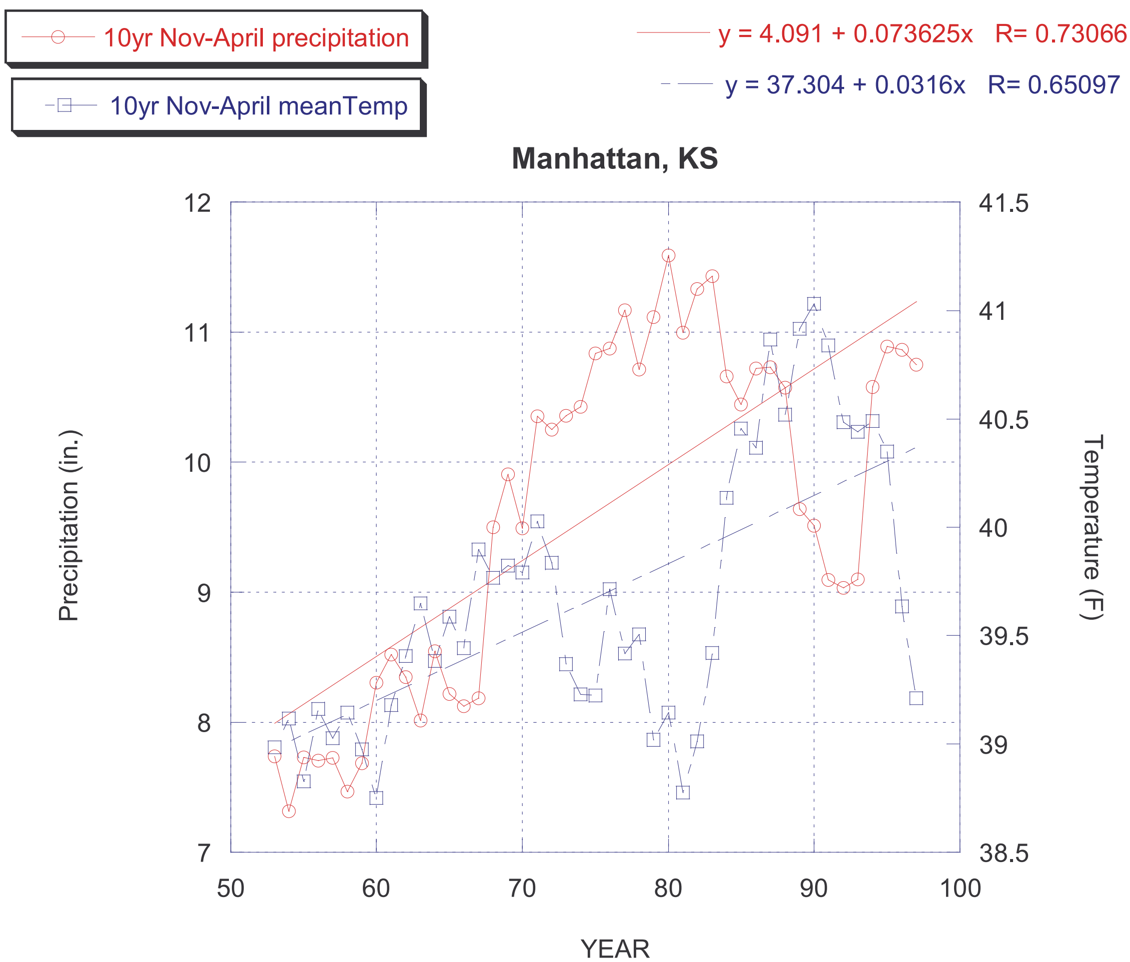


Figure 1e

Ten Year Running Average of Cool Period Mean Temperature and Precipitation

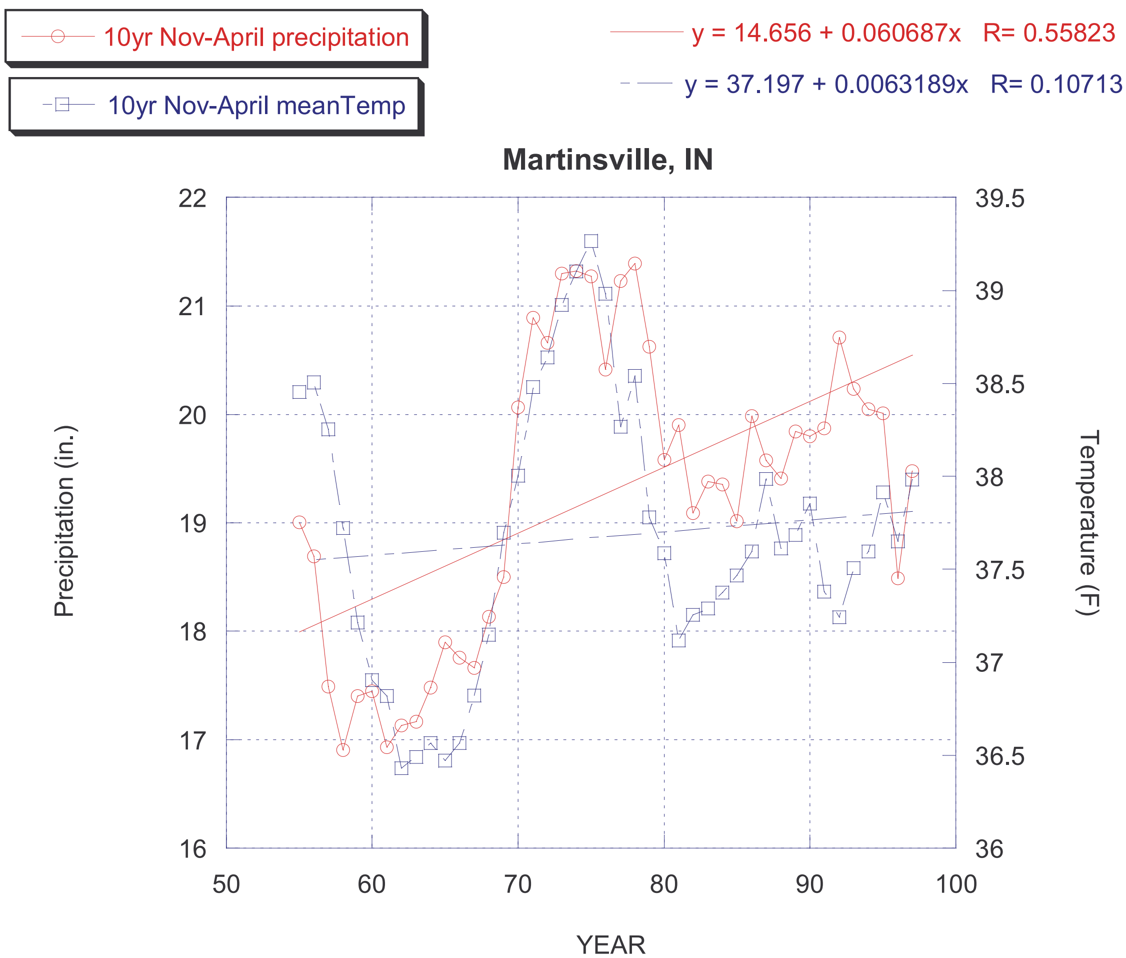


Figure 1f

Ten Year Running Average of Cool Period Mean Temperature and Precipitation

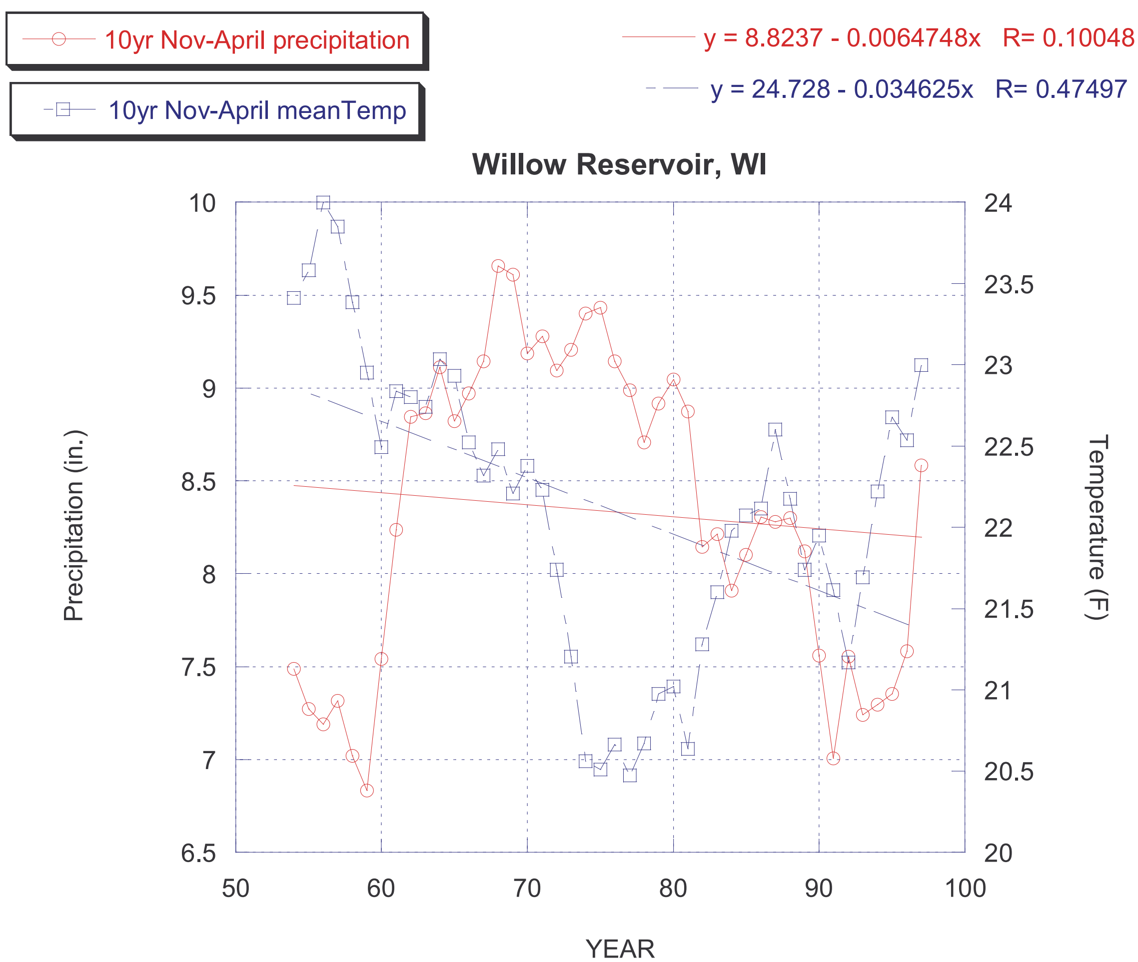


Figure 2a

Twenty Year Running Average of Cool Period Mean Temperature and Precipitation

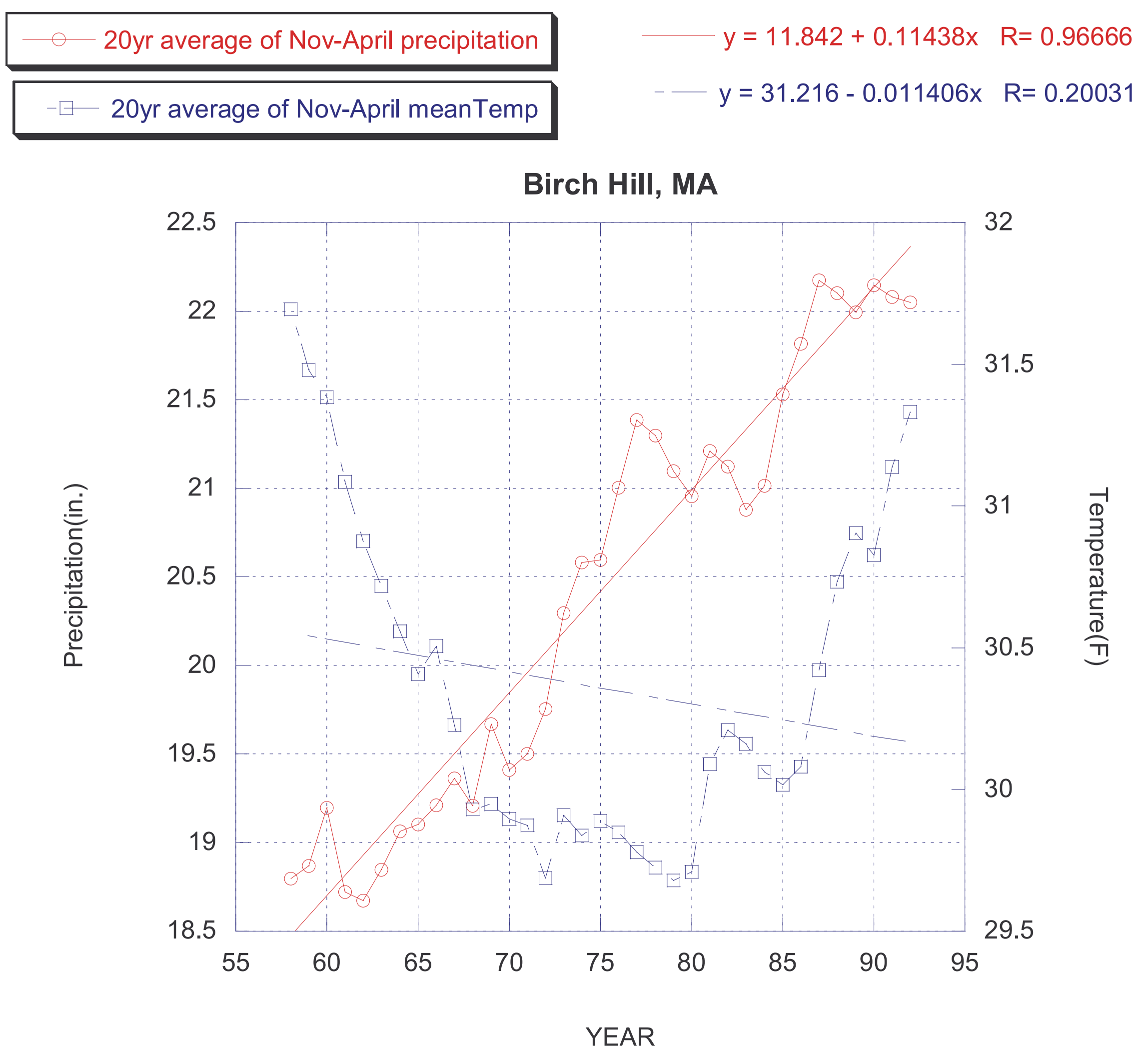


Figure 2b

Twenty Year Running Average of Cool Period Mean Temperature and Precipitation

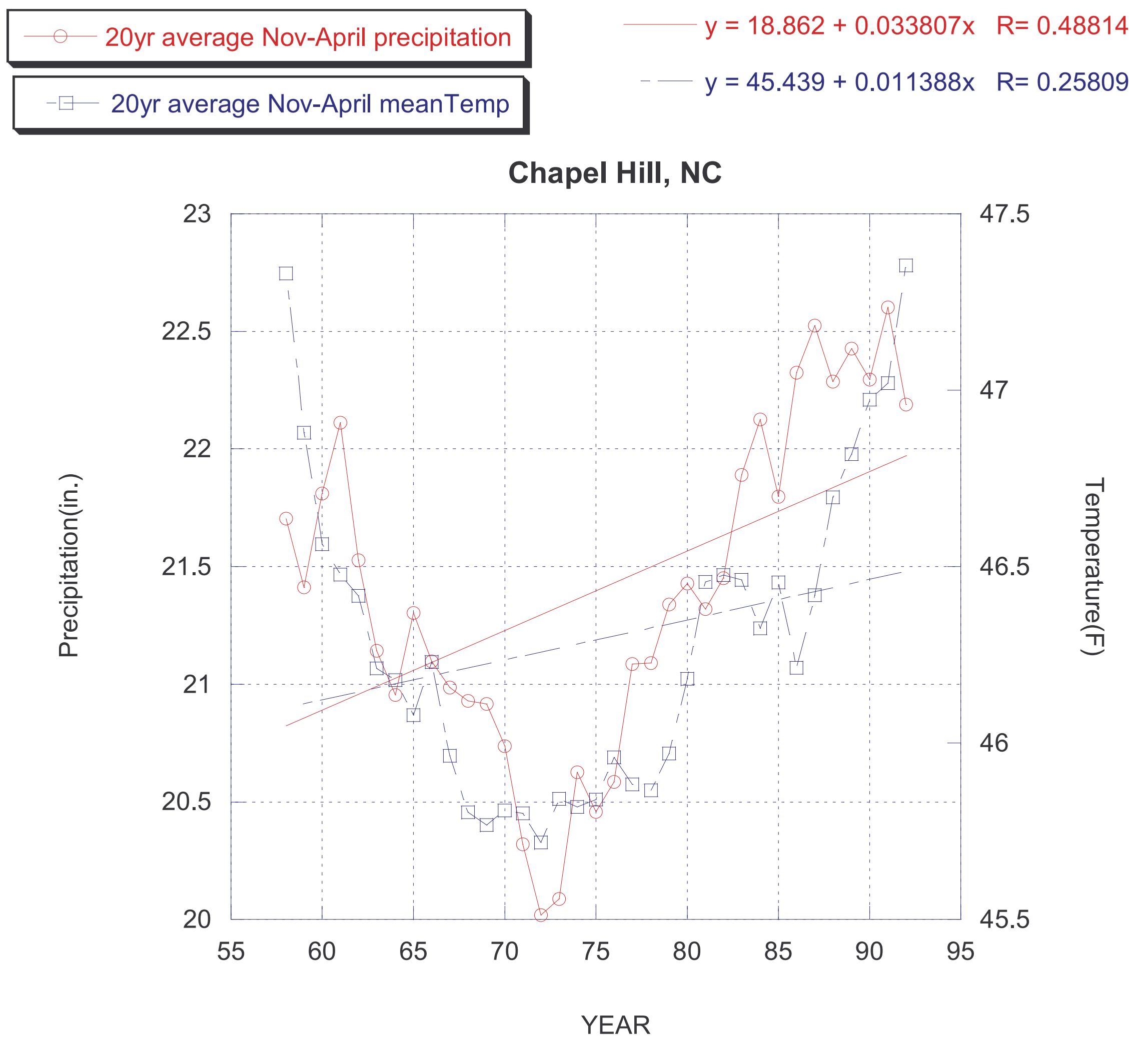
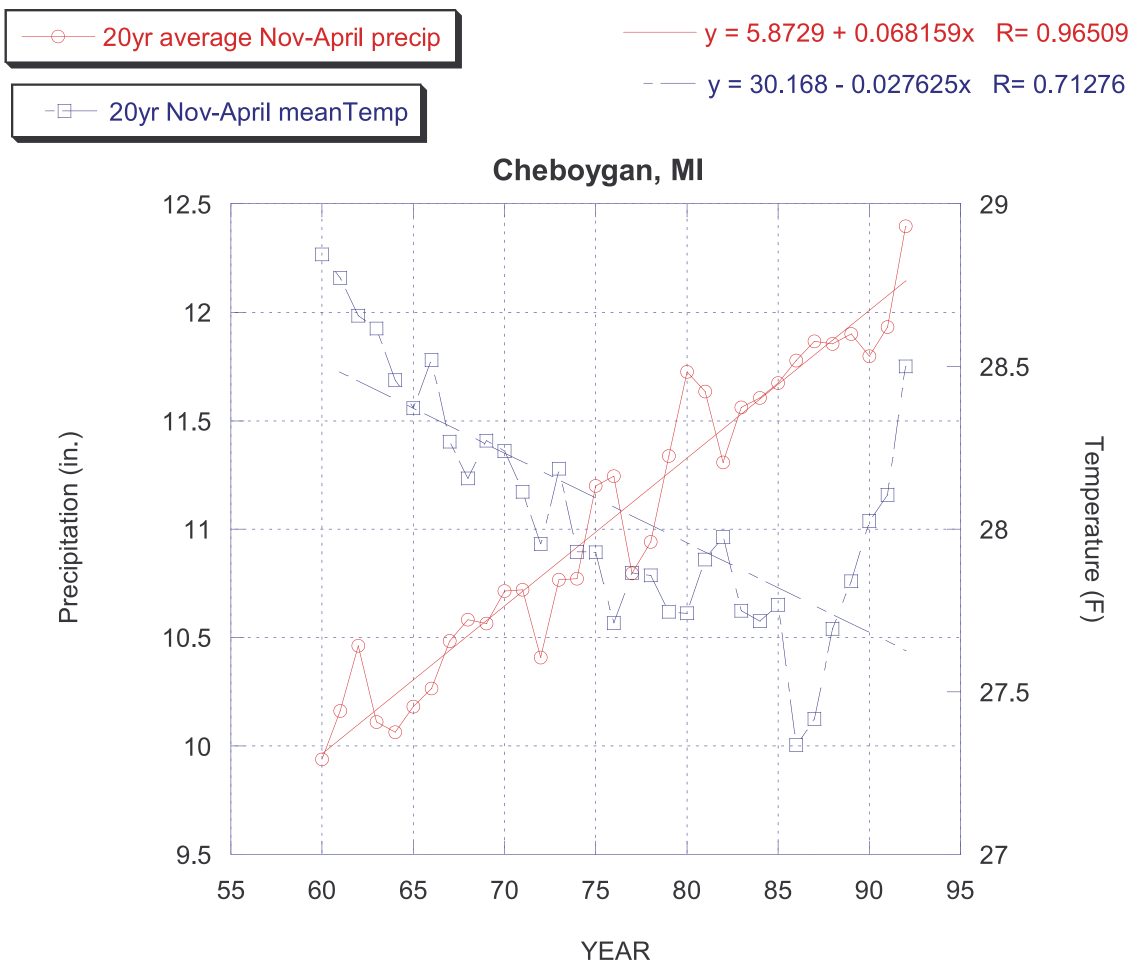


Figure 2c

Twenty Year Running Average of Cool Period Mean Temperature and Precipitation



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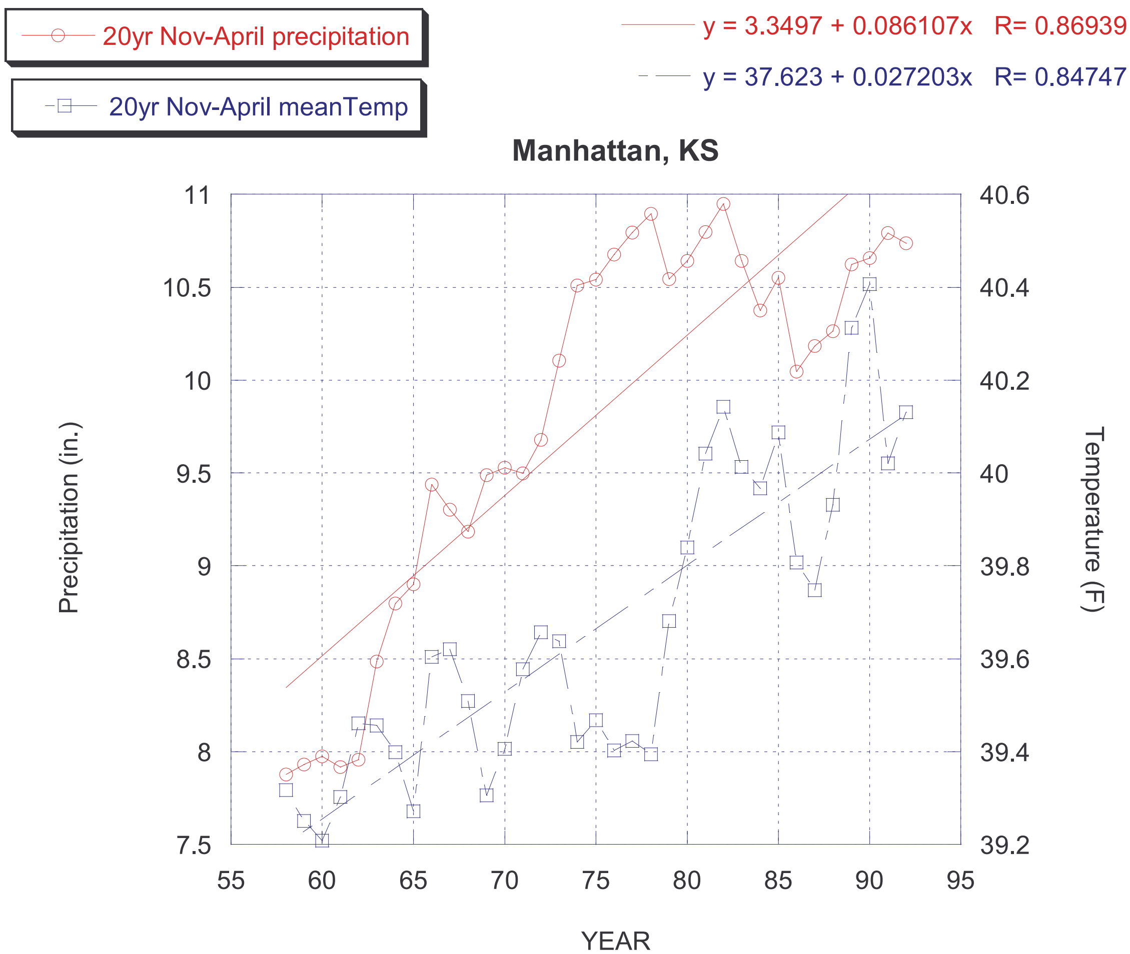

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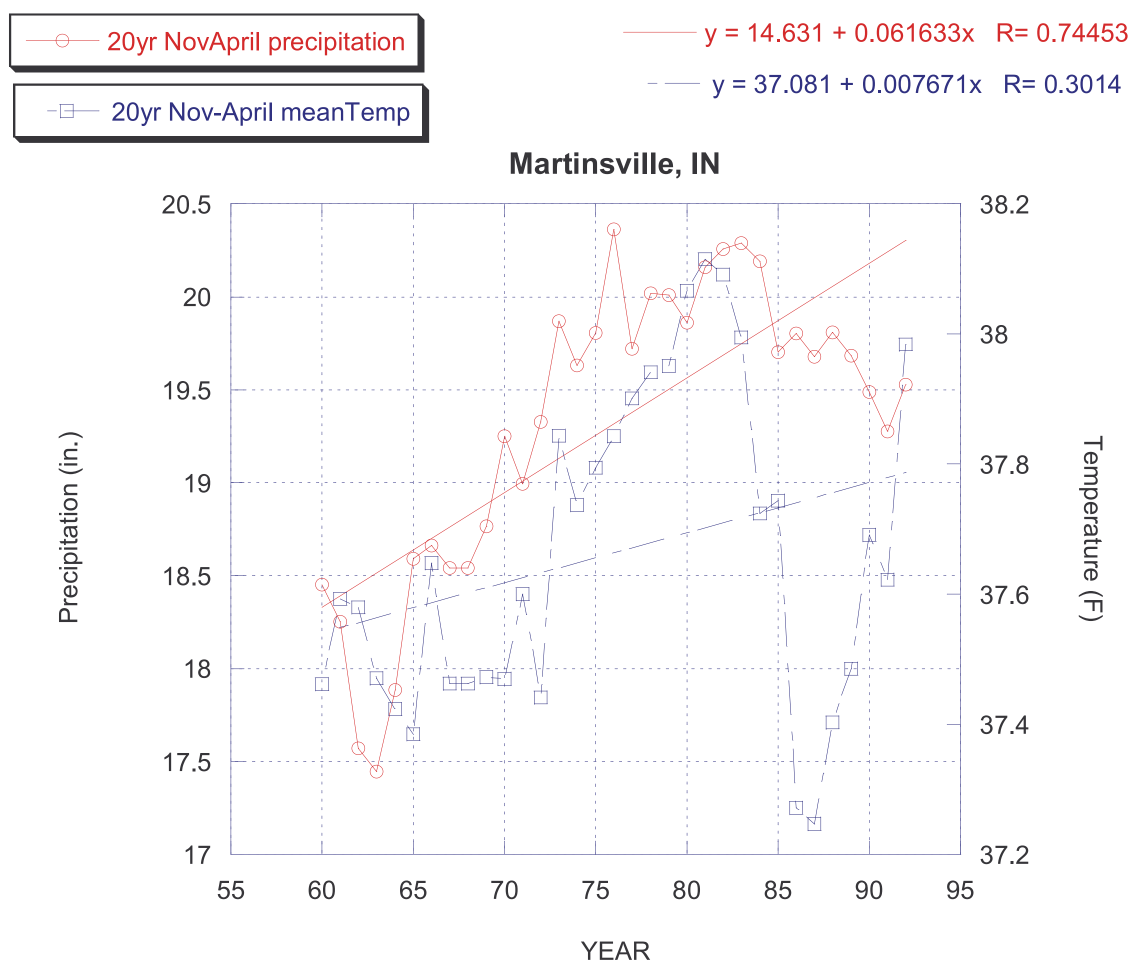
Twenty Year Running Average of Cool Period Mean Temperature and Precipitation



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Twenty Year Running Average of Cool Period Mean Temperature and Precipitation

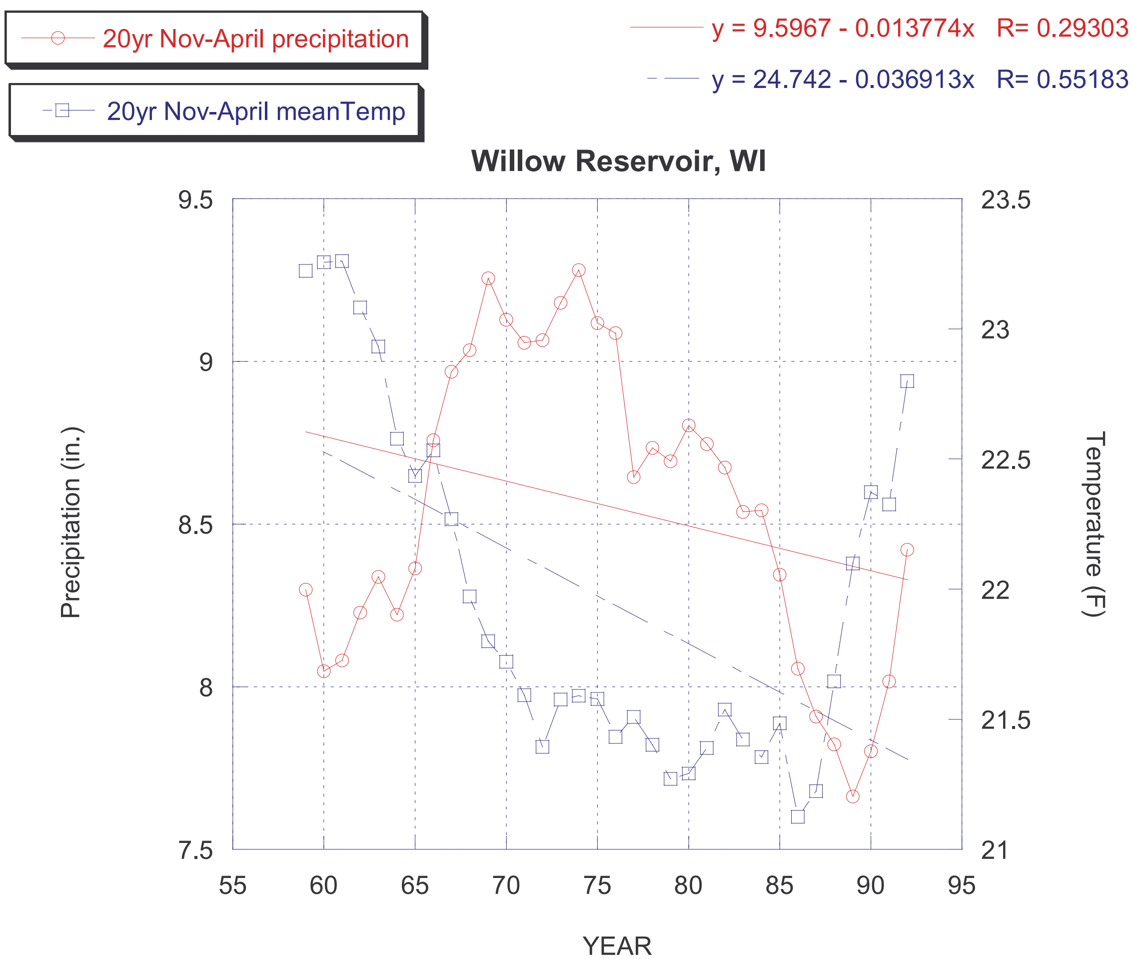


Figure 3a

Thirty Year Running Average of Cool Period Mean Temperature and Precipitation

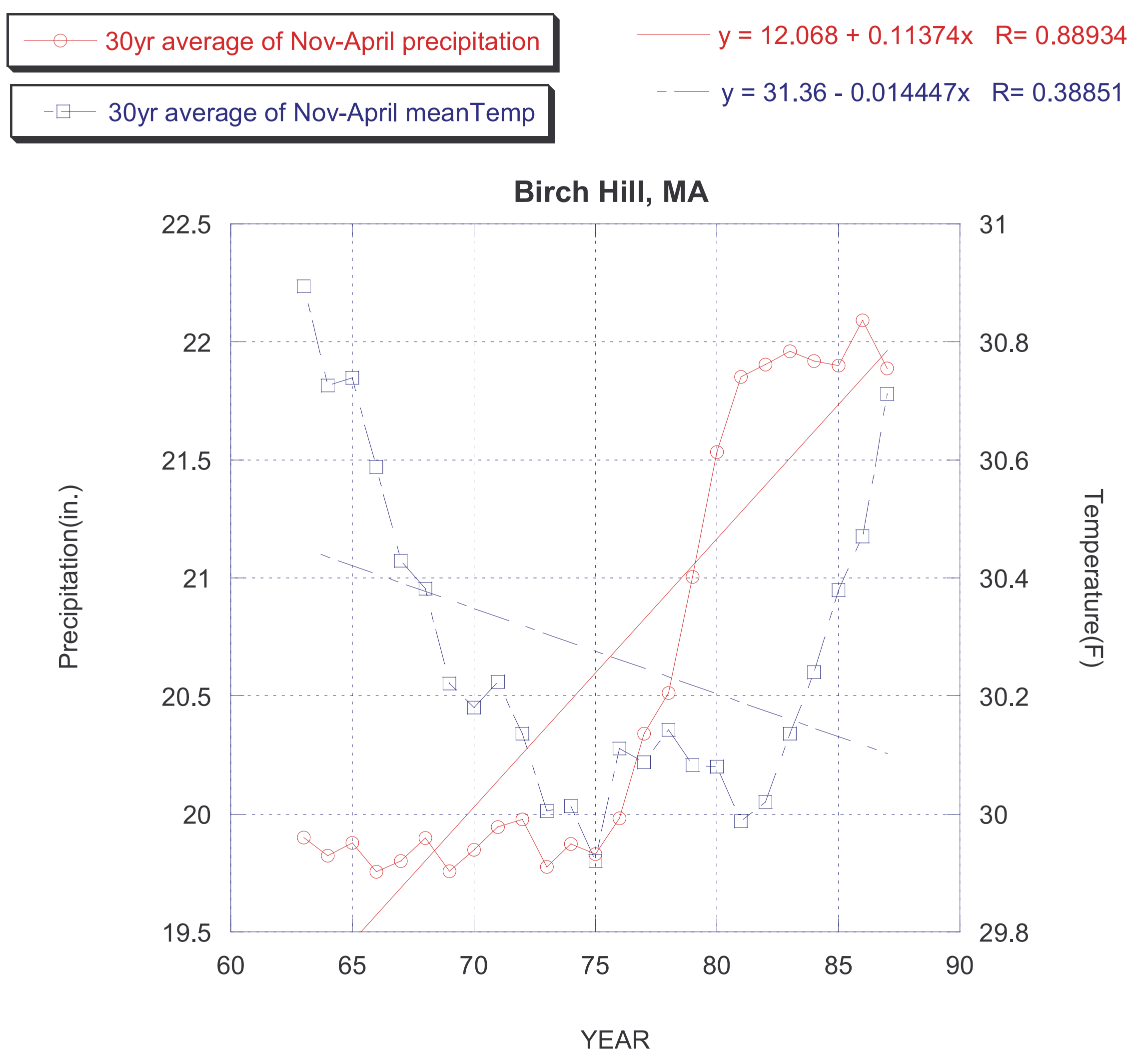


Figure 3b

Thirty Year Running Average of Cool Period Mean Temperature and Precipitation

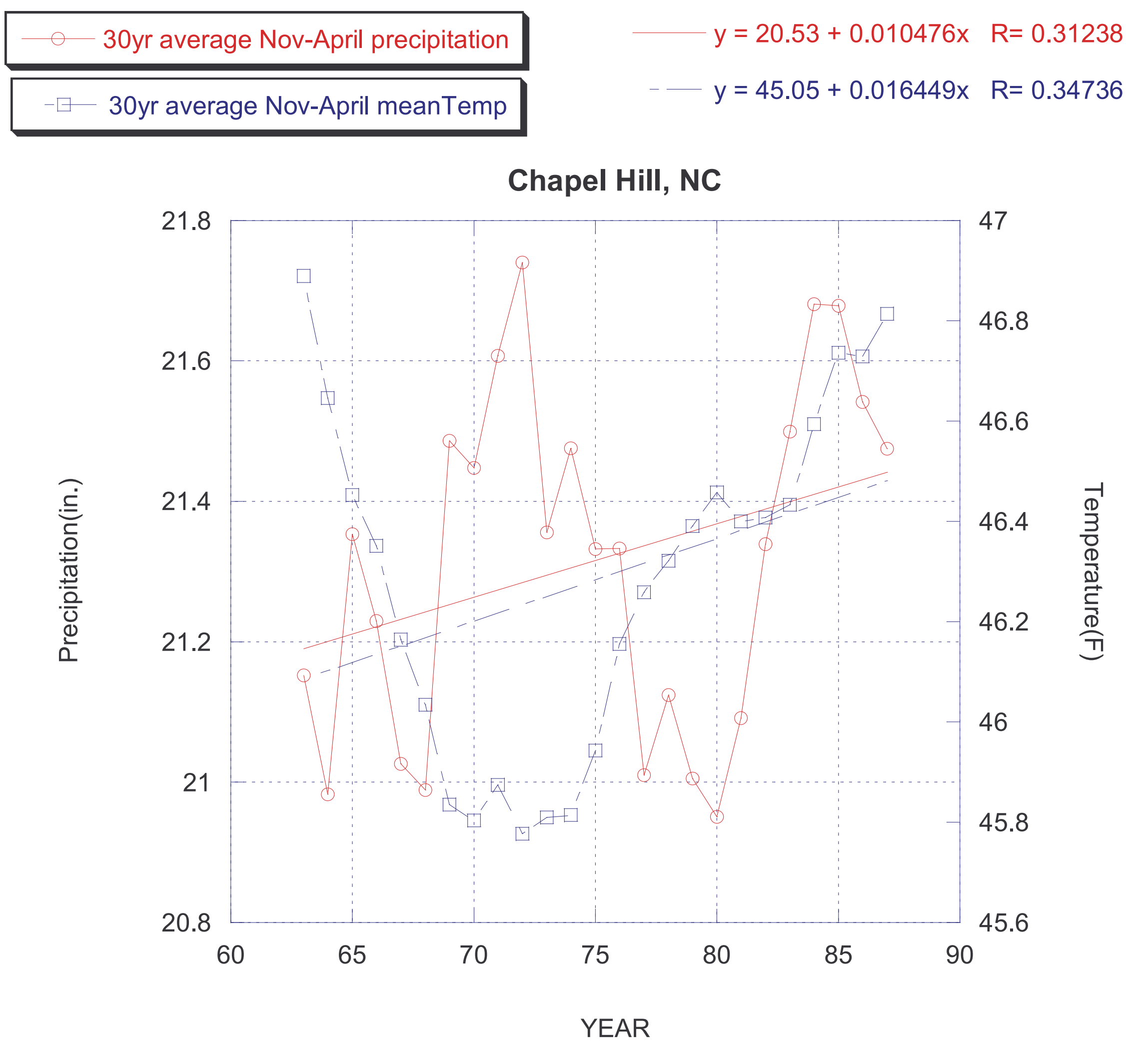


Figure 3c

Thirty Year Running Average of Cool Period Mean Temperature and Precipitation

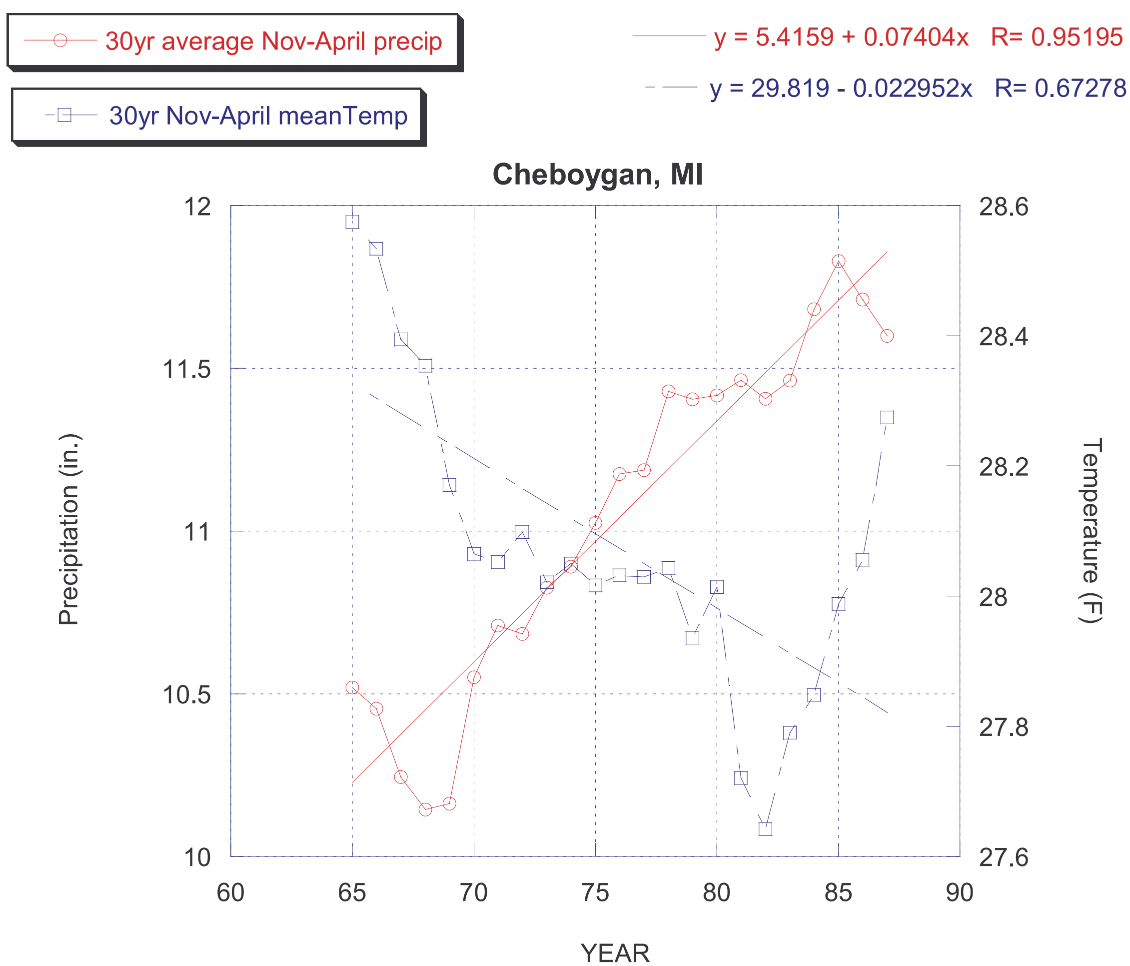
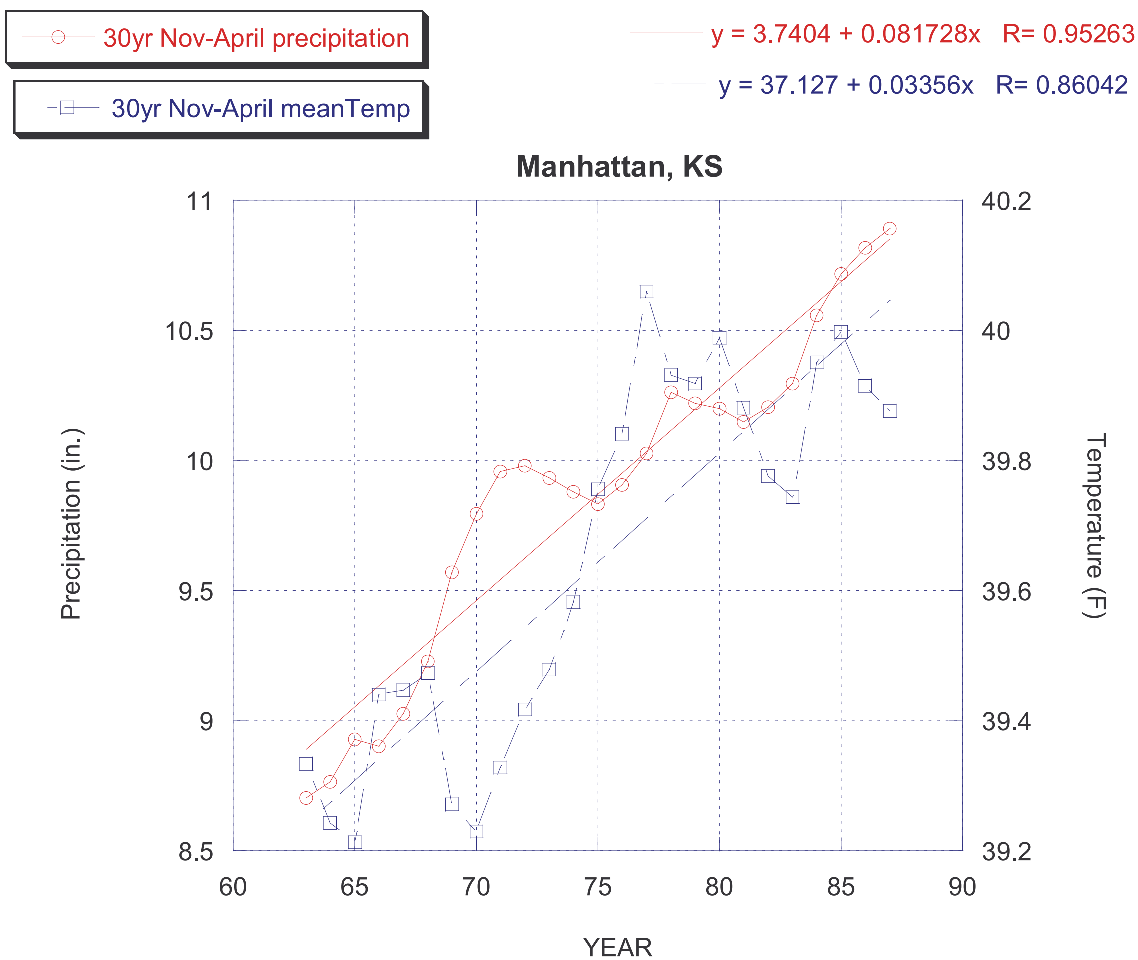


Figure 3d

Thirty Year Running Average of Cool Period Mean Temperature and Precipitation



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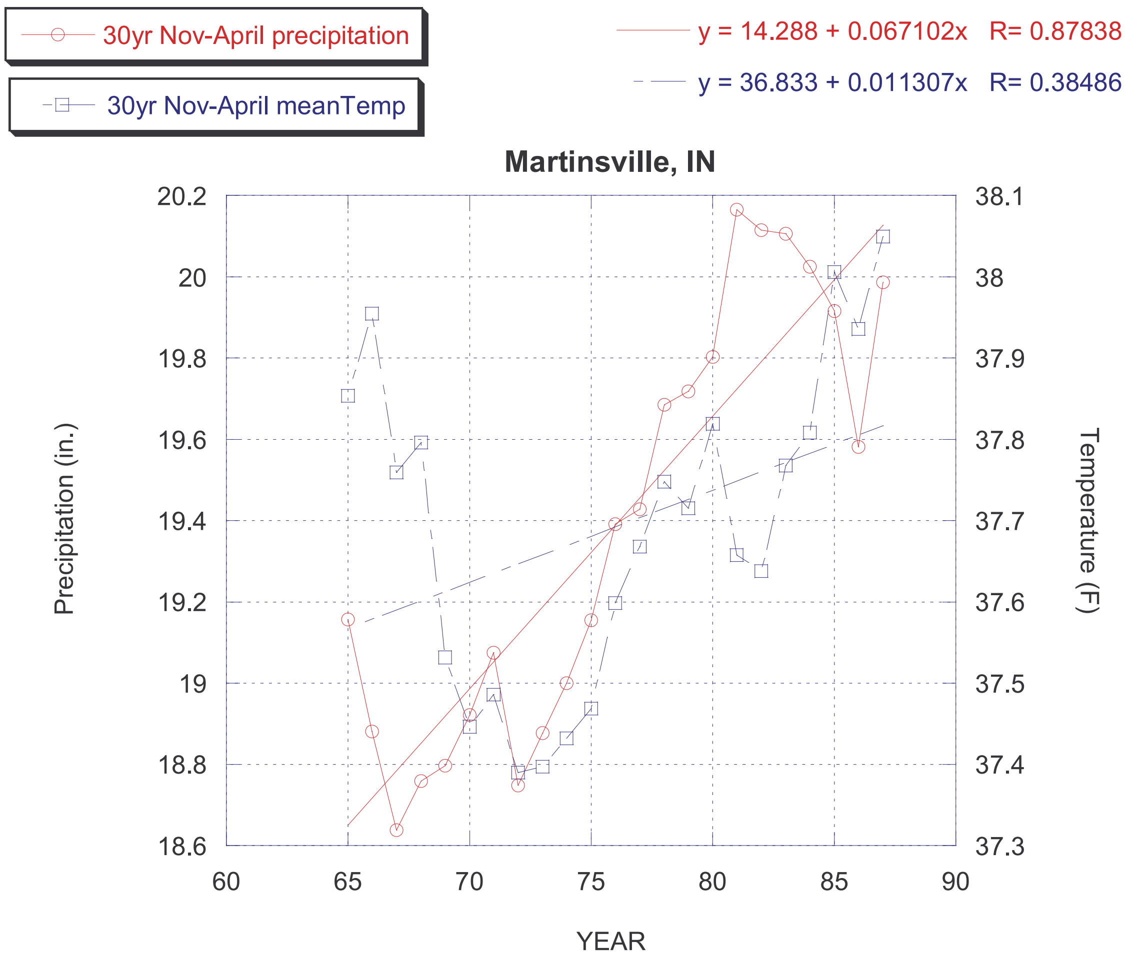

Figure 3f

Thirty Year Running Average of Cool Period Mean Temperature and Precipitation

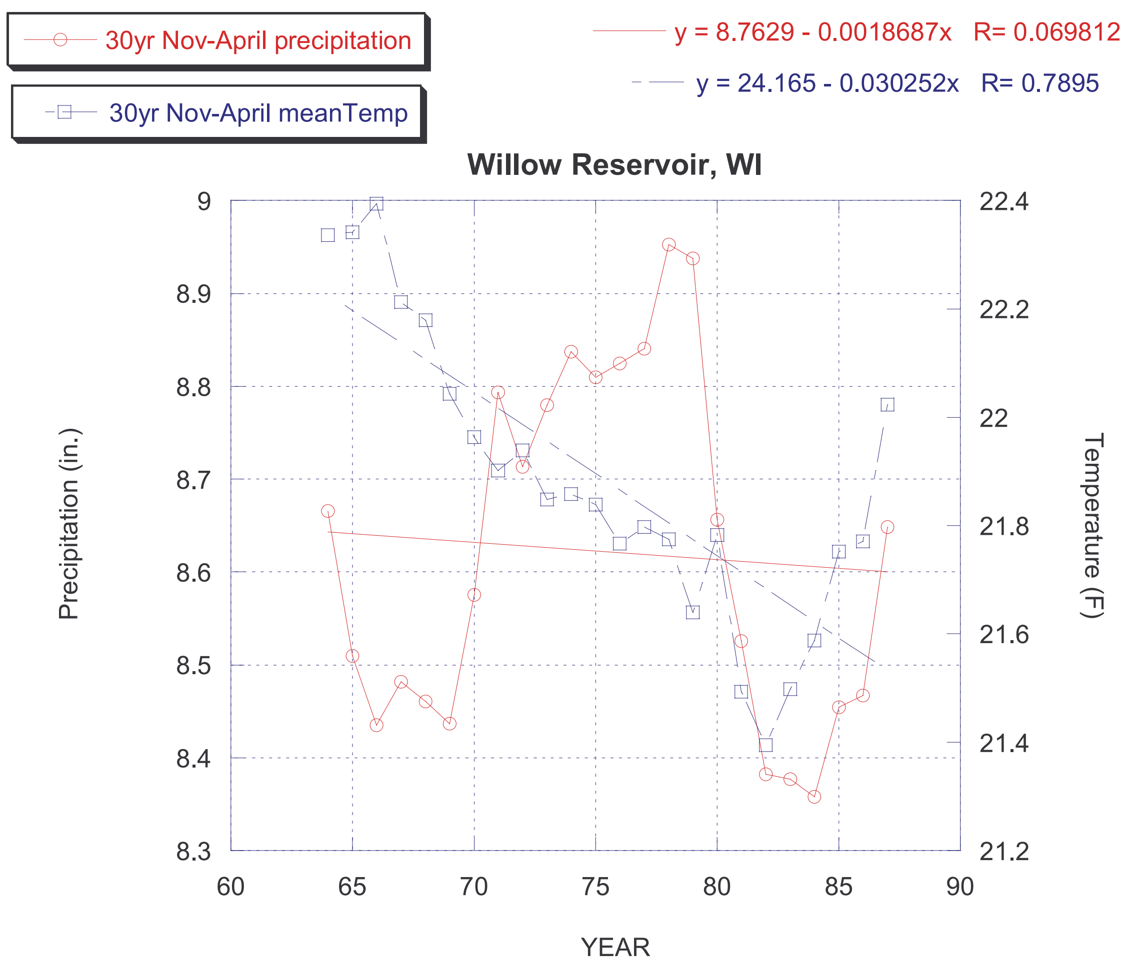

Figure 4a

Ten Year Running Average of Warm Period Mean Temperature and Precipitation

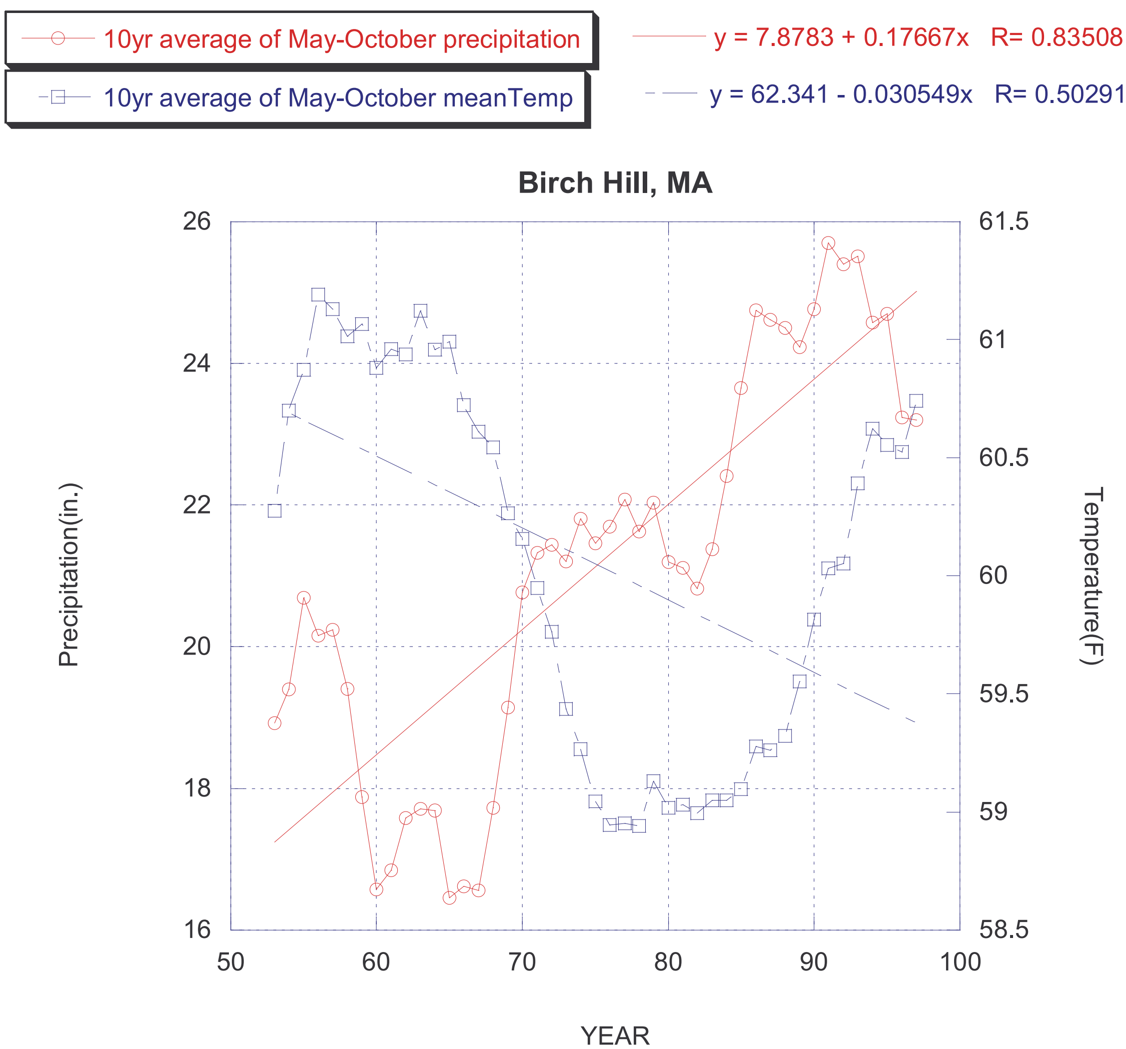

Figure 4b

Ten Year Running Average of Warm Period Mean Temperature and Precipitation

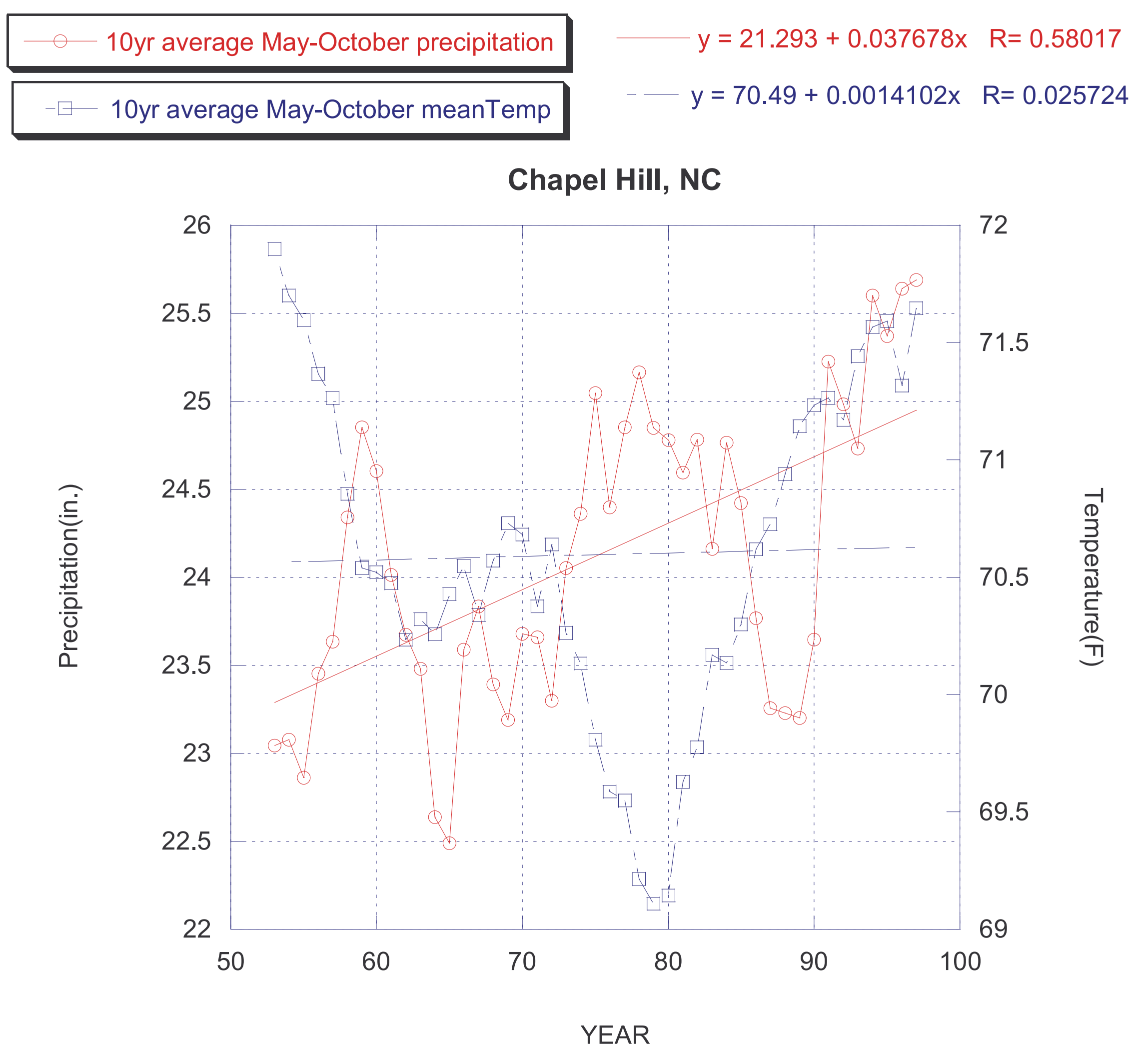

Figure 4c

Ten Year Running Average of Warm Period Mean Temperature and Precipitation

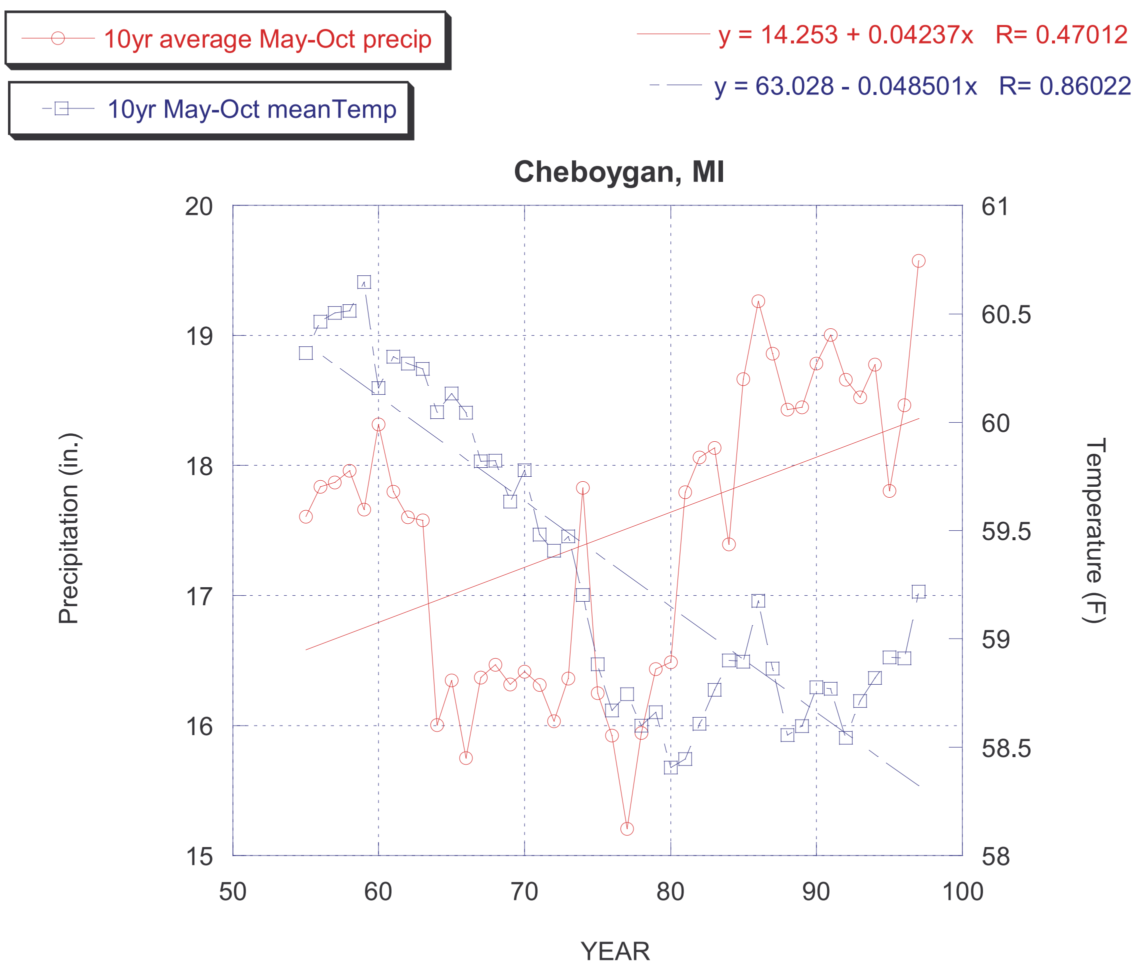

Figure 4d

Ten Year Running Average of Warm Period Mean Temperature and Precipitation

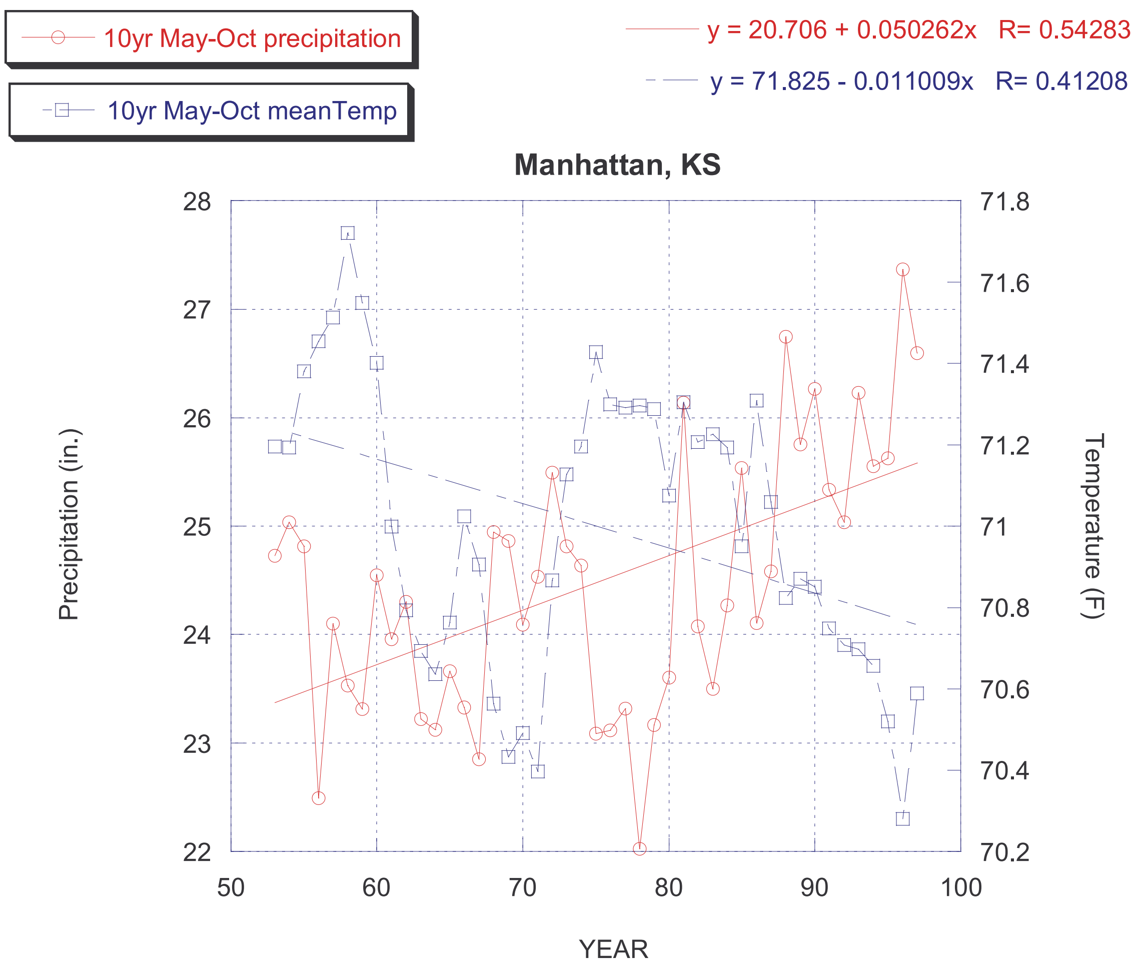

Figure 4e

Ten Year Running Average of Warm Period Mean Temperature and Precipitation

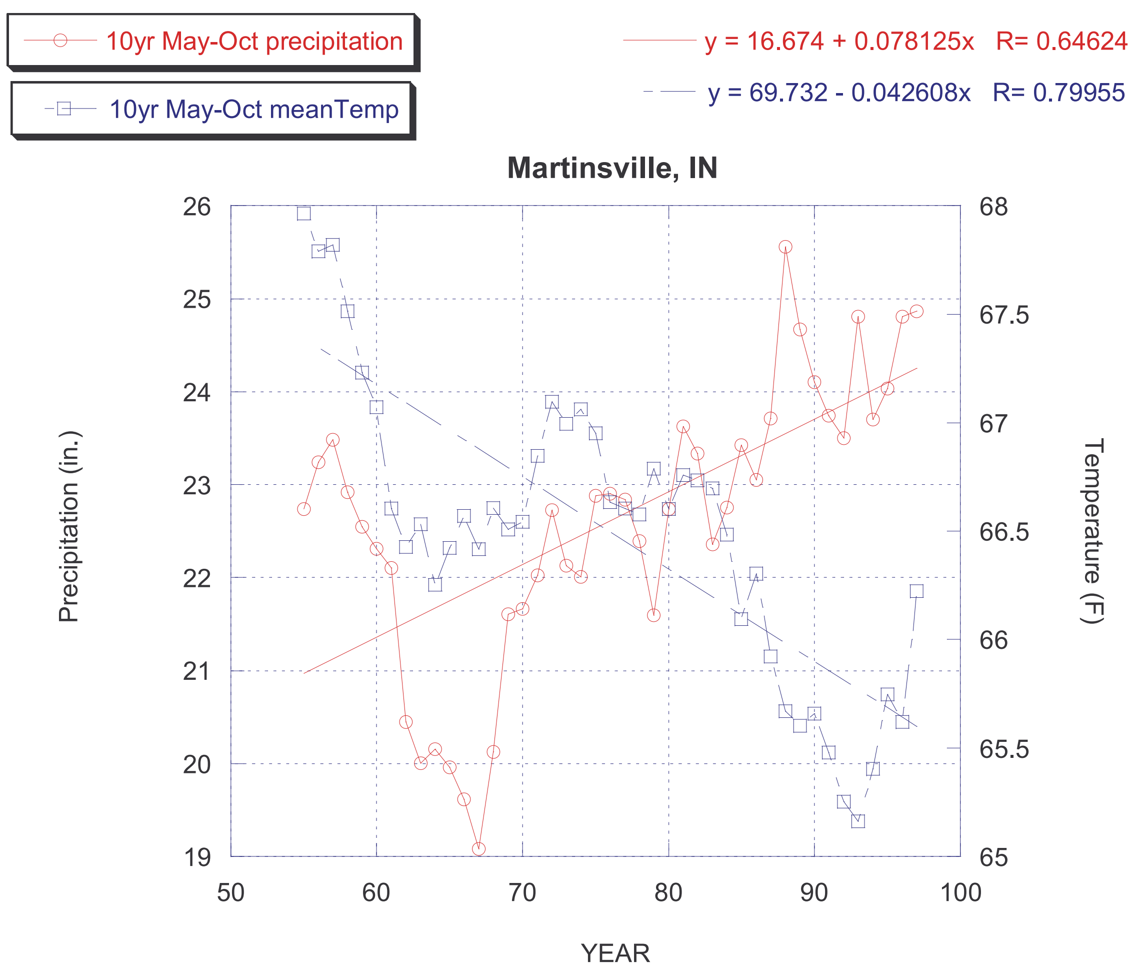

Figure 4f

Ten Year Running Average of Warm Period Mean Temperature and Precipitation

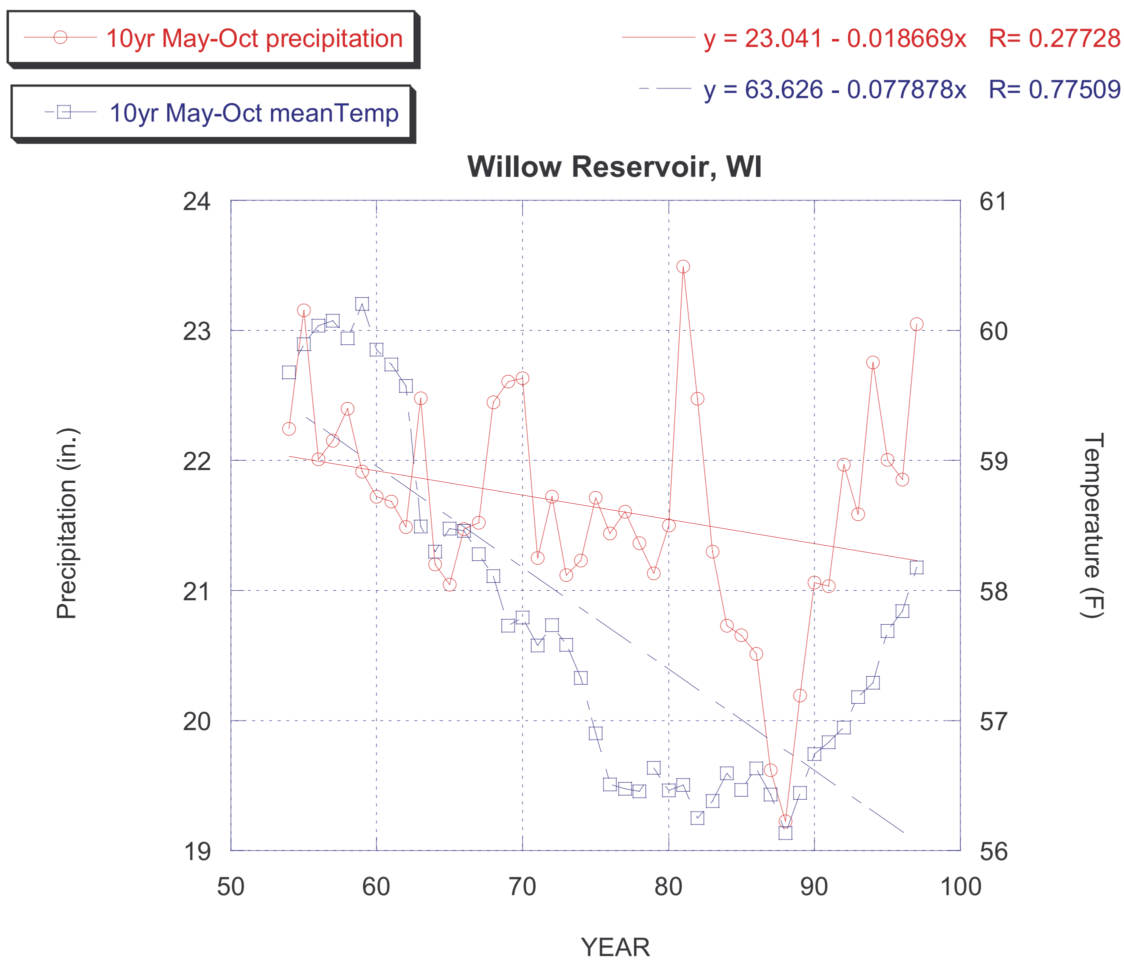

Figure 5a

Twenty Year Running Average of Warm Period Mean Temperature and Precipitation

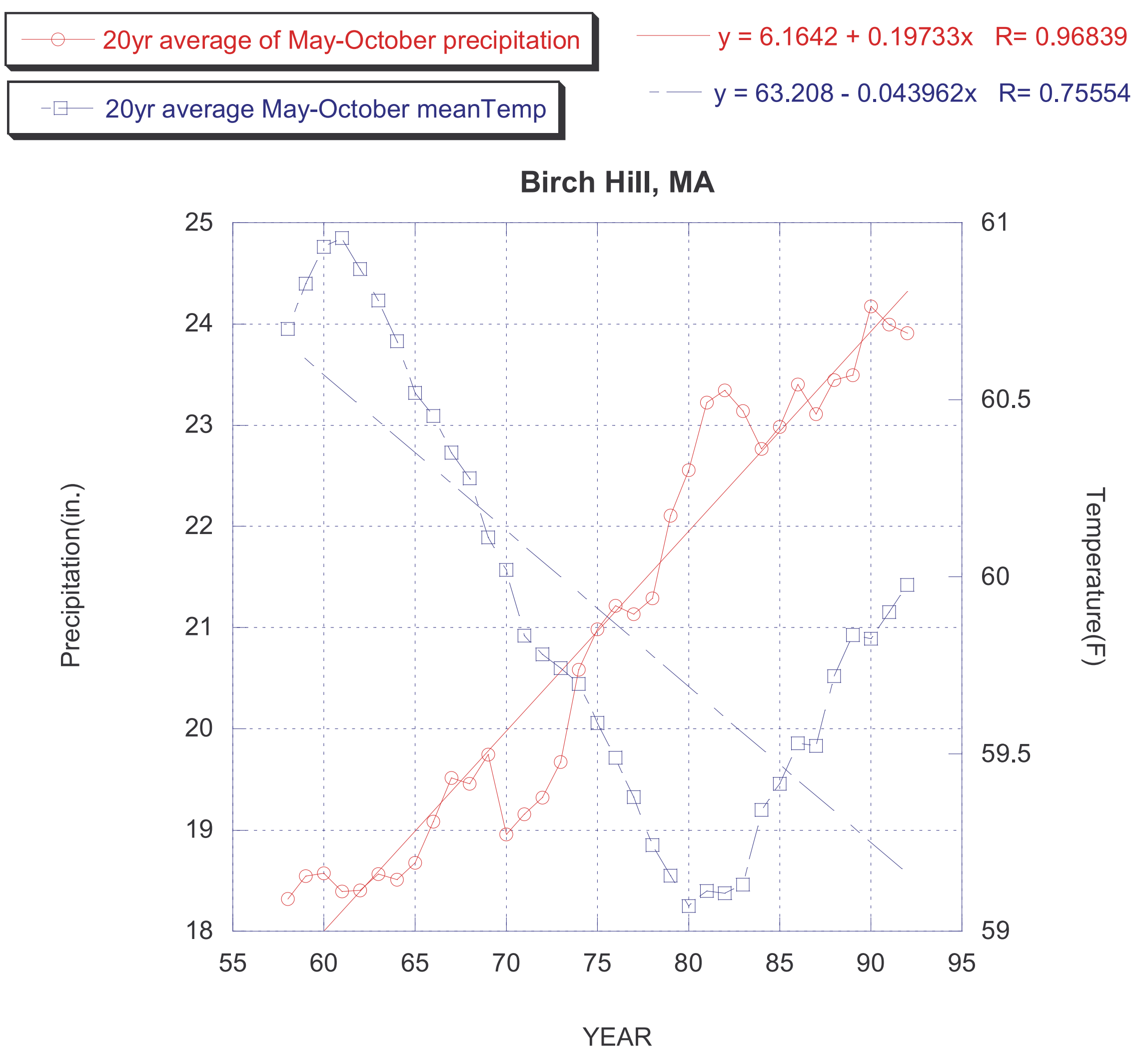

Figure 5b

Twenty Year Running Average of Warm Period Mean Temperature and Precipitation

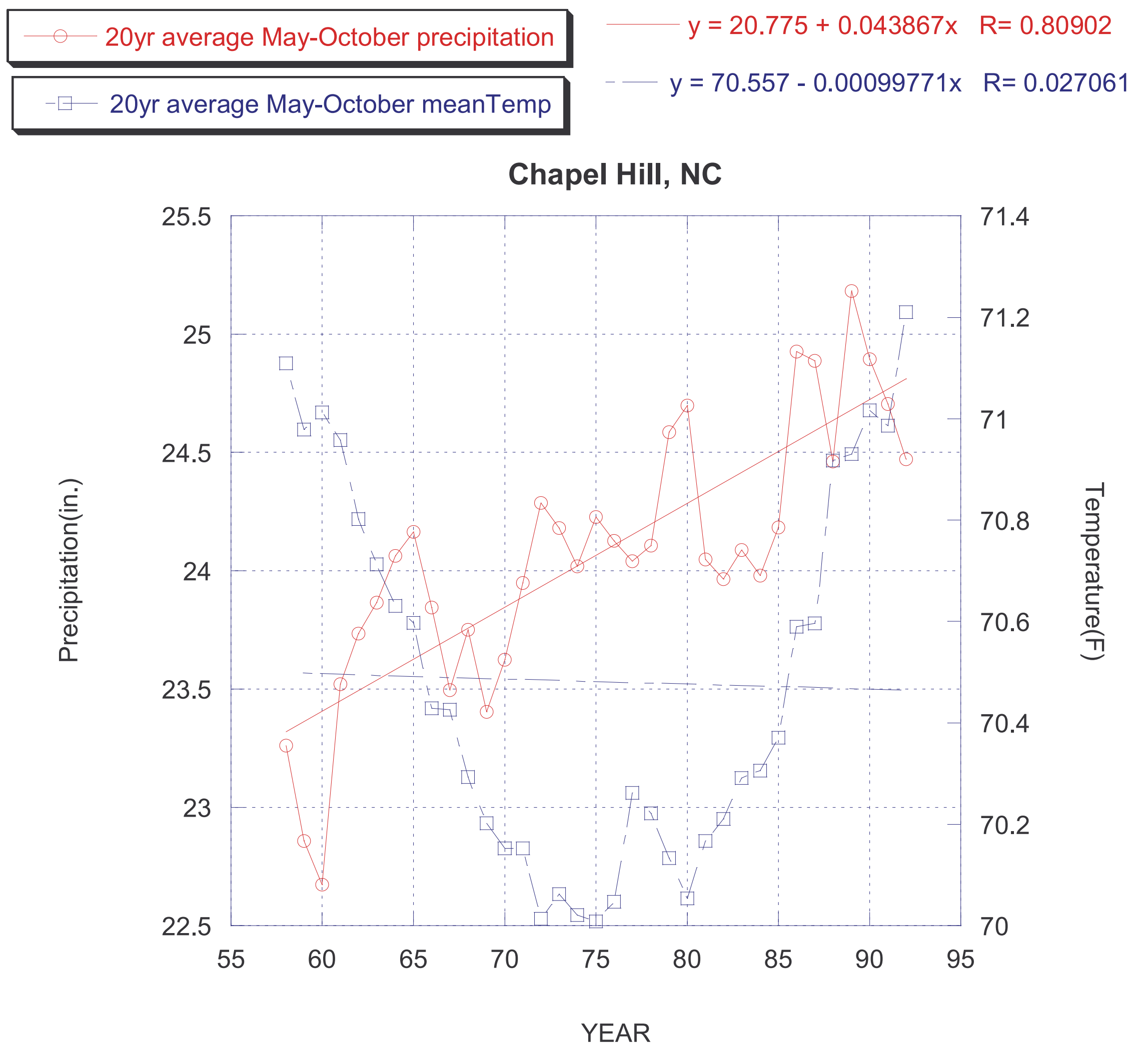

Figure 5c

Twenty Year Running Average of Warm Period Mean Temperature and Precipitation

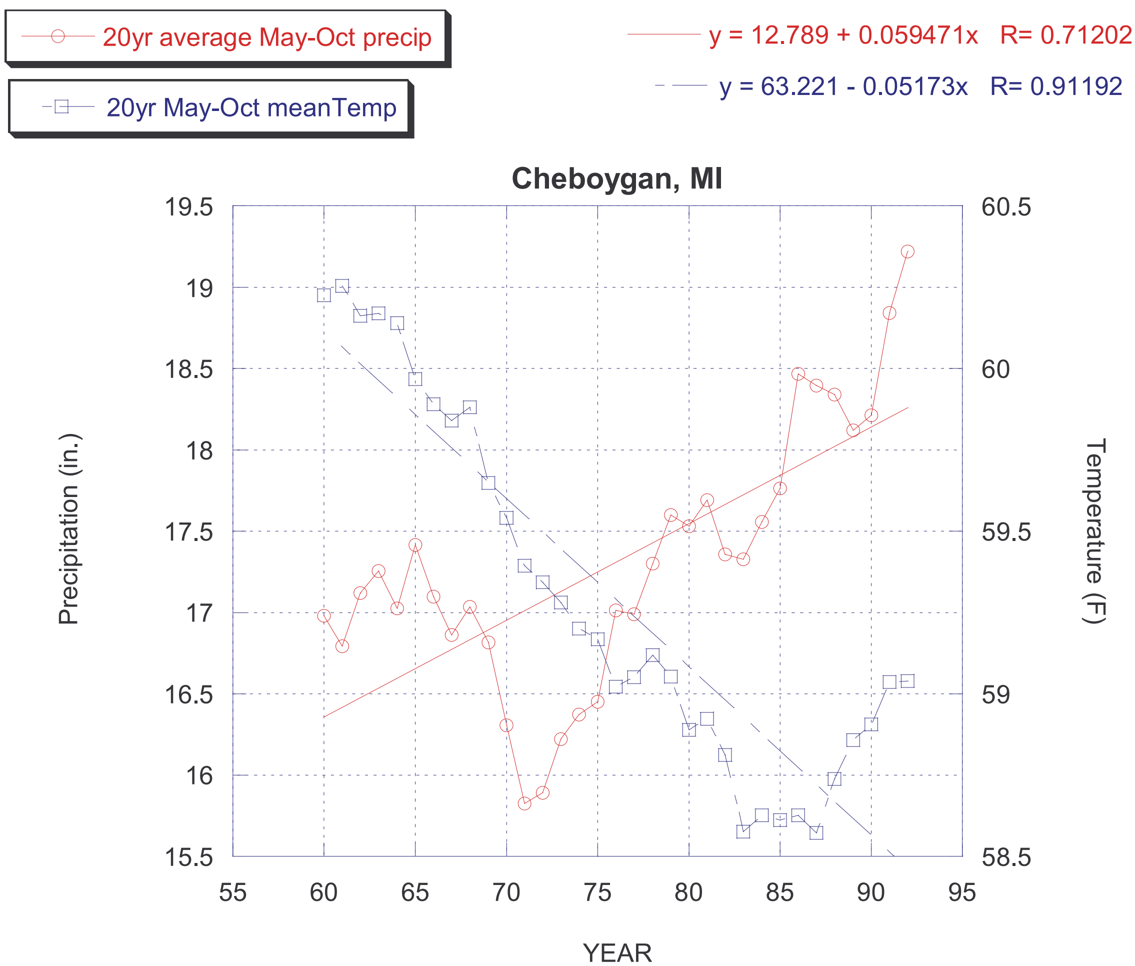

Figure 5d

Twenty Year Running Average of Warm Period Mean Temperature and Precipitation

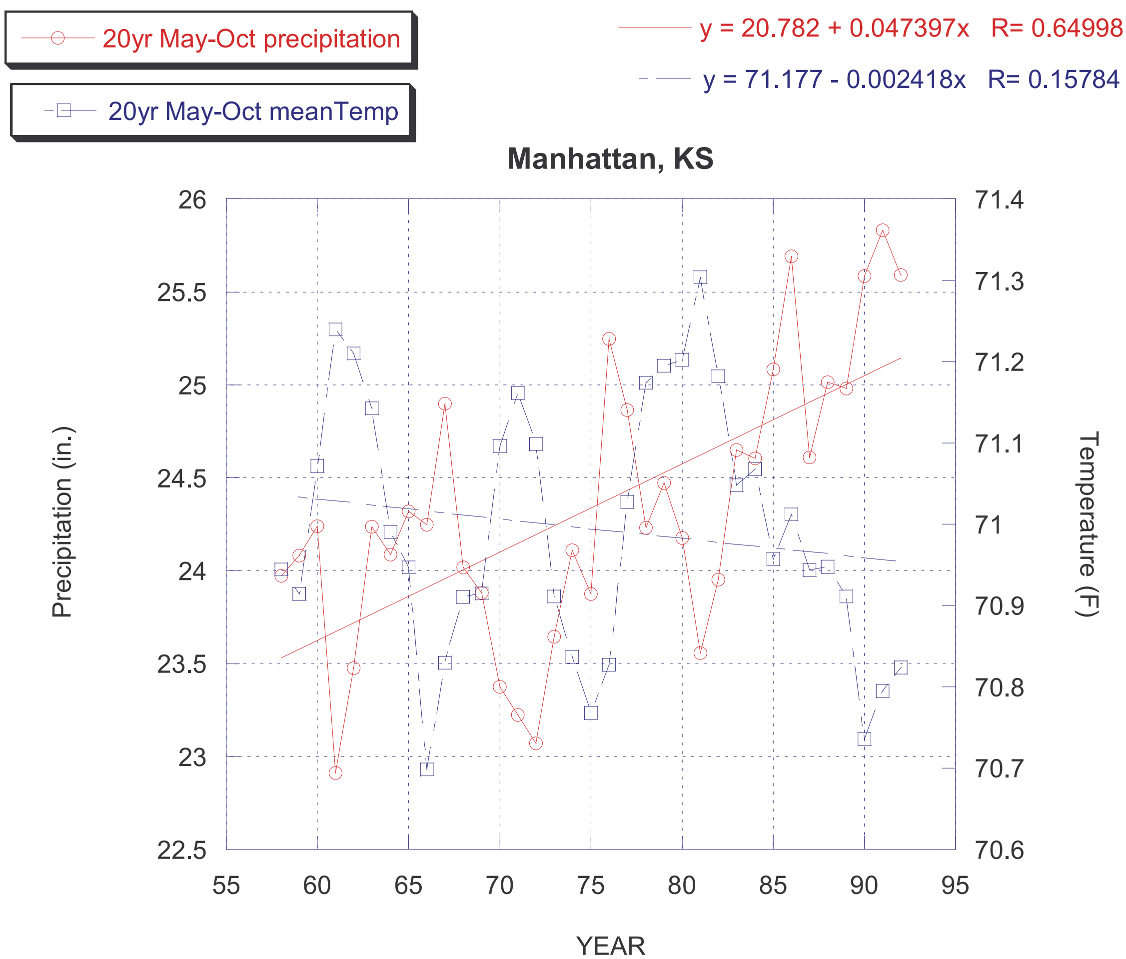

Figure 5e

Twenty Year Running Average of Warm Period Mean Temperature and Precipitation

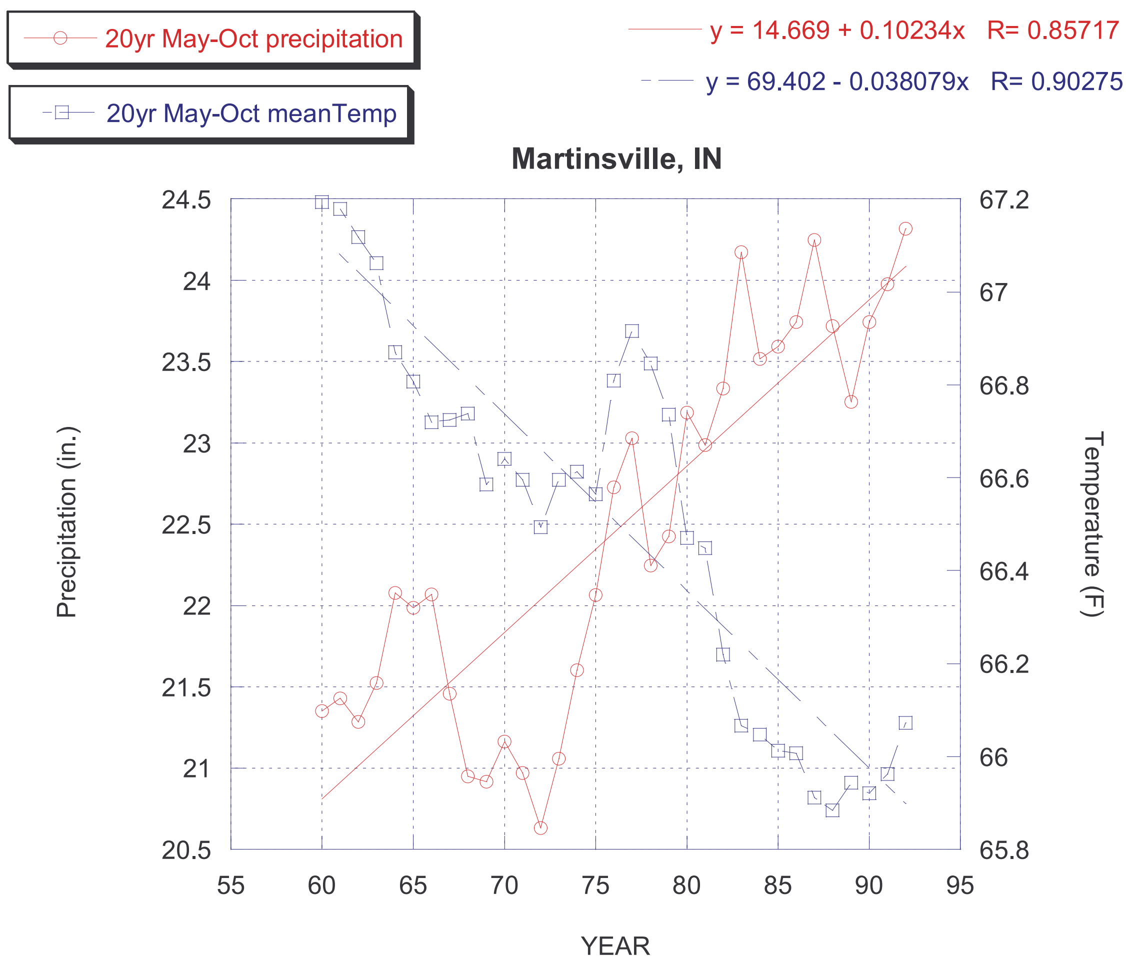

Figure 5f

Twenty Year Running Average of Warm Period Mean Temperature and Precipitation

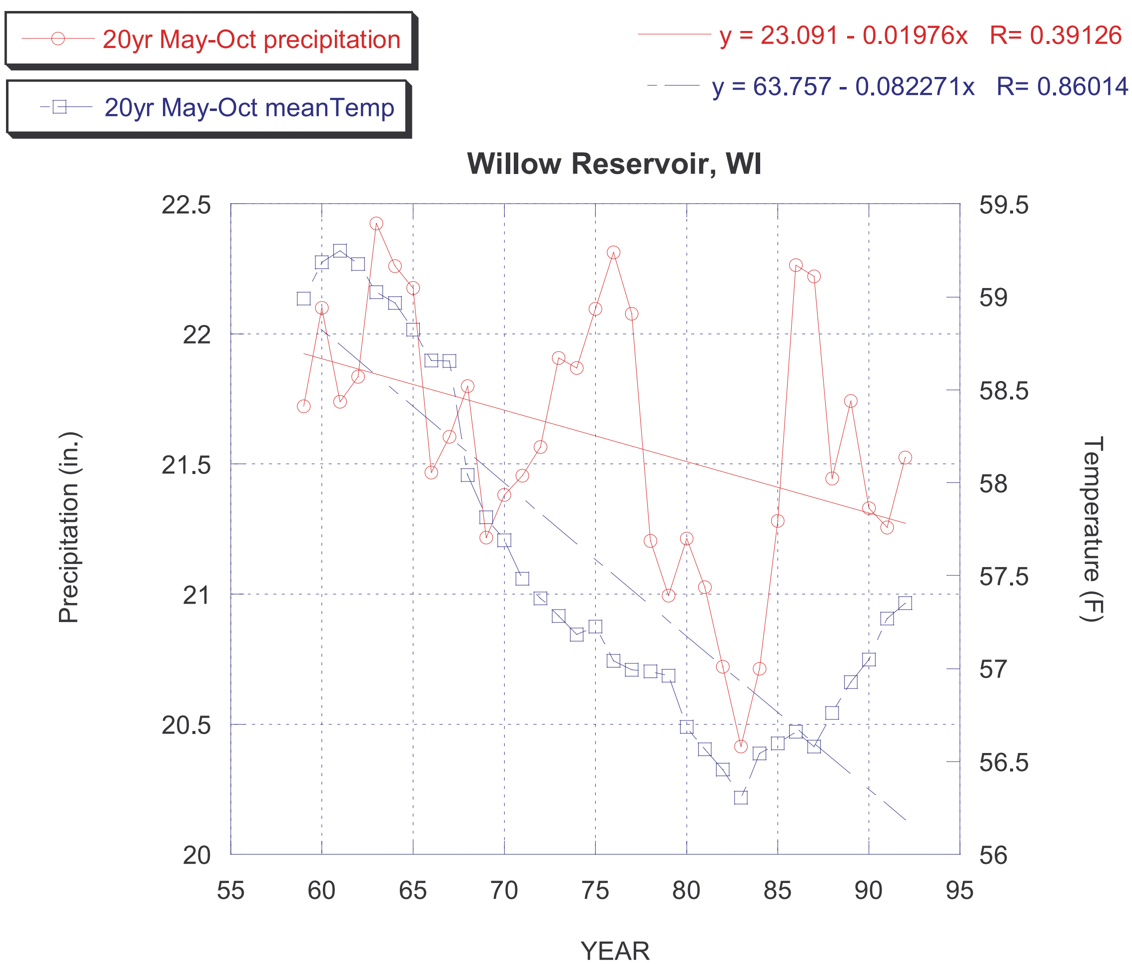

Figure 6a

Thirty Year Running Average of Warm Period Mean Temperature and Precipitation

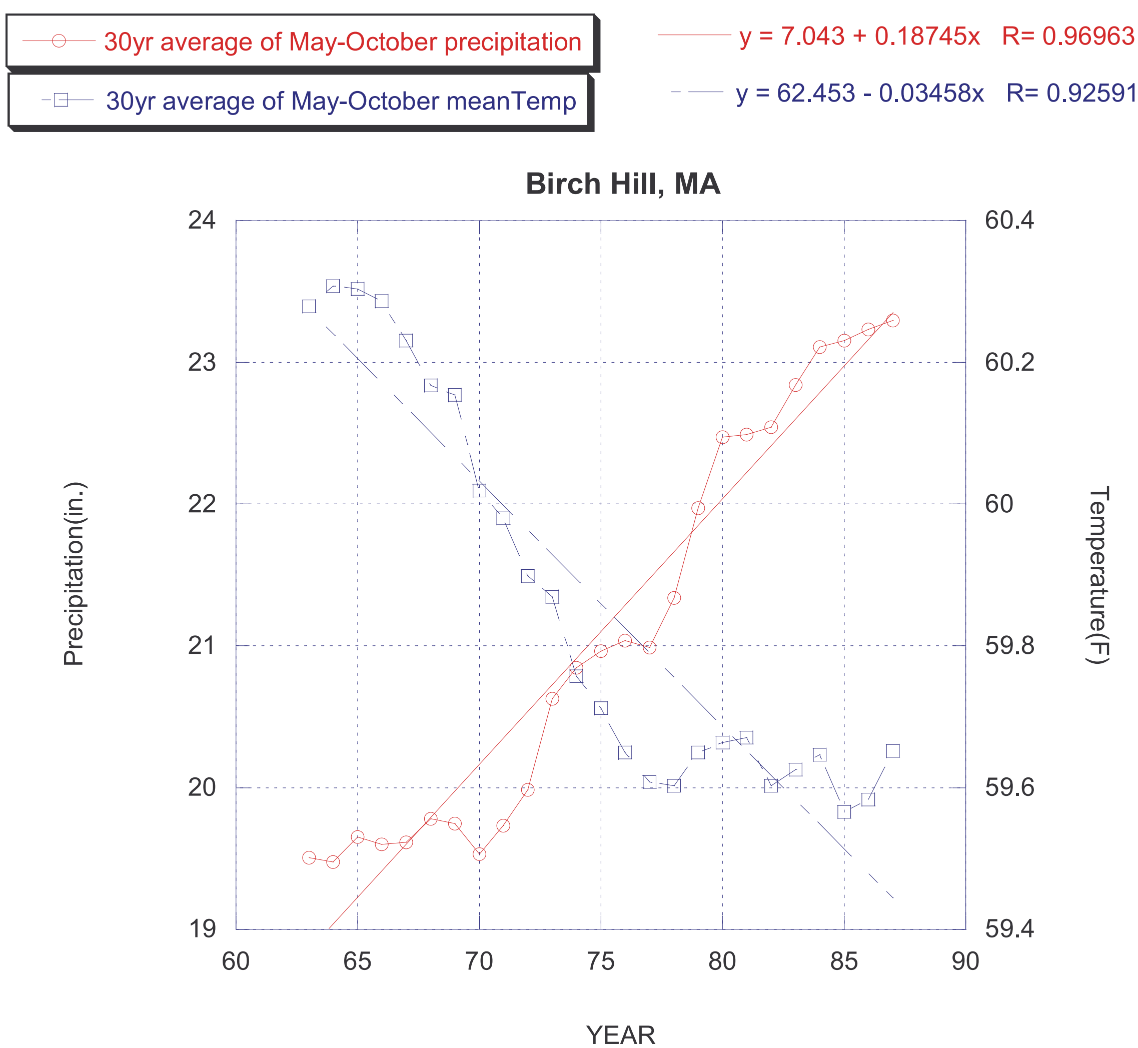

Figure 6b

Thirty Year Running Average of Warm Period Mean Temperature and Precipitation

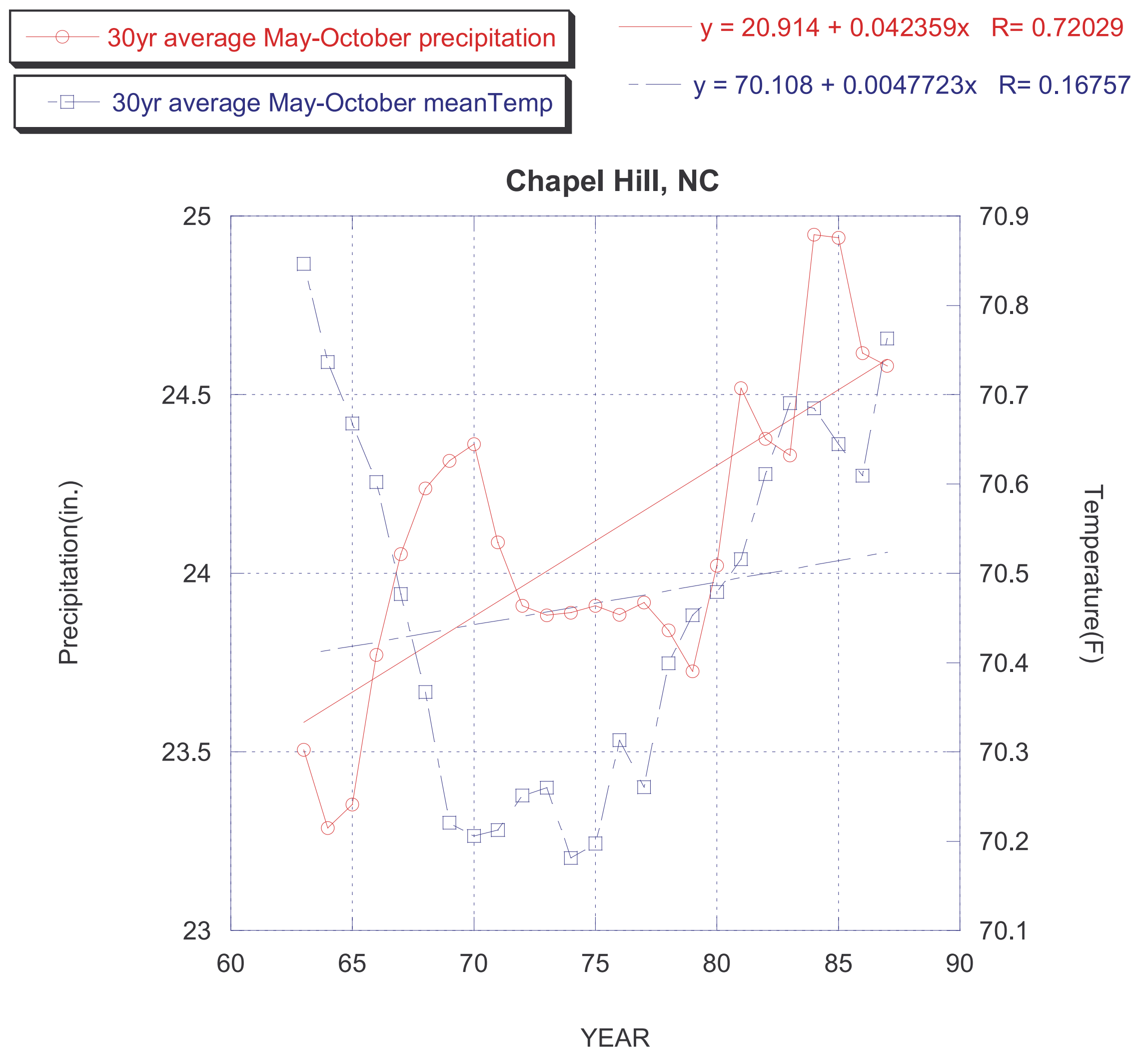

Figure 6c

Thirty Year Running Average of Warm Period Mean Temperature and Precipitation

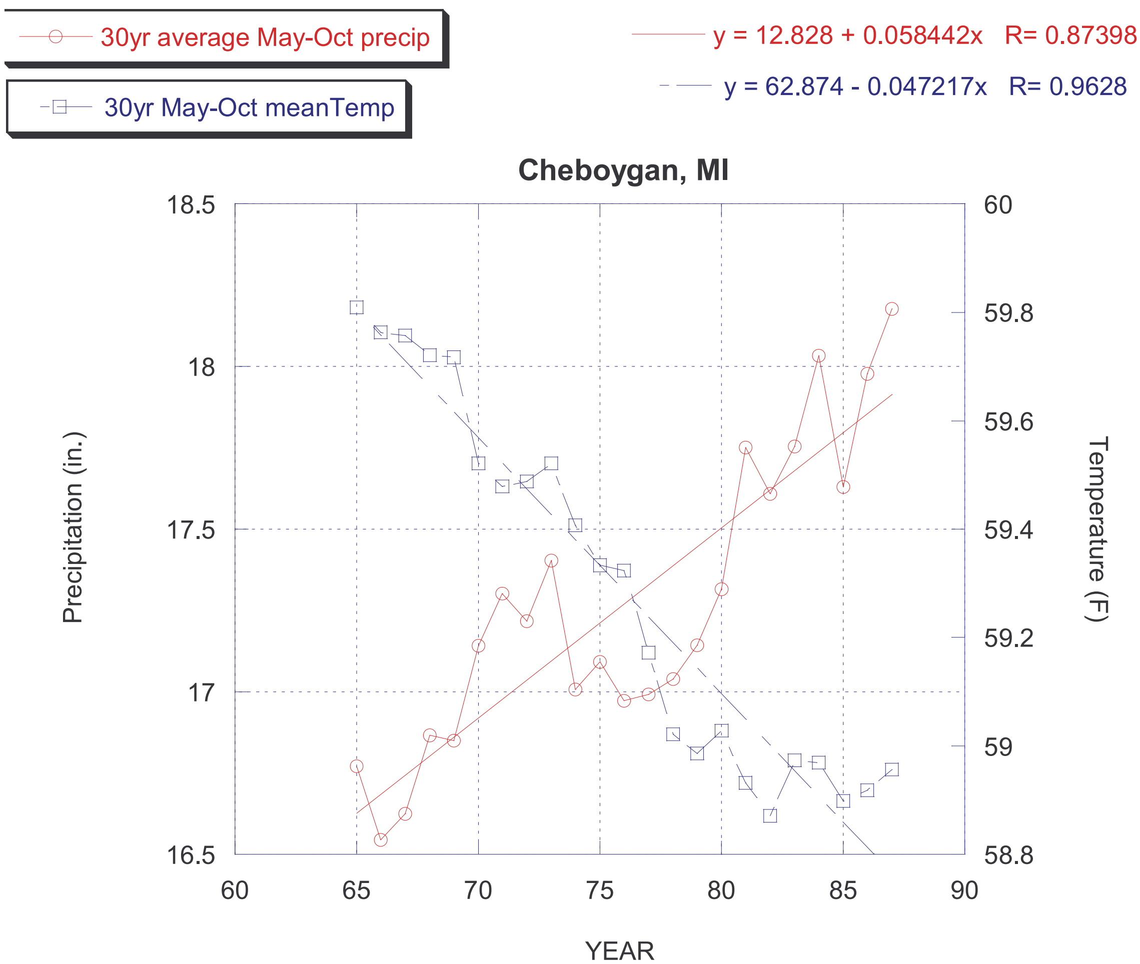

Figure 6d

Thirty Year Running Average of Warm Period Mean Temperature and Precipitation

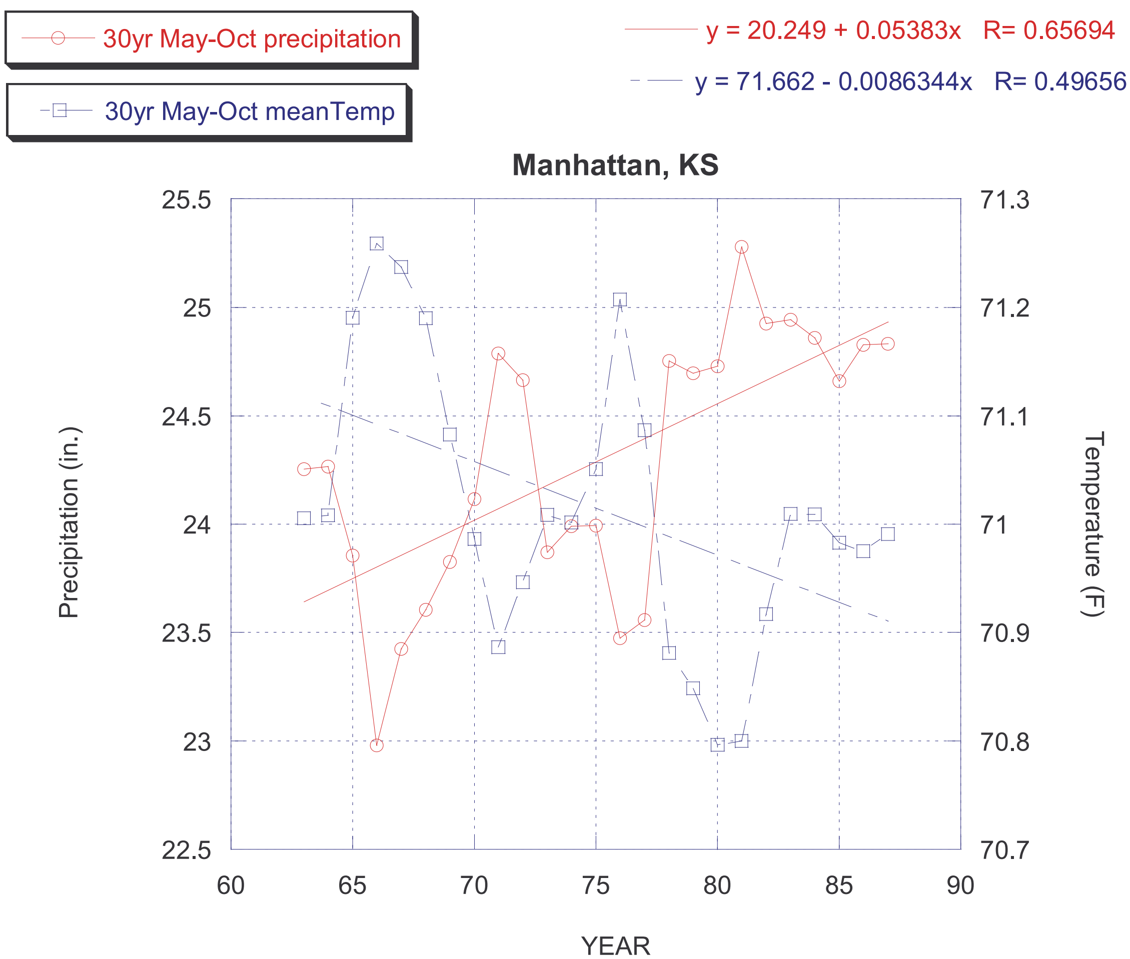

Figure 6e

Thirty Year Running Average of Warm Period Mean Temperature and Precipitation

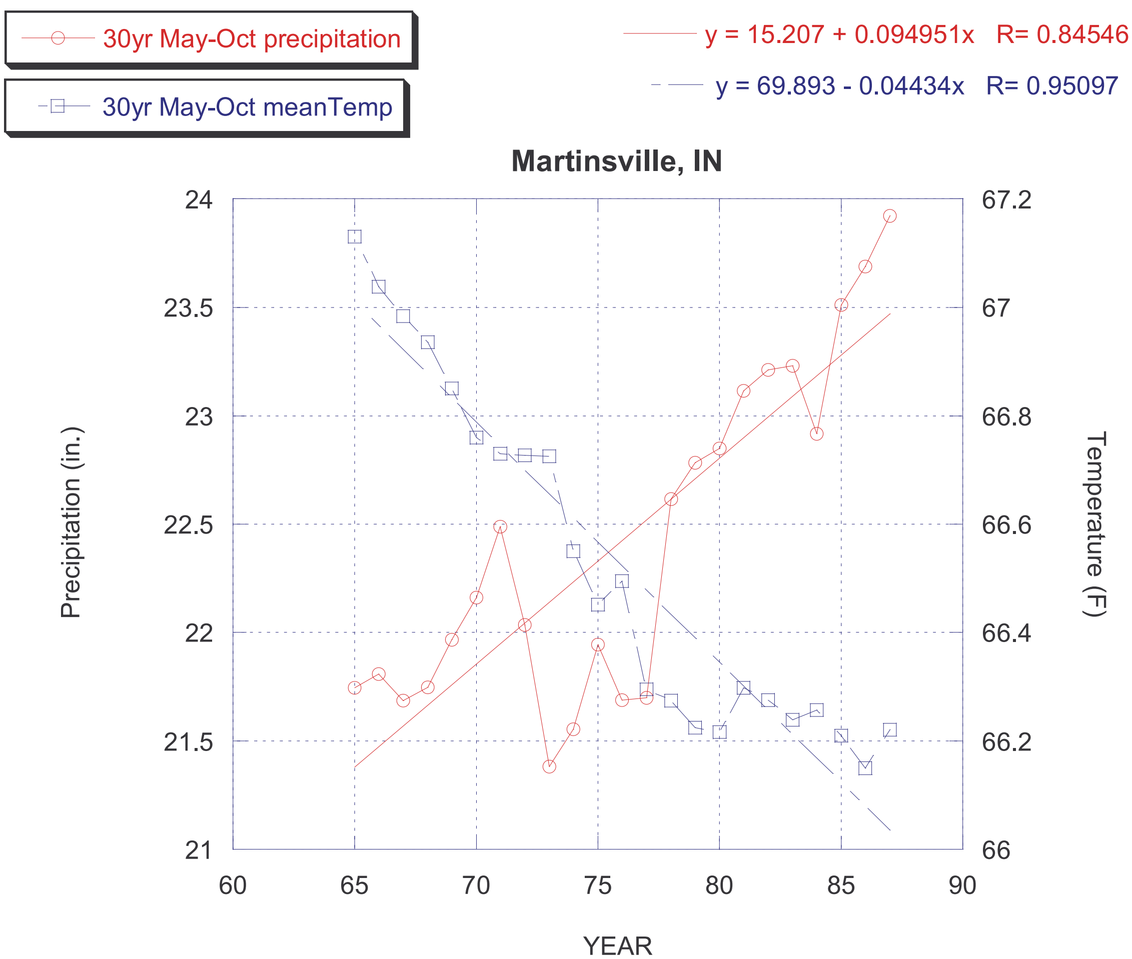

Figure 6f

Thirty Year Running Average of Warm Period Mean Temperature and Precipitation

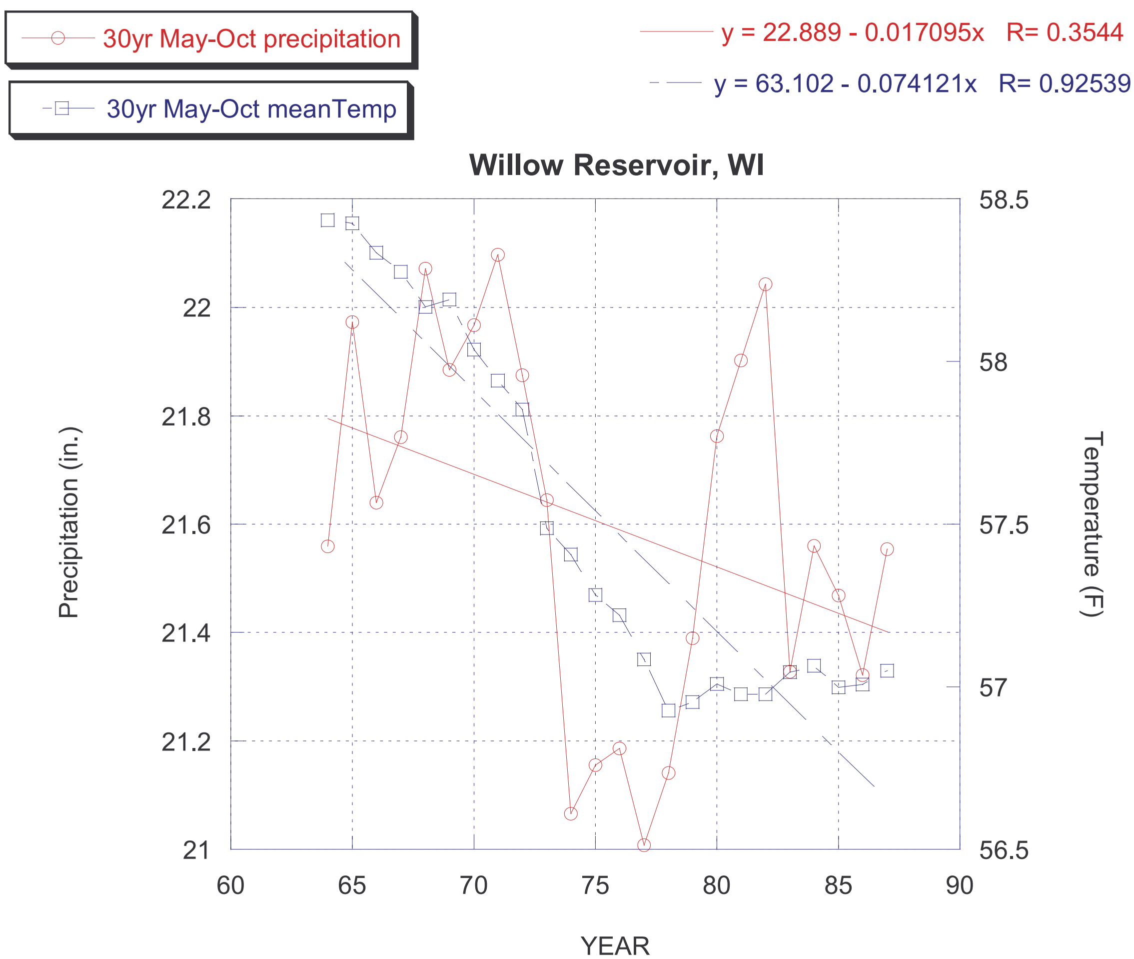

Figure 7a

Cool Period Temperatures

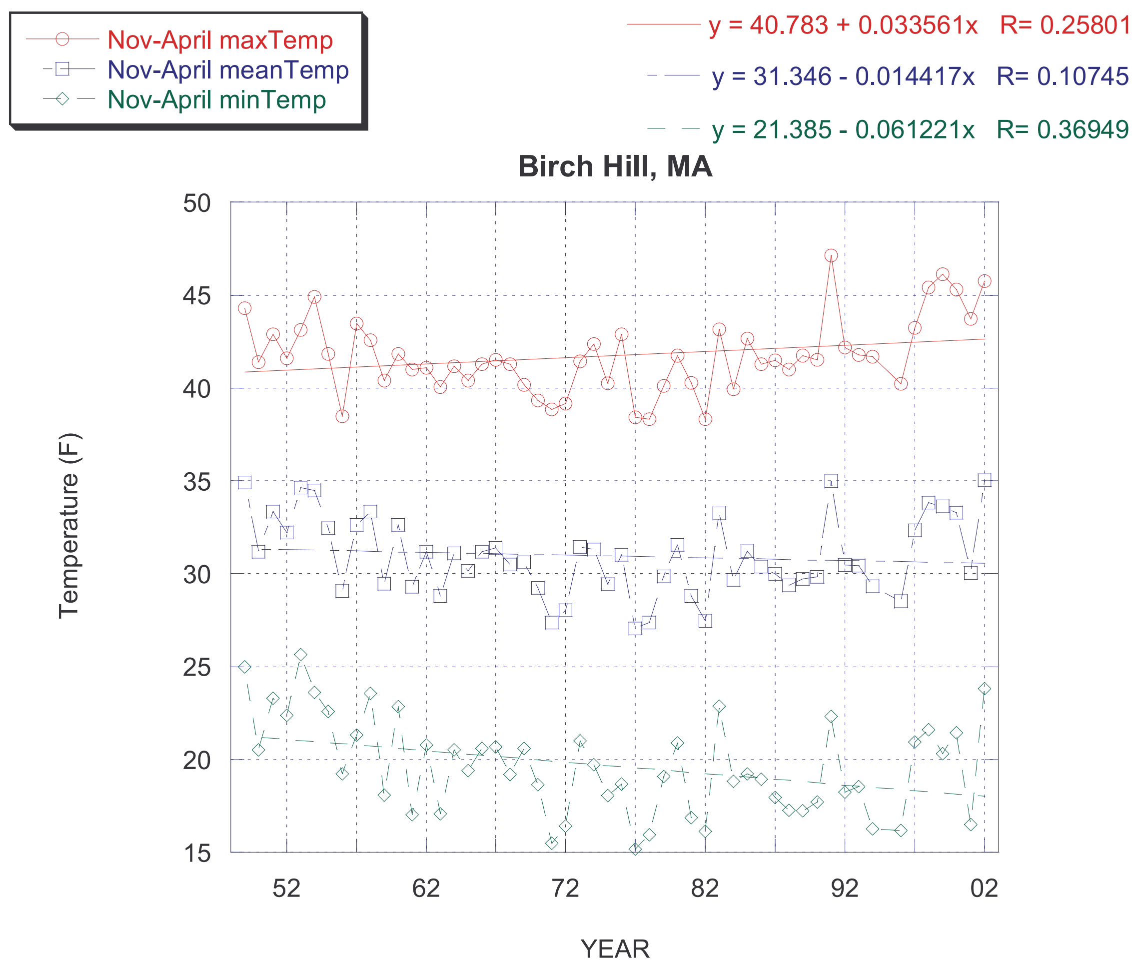

Figure 7b

Cool Period Temperatures

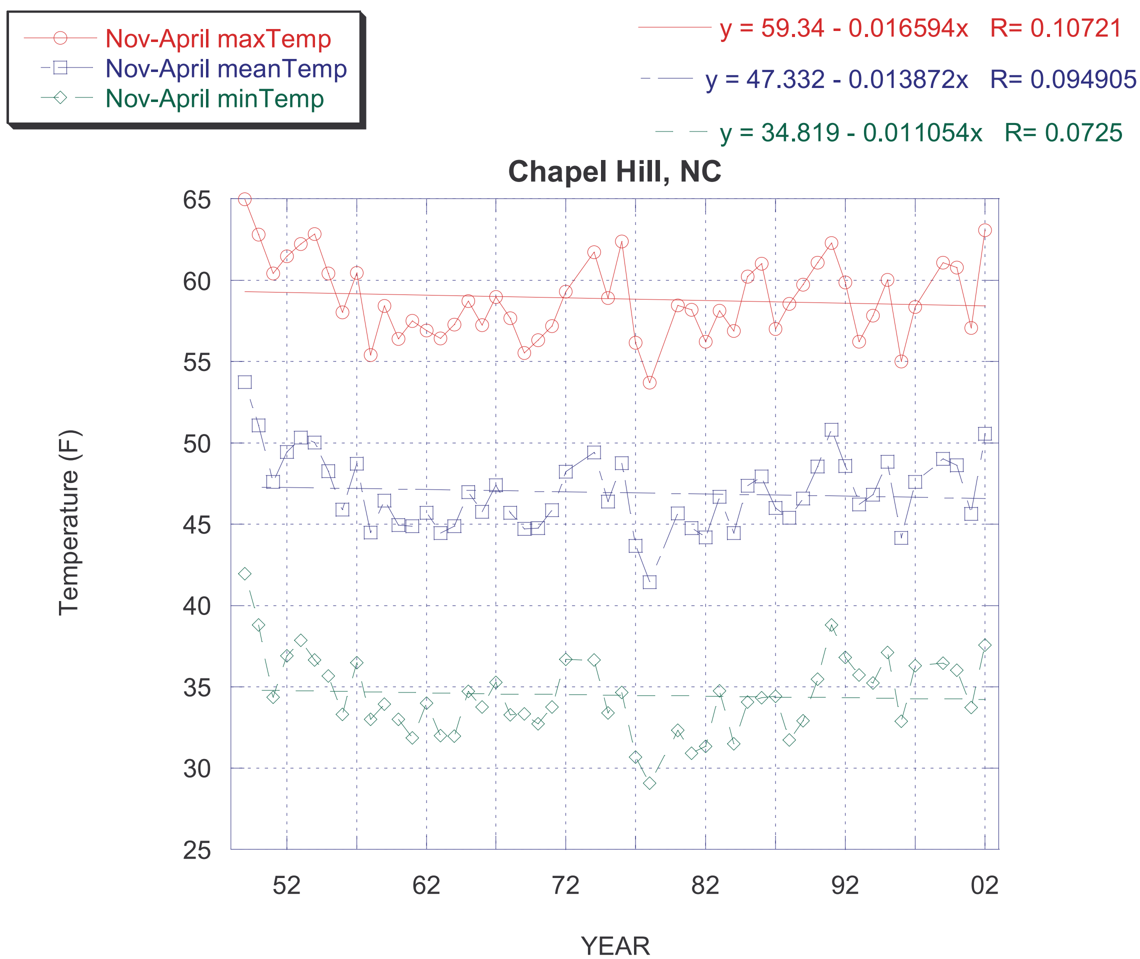

Figure 7c

Cool Period Temperatures

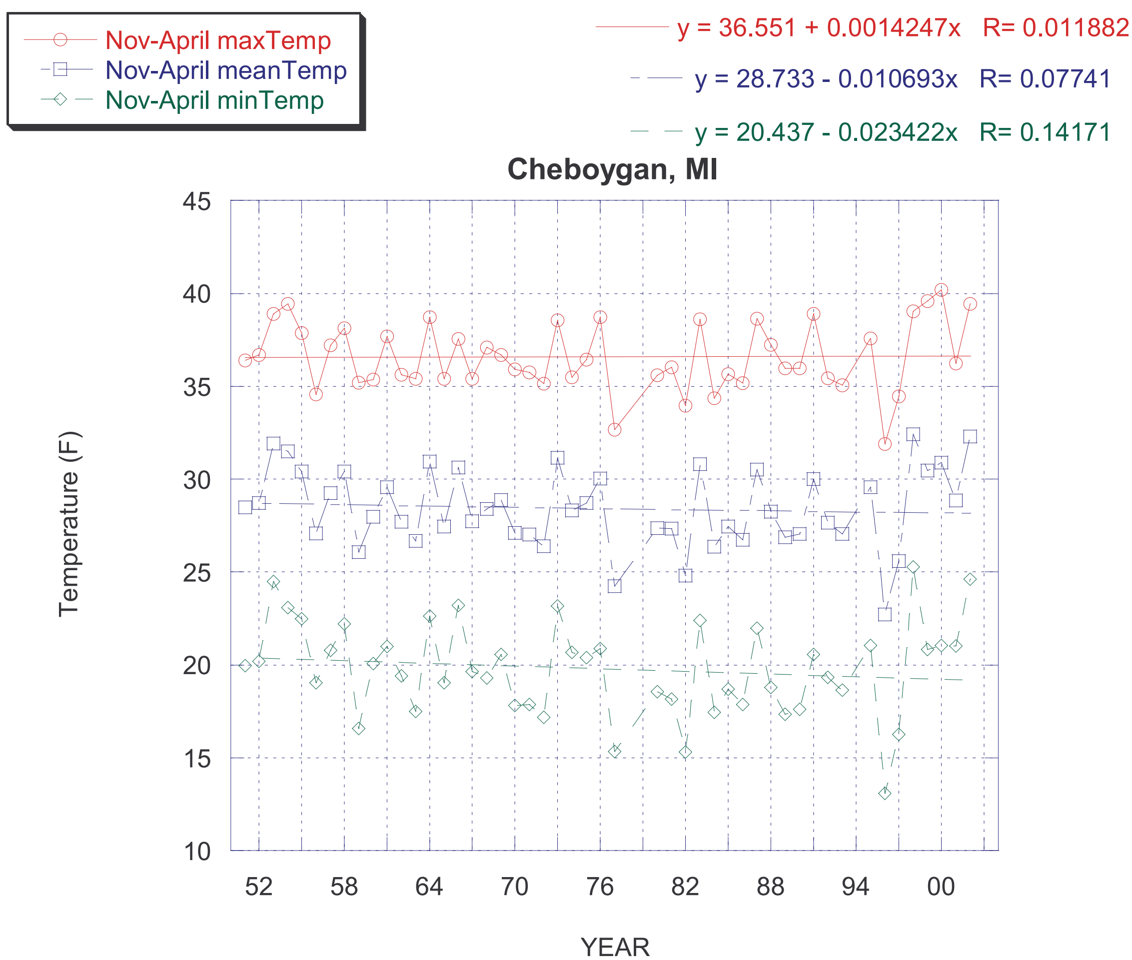

Figure 7d

Cool Period Temperatures

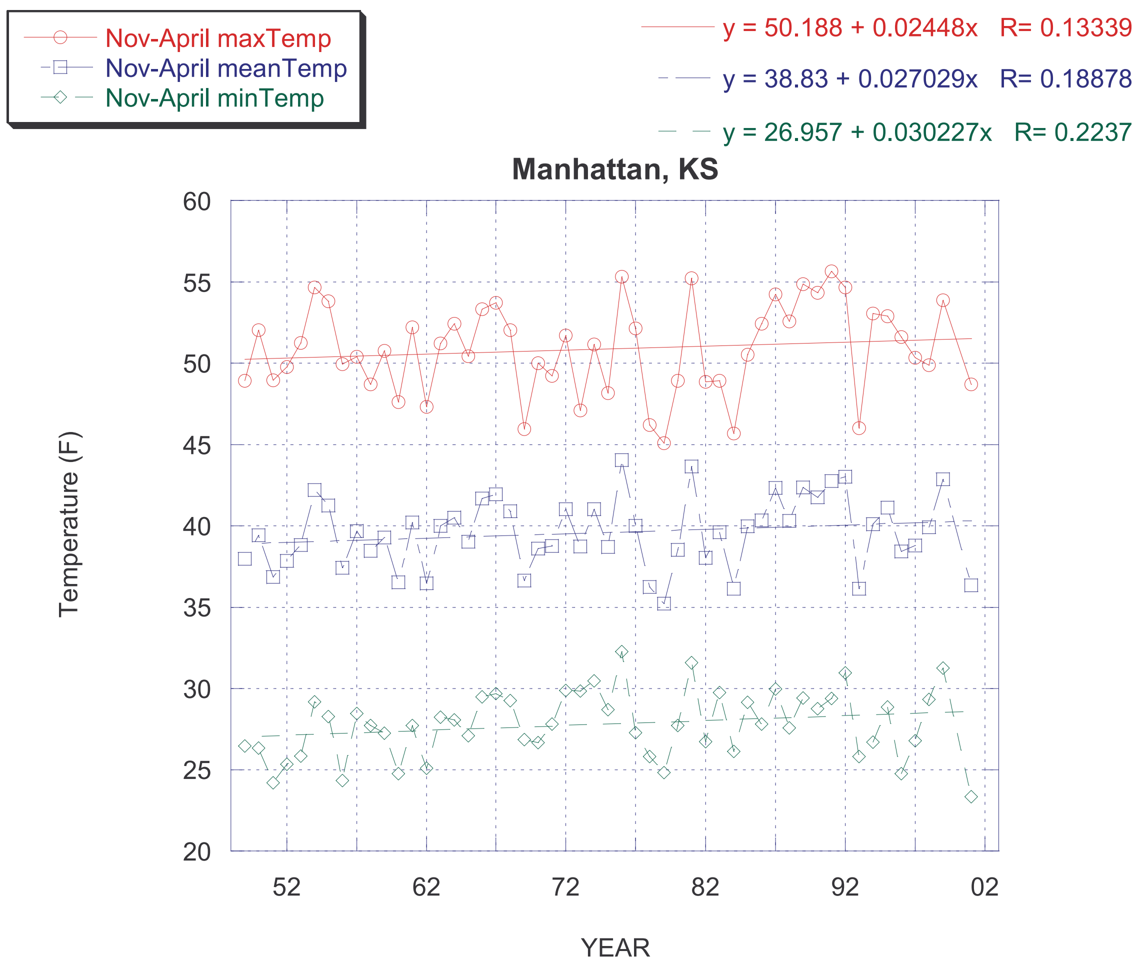

Figure 7e

Cool Period Temperatures

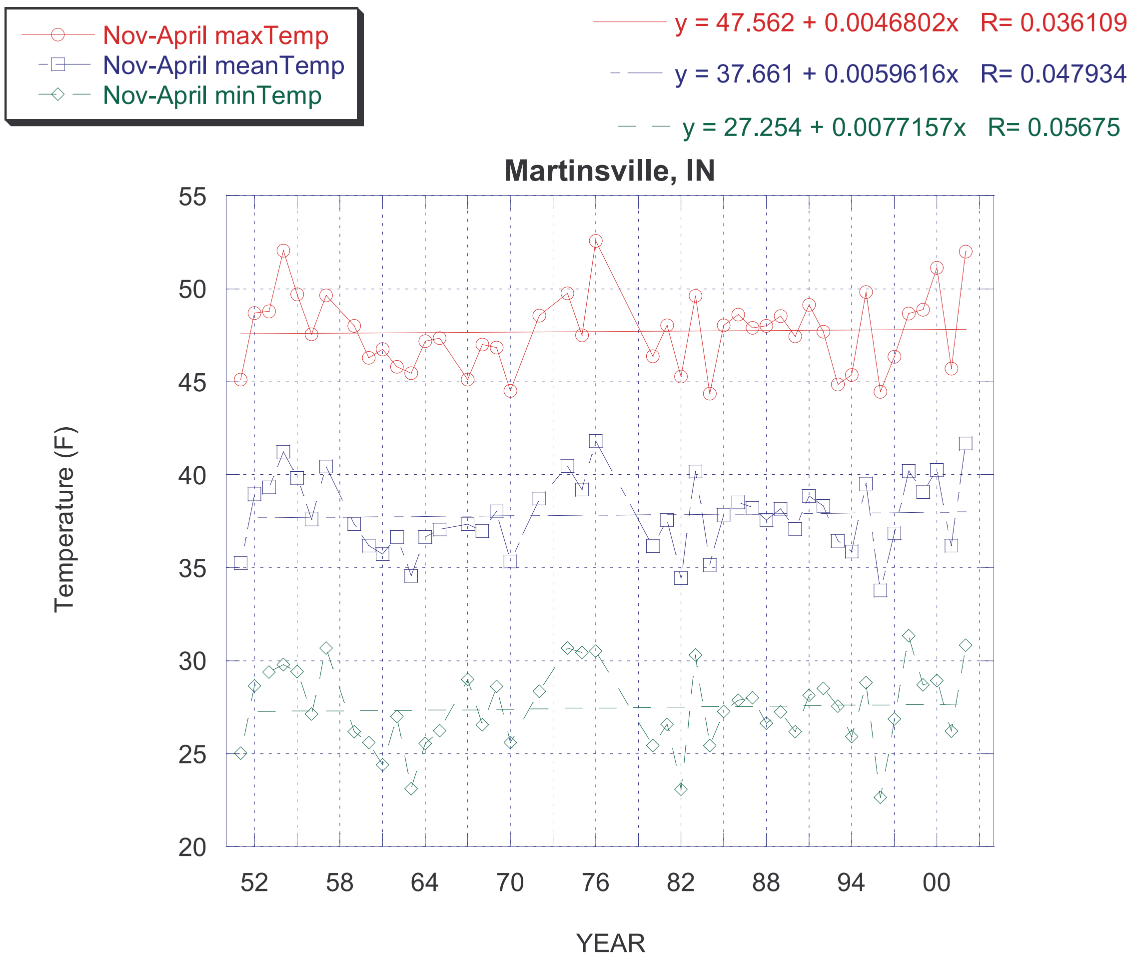

Figure 7f

Cool Period Temperatures

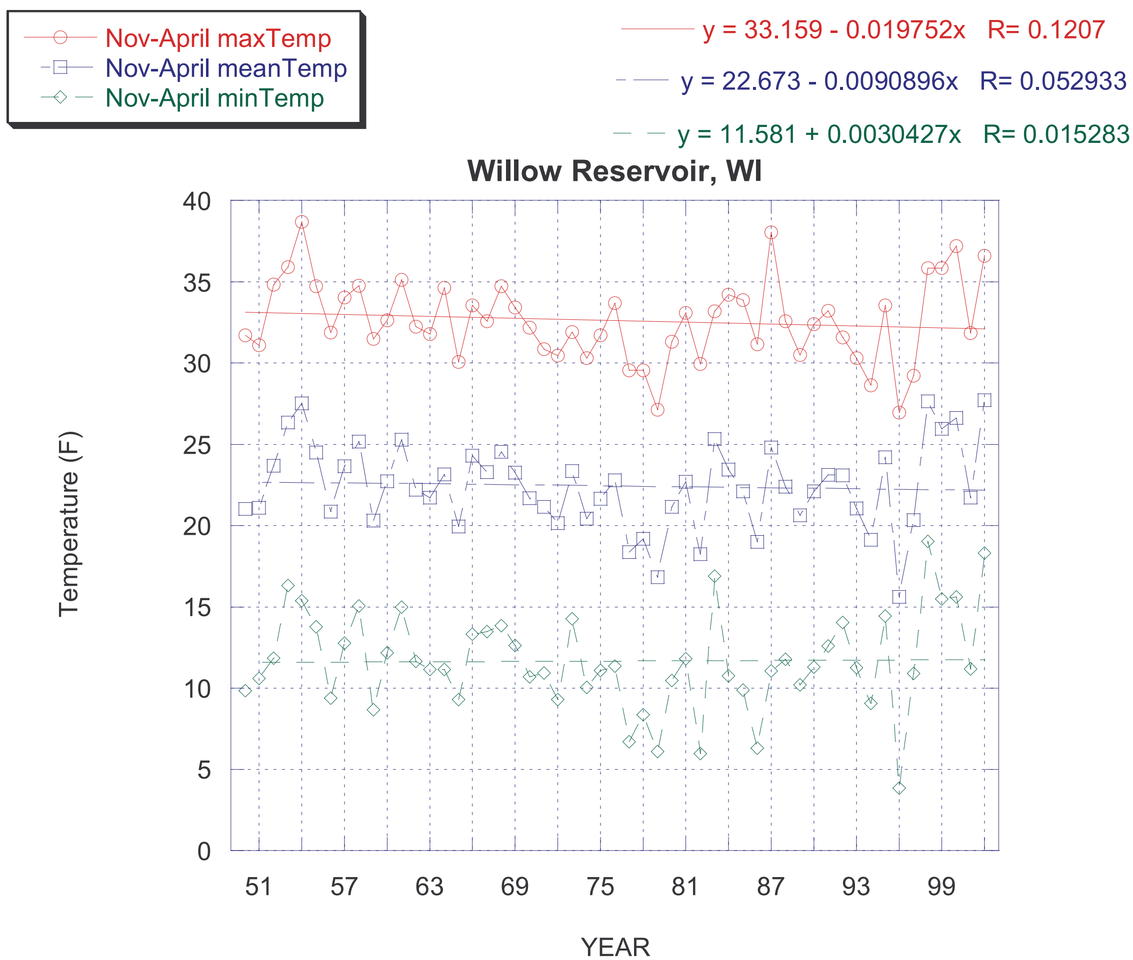

Figure 8a

Total Cool Period Precipitation

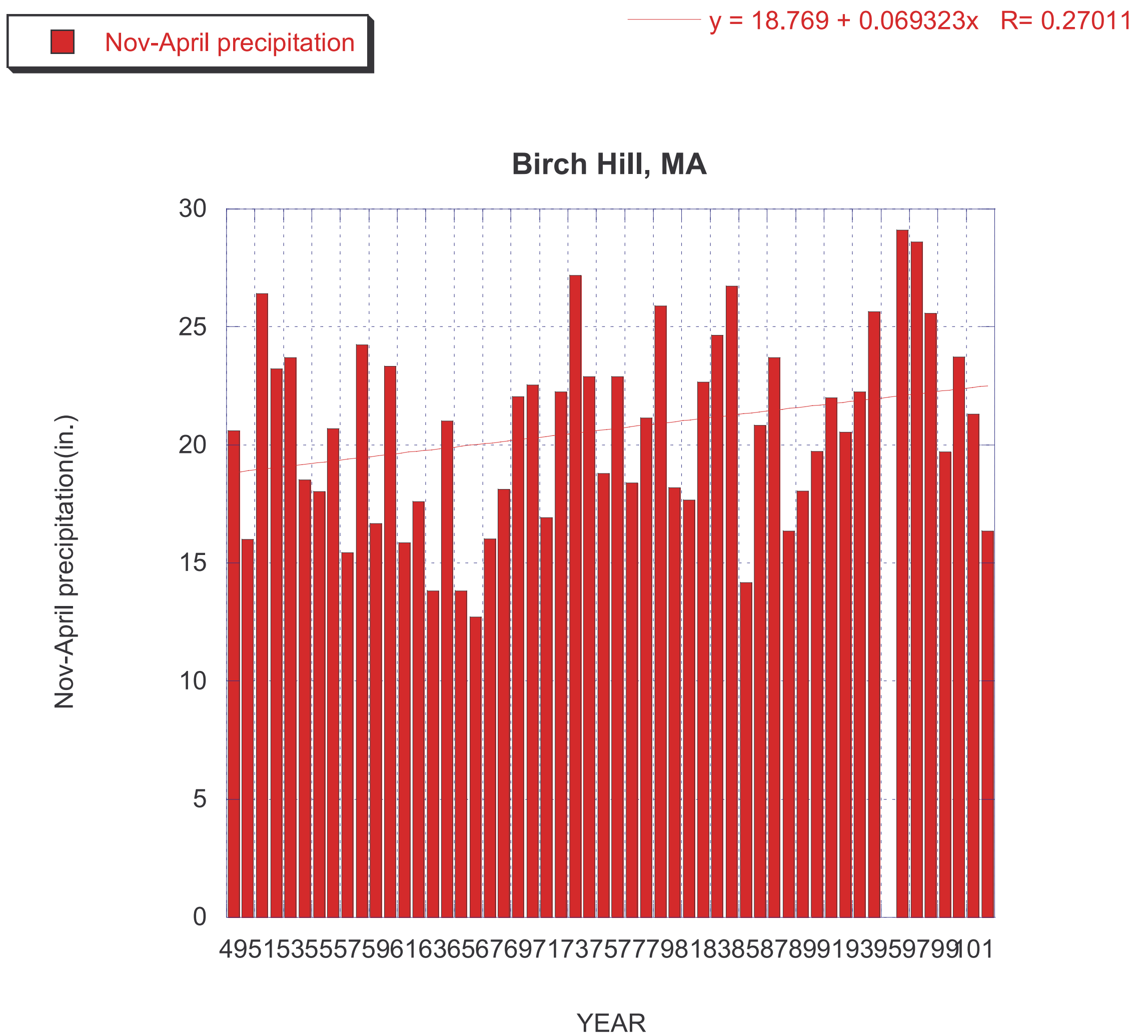

Figure 8b

Total Cool Period Precipitation

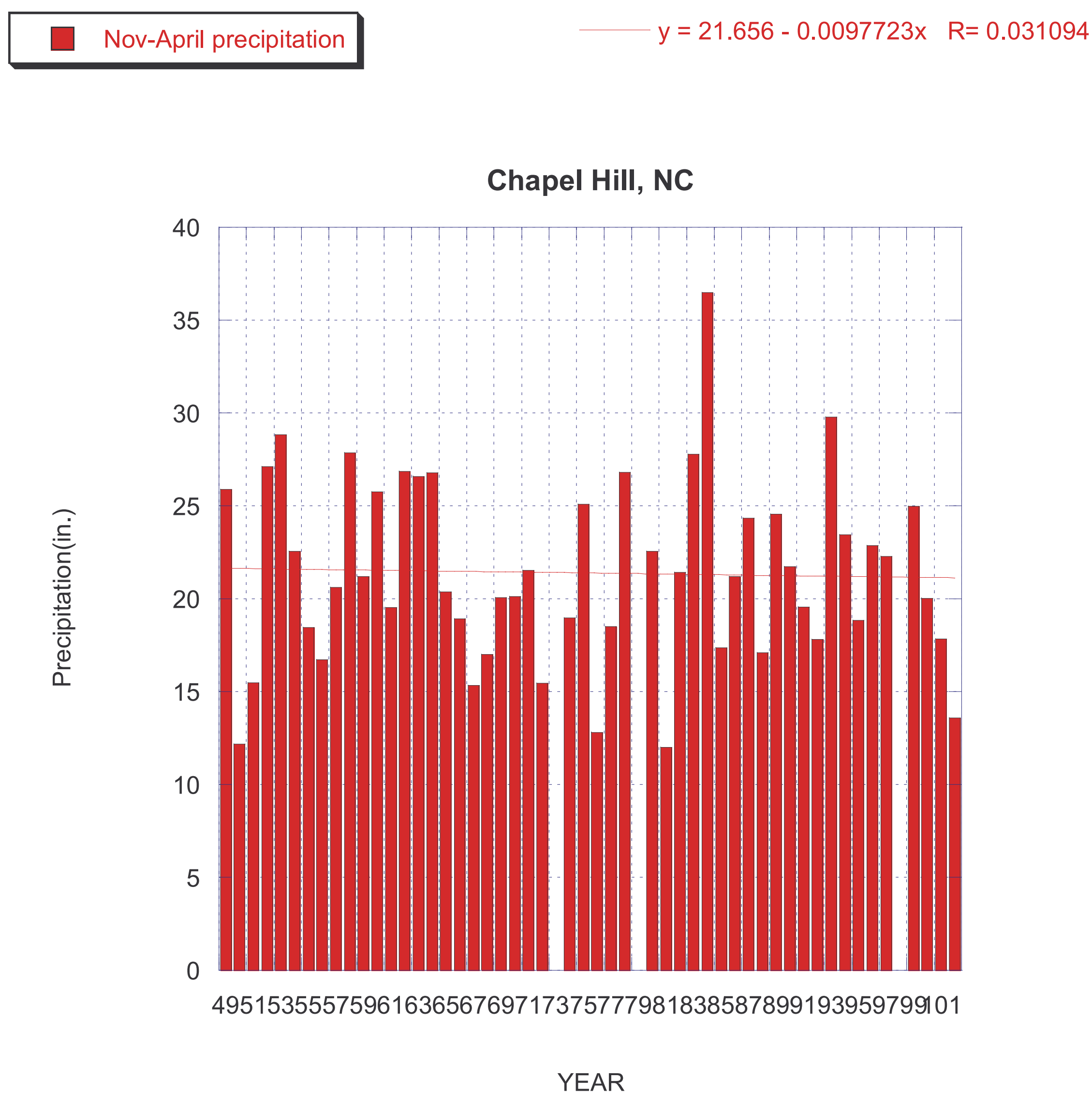

Figure 8c

Total Cool Period Precipitation

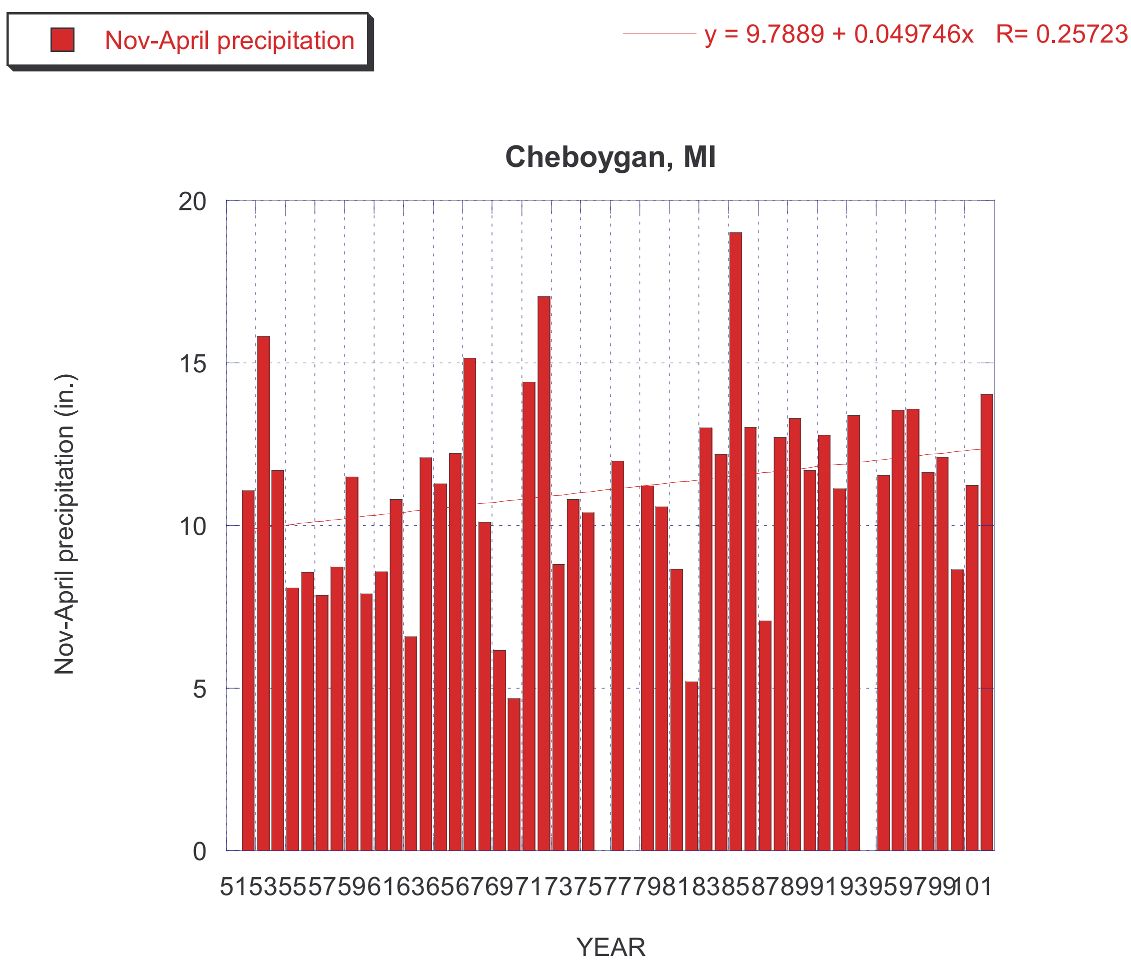

Figure 8d

Total Cool Period Precipitation

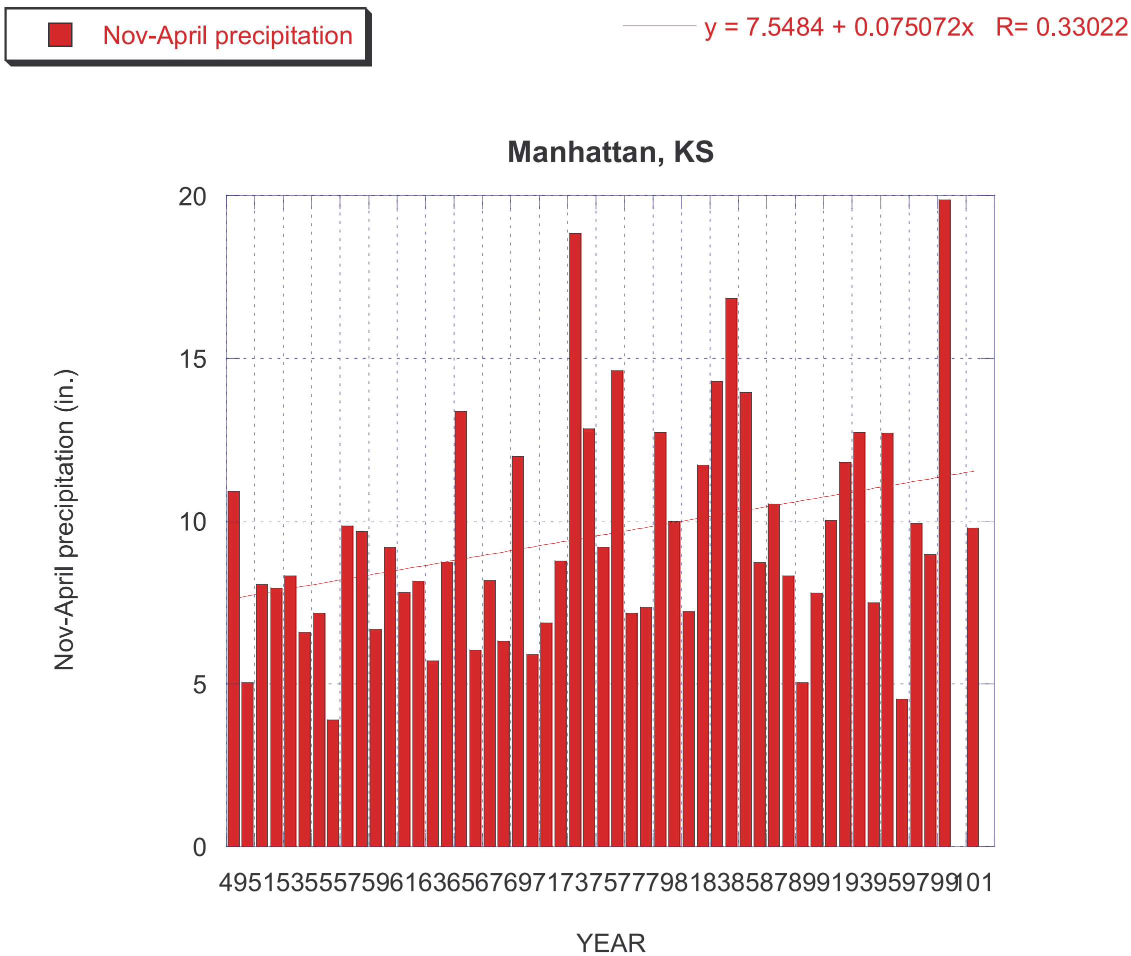

Figure 8e

Total Cool Period Precipitation

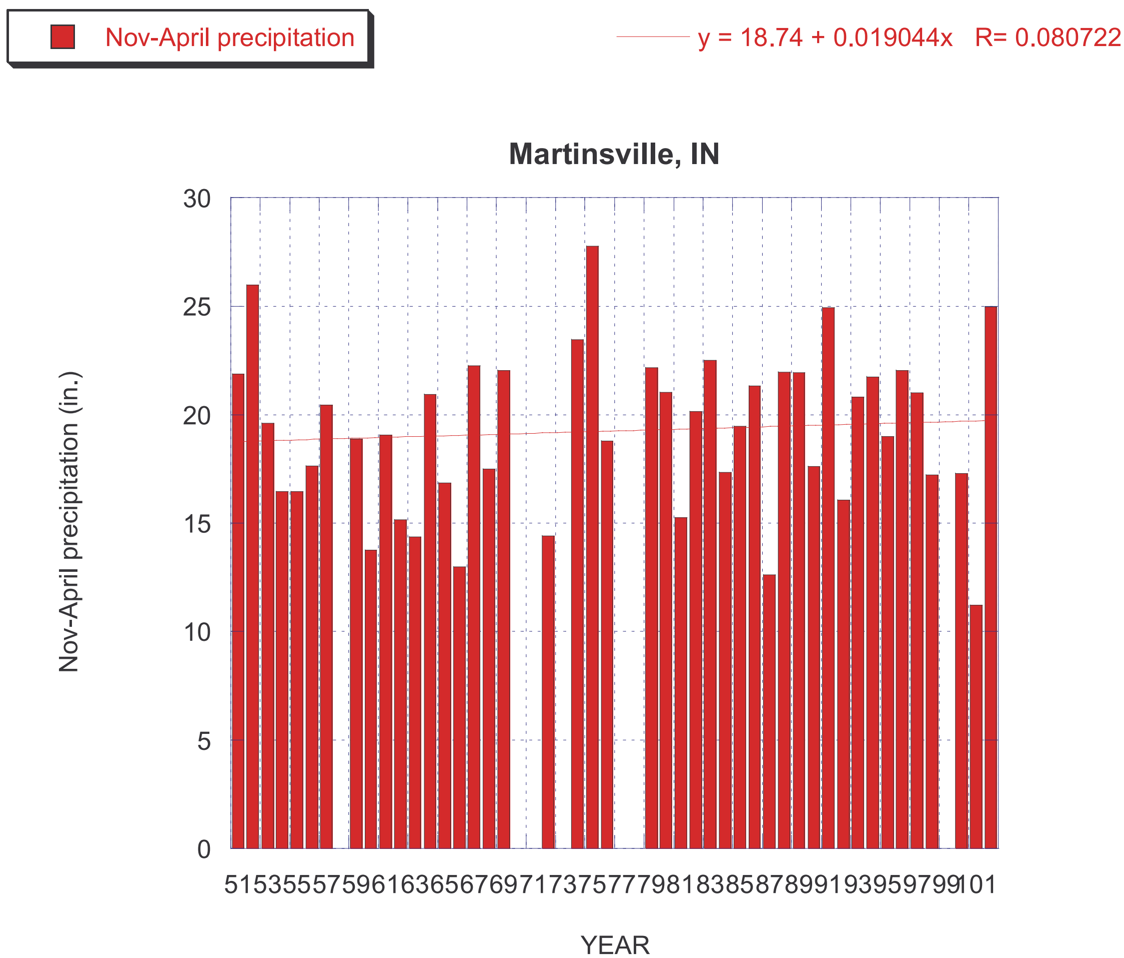

Figure 8f

Total Cool Period Precipitation

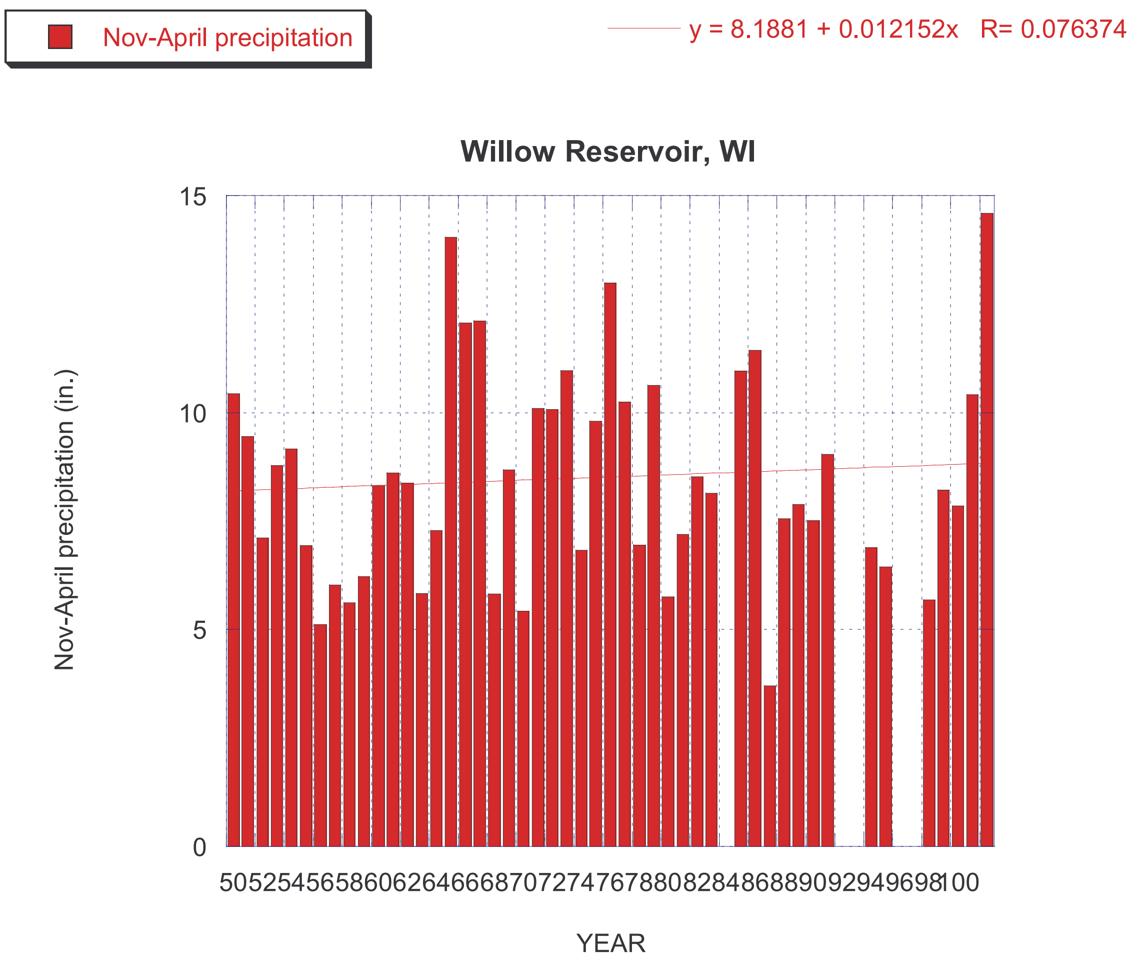

Figure 9a

Warm Period Temperatures

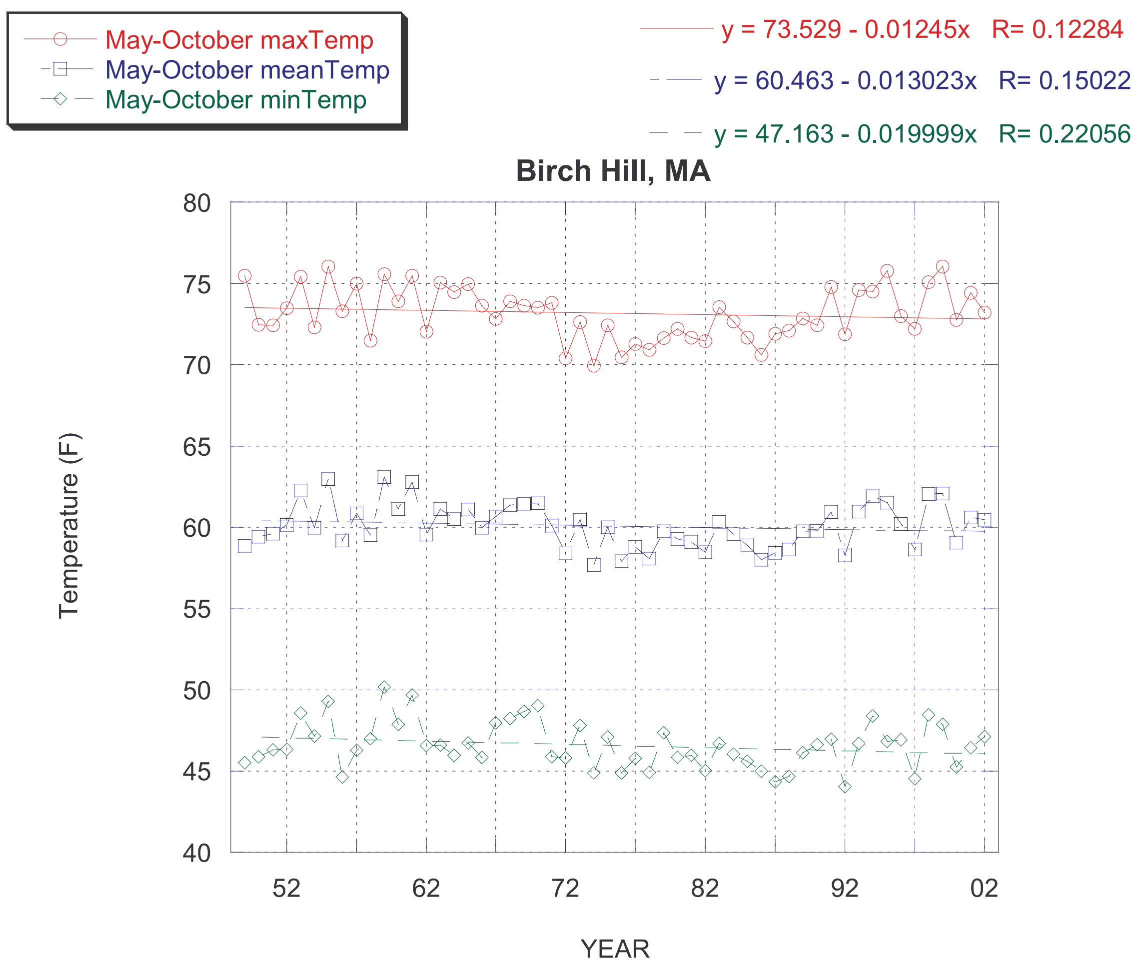

Figure 9b

Warm Period Temperatures

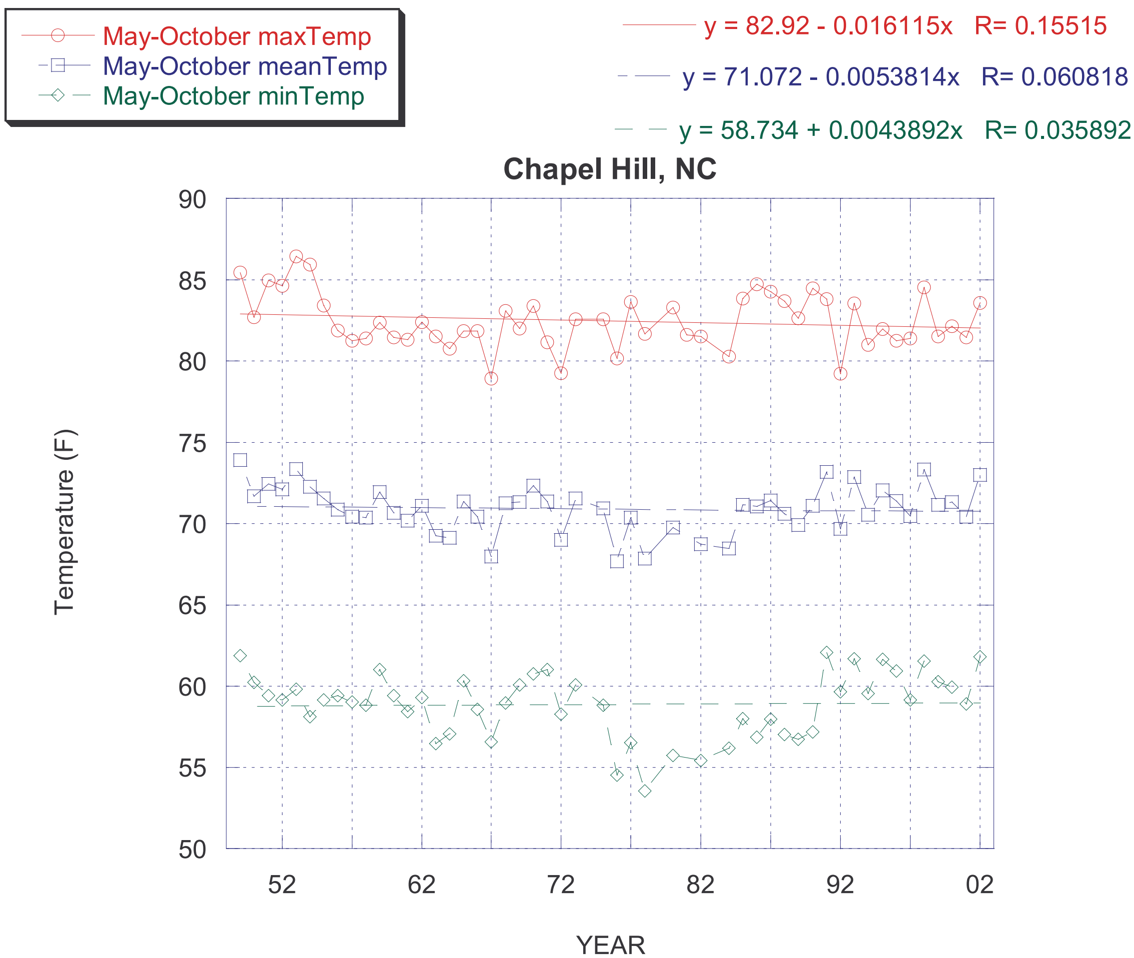

Figure 9c

Warm Period Temperatures

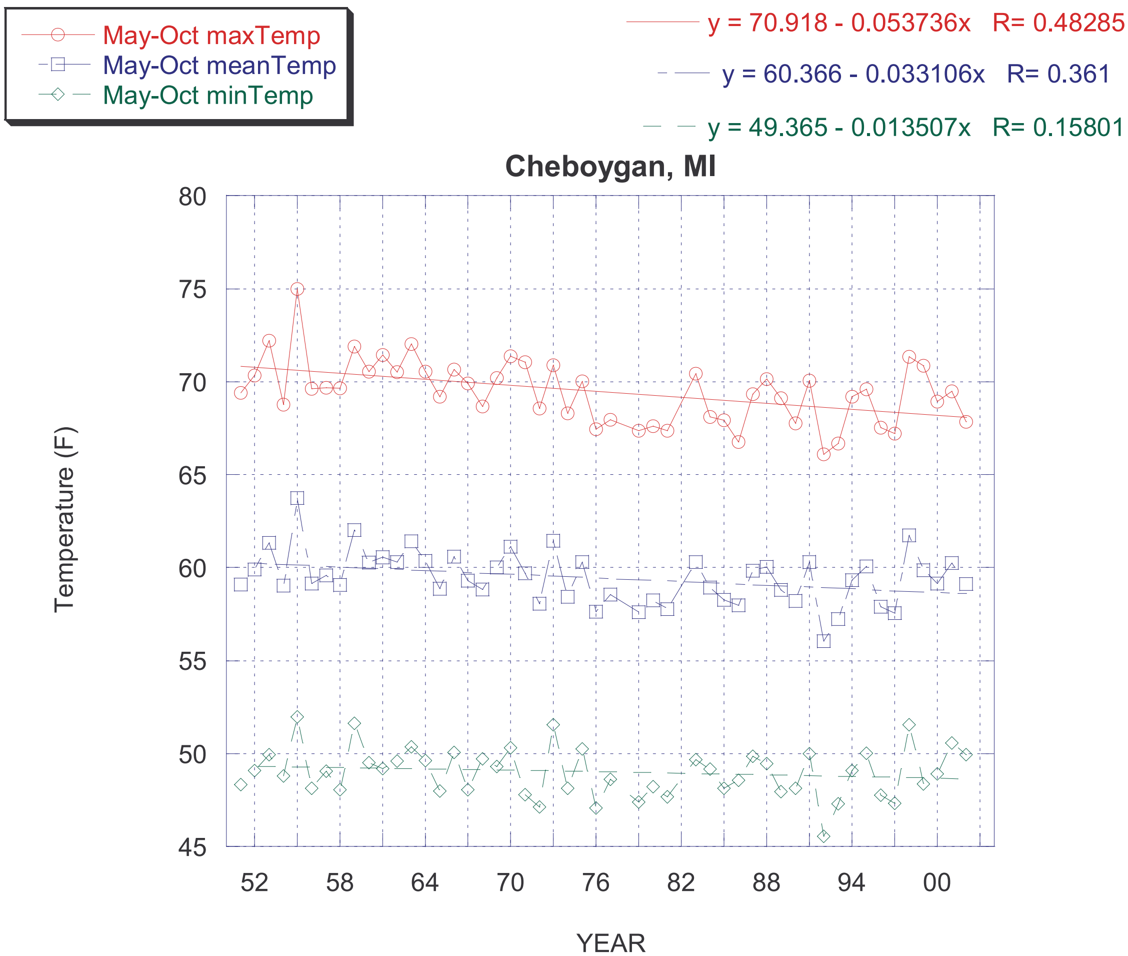

Figure 9d

Warm Period Temperatures

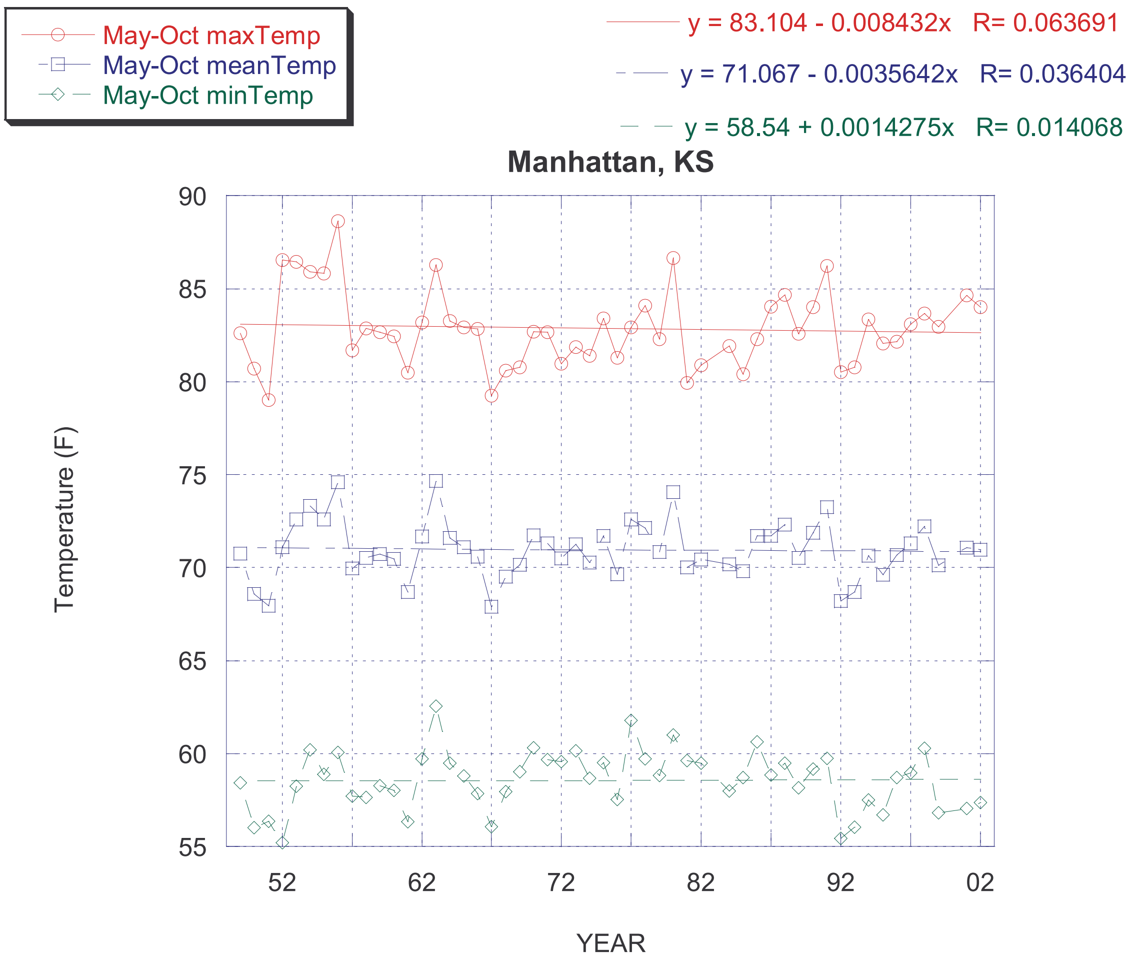

Figure 9e

Warm Period Temperatures

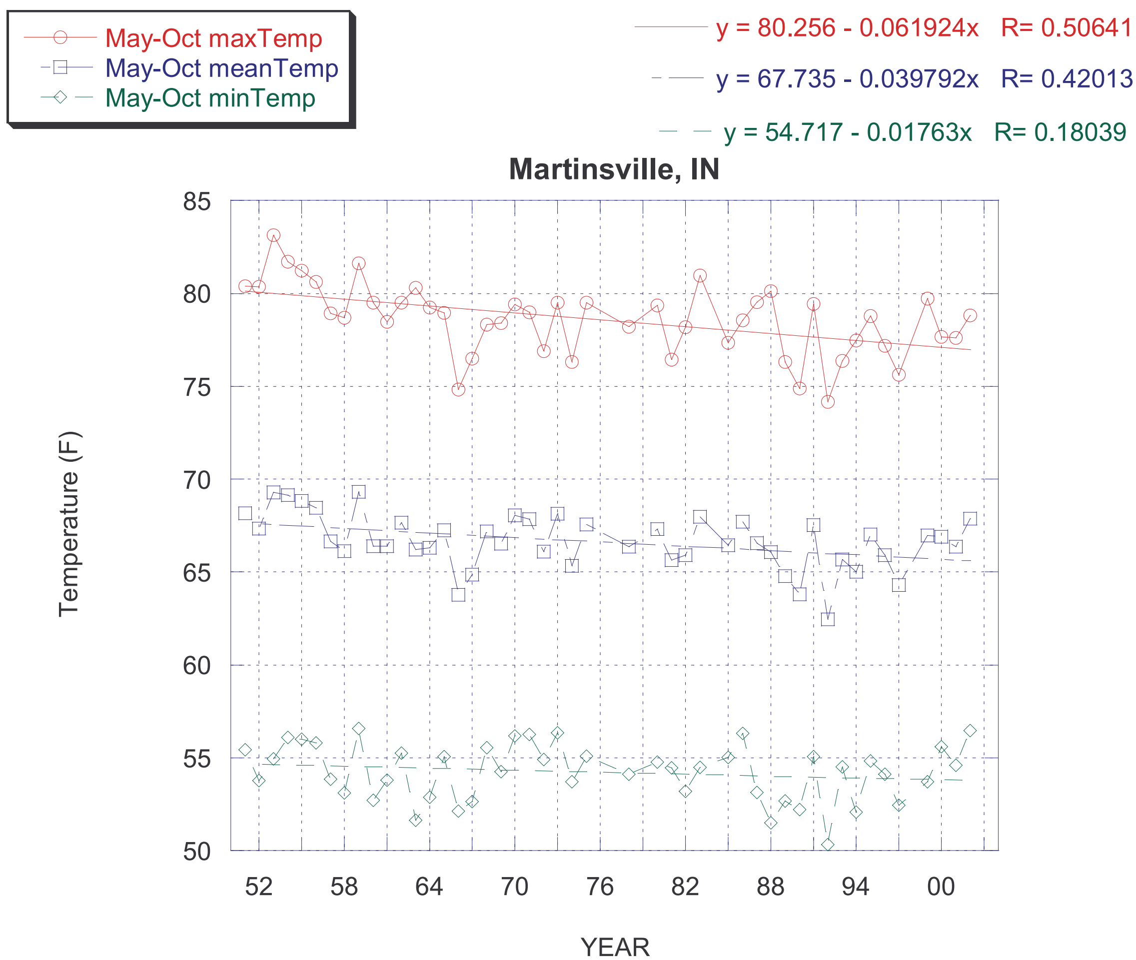

Figure 9f

Warm Period Temperatures

Figure 10a

Total Warm Period Precipitation

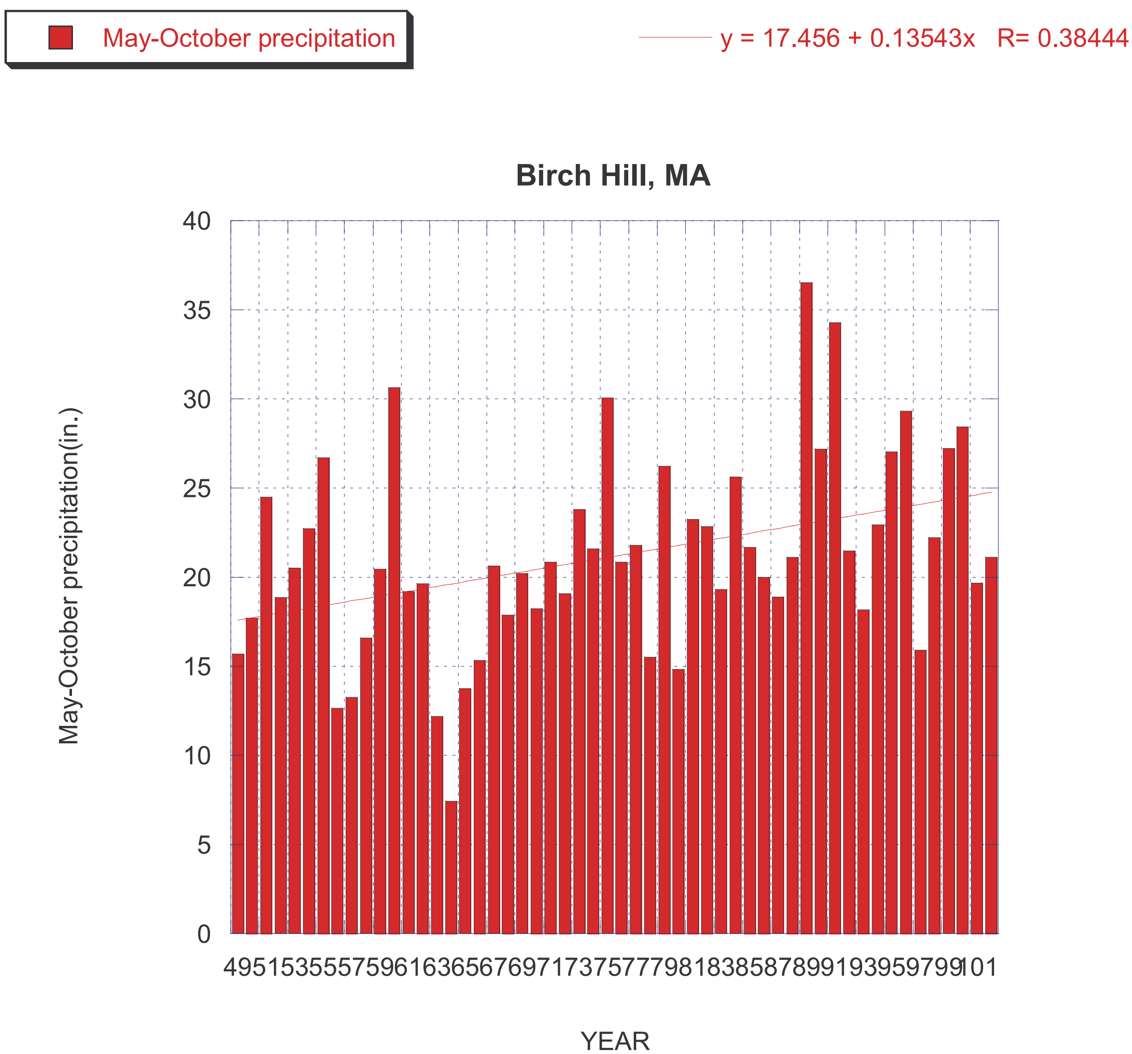

Figure 10b

Total Warm Period Precipitation

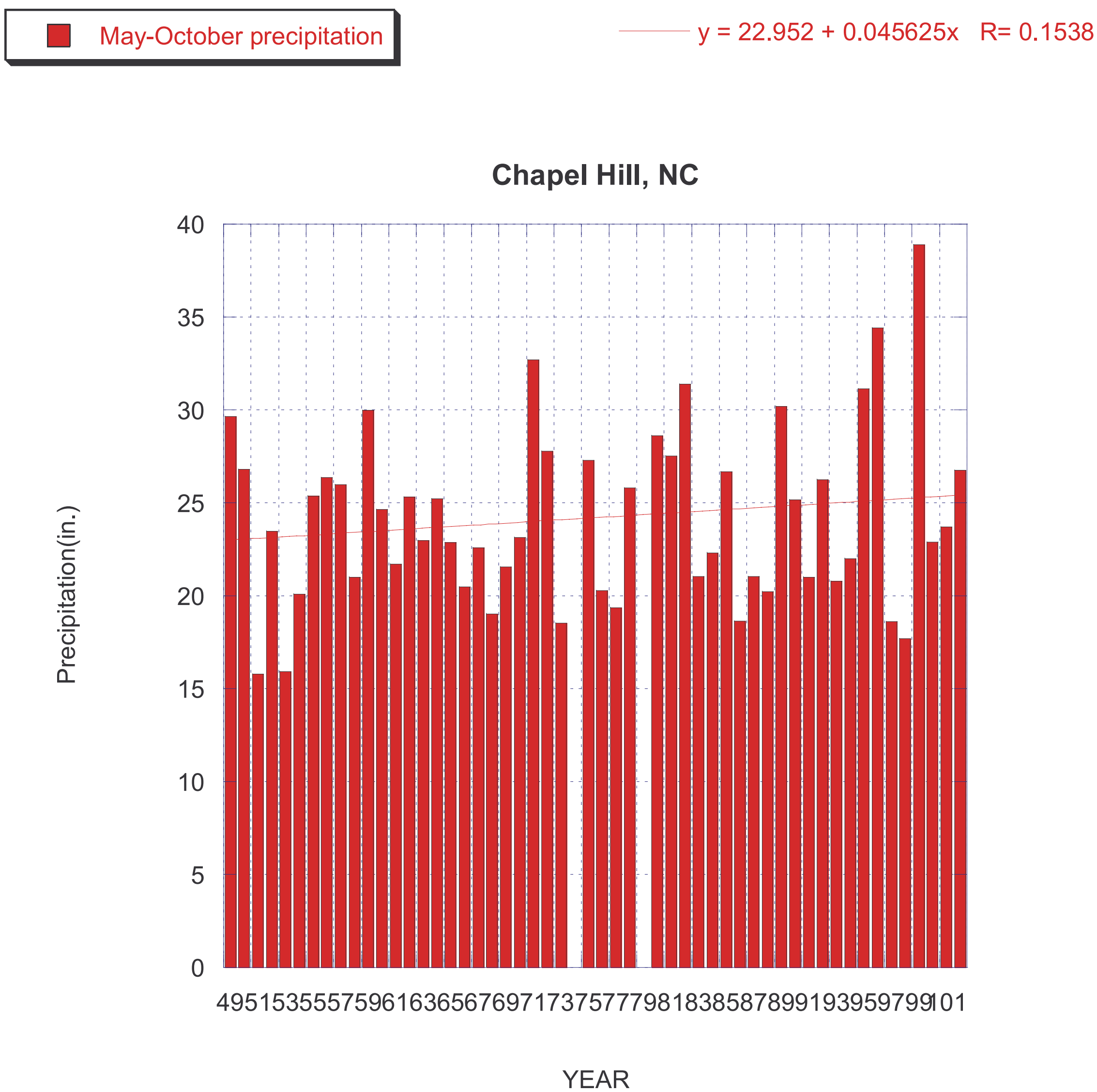

Figure 10c

Total Warm Period Precipitation

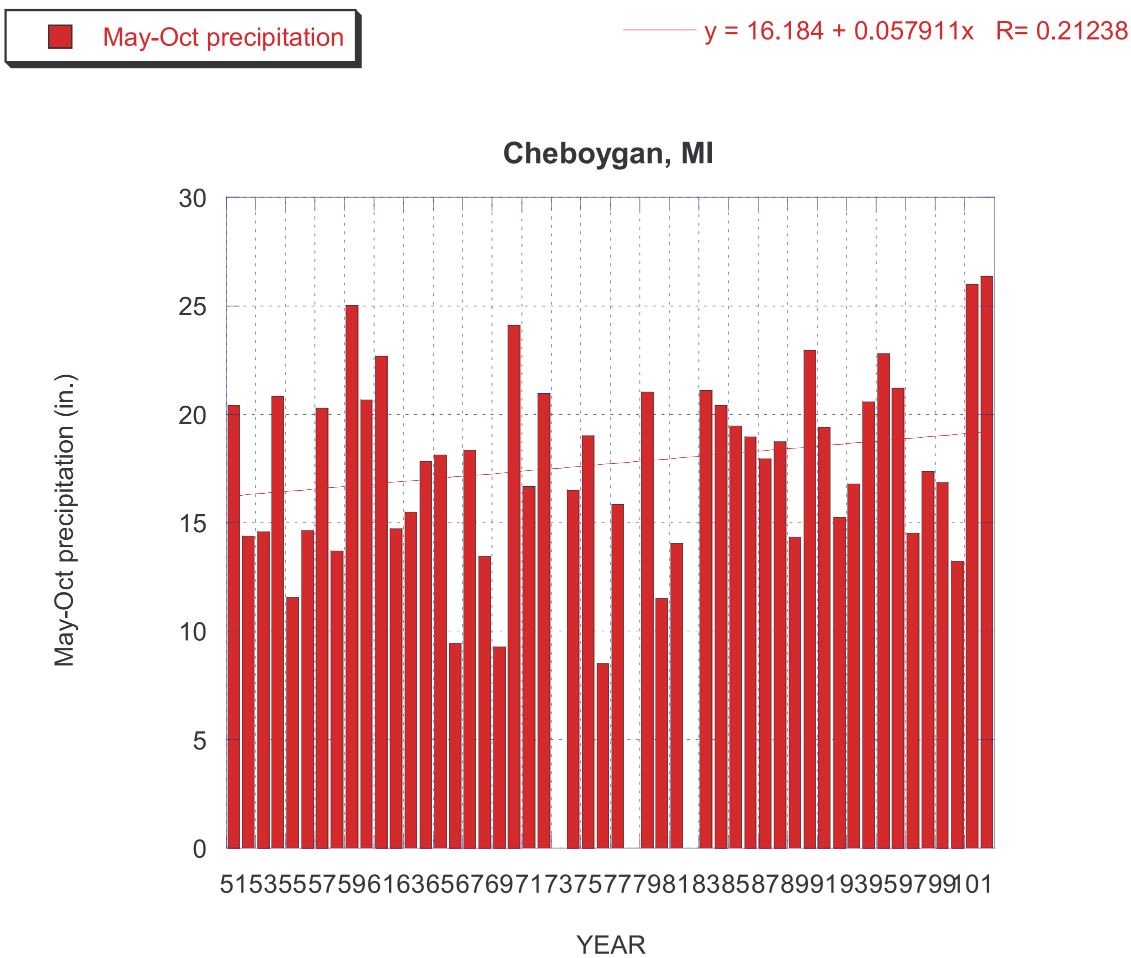

Figure 10d

Total Warm Period Precipitation

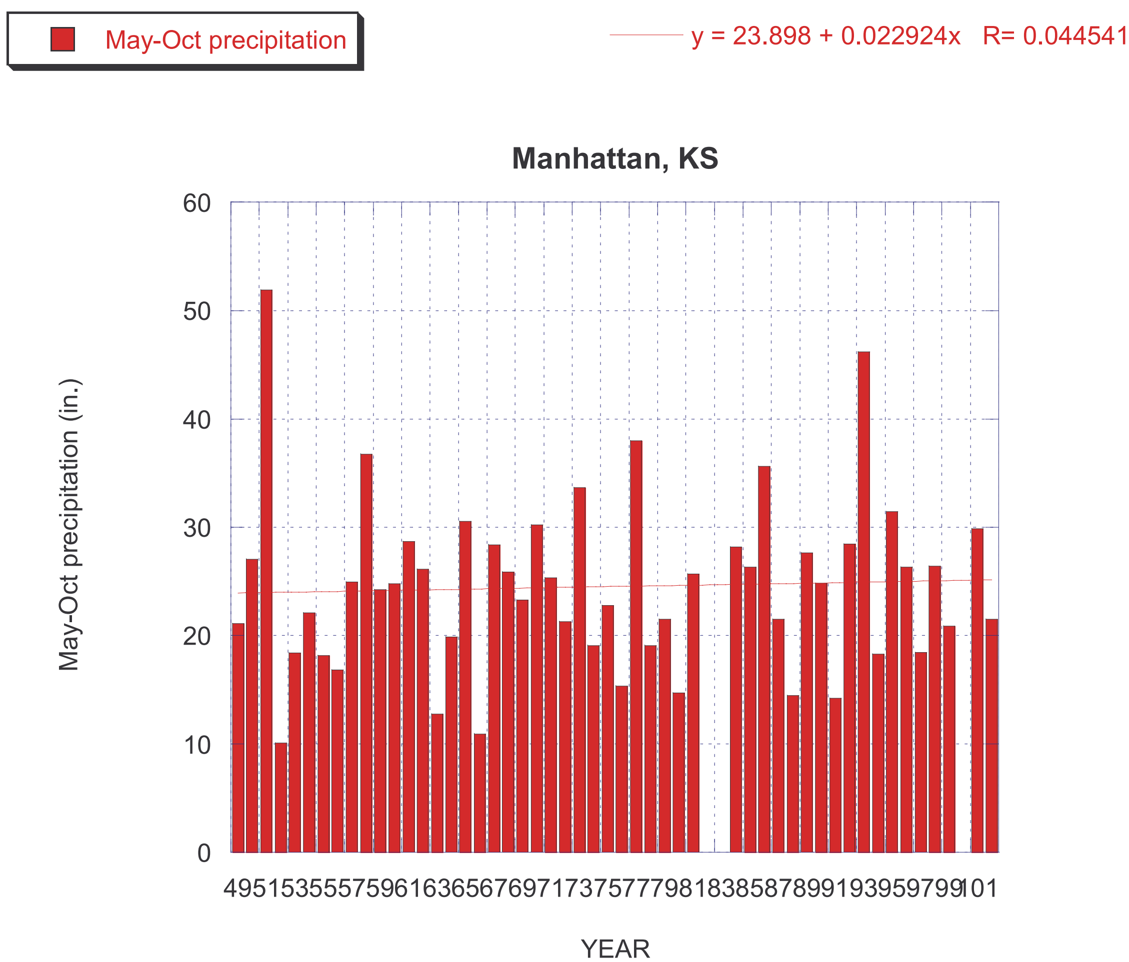

Figure 10e

Total Warm Period Precipitation

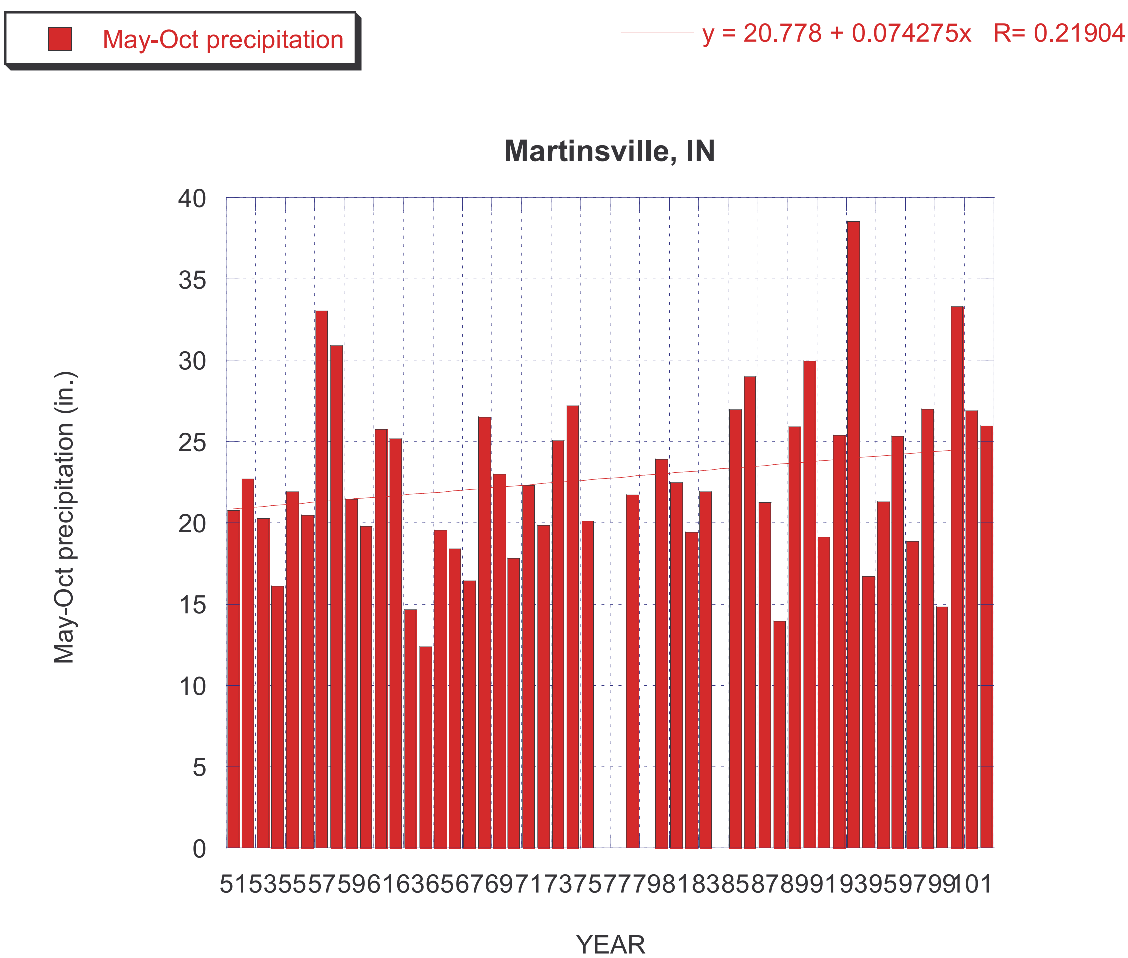

Figure 10f

Total Warm Period Precipitation

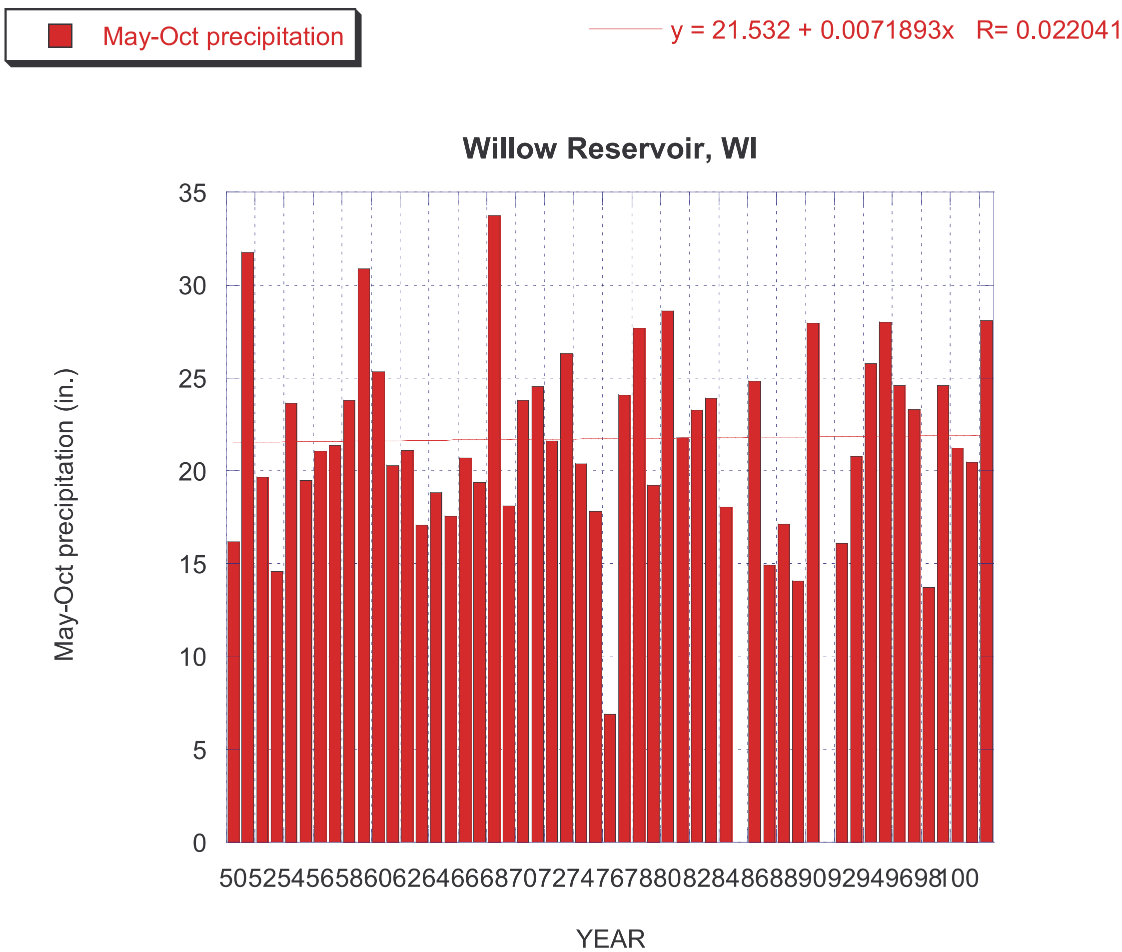

Figure 11a

Start of the Growing Season

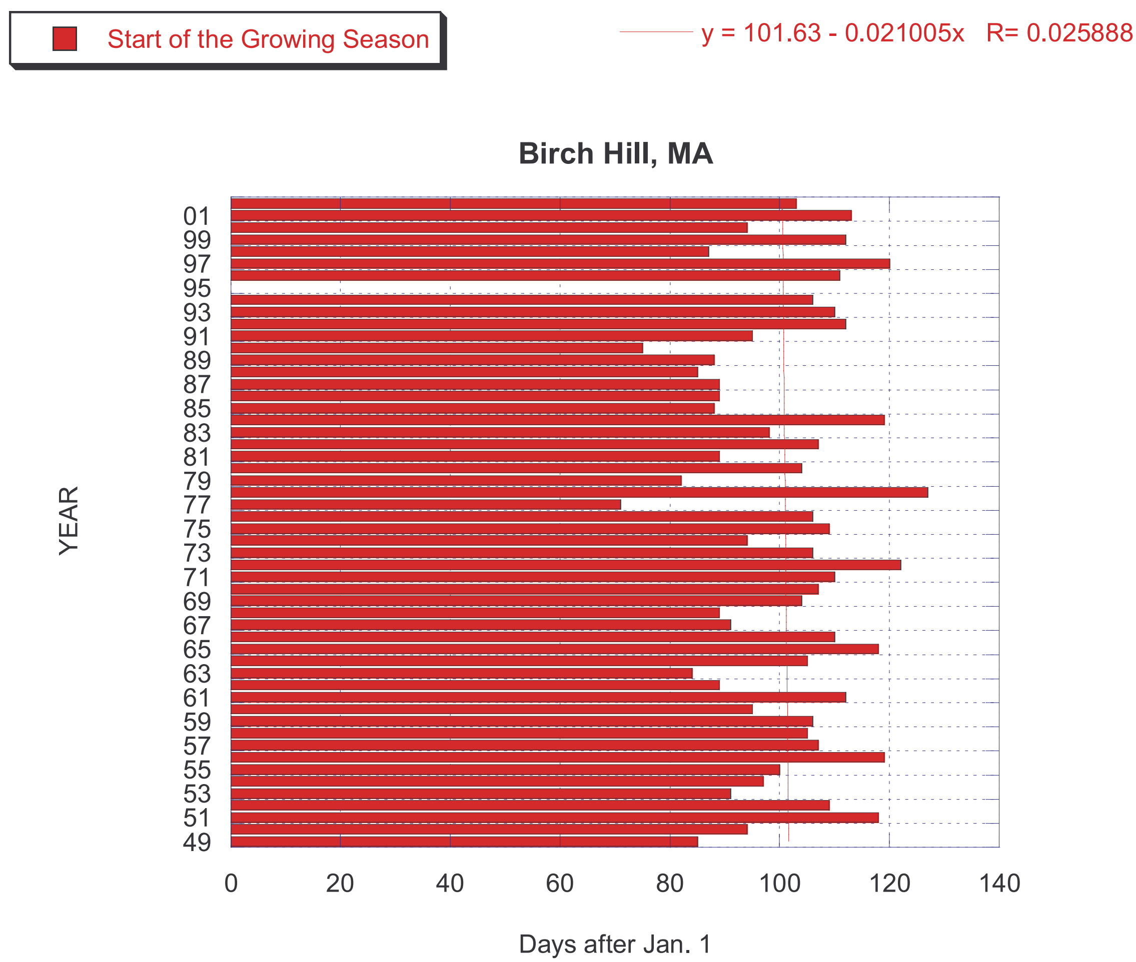

Figure 11b

Start of the Growing Season

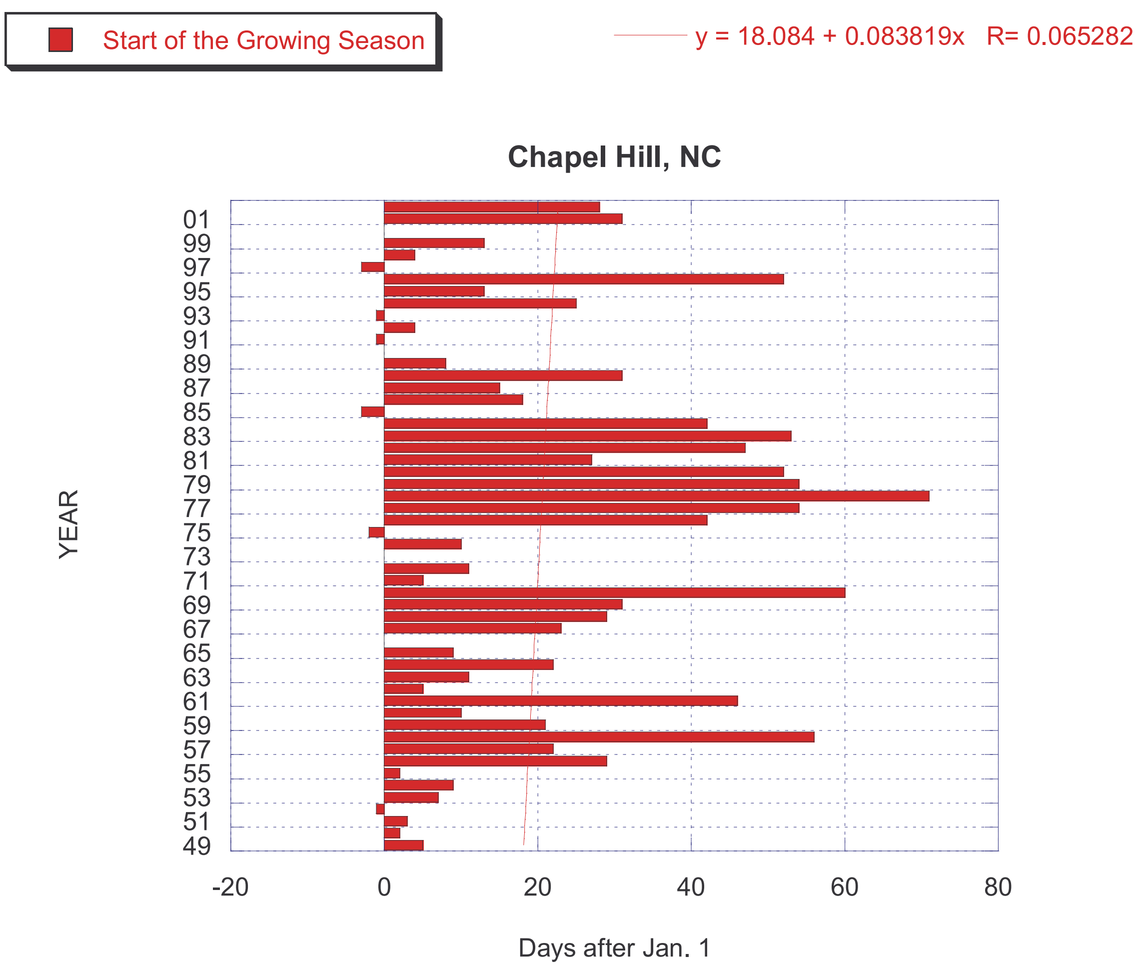

Figure 11c

Start of the Growing Season

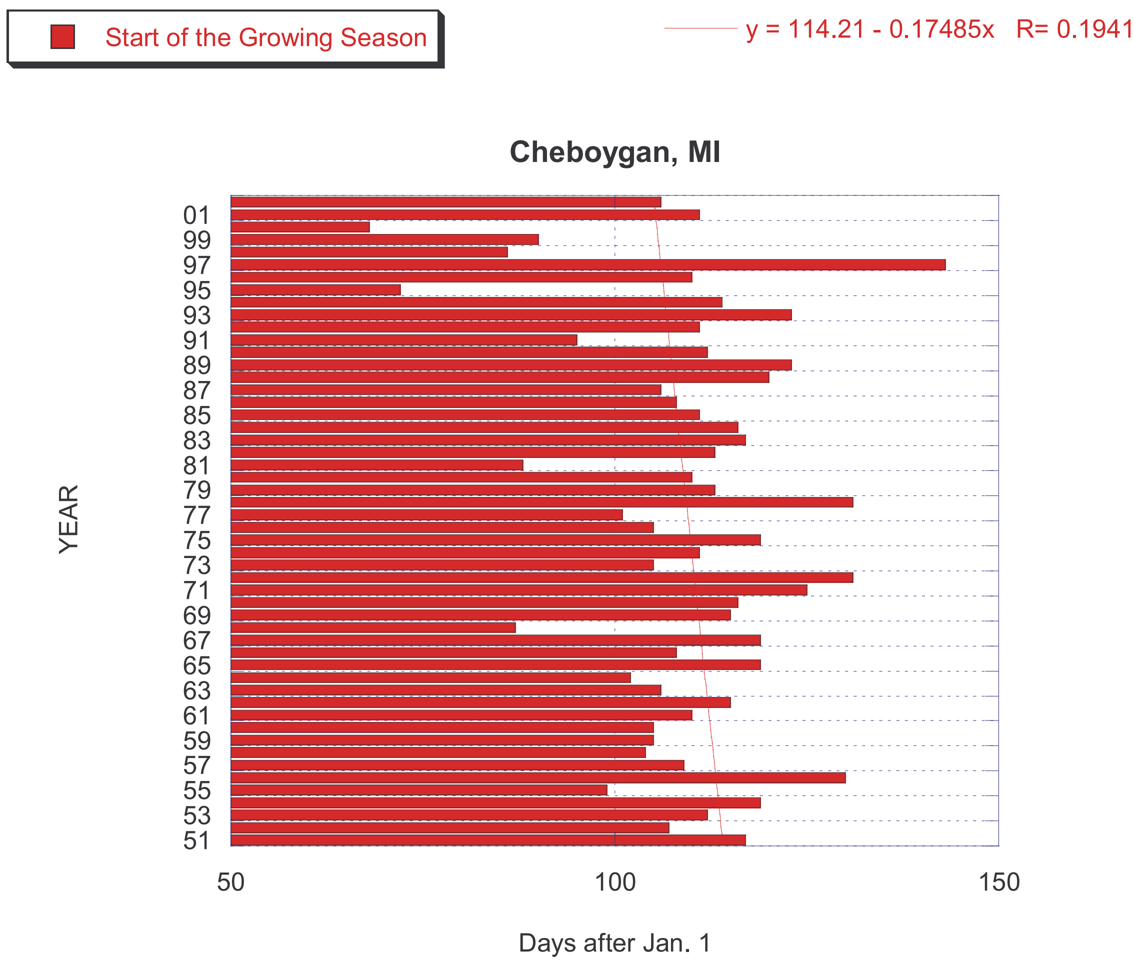

Figure 11d

Start of the Growing Season

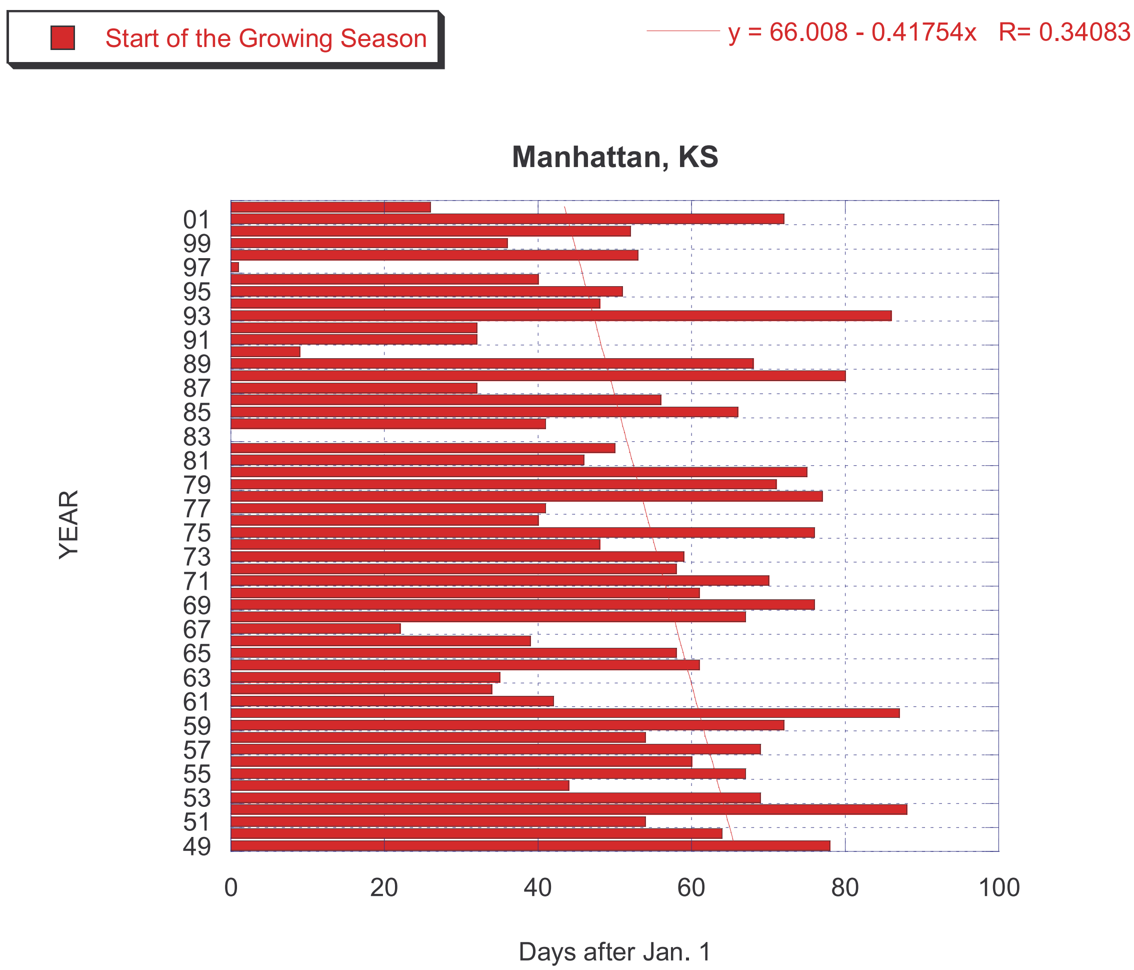

Figure 11e

Start of the Growing Season

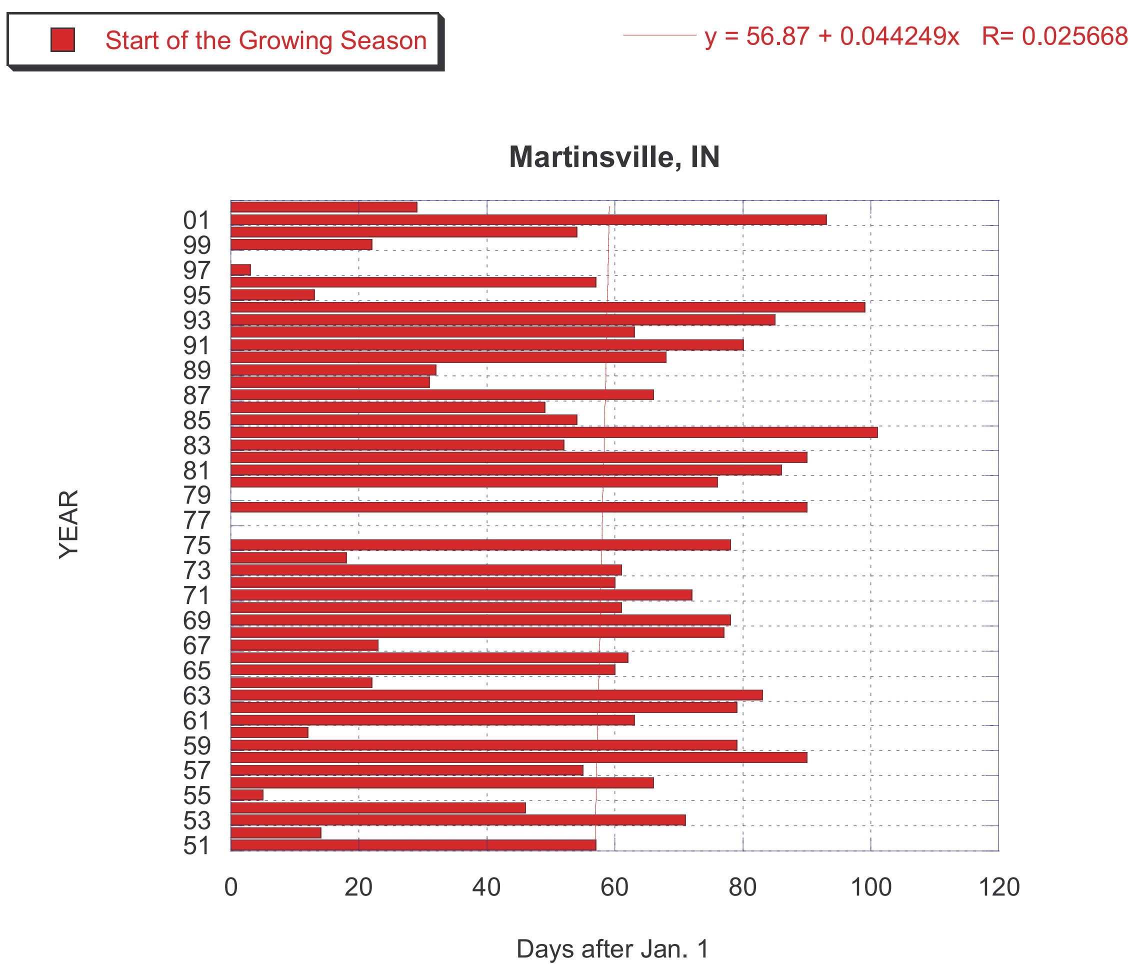

Figure 11f

Start of the Growing Season

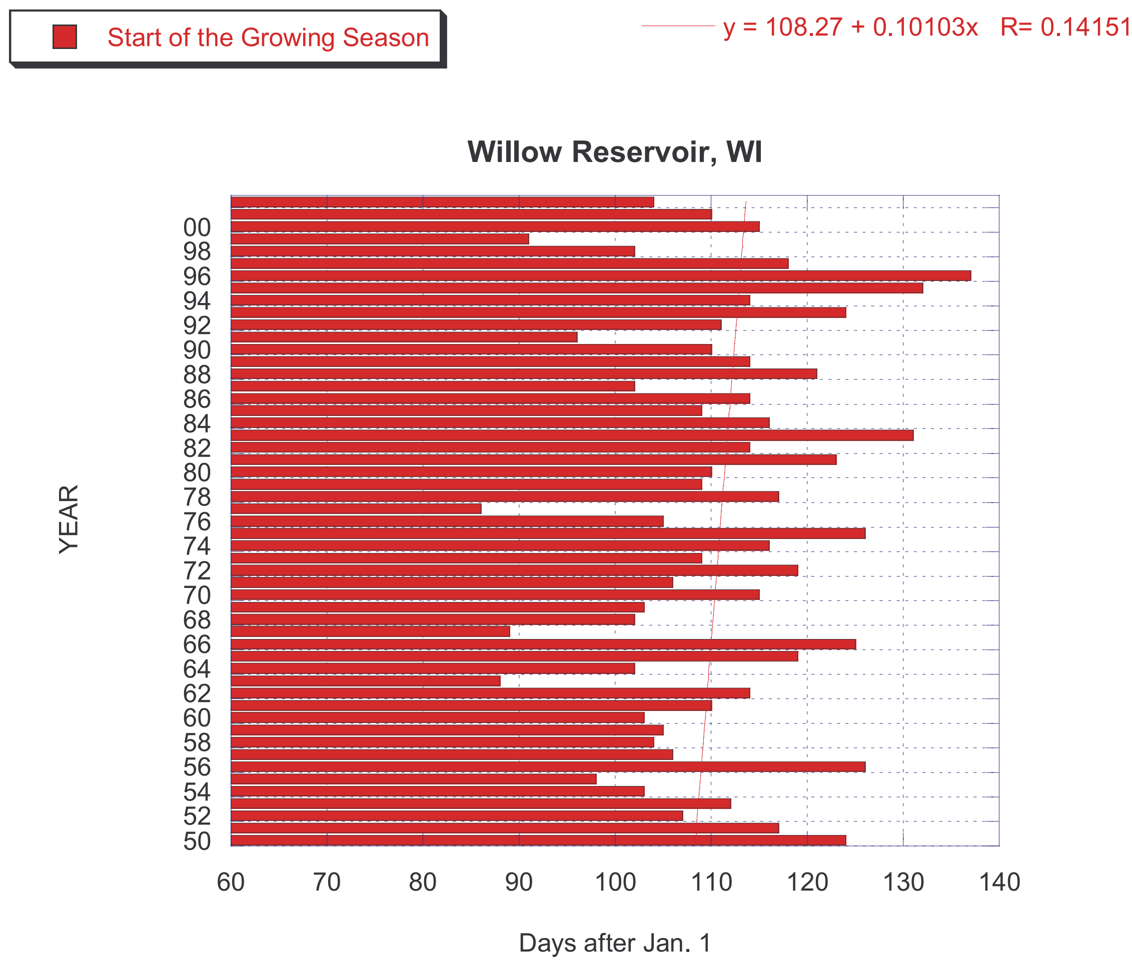

Figure 12a

End of the Growing Season

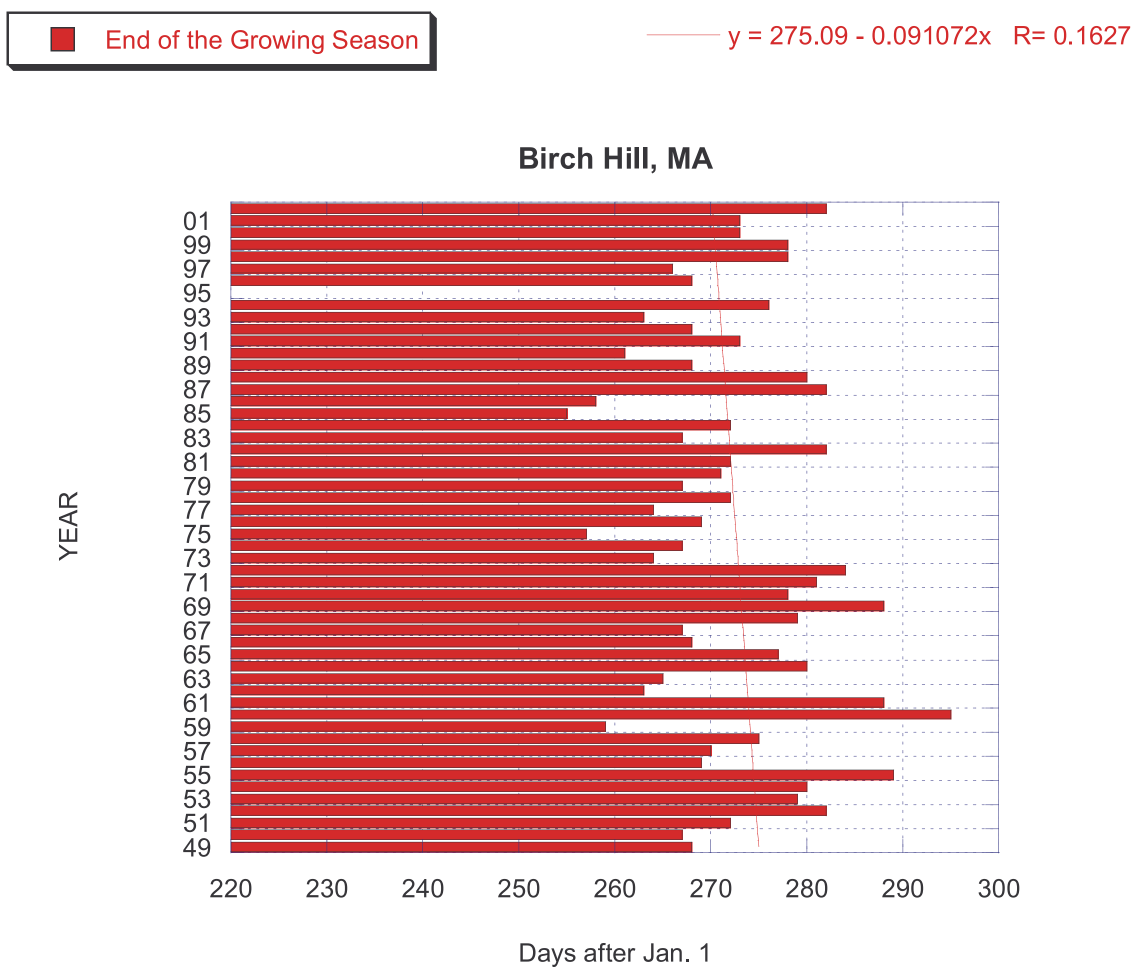

Figure 12b

End of the Growing Season

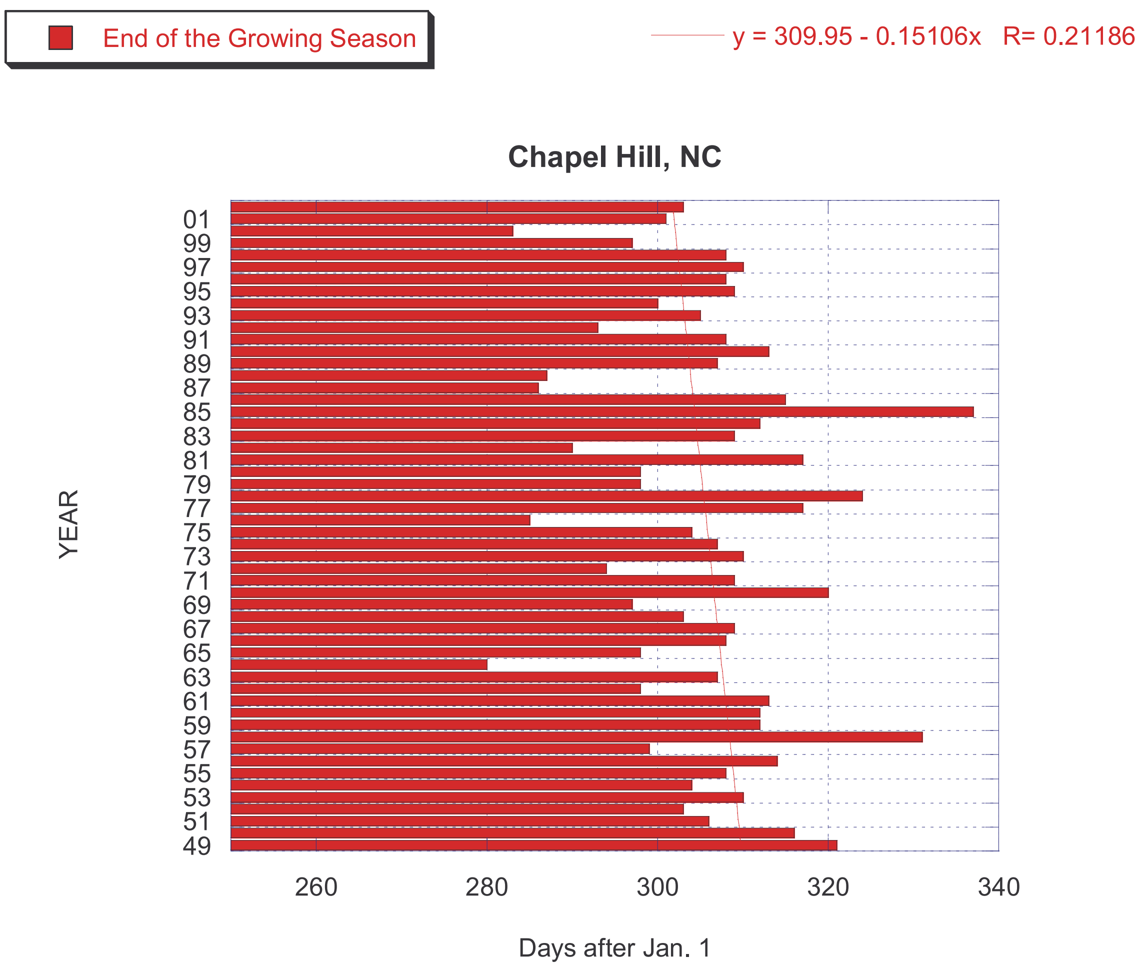

Figure 12c

End of the Growing Season

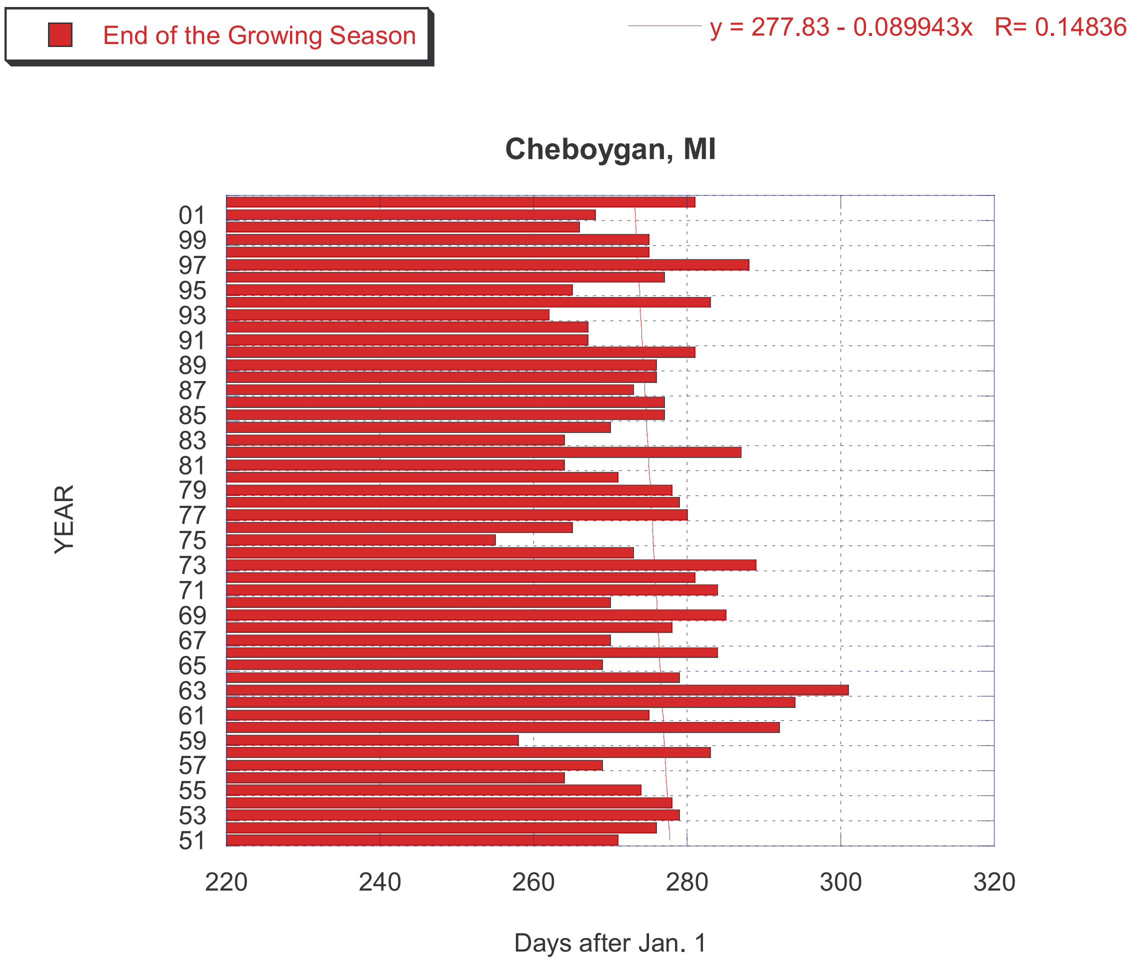

Figure 12d

End of the Growing Season

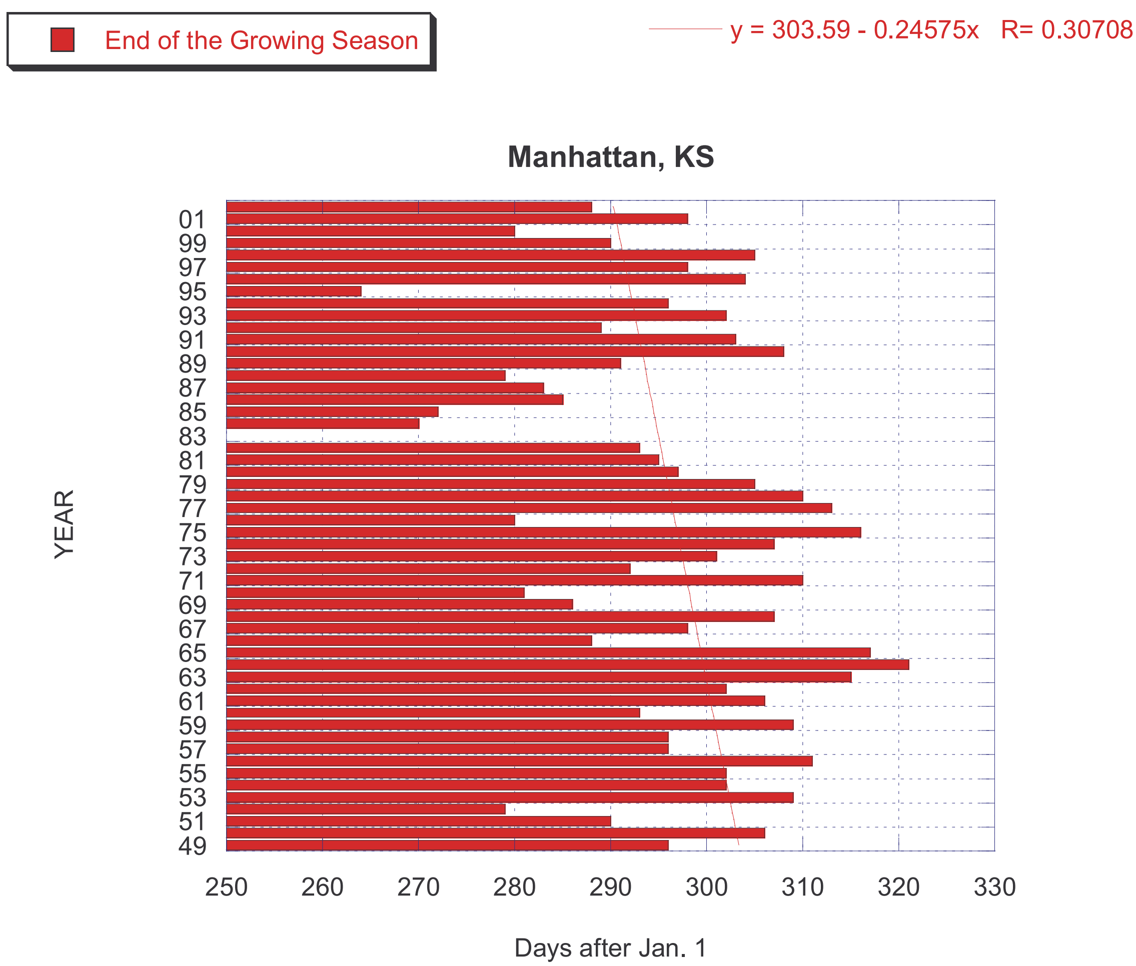

Figure 12e

End of the Growing Season

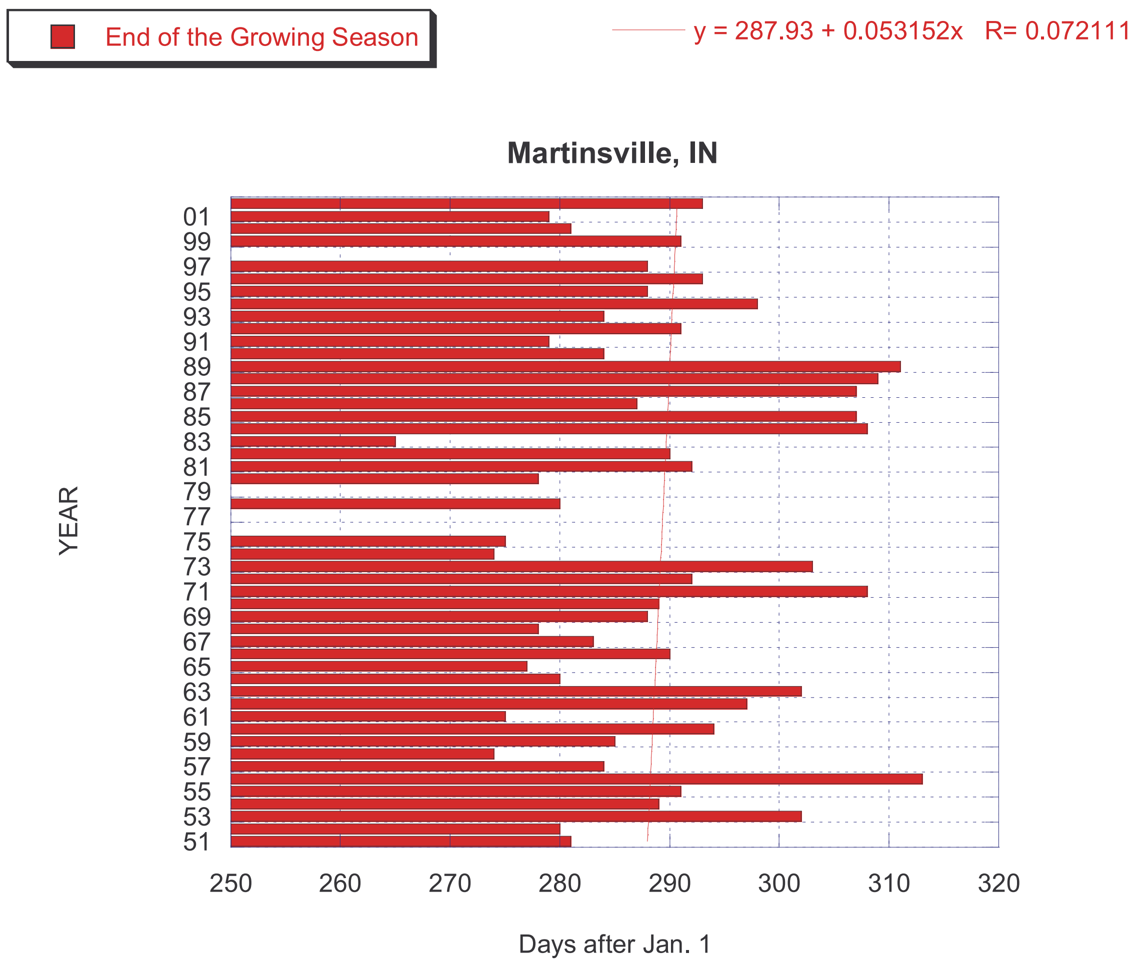

Figure 12f

End of the Growing Season

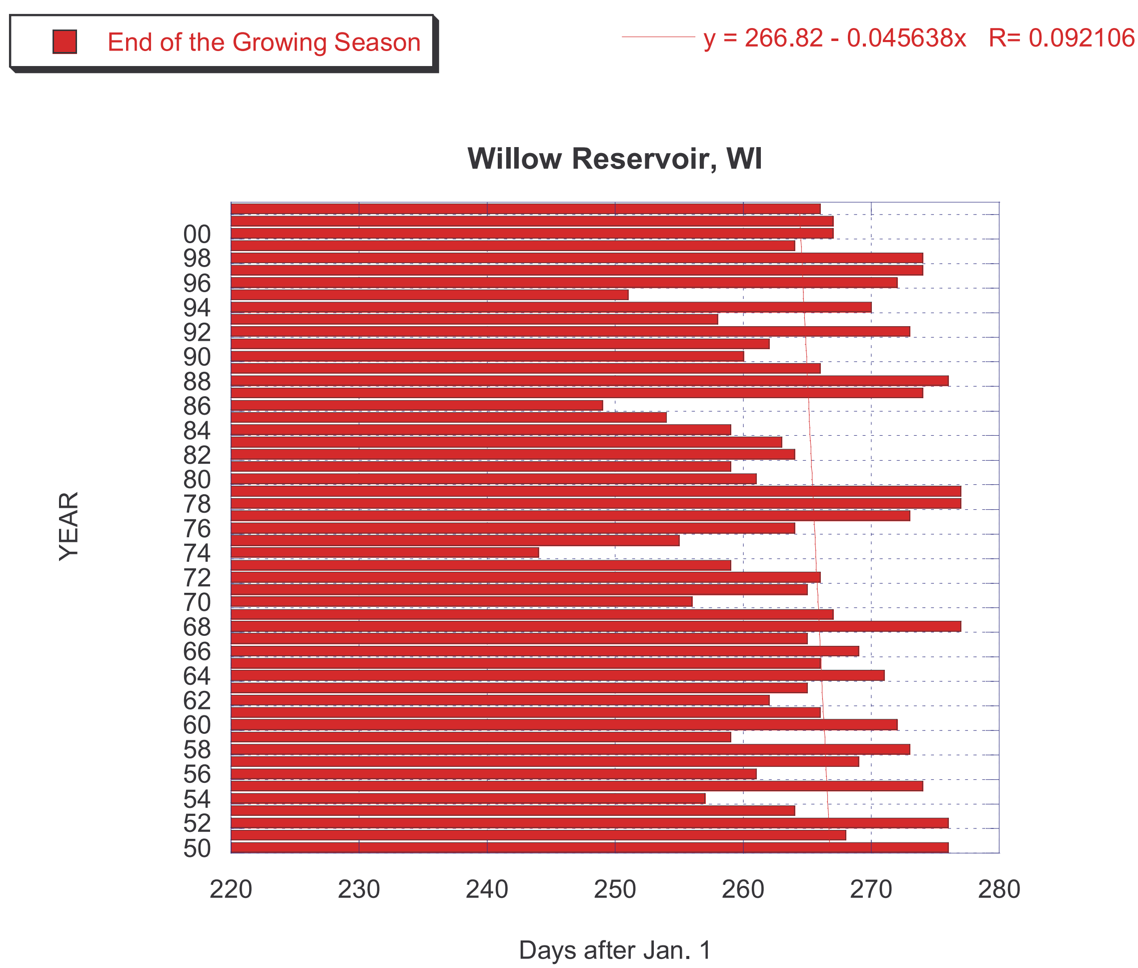

Figure 13a

Length of the Growing Season

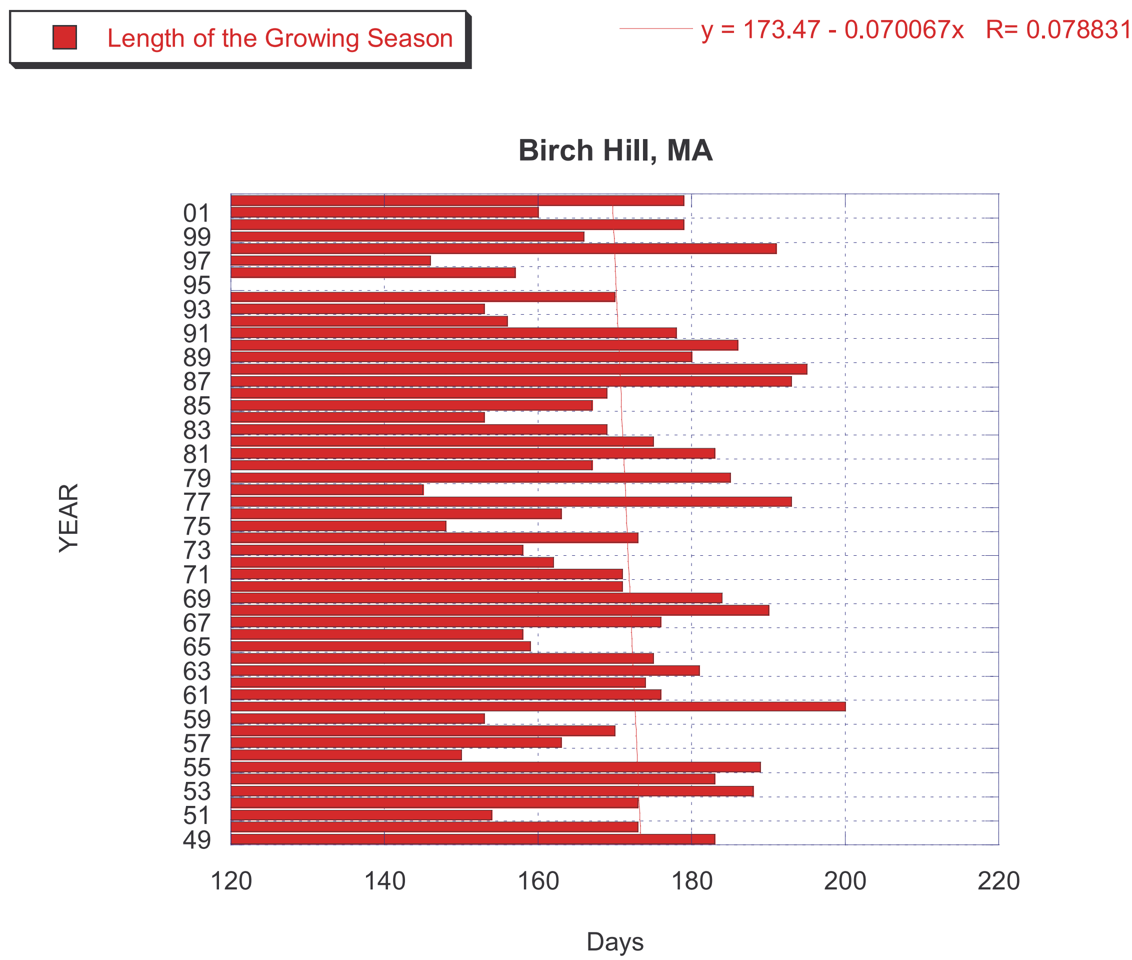

Figure 13b

Length of the Growing Season

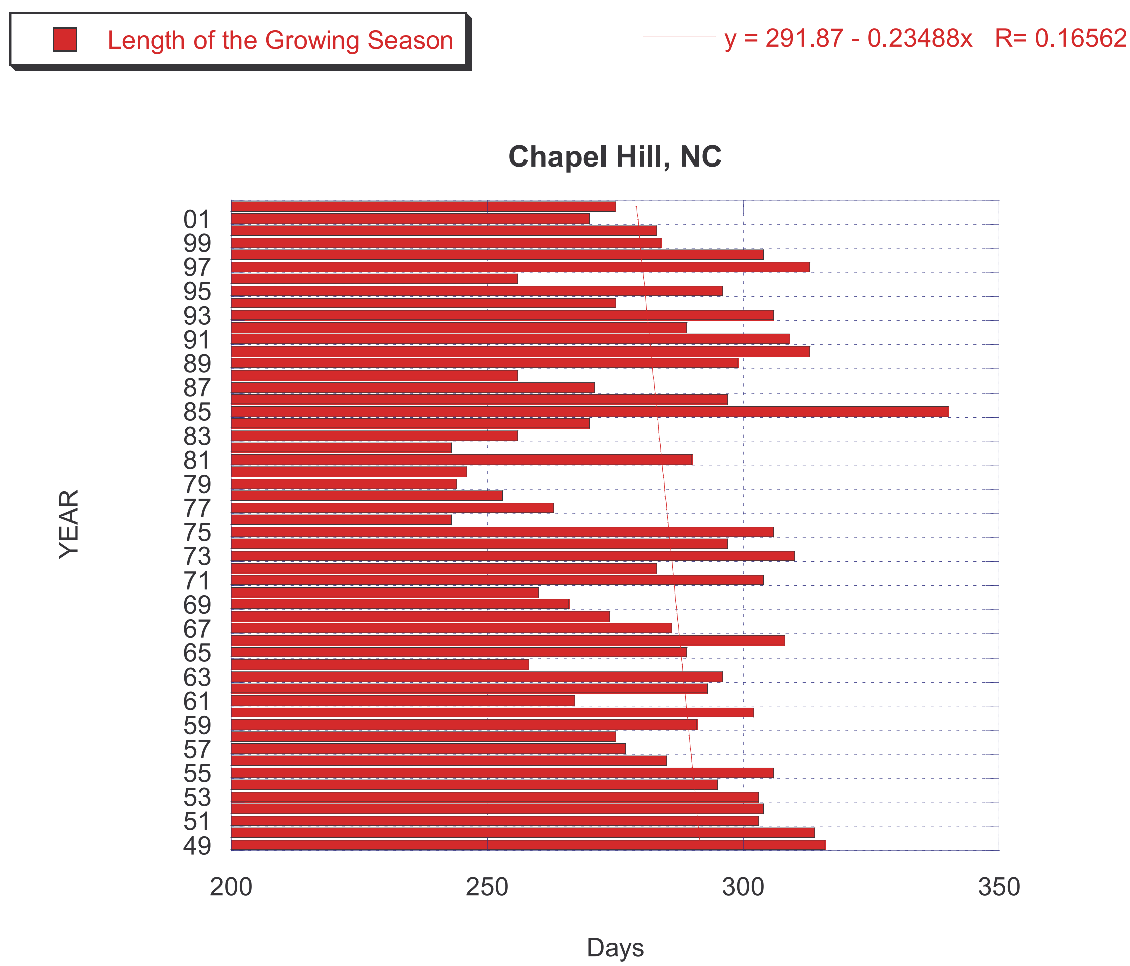

Figure 13c

Length of the Growing Season

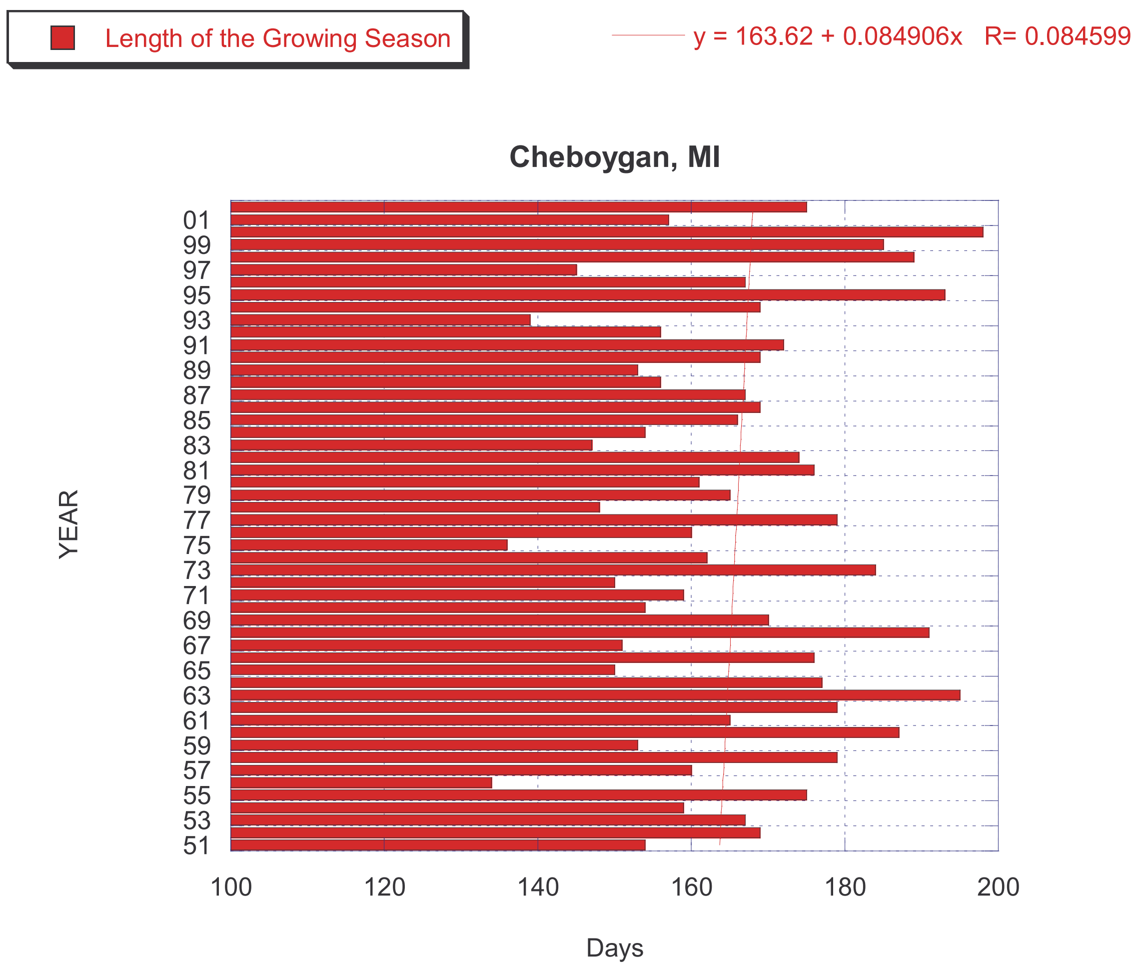

Figure 13d

Length of the Growing Season

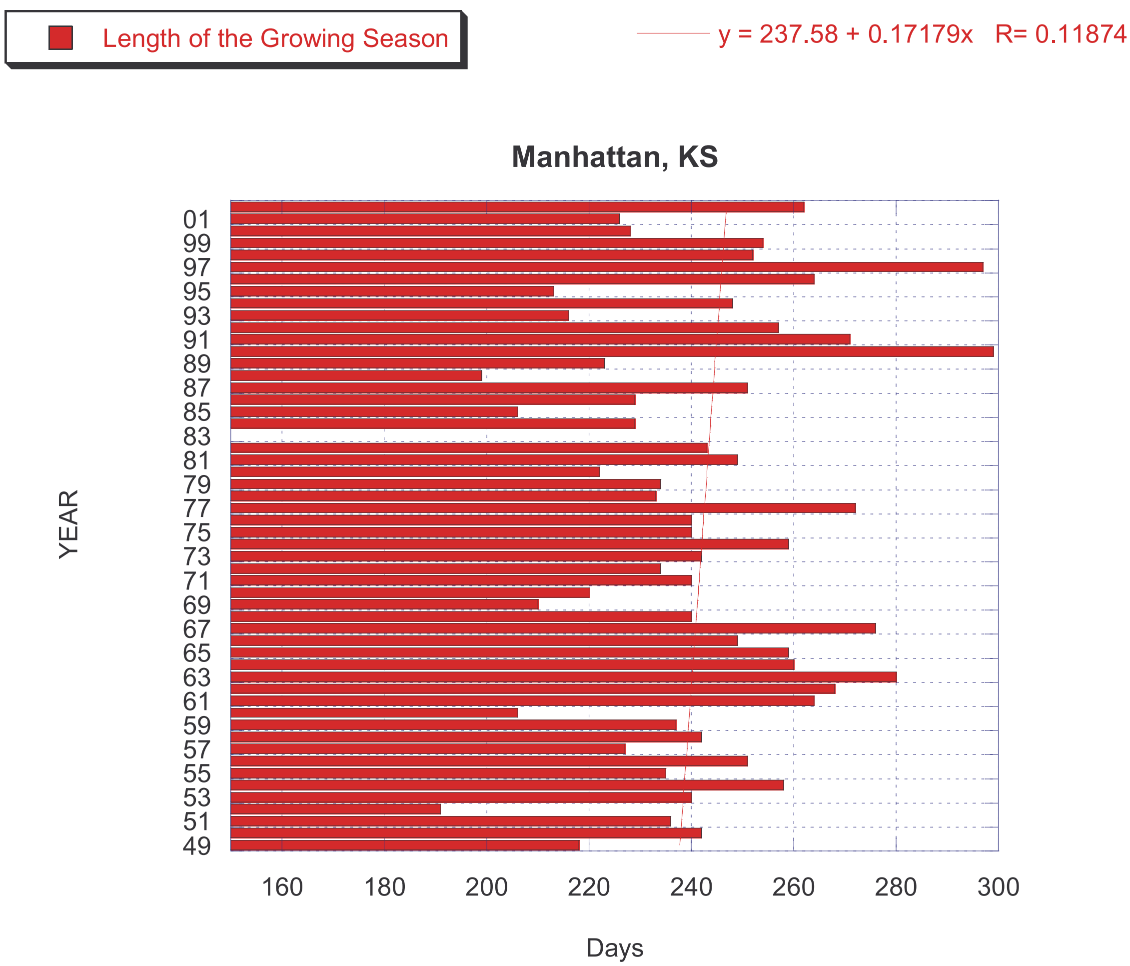

Figure 13e

Length of the Growing Season

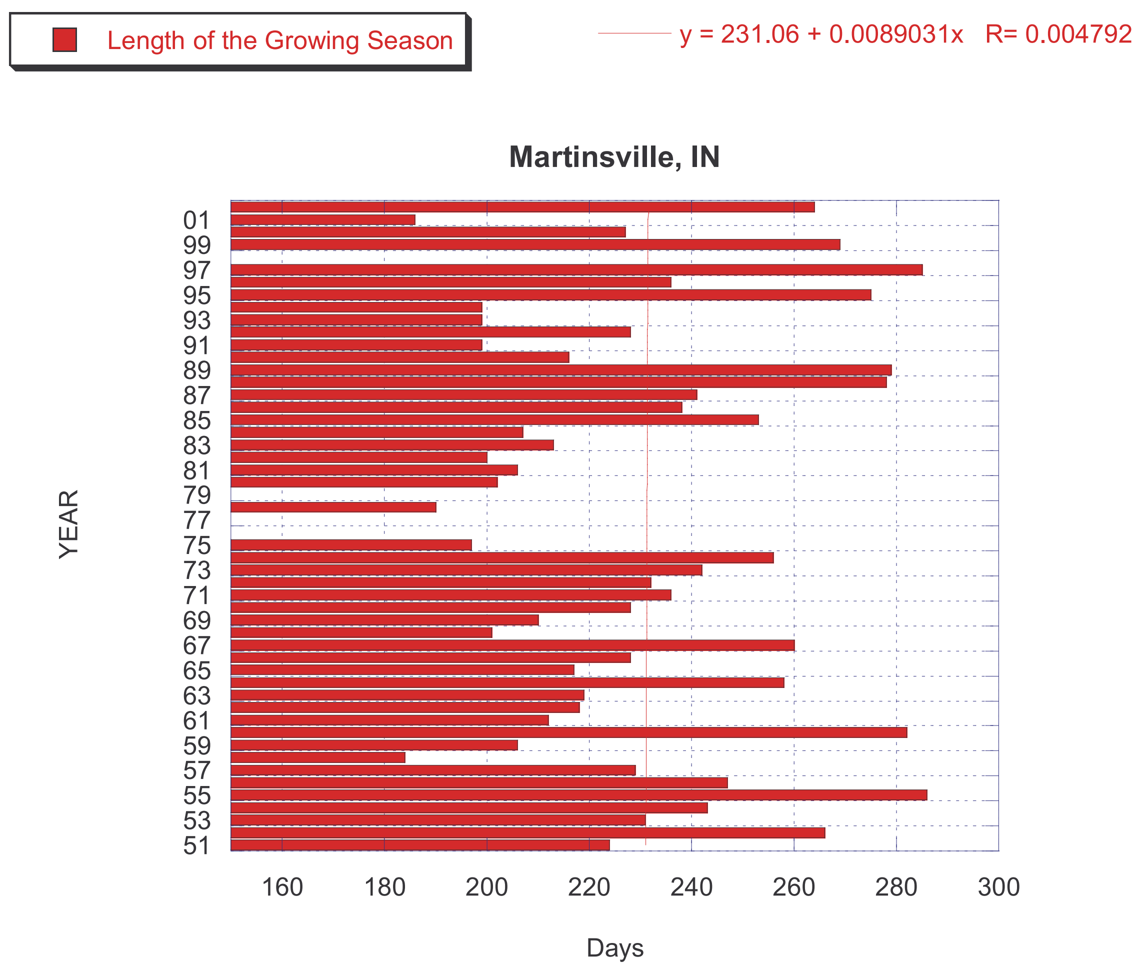

Figure 13f

Length of the Growing Season

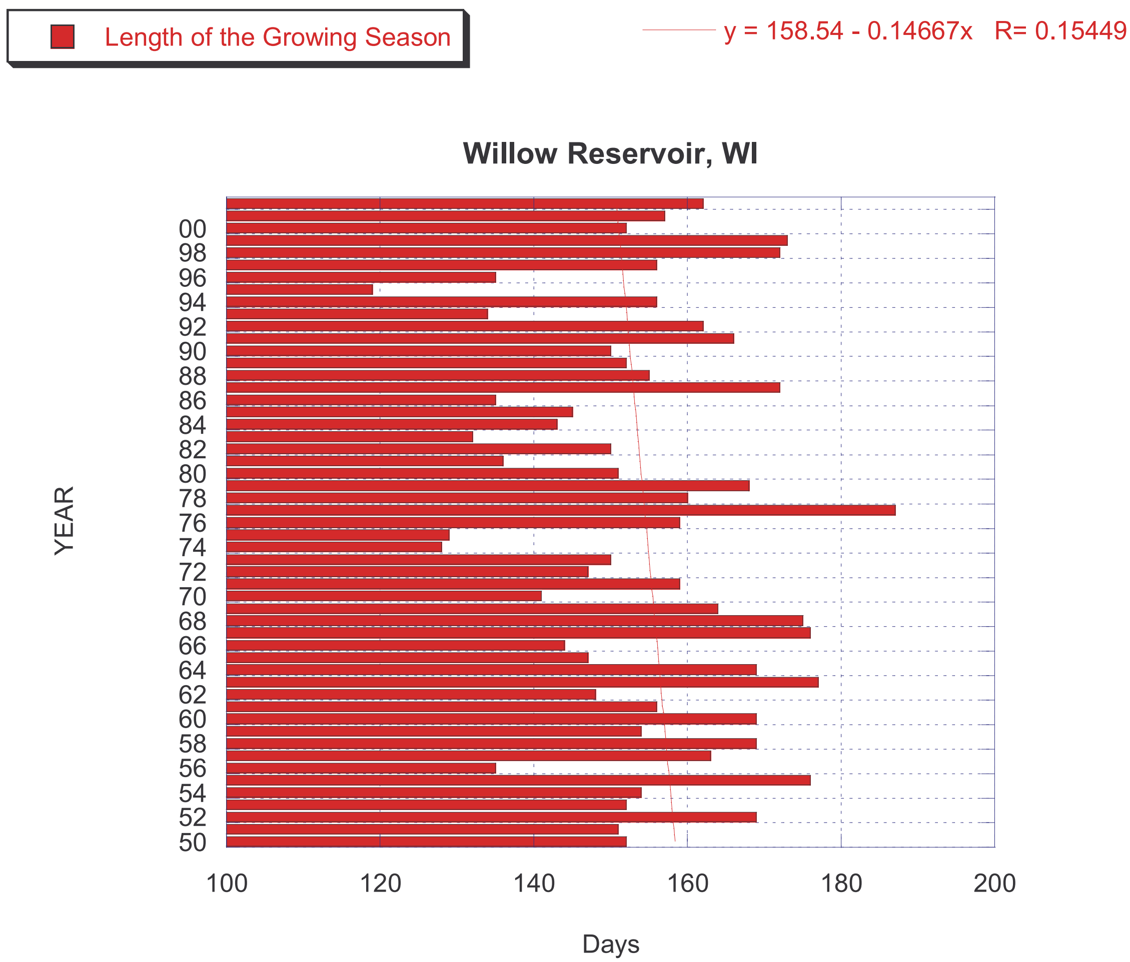

Figure 14a

Last Freeze

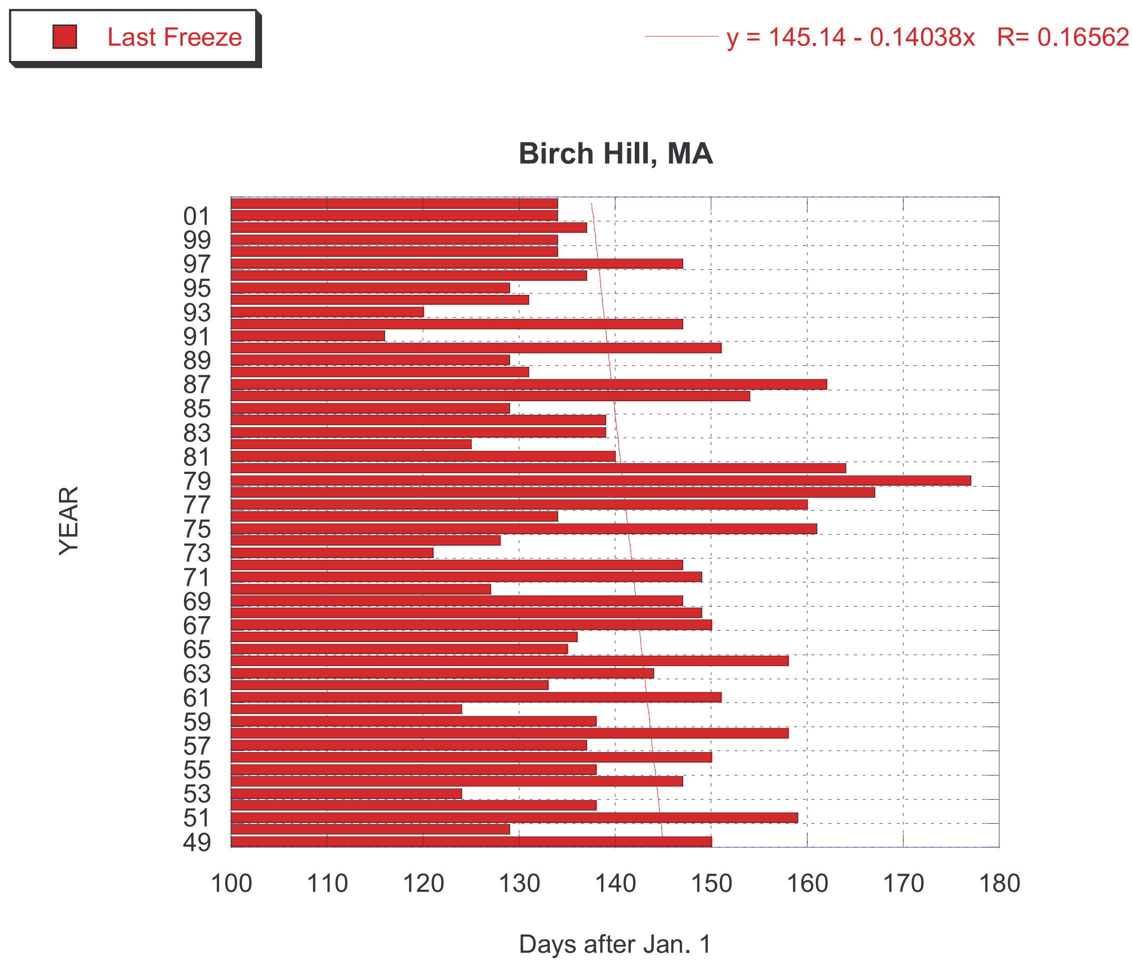

Figure 14b

Last Freeze

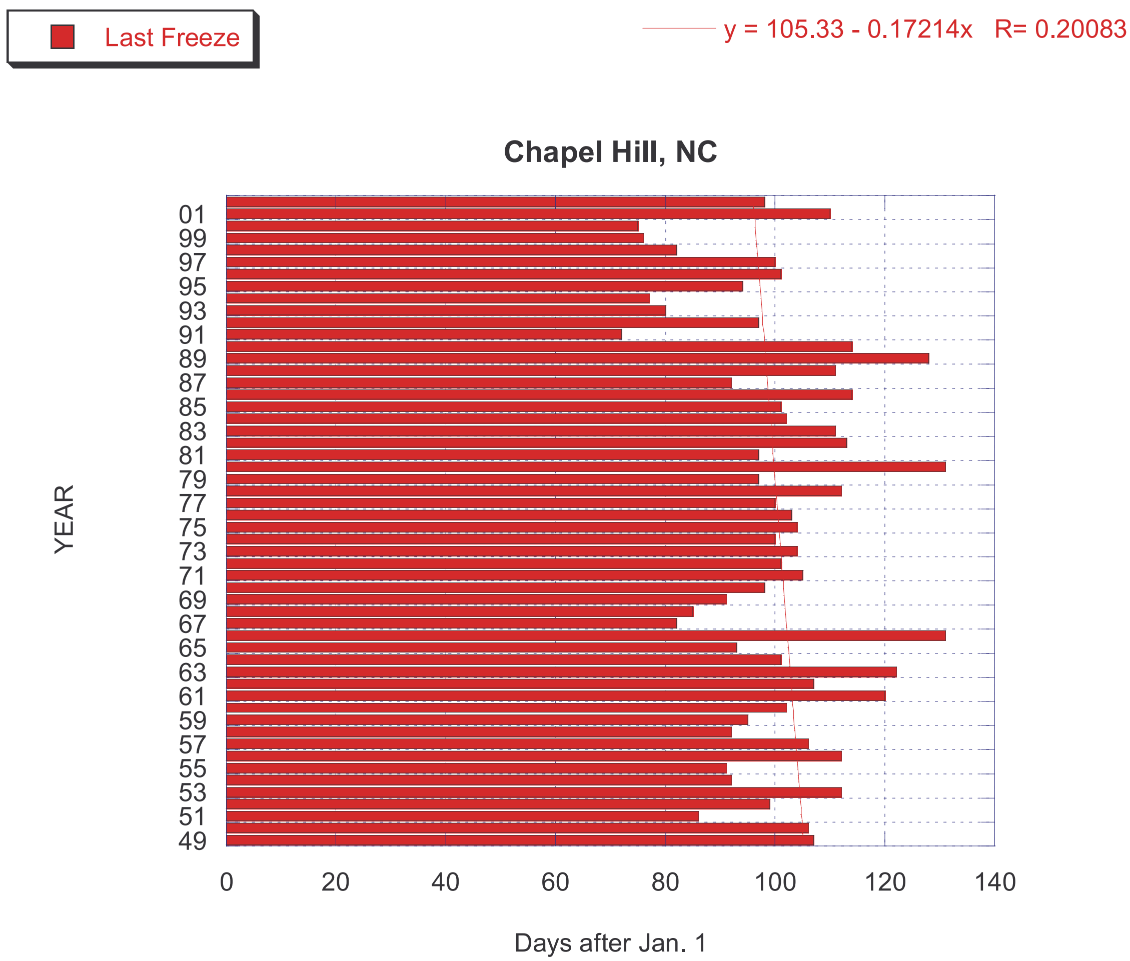

Figure 14c

Last Freeze

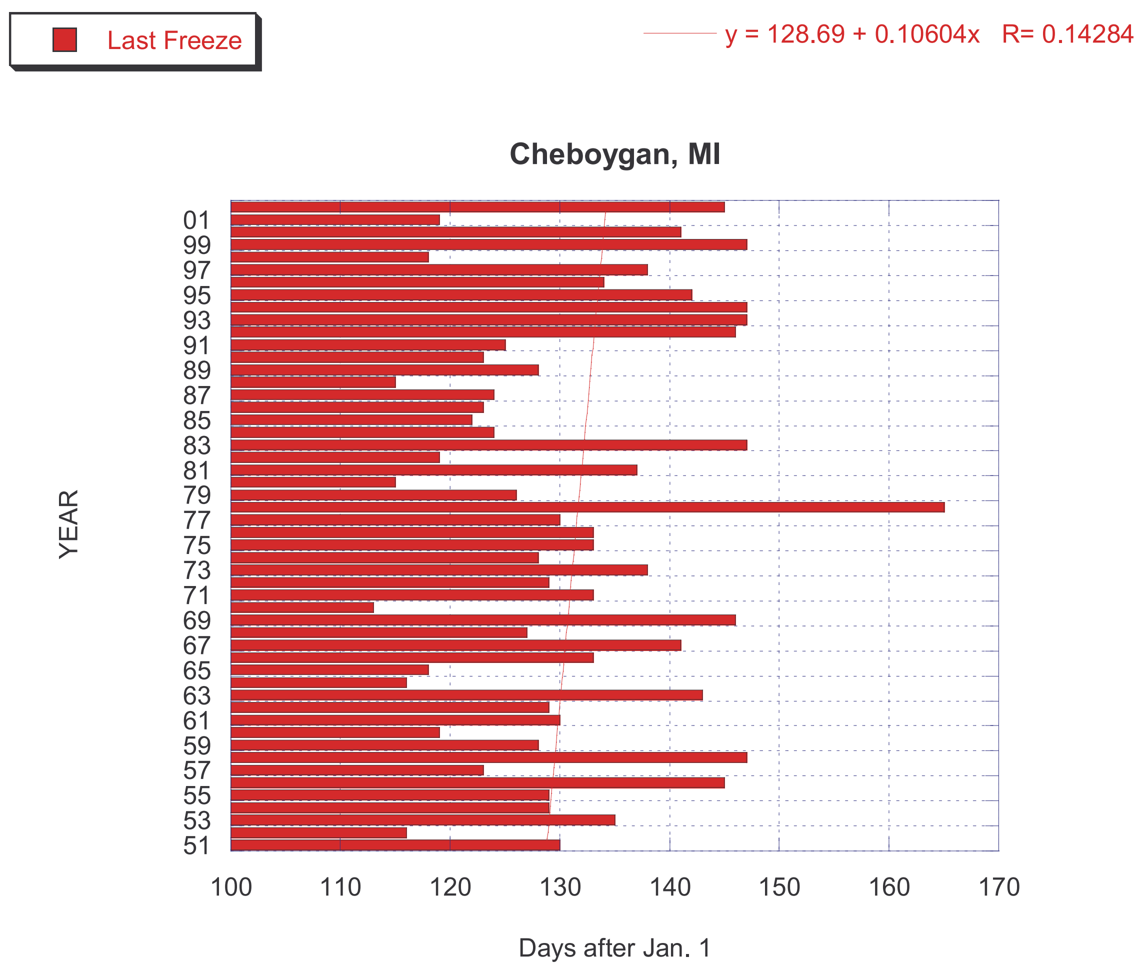

Figure 14d

Last Freeze

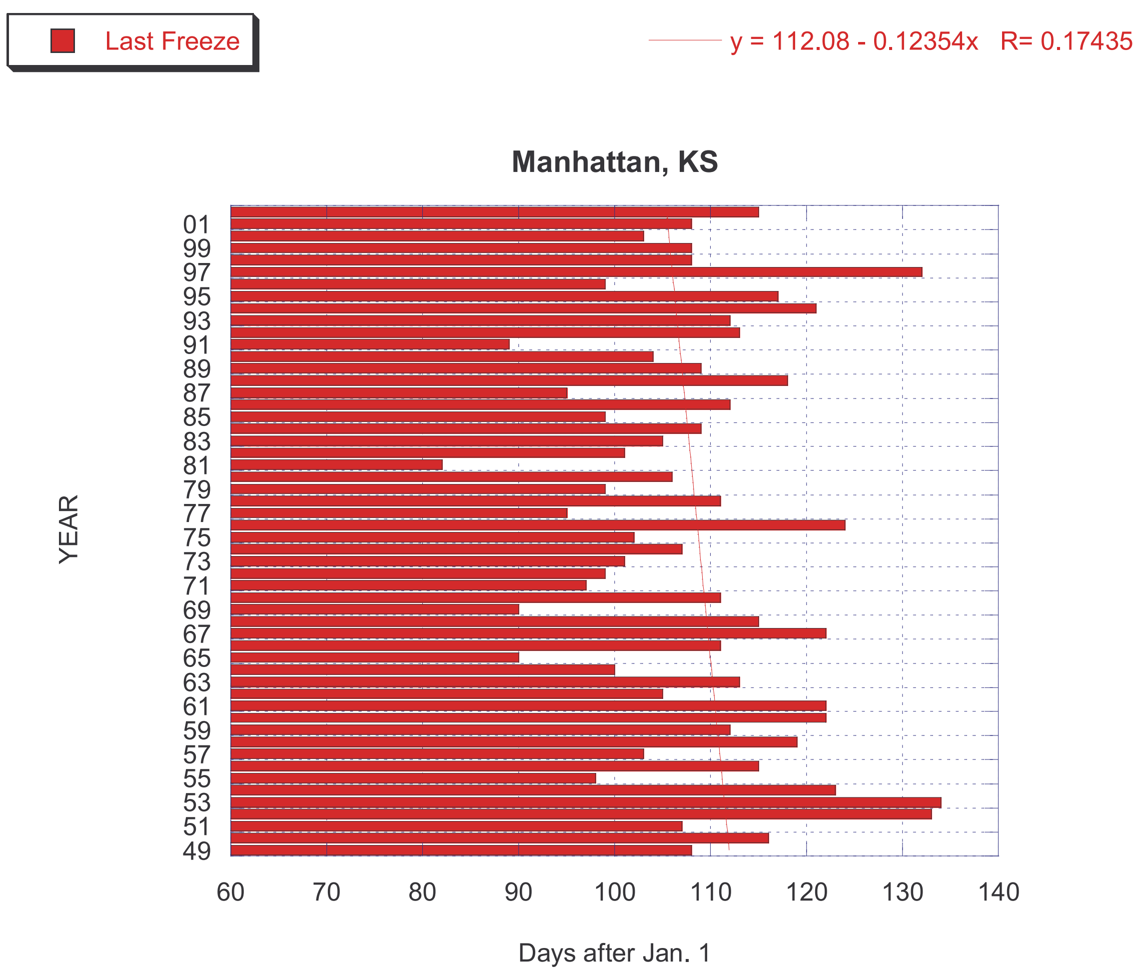

Figure 14e

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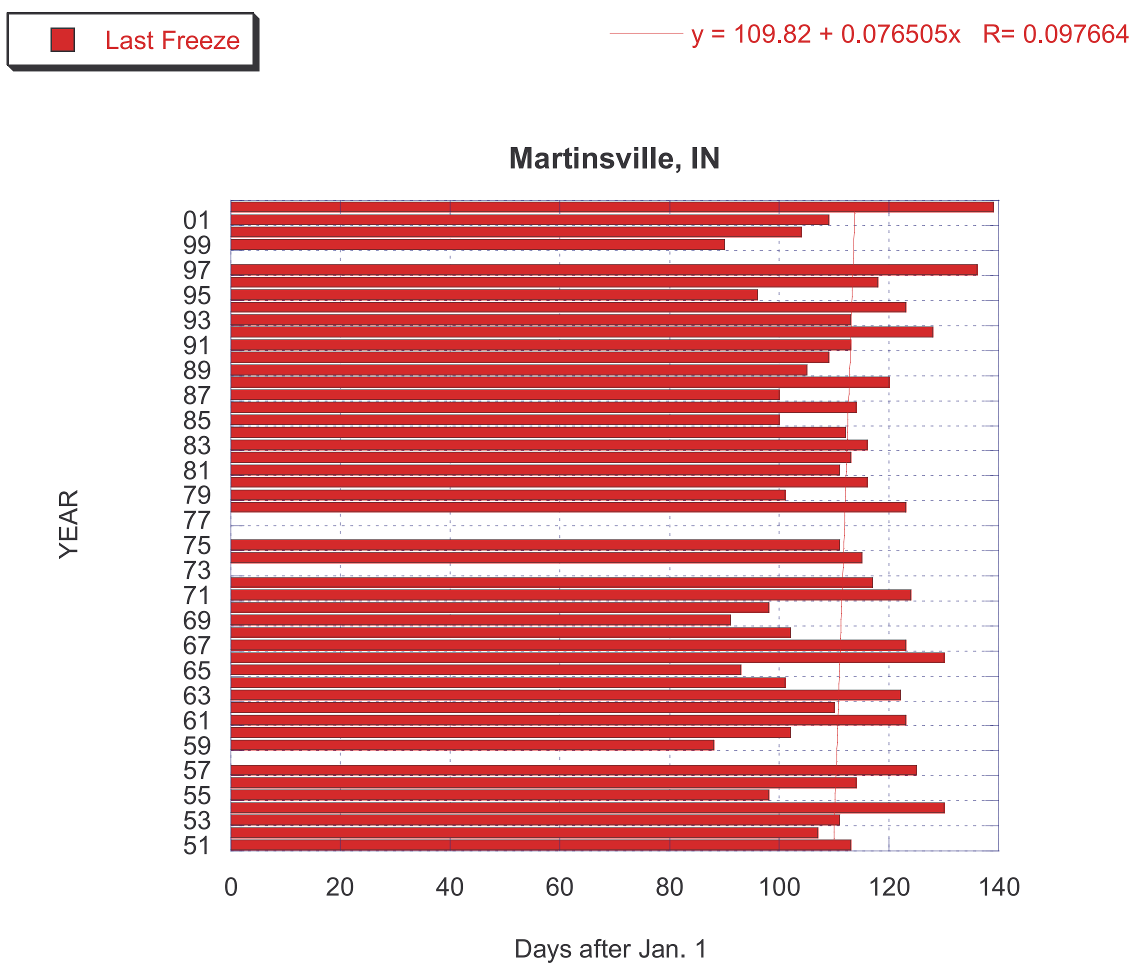

Figure 14f

Last Freeze

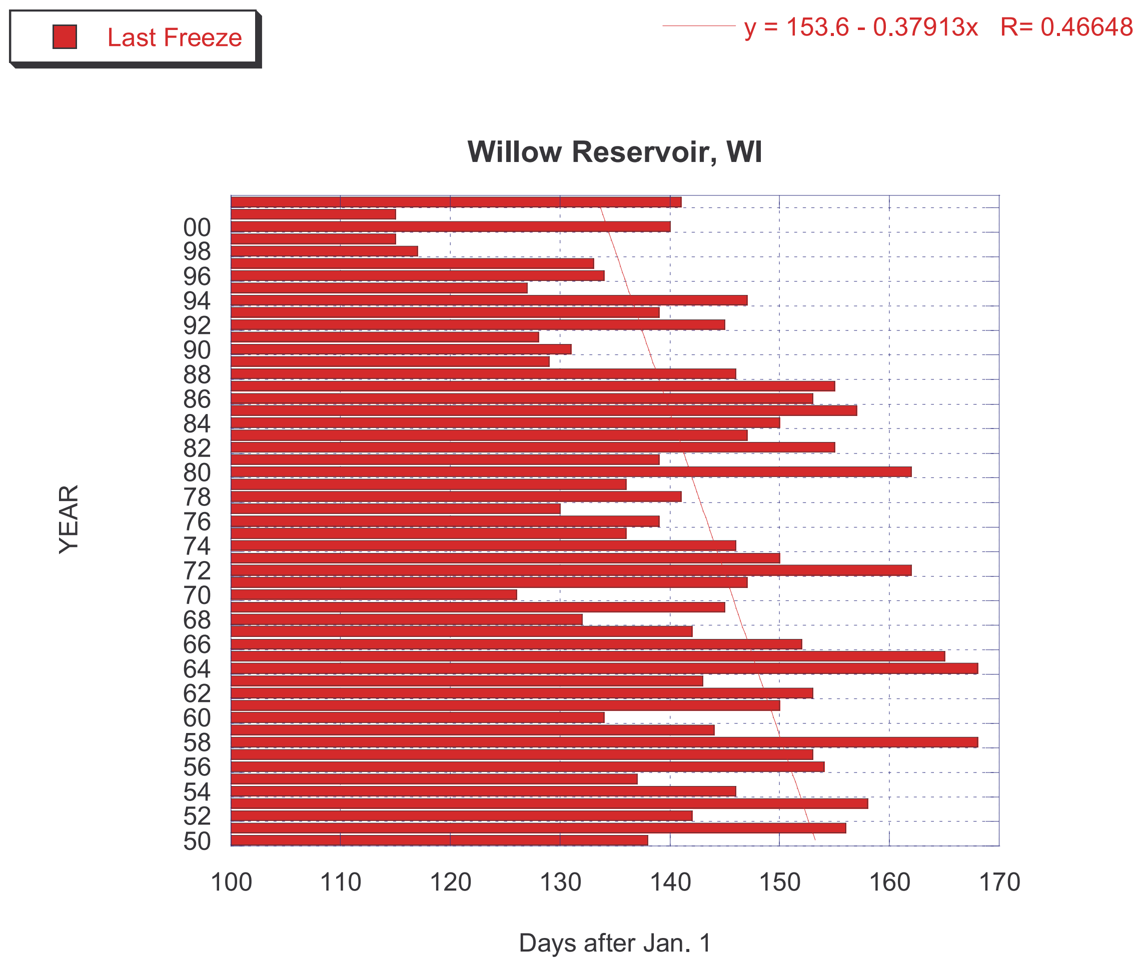

Figure 15a

First Freeze

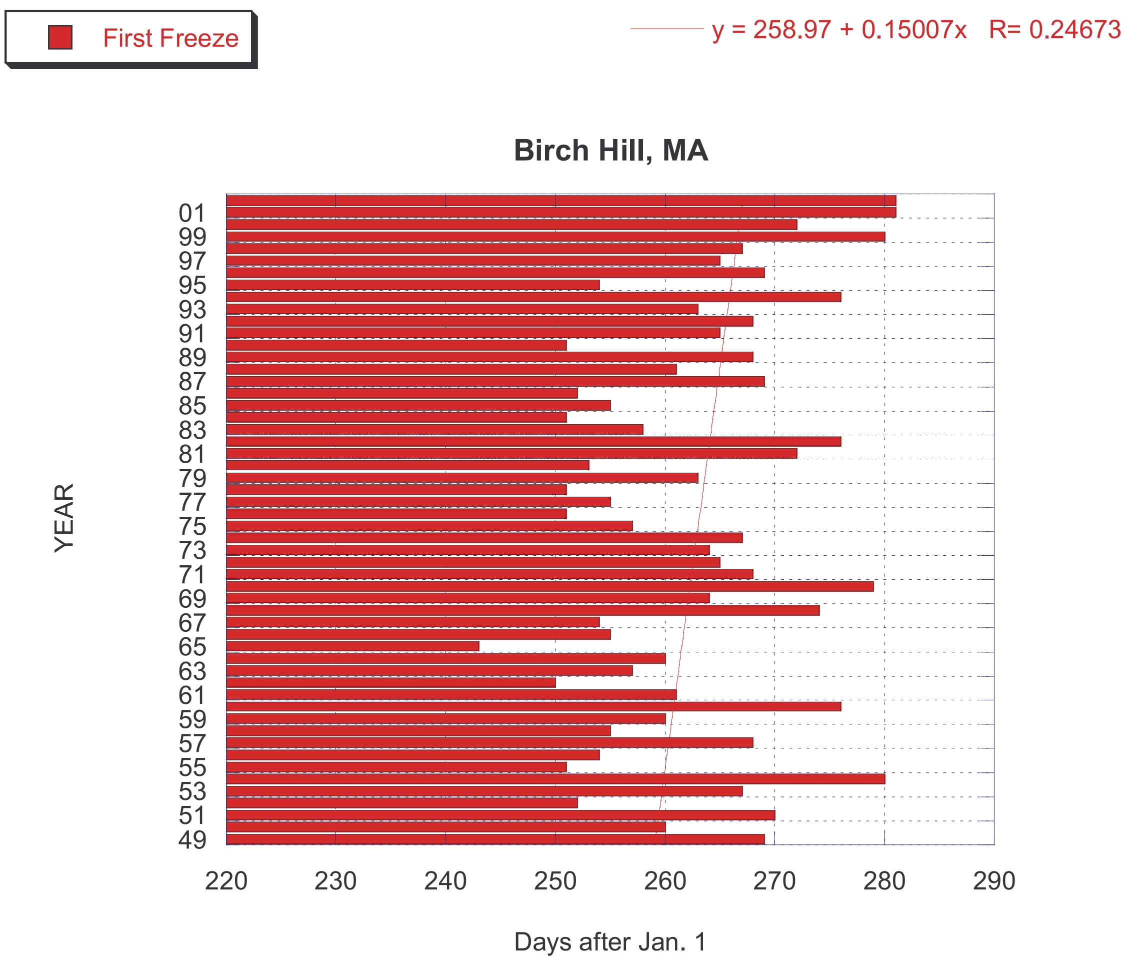

Figure 15b

First Freeze

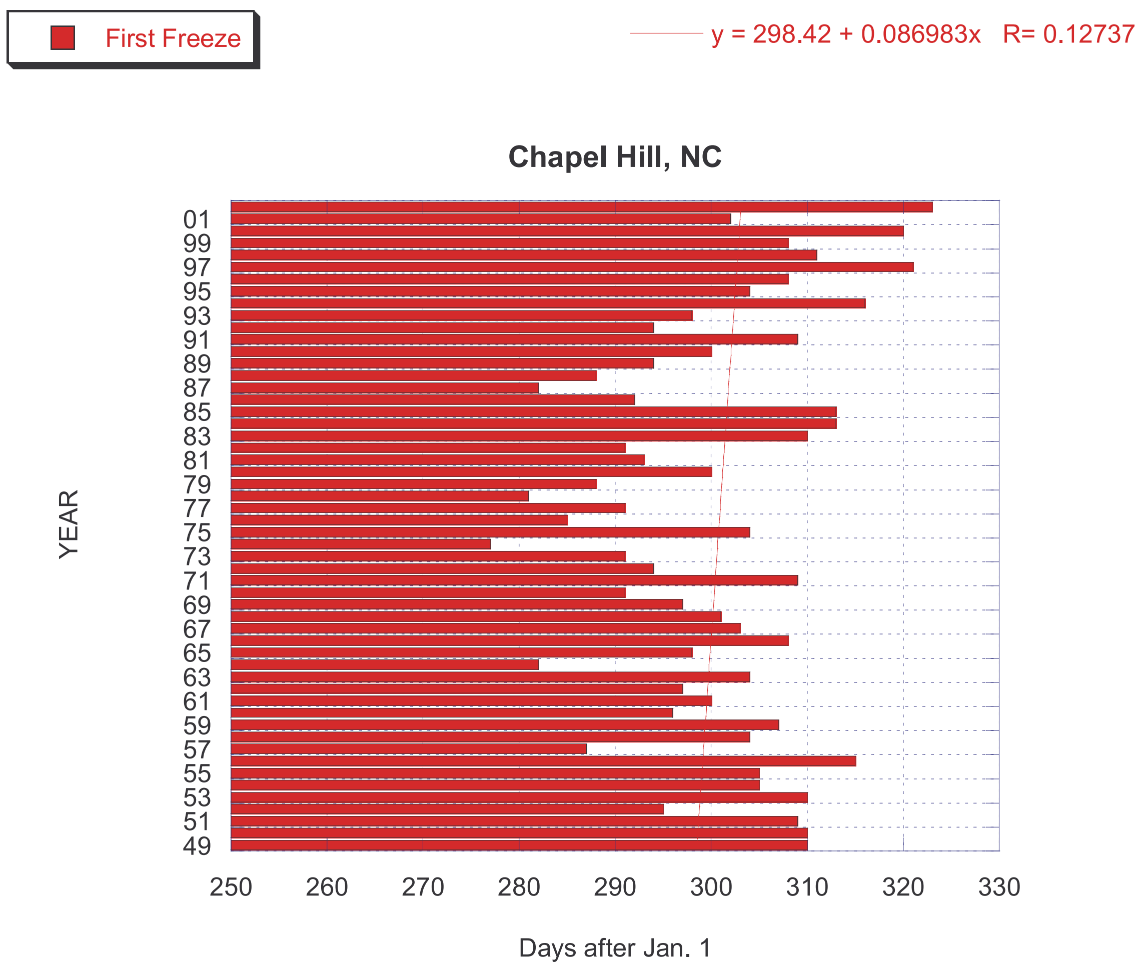

Figure 15c

First Freeze

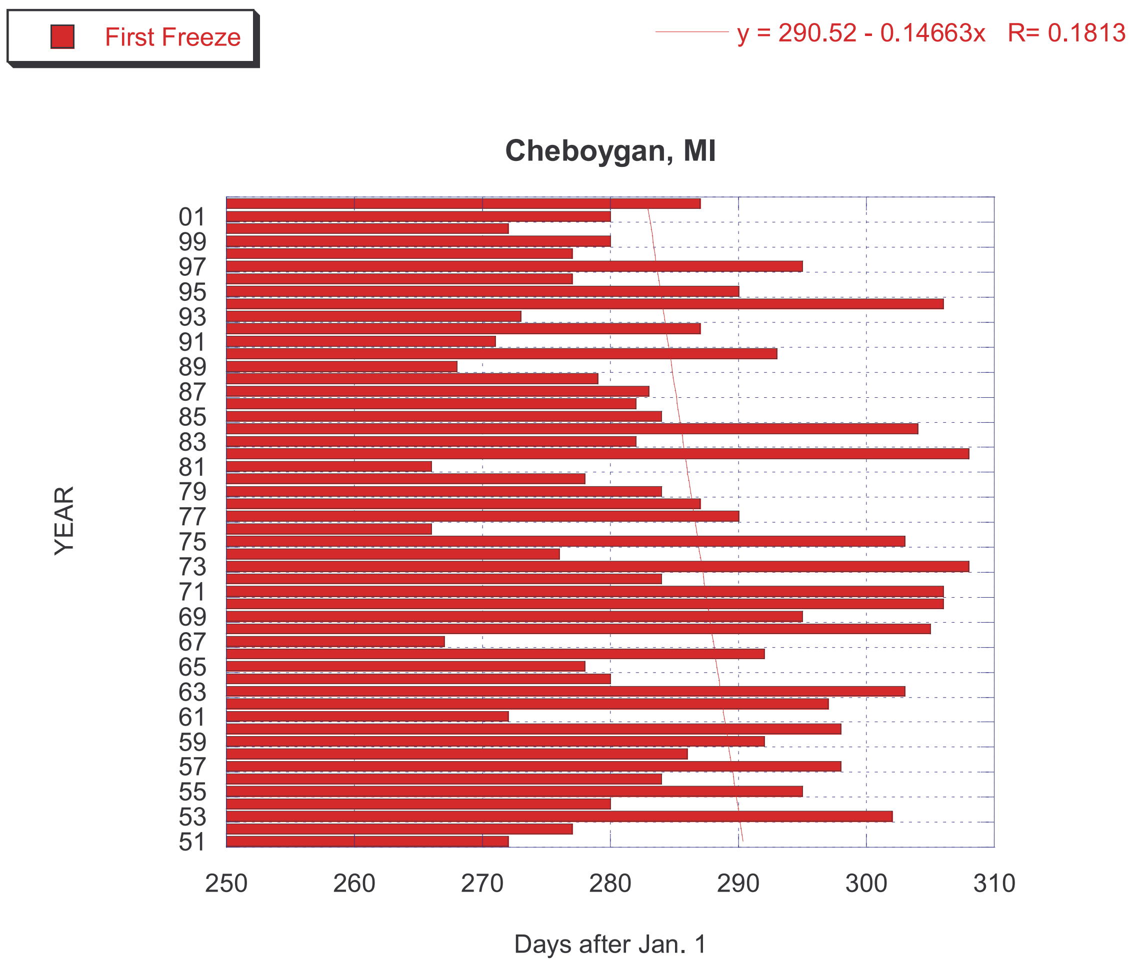

Figure 15d

First Freeze

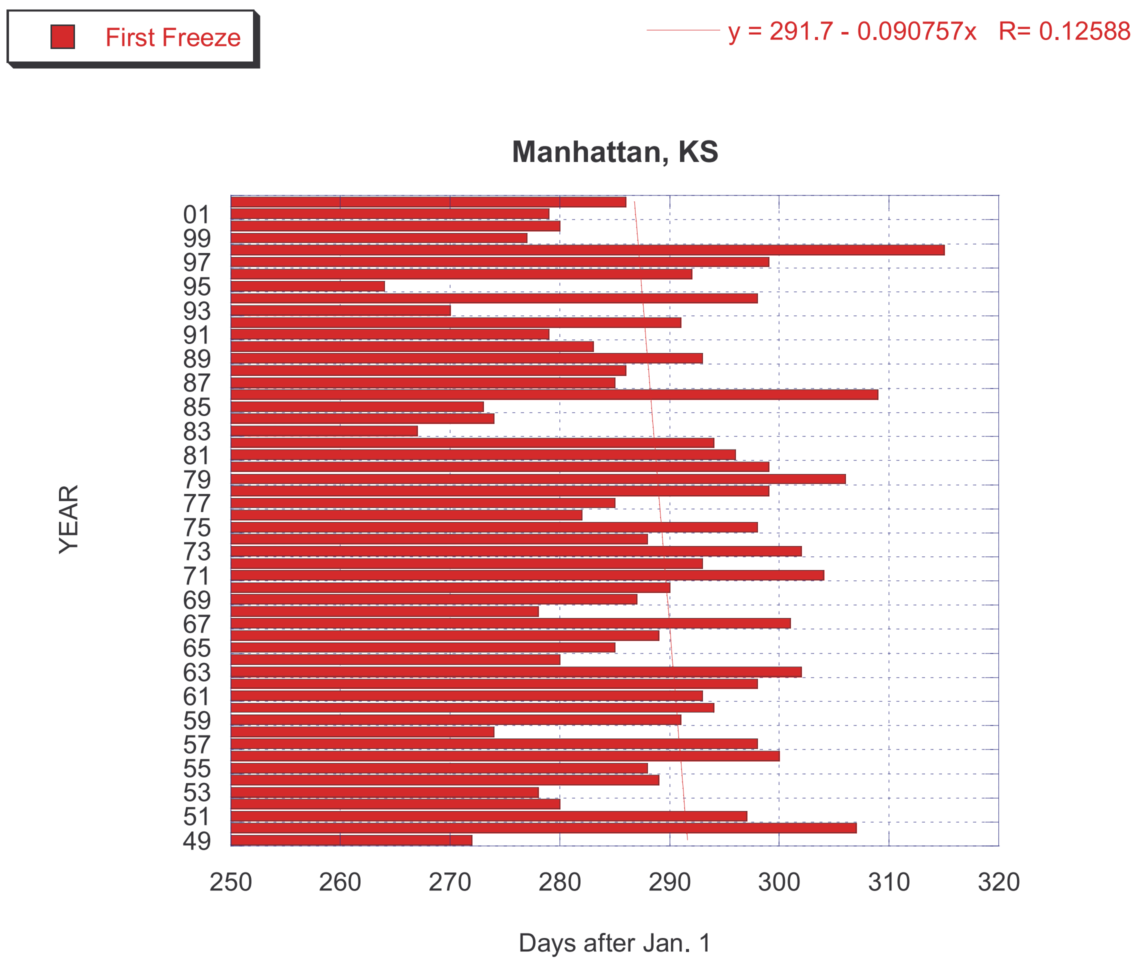

Figure 15e

First Freeze

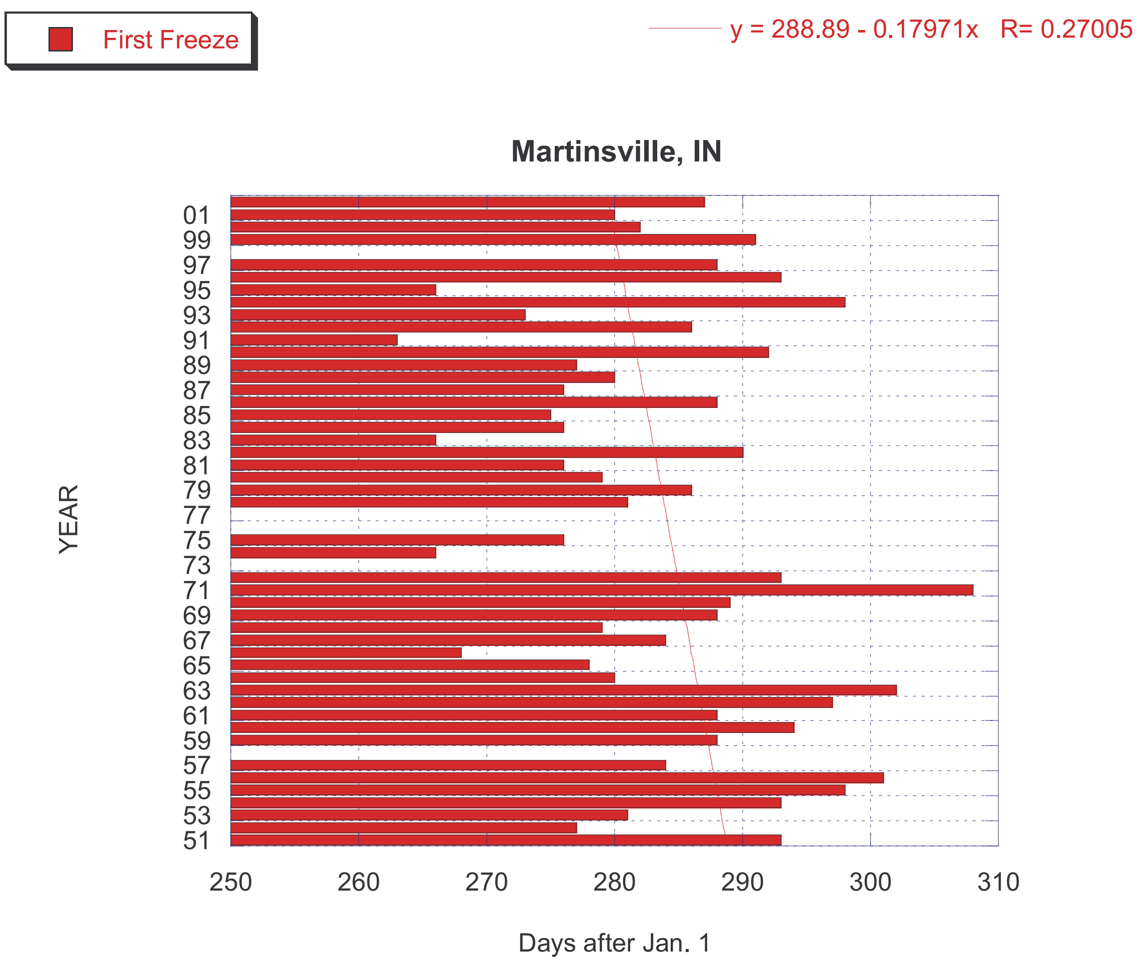

Figure 15f

First Freeze

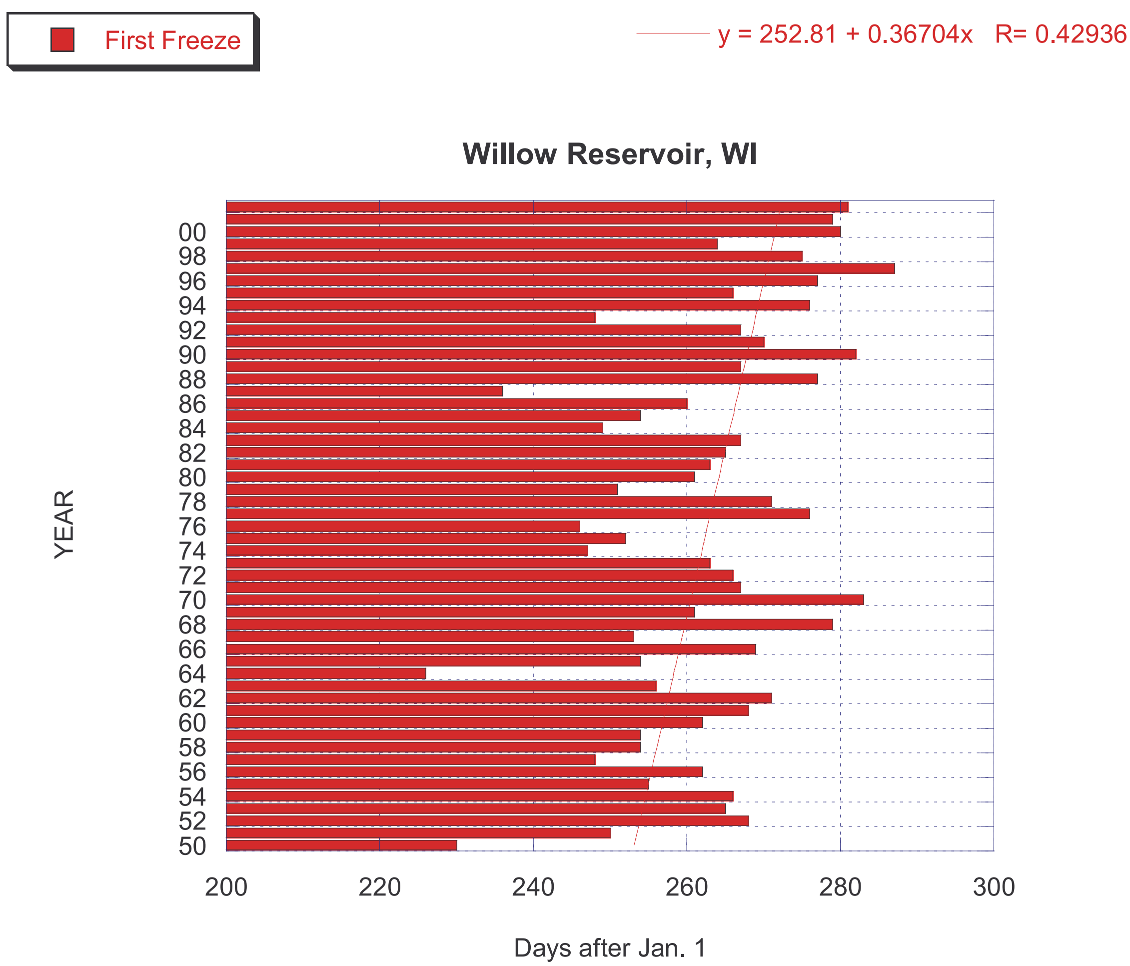

Figure 16a

Freeze Free Period

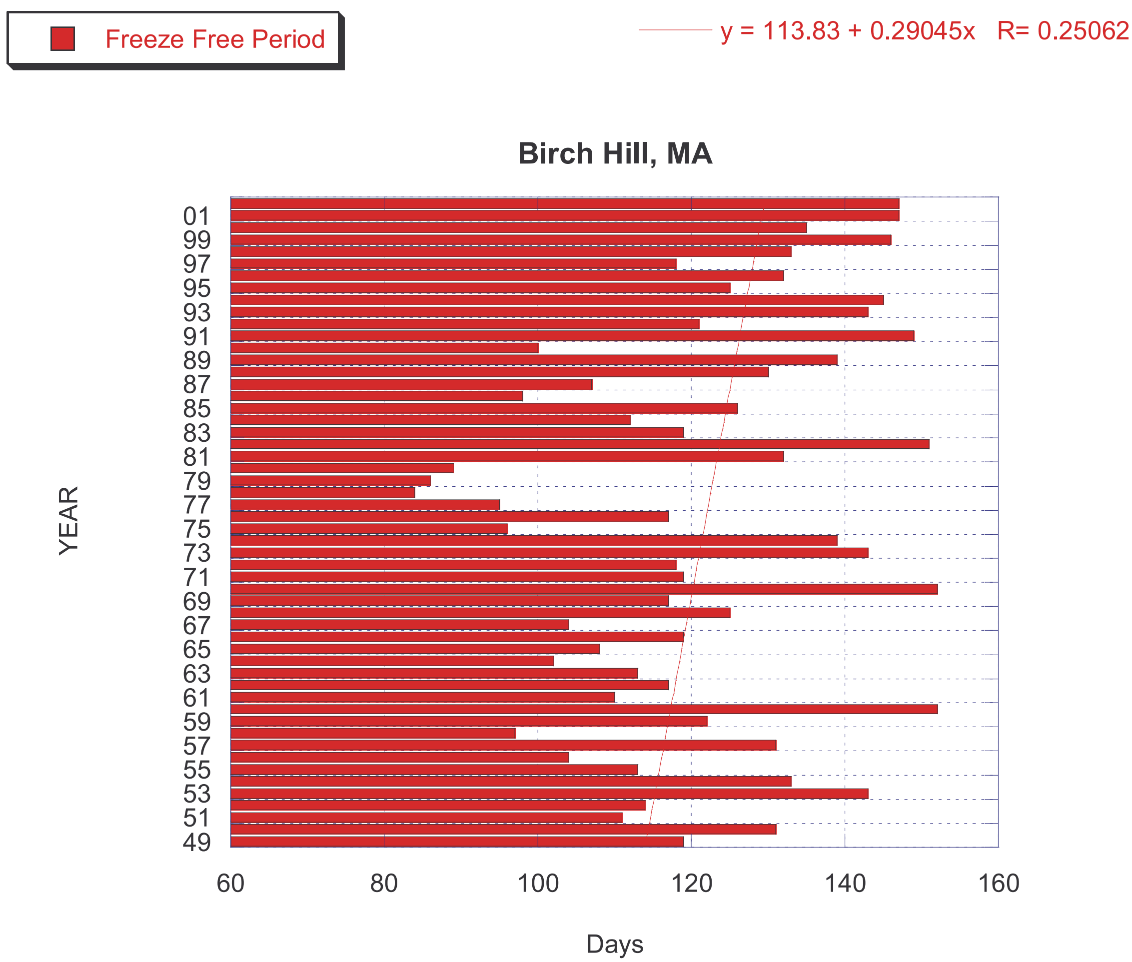

Figure 16b

Freeze Free Period

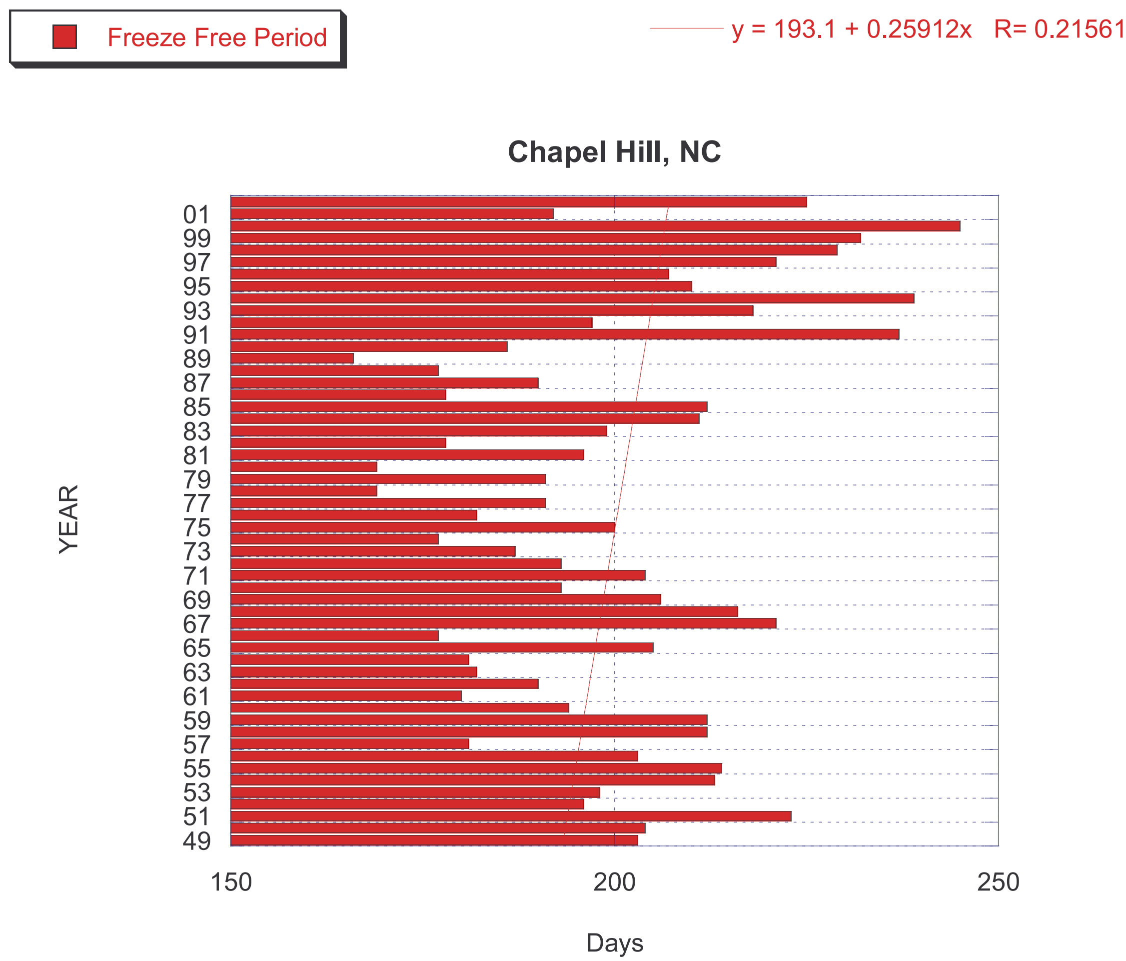

Figure 16c

Freeze Free Period

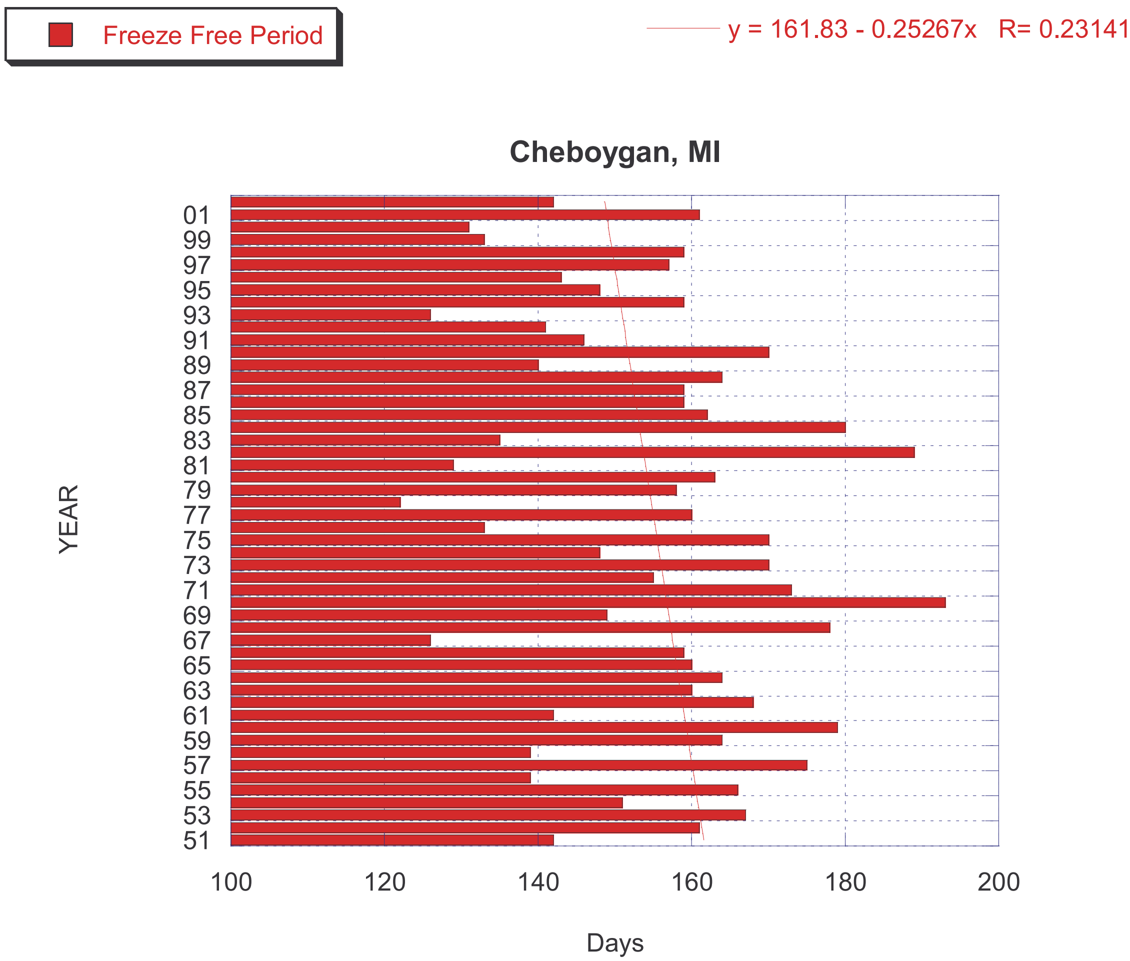

Figure 16d

Freeze Free Period

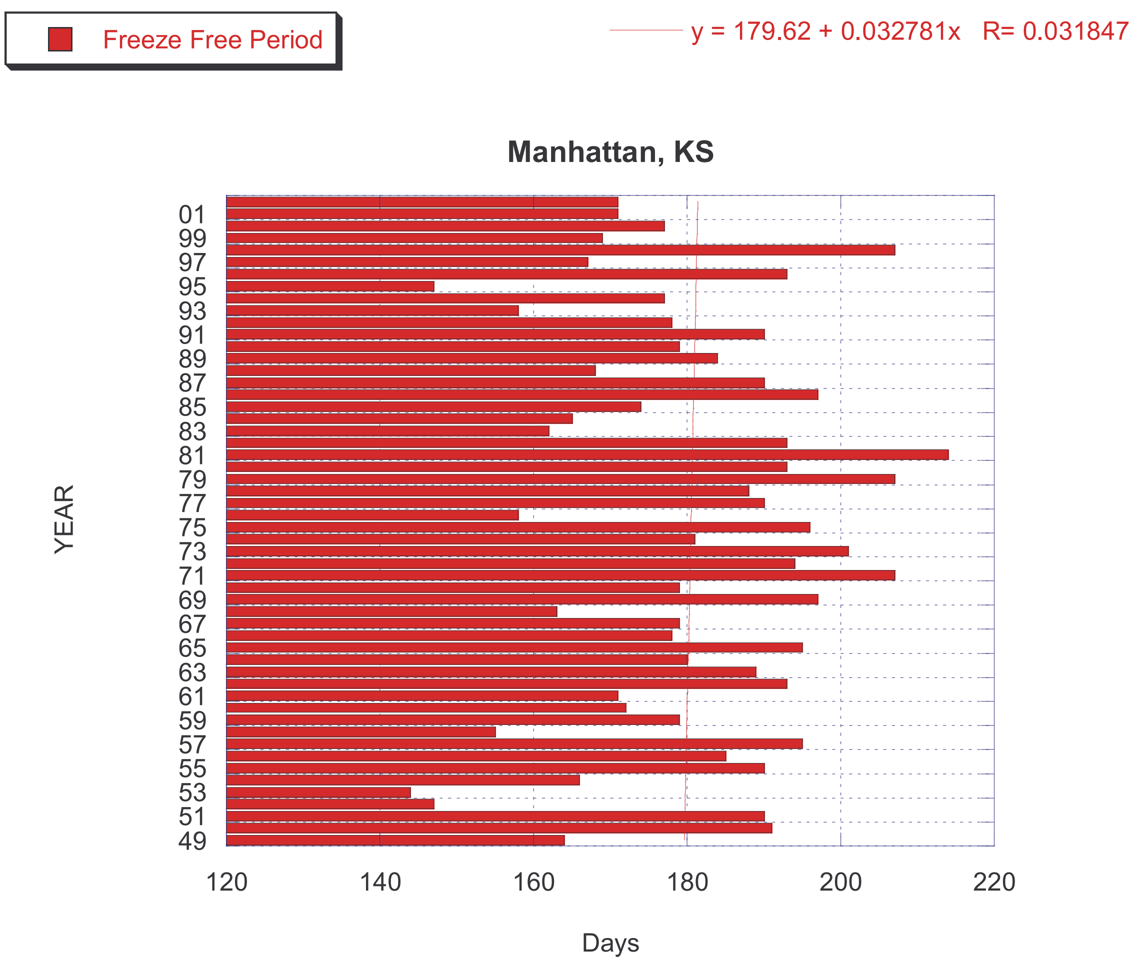

Figure 16e

Freeze Free Period

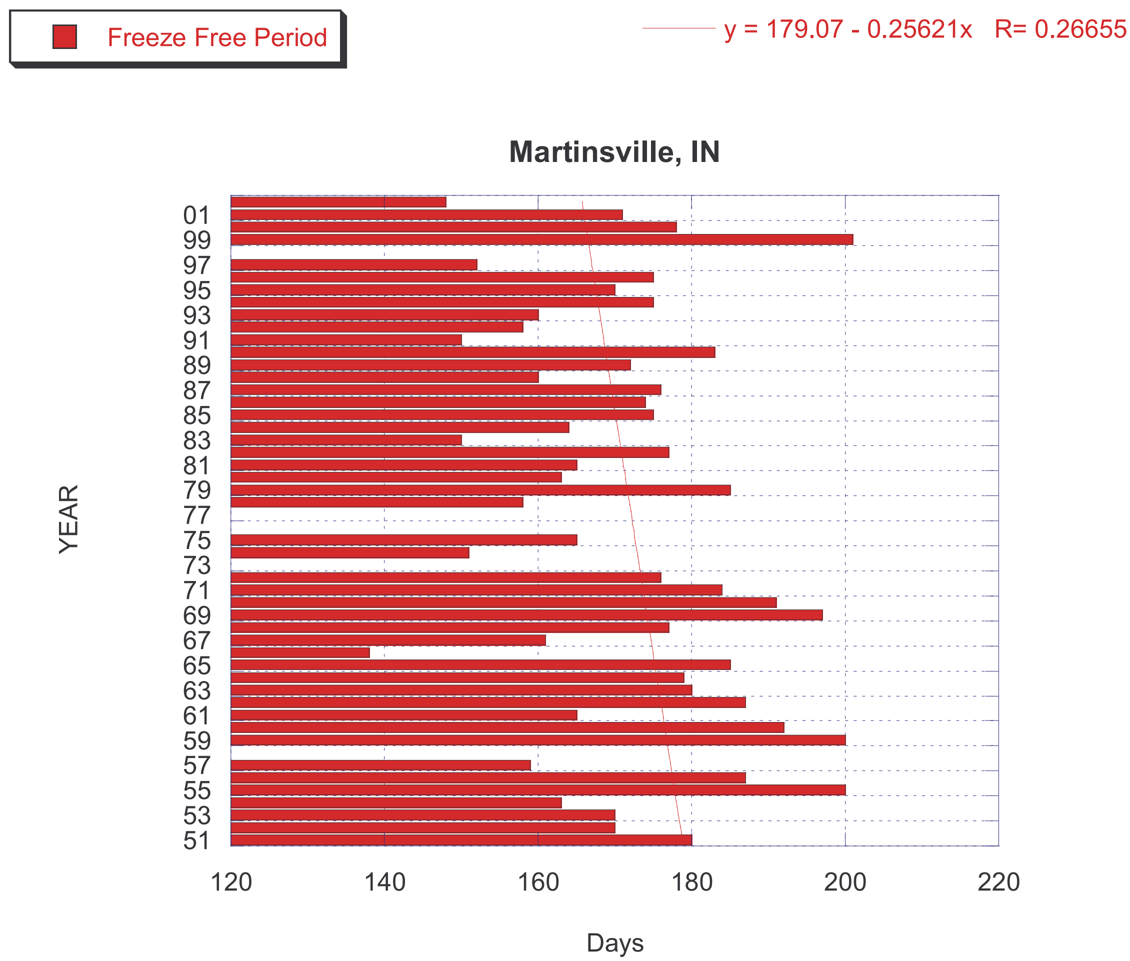

Figure 16f

Freeze Free Period

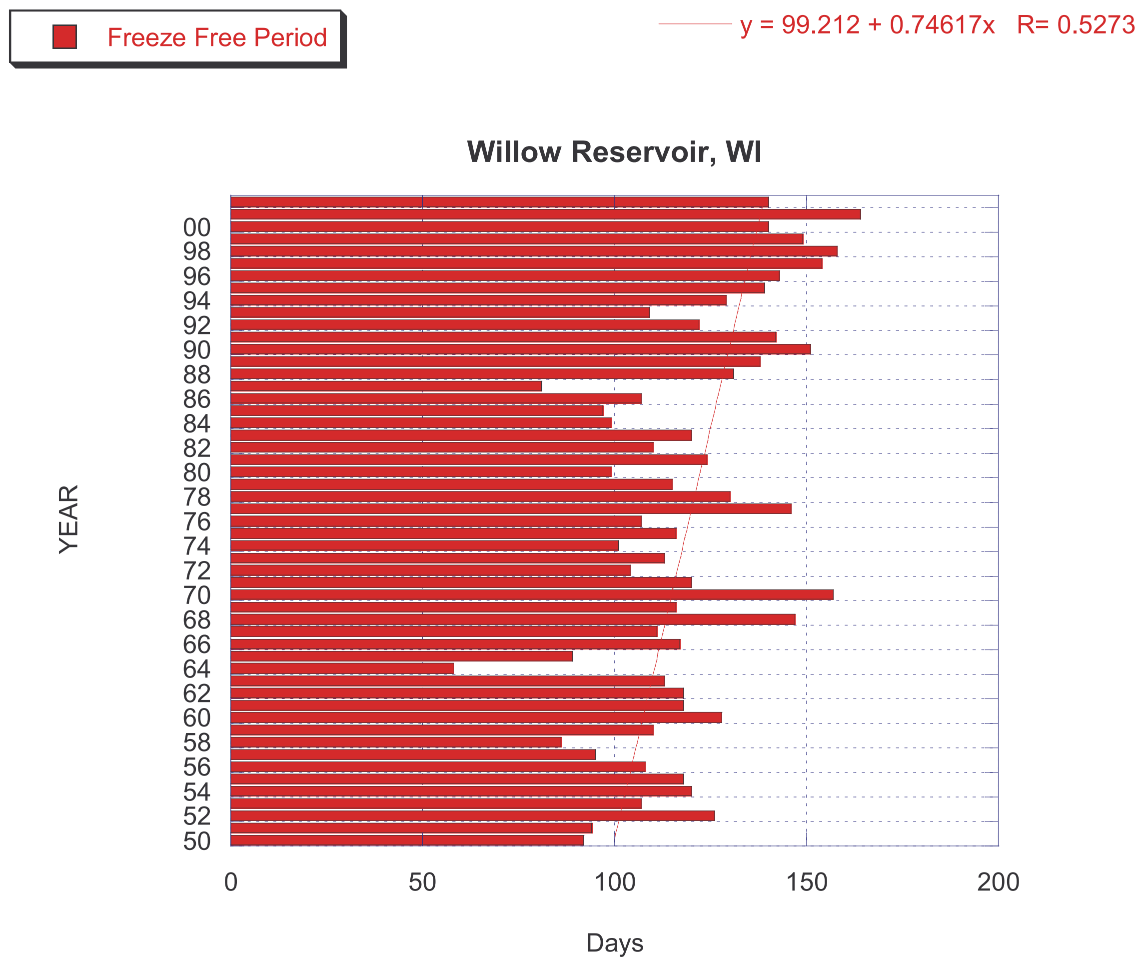

Figure 17a

End of Snow Cover

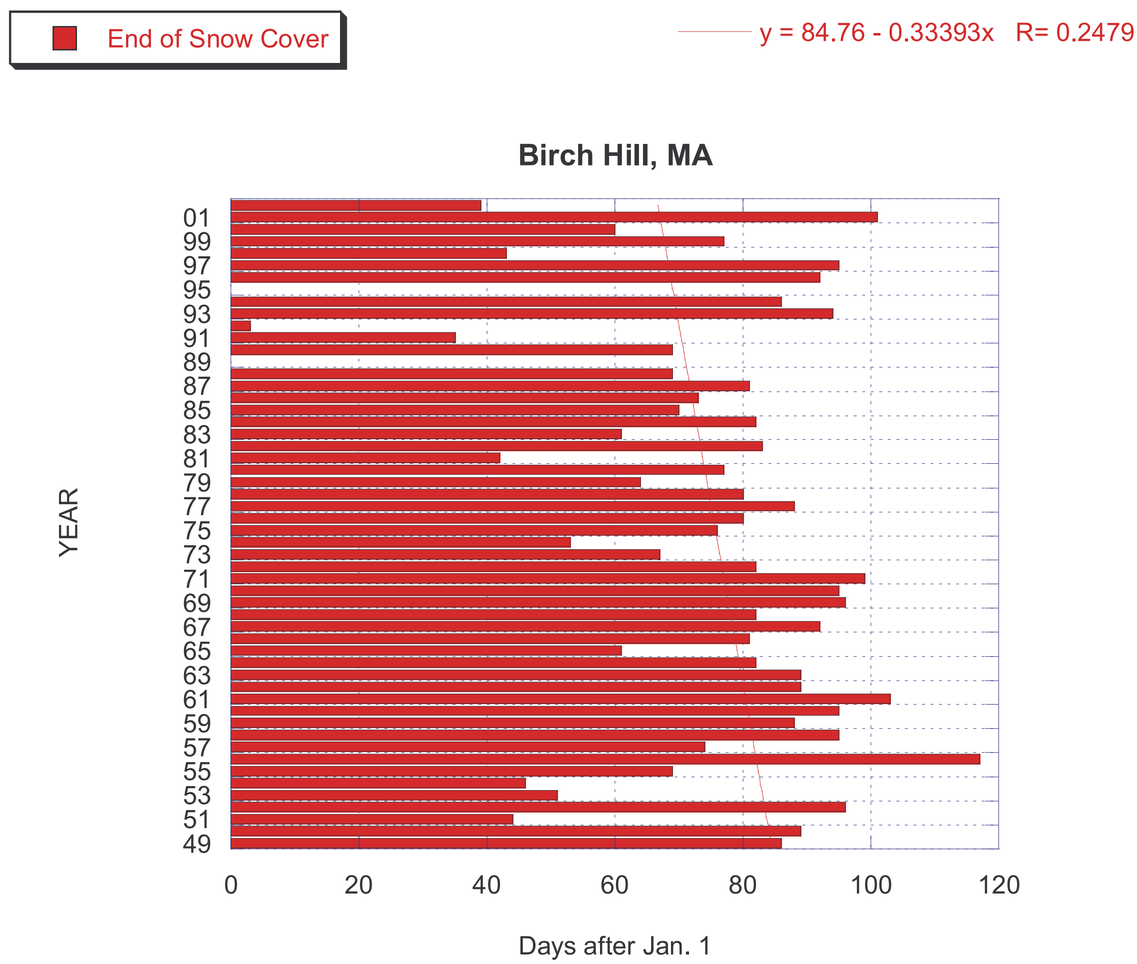

Figure 17b

End of Snow Cover

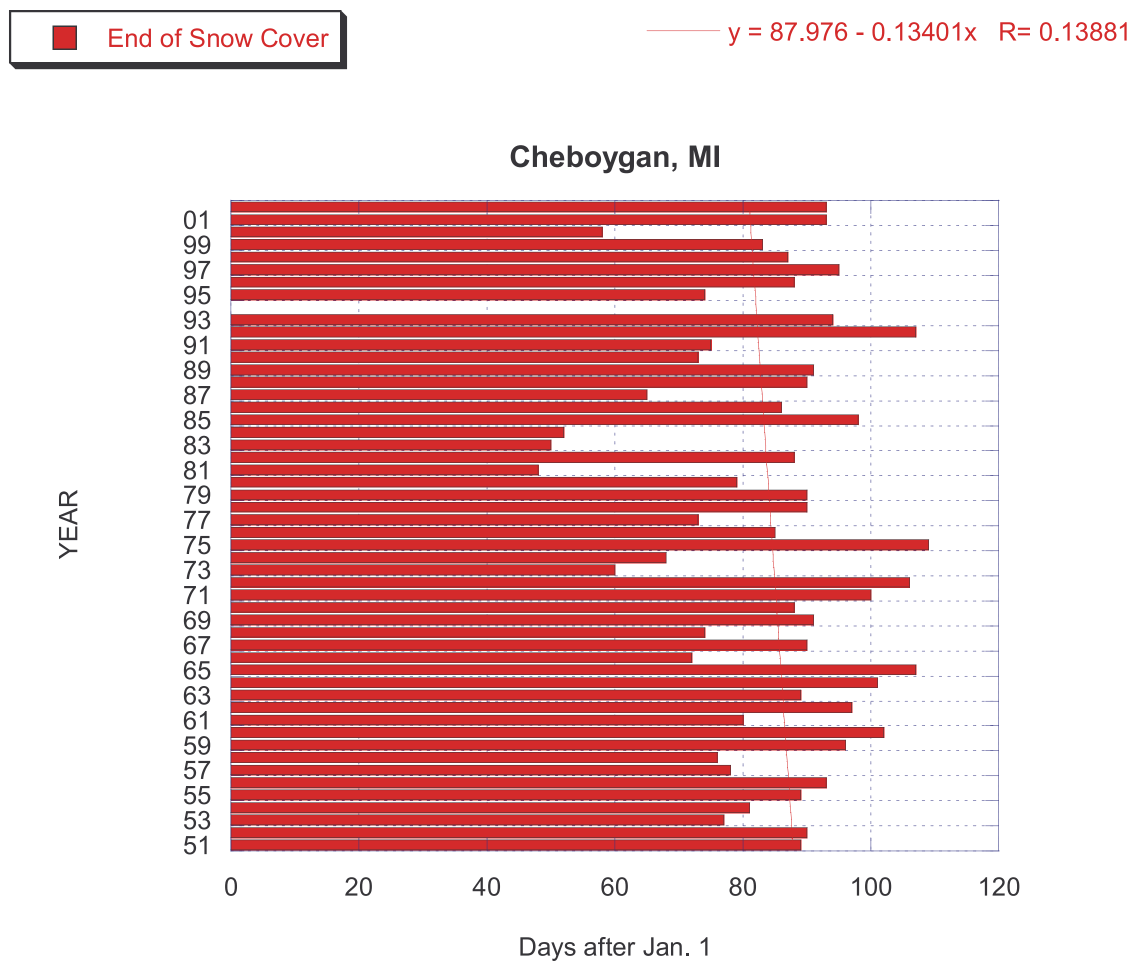

Figure 17c

End of Snow Cover

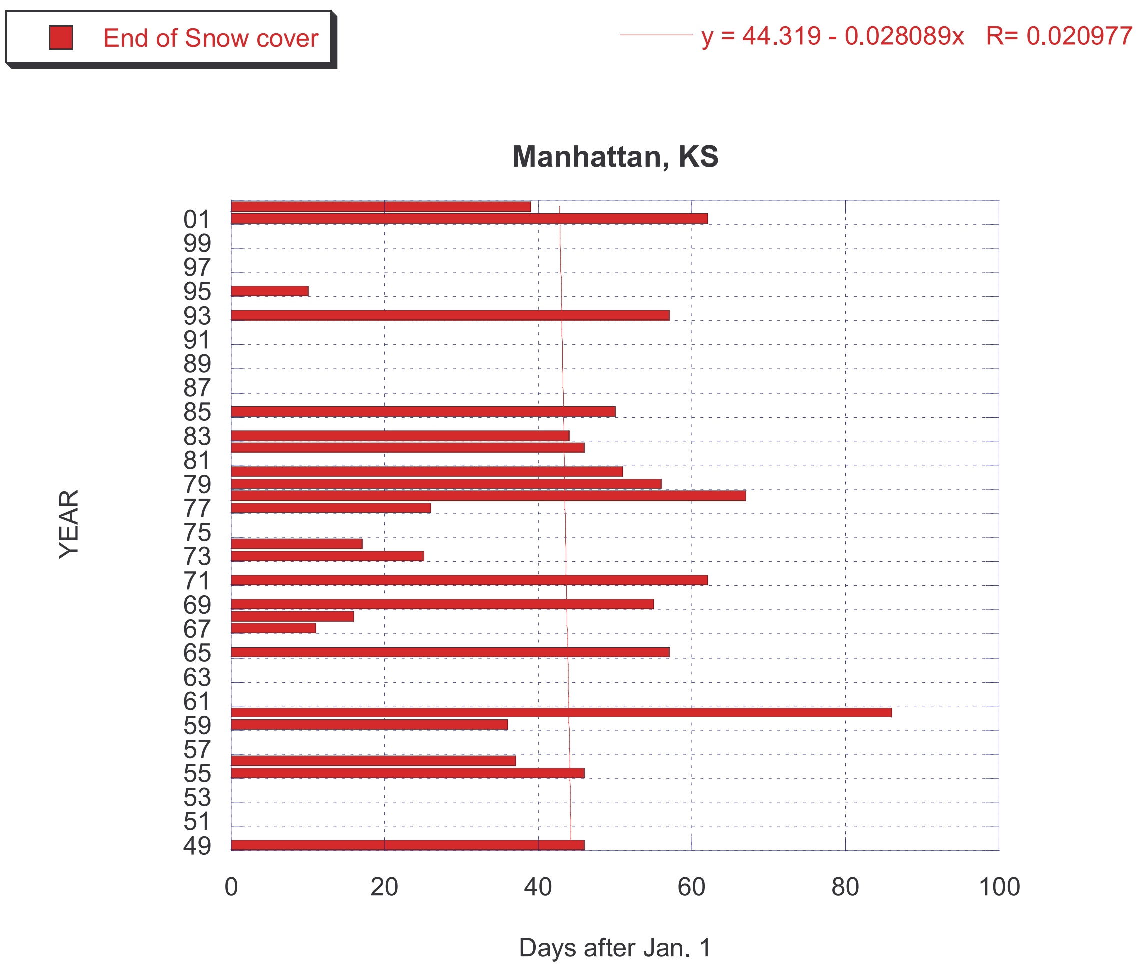

Figure 17d

End of Snow Cover

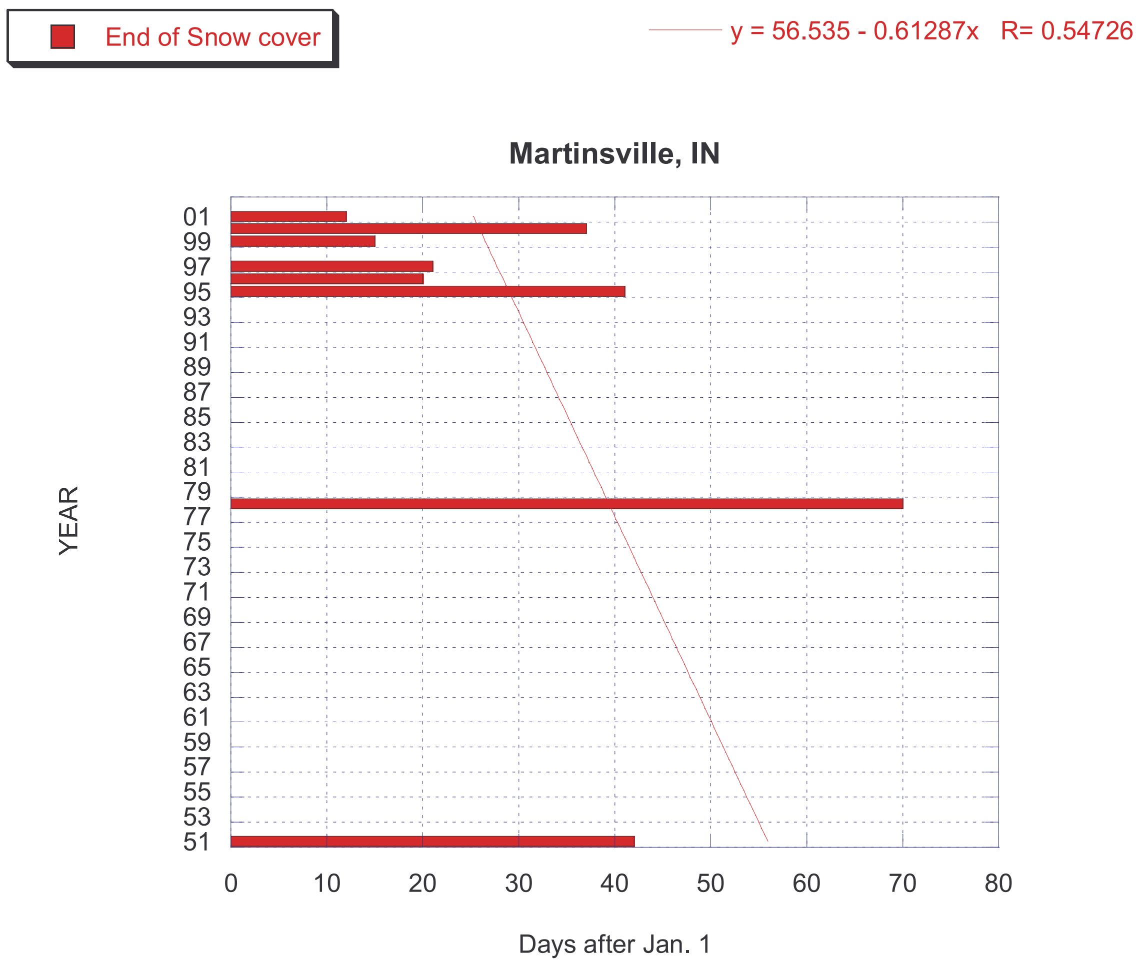

Figure 17e

End of Snow Cover

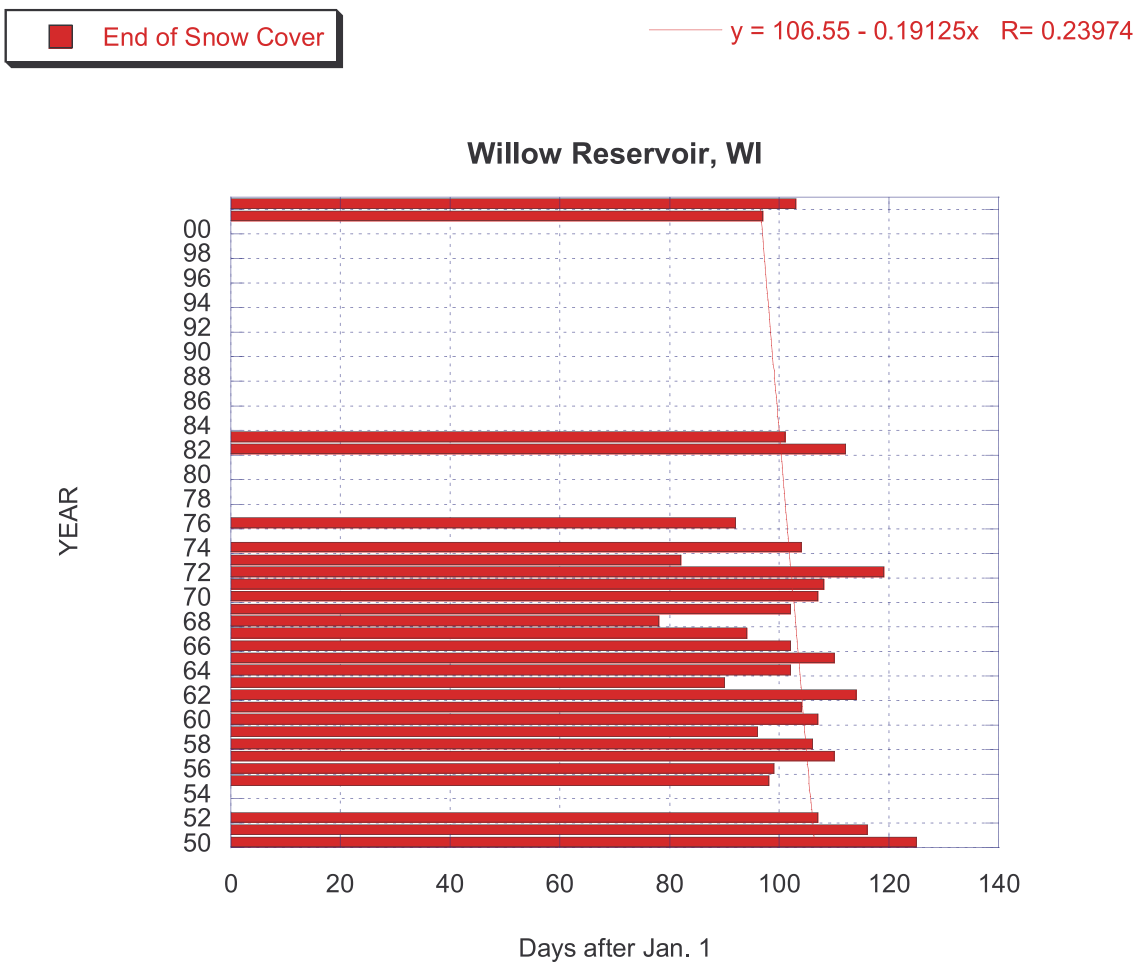

Figure 18a

Snow Cover Period

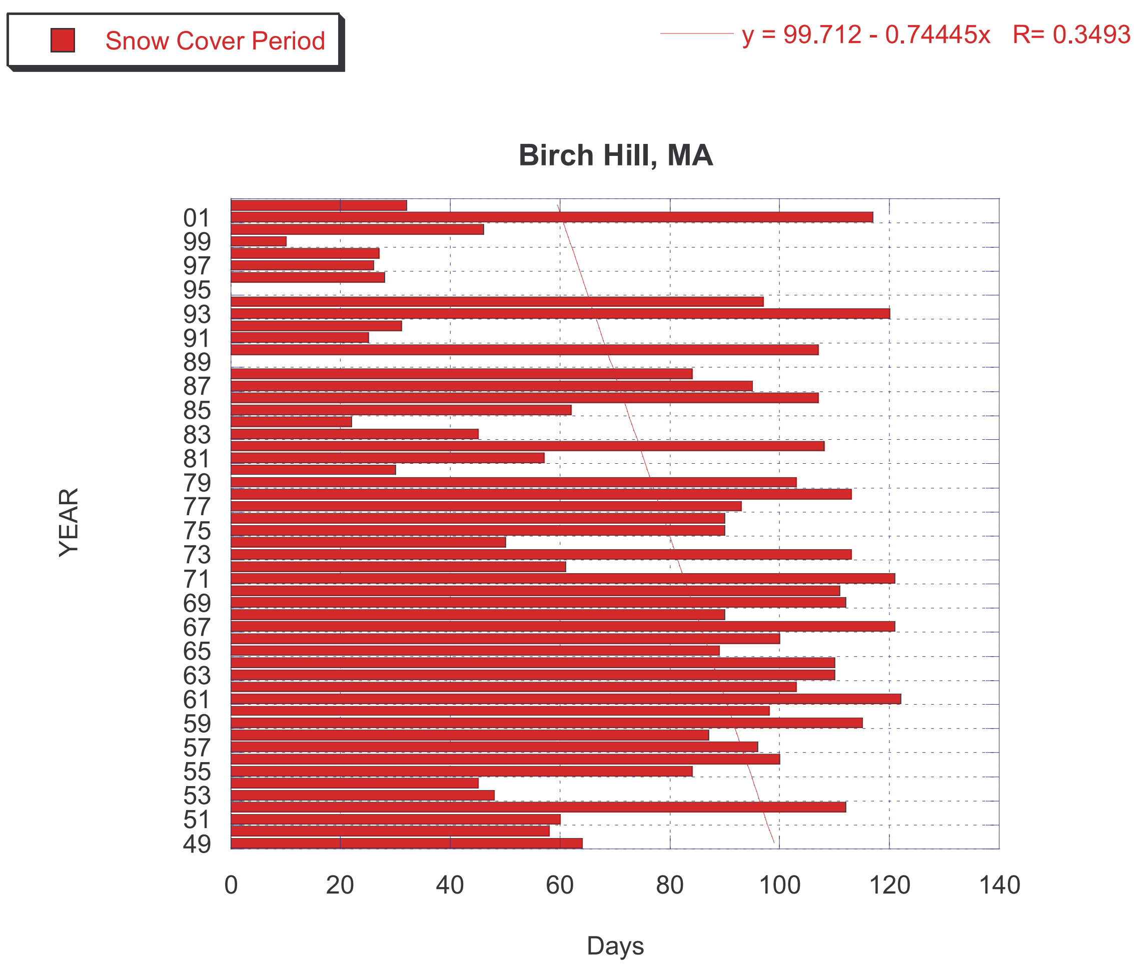

Figure 18b

Snow Cover Period

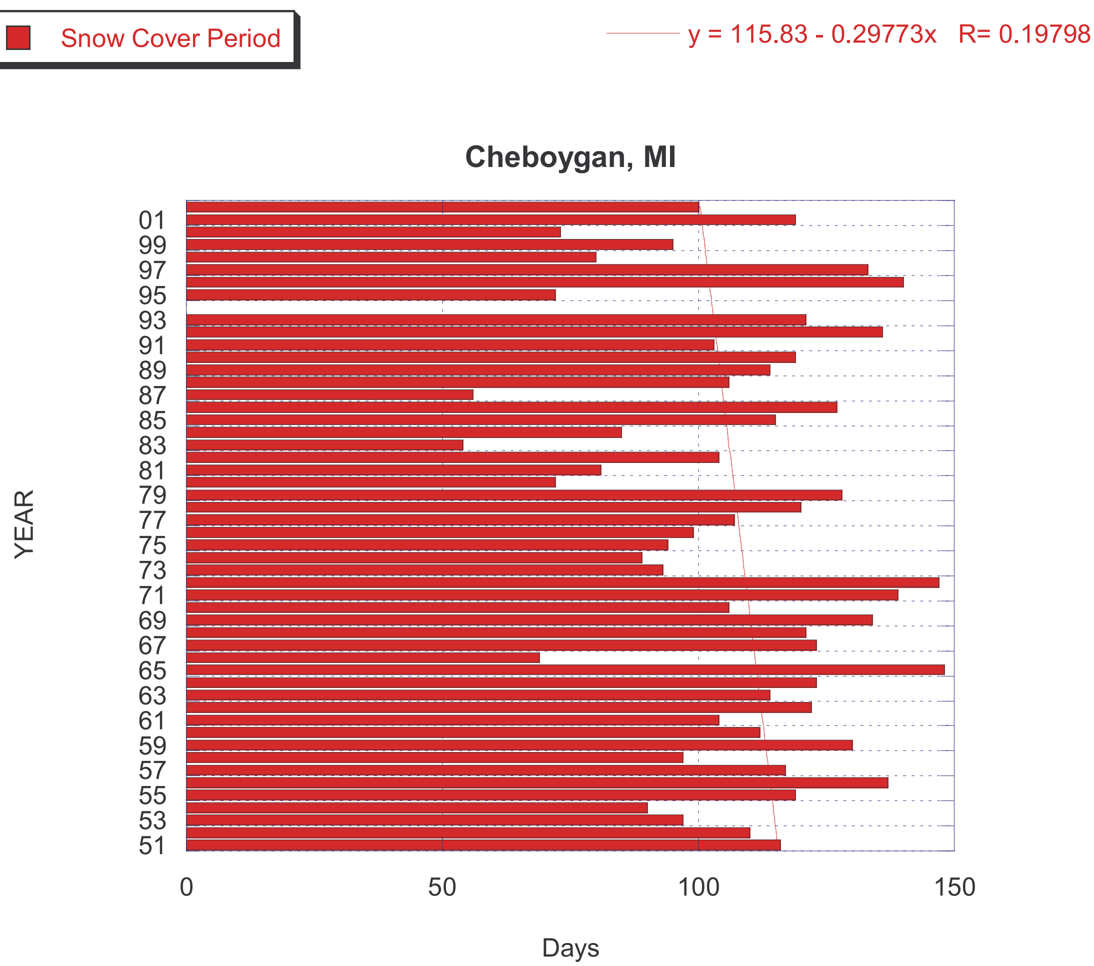

Figure 18c

Snow Cover Period

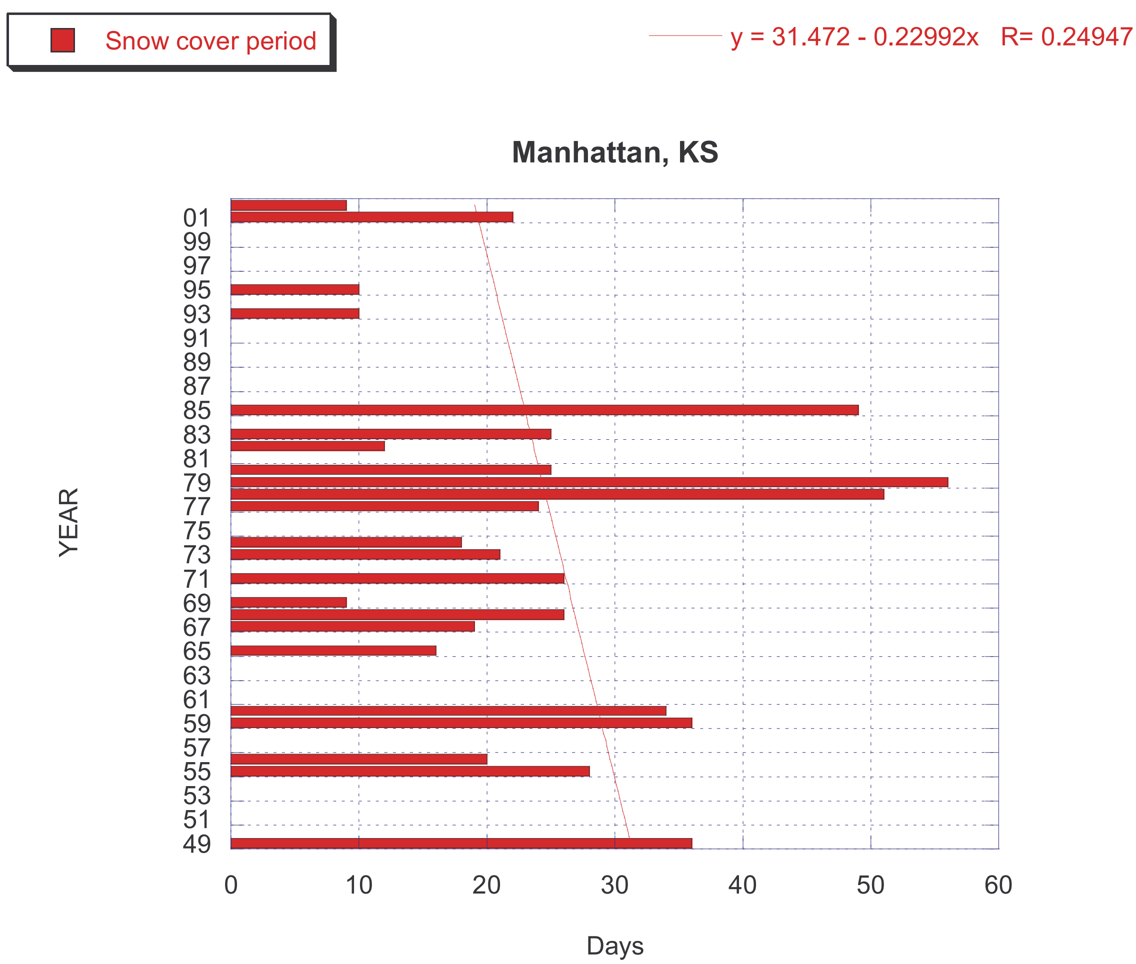

Figure 18d

Snow Cover Period

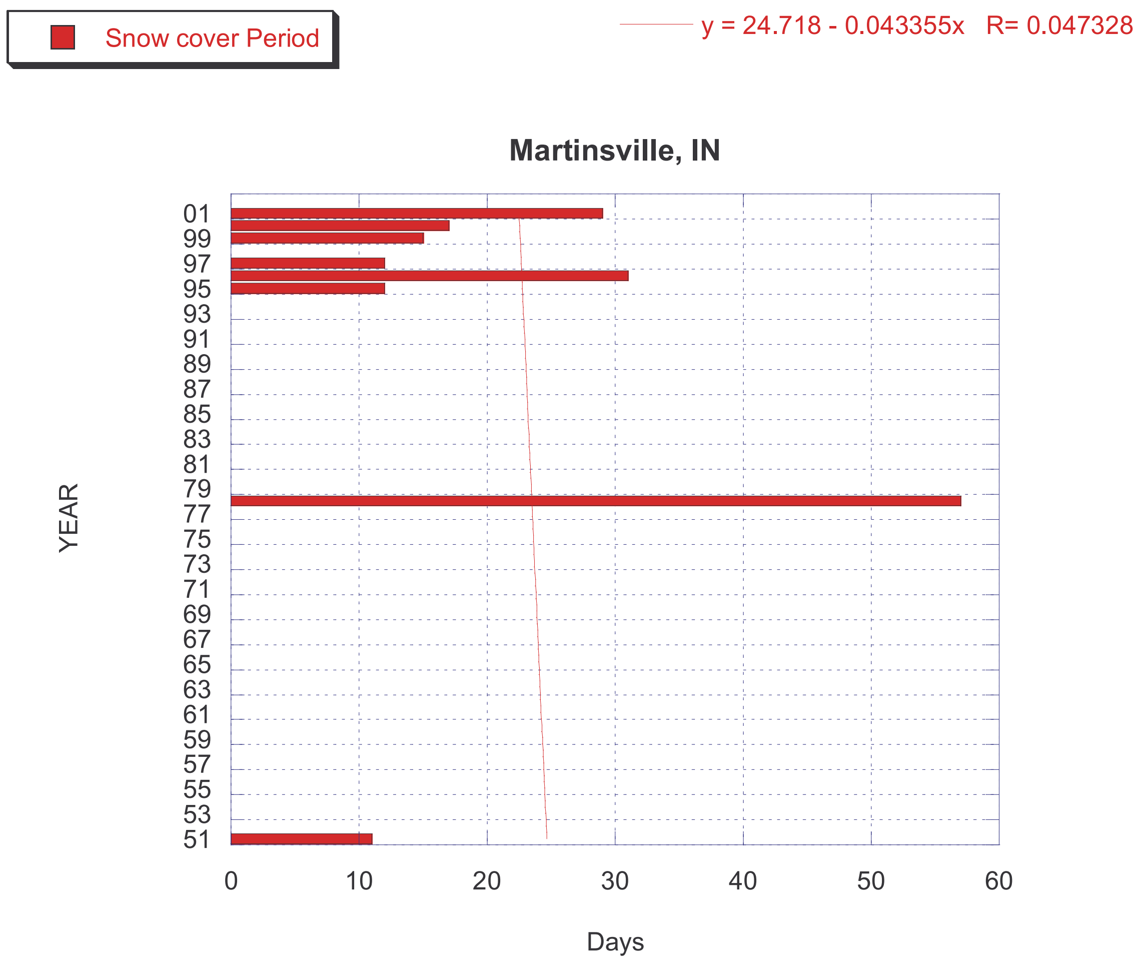

Figure 18e

Snow Cover Period

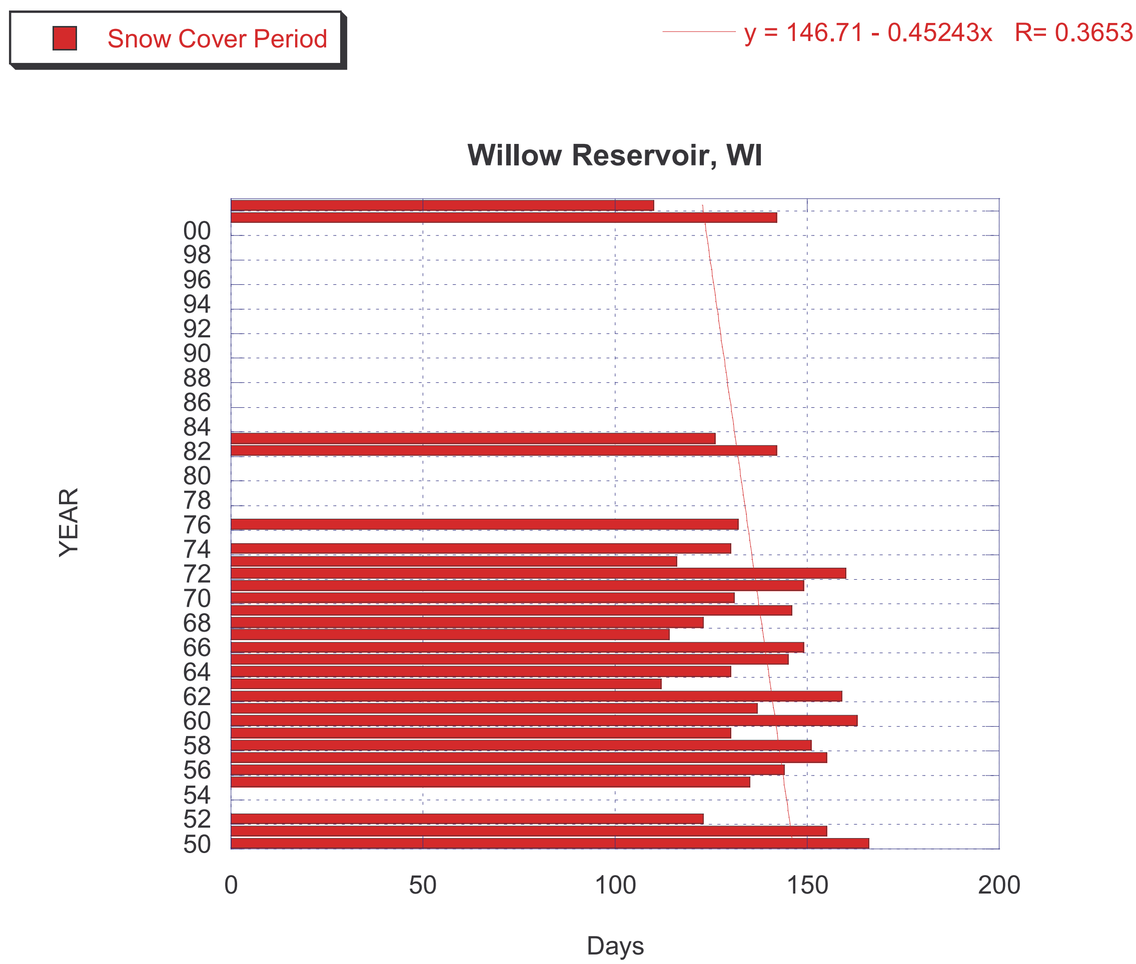

Figure 19a

Correlation between the Start and the End of the Growing Season to the Length of the Growing Season

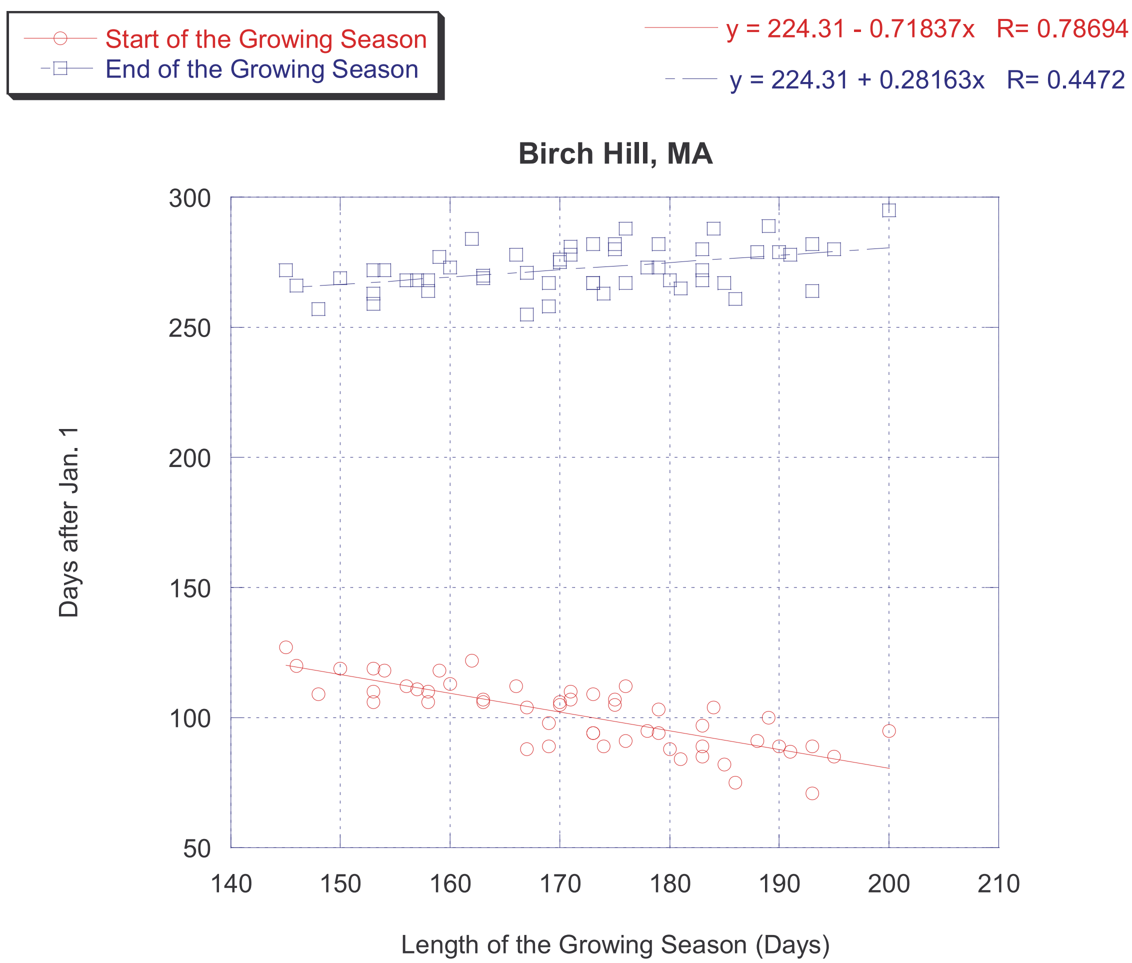

Figure 19b

Correlation between the Start and the End of the Growing Season to the Length of the Growing Season

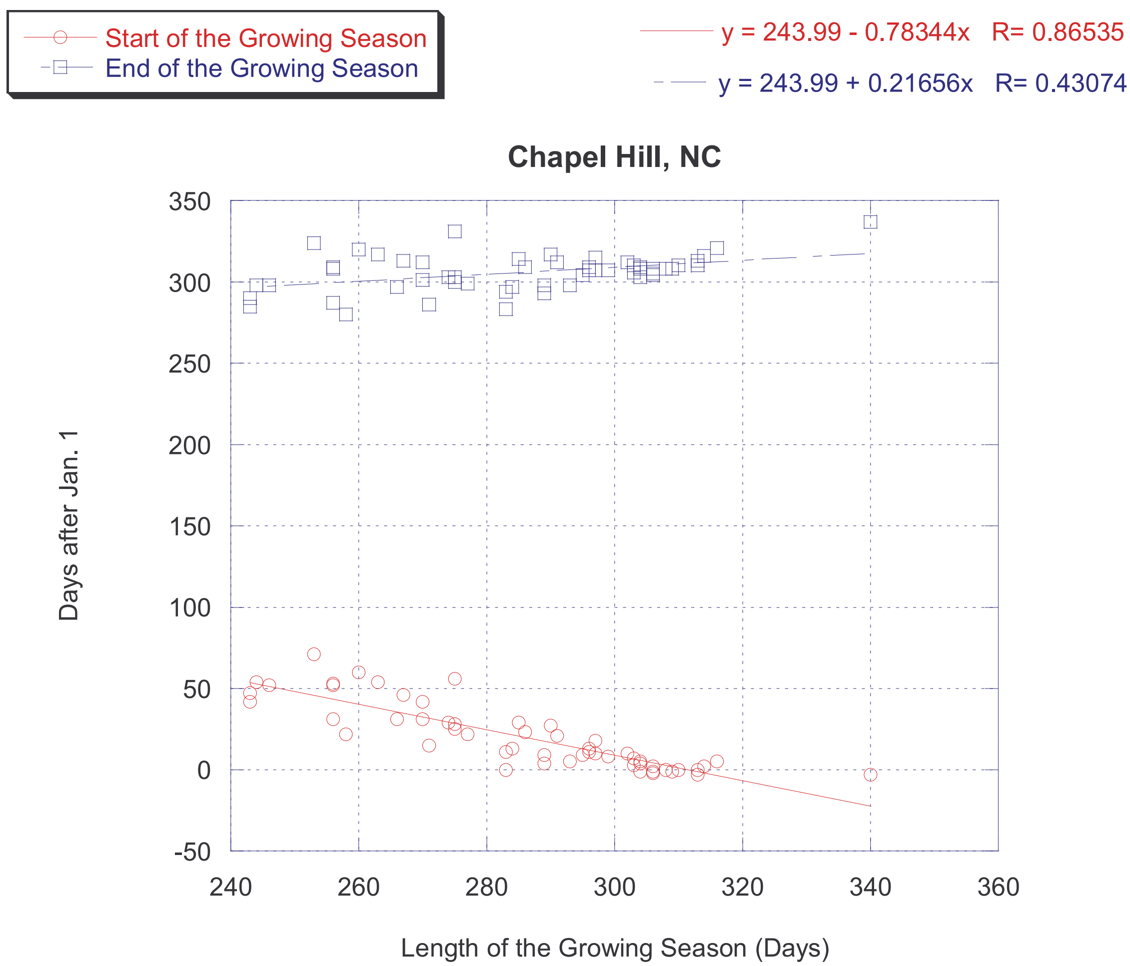

Figure 19c

Correlation between the Start and the End of the Growing Season to the Length of the Growing Season

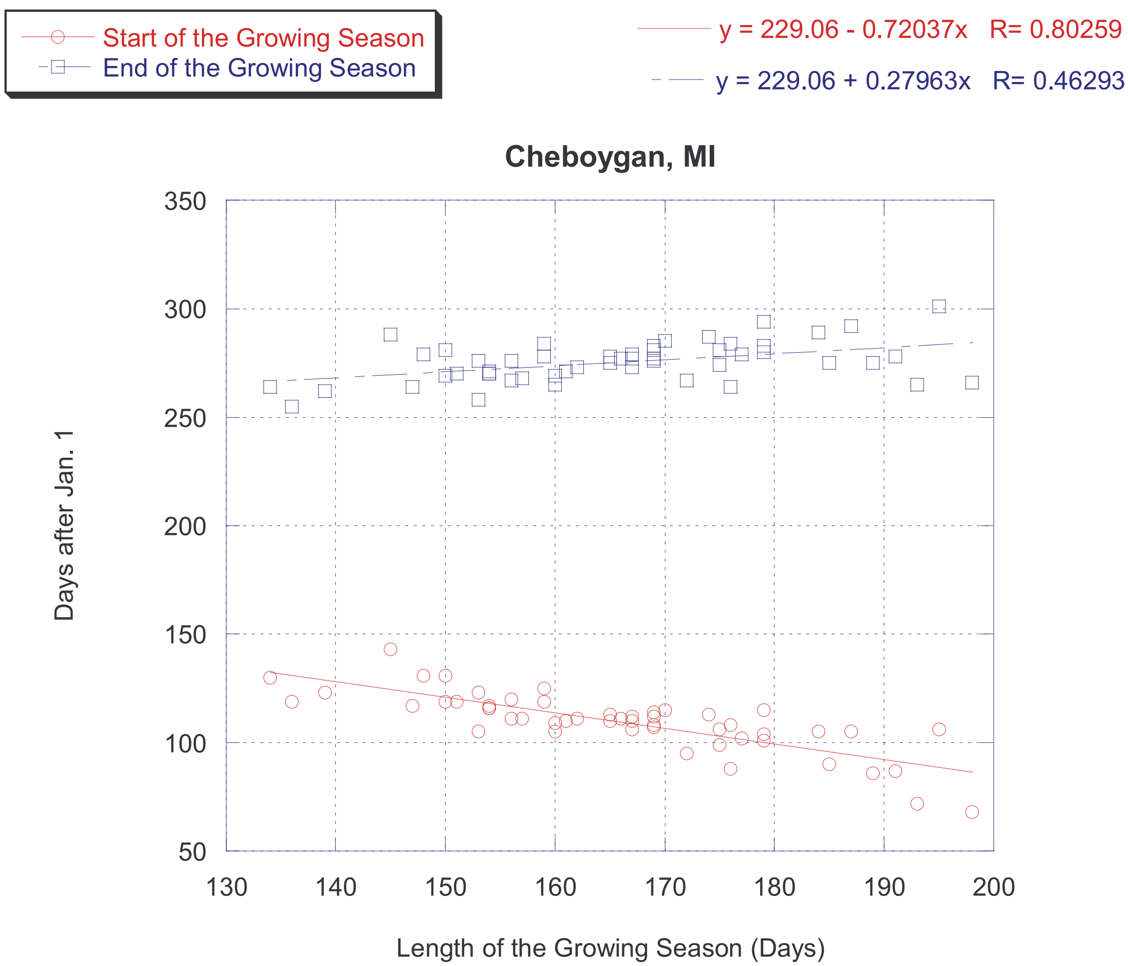

Figure 19d

Correlation between the Start and the End of the Growing Season to the Length of the Growing Season

Figure 19e

Correlation between the Start and the End of the Growing Season to the Length of the Growing Season

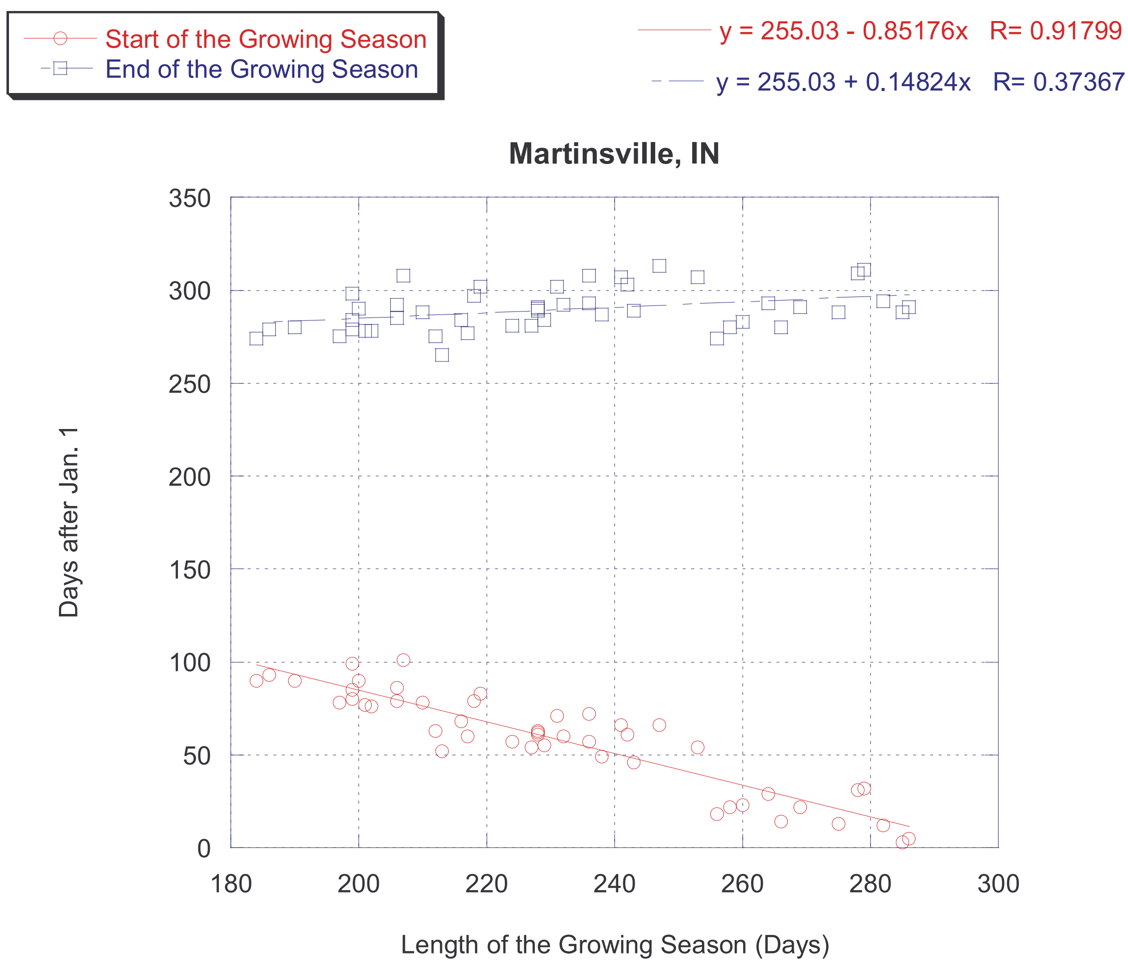

Figure 19f

Correlation between the Start and the End of the Growing Season to the Length of the Growing Season

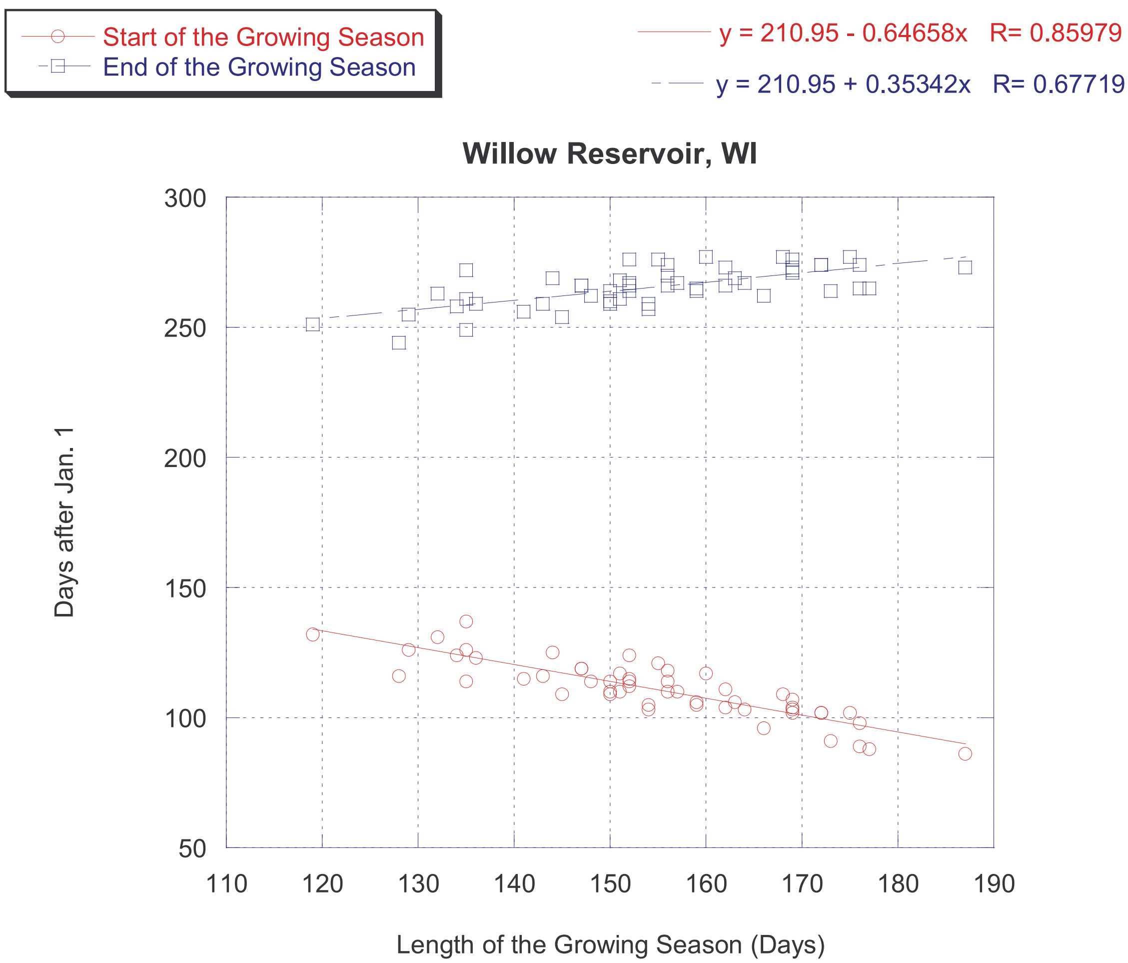

Figure 20a

Correlation between the Last and First Freeze to the Freeze Free Period

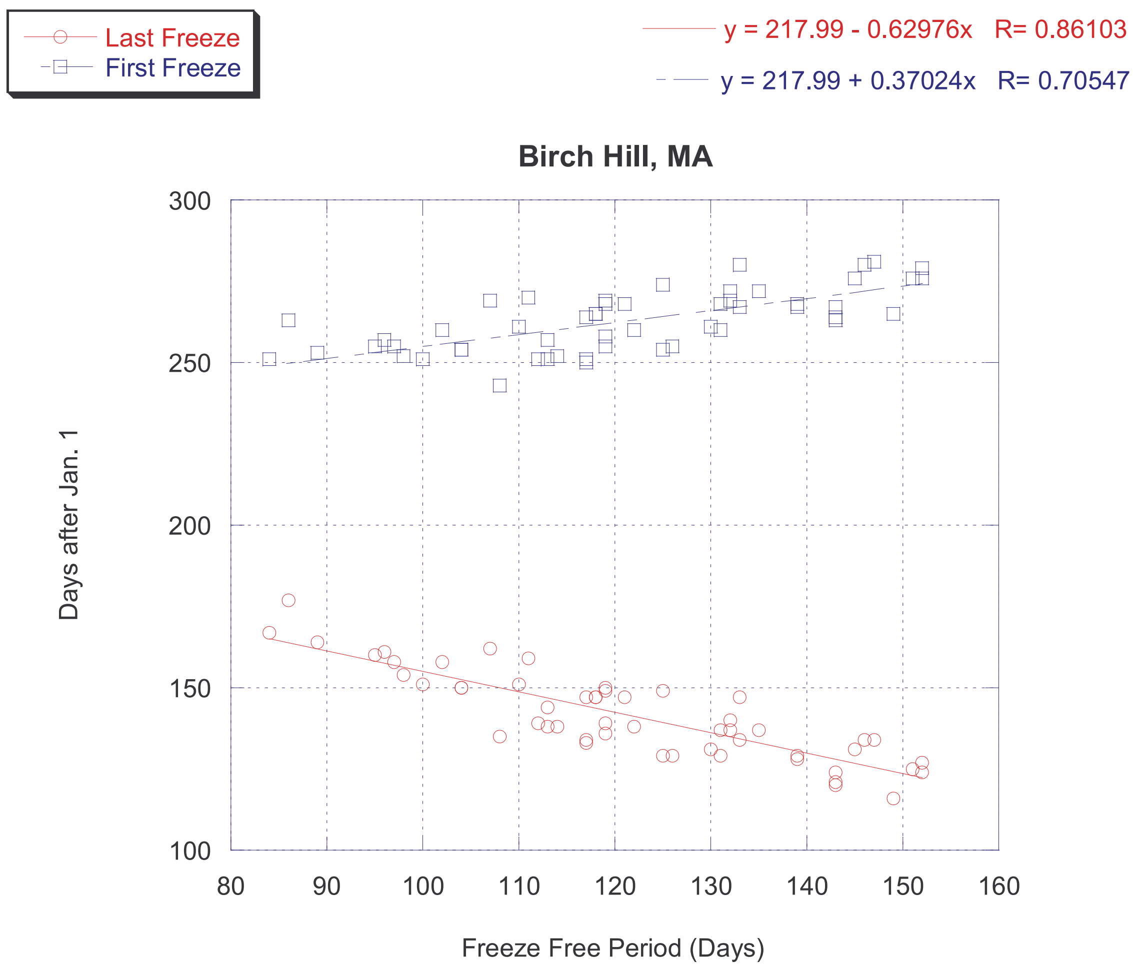

Figure 20b

Correlation between the Last and First Freeze to the Freeze Free Period

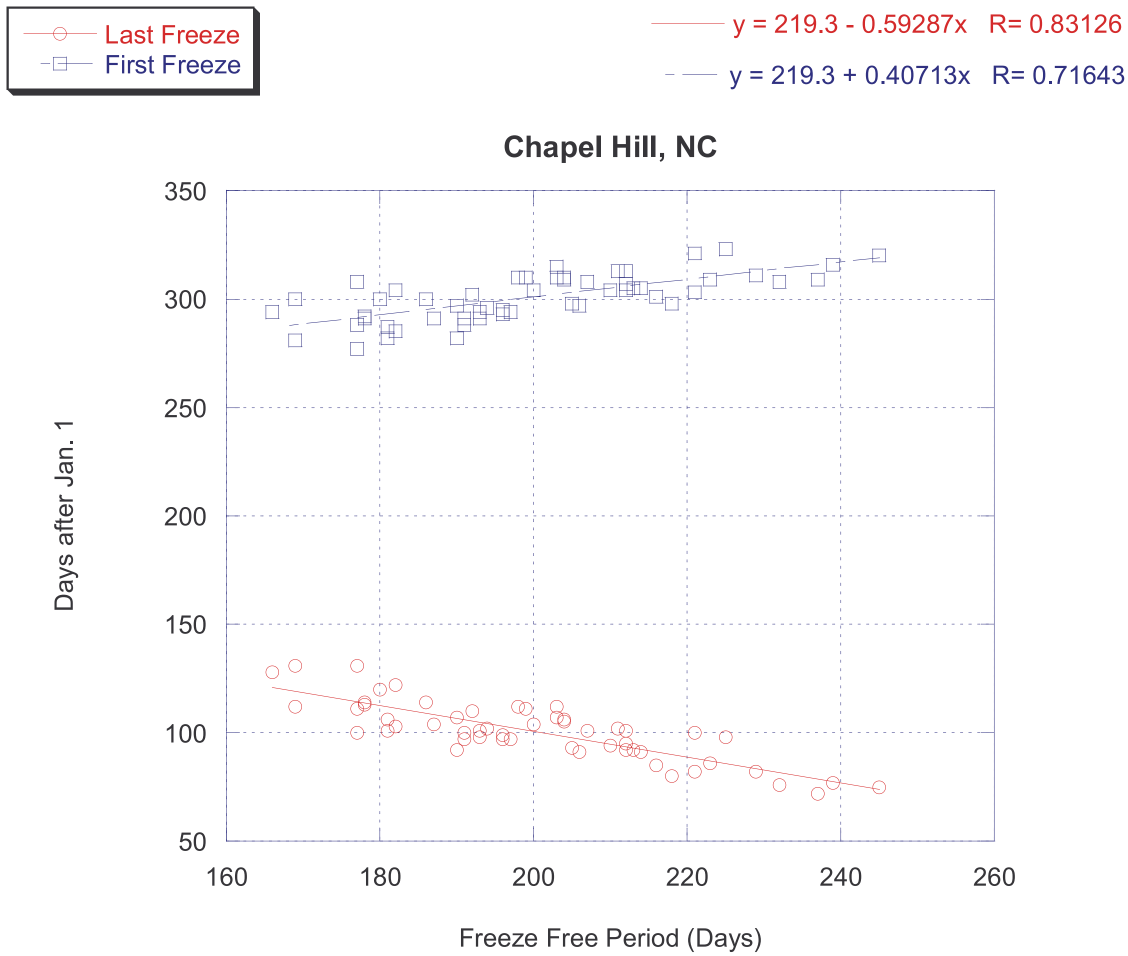

Figure 20c

Correlation between the Last and First Freeze to the Freeze Free Period

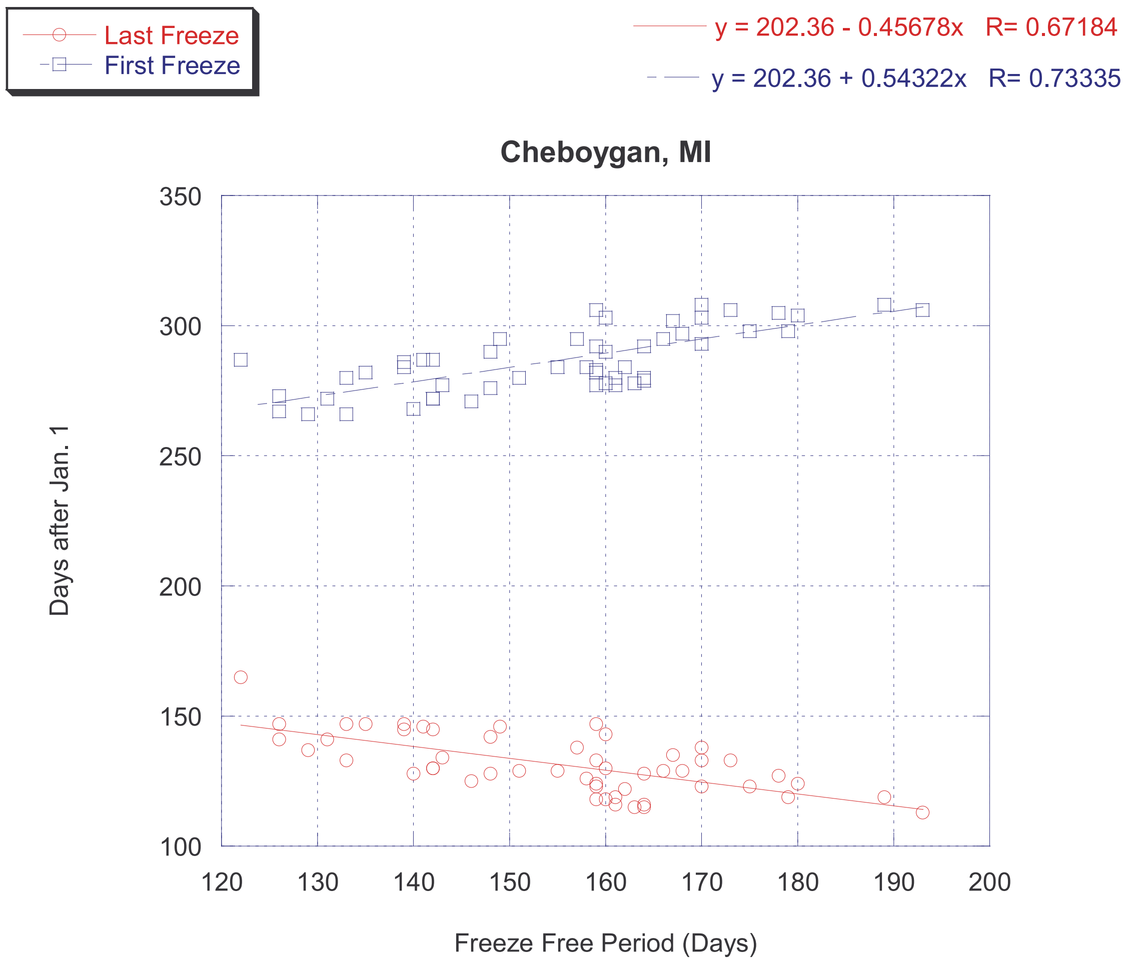

Figure 20d

Correlation between the Last and First Freeze to the Freeze Free Period

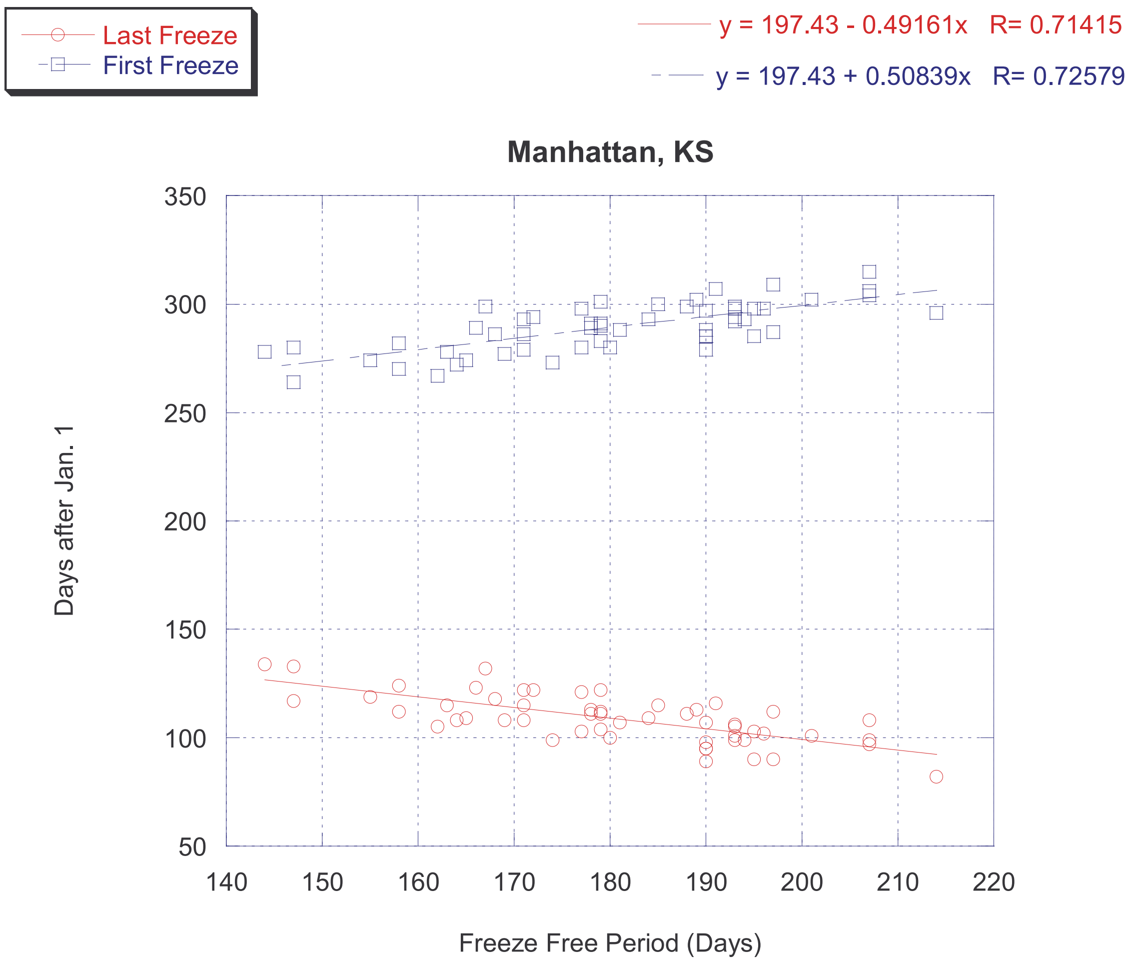

Figure 20e

Correlation between the Last and First Freeze to the Freeze Free Period

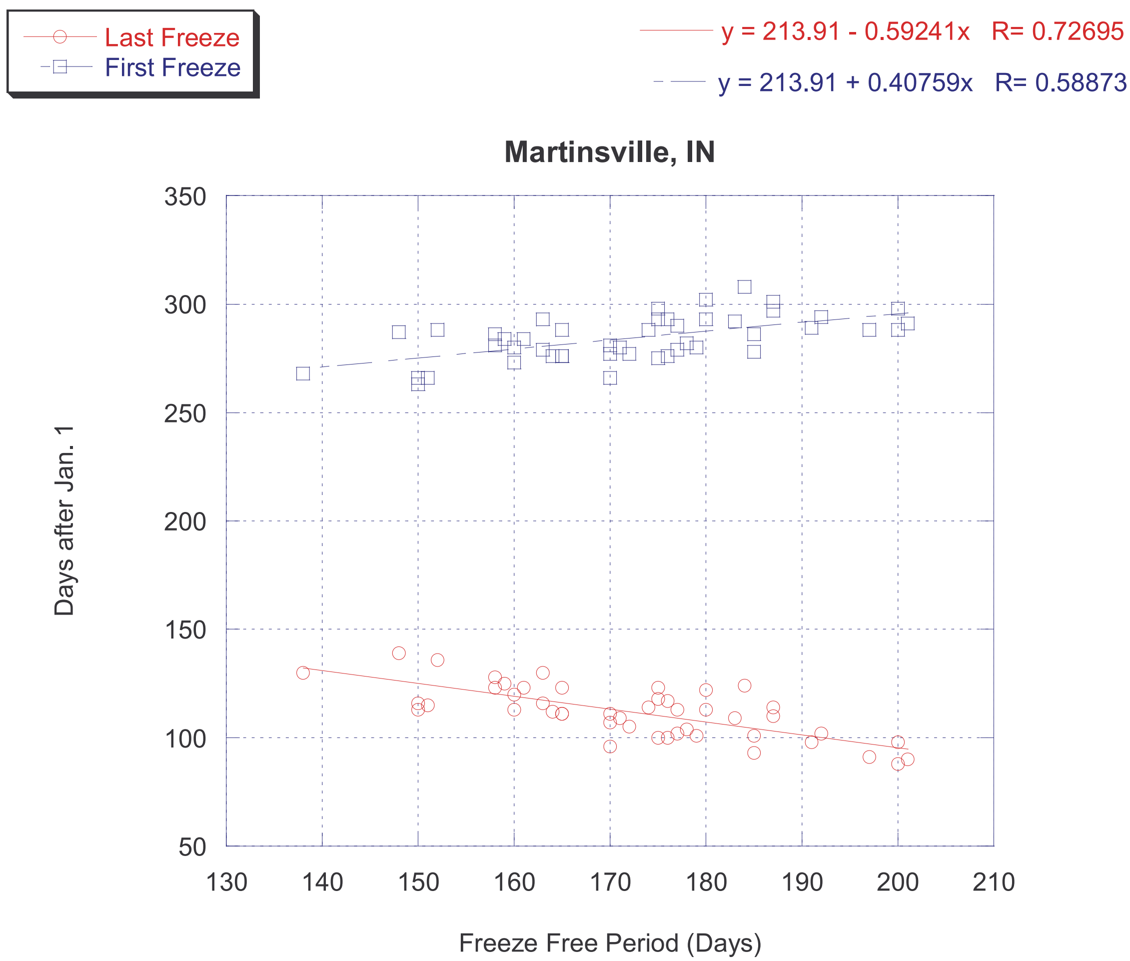

Figure 20f

Correlation between the Last and First Freeze to the Freeze Free Period

Figure 21a

Correlation between the Freeze Free Period and the Length of the Growing Season

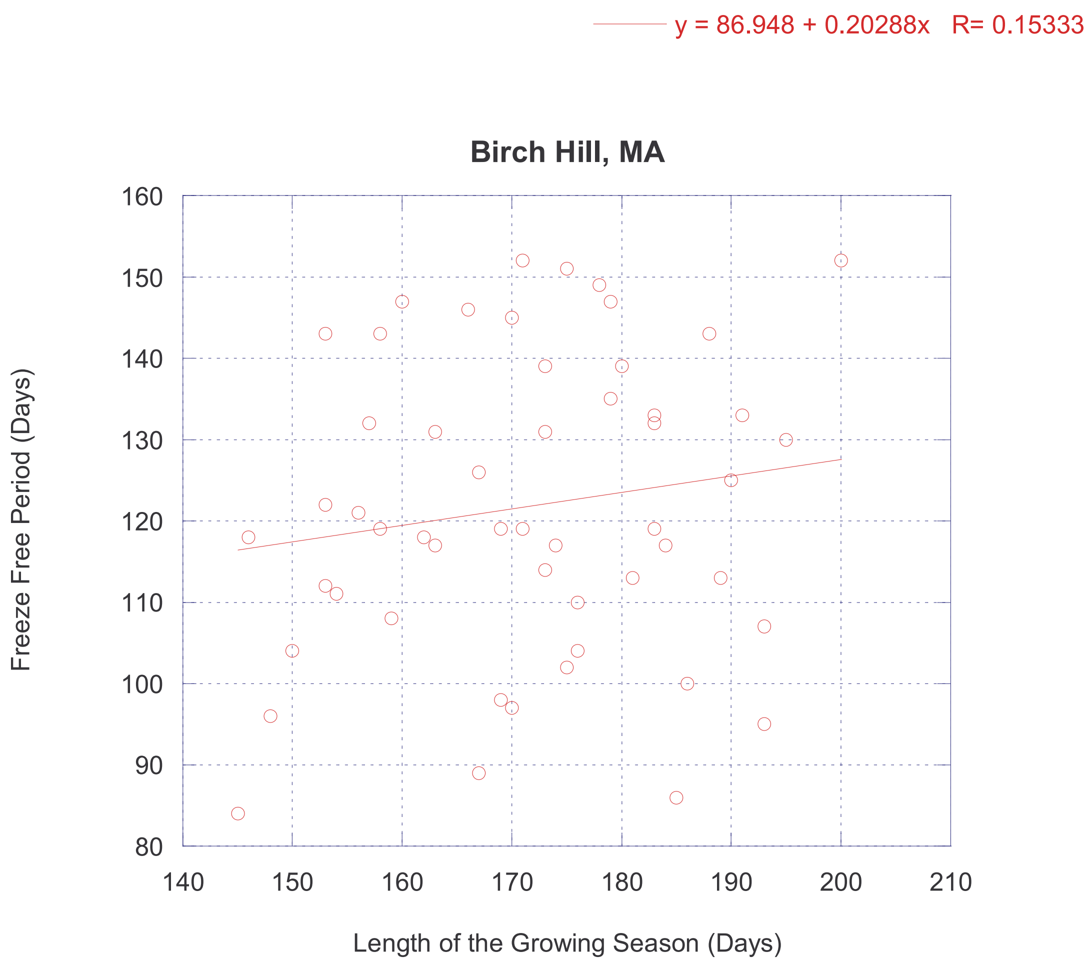

Figure 21b

Correlation between the Freeze Free Period and the Length of the Growing Season

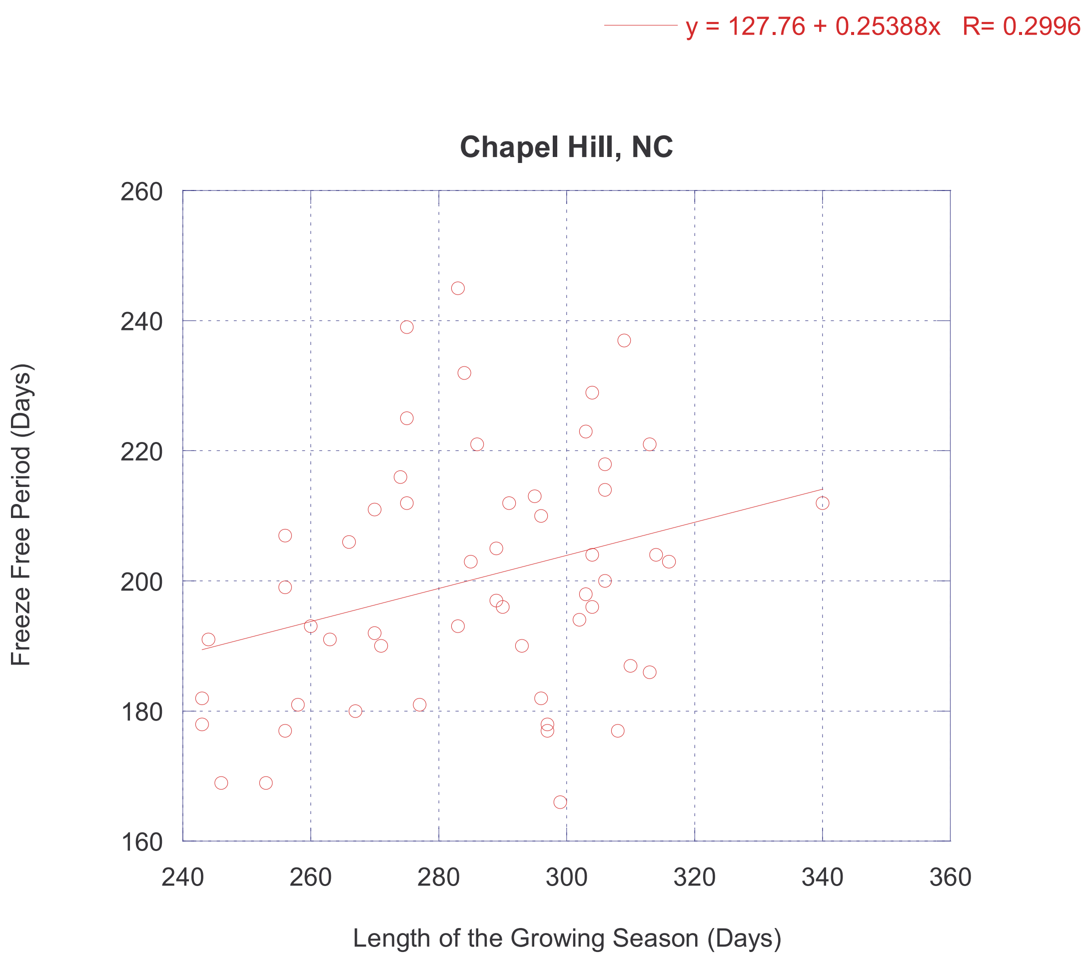

Figure 21c

Correlation between the Freeze Free Period and the Length of the Growing Season

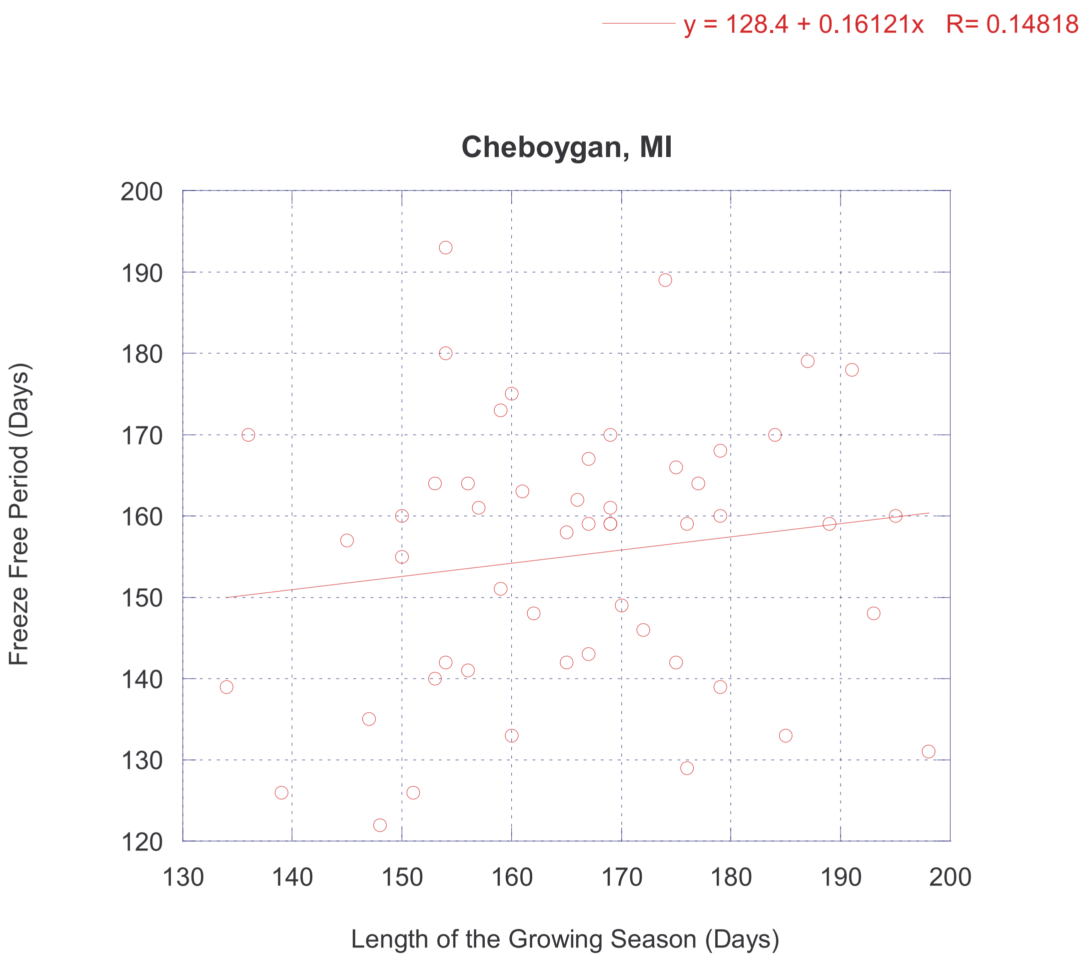

Figure 21d

Correlation between the Freeze Free Period and the Length of the Growing Season

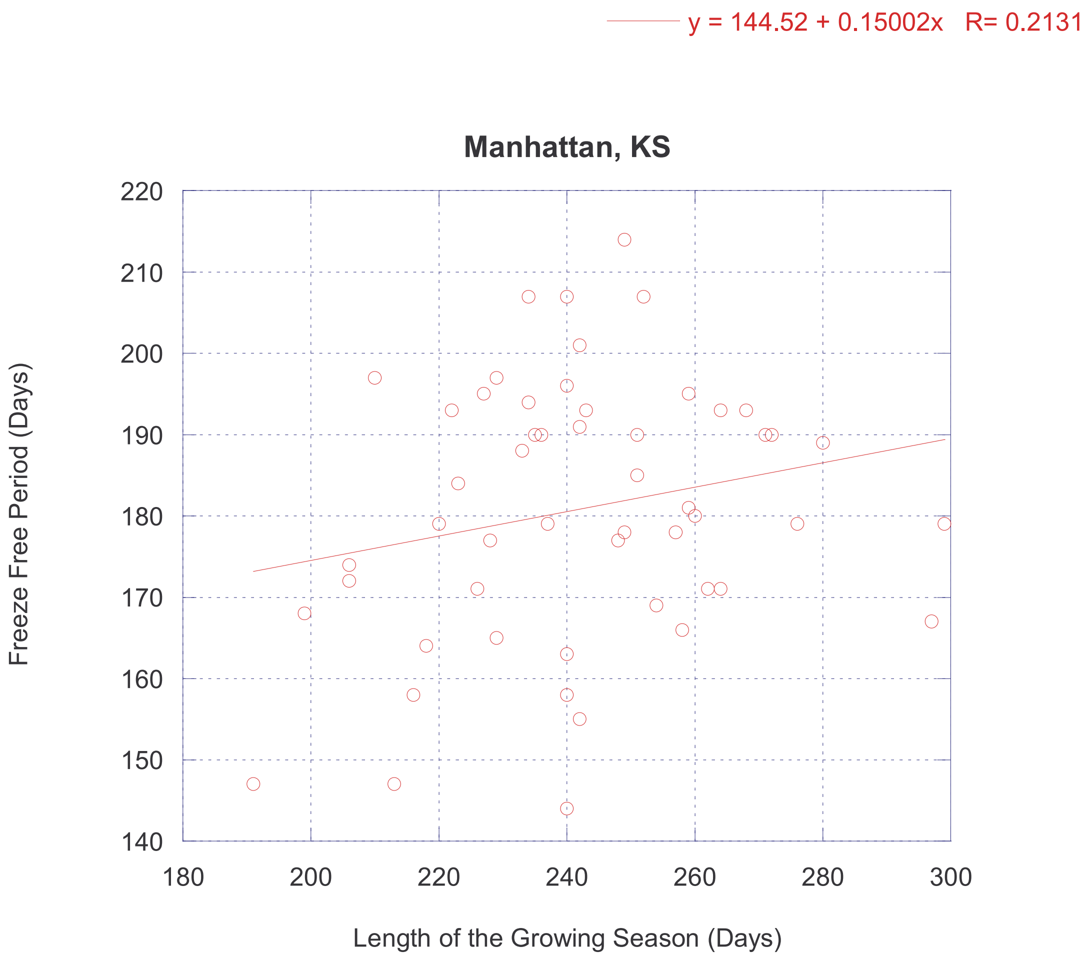

Figure 21e

Correlation between the Freeze Free Period and the Length of the Growing Season

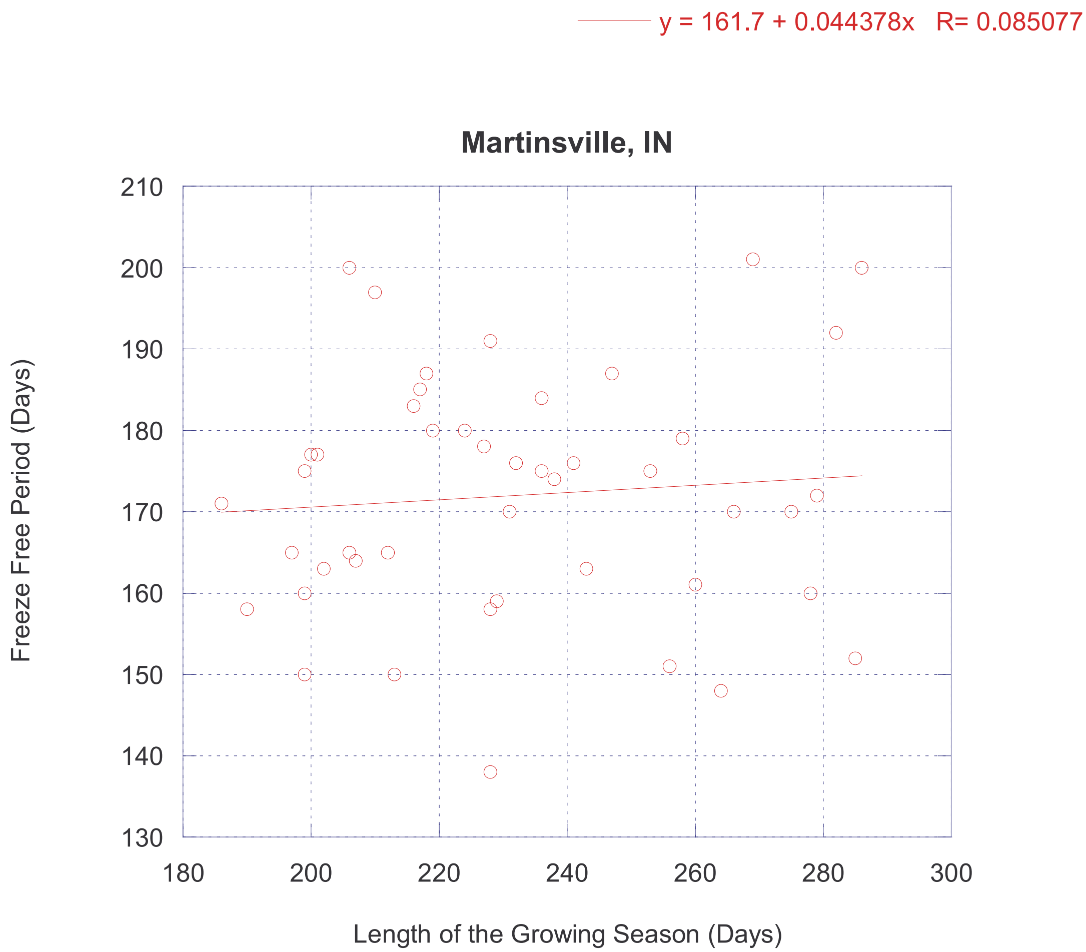

Figure 21f

Correlation between the Freeze Free Period and the Length of the Growing Season

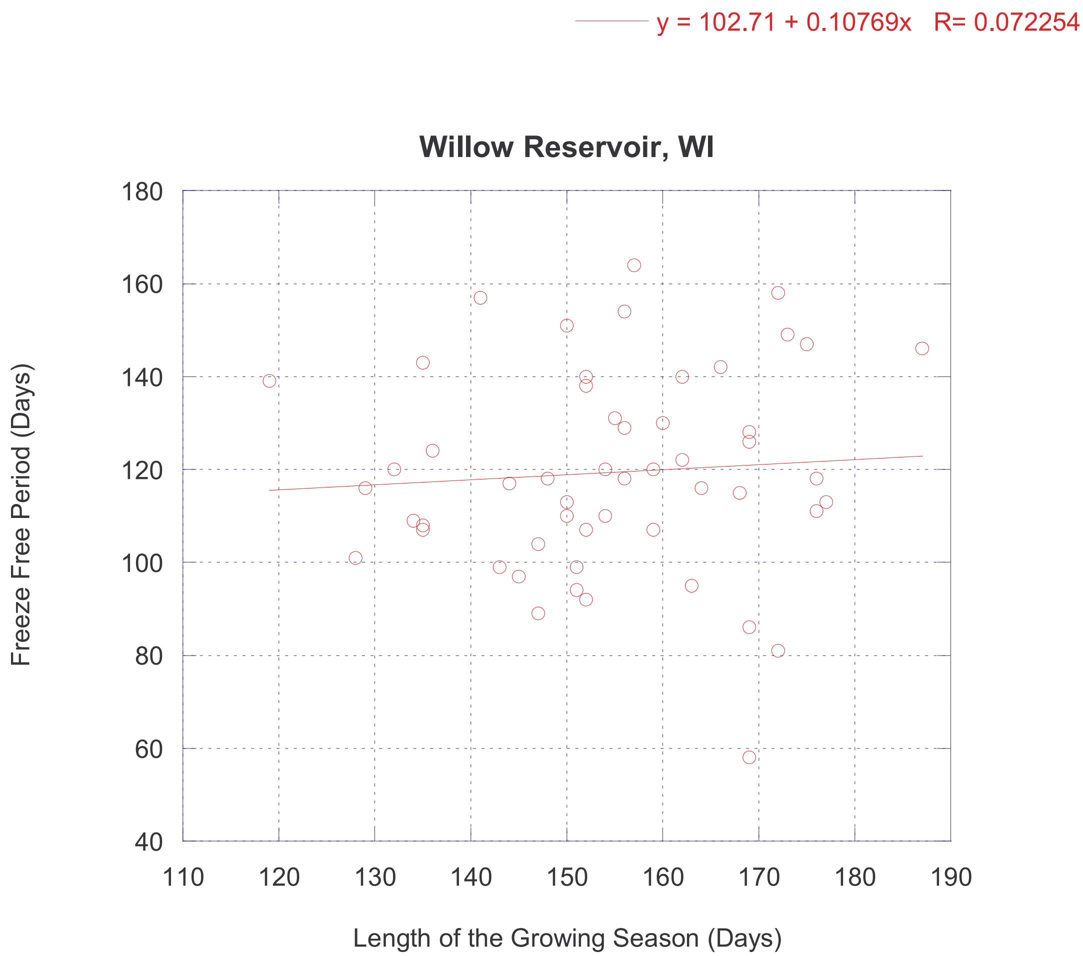

Figure 22a

Correlation between the Start of the Growing Season and Cool Period Mean Temperatures

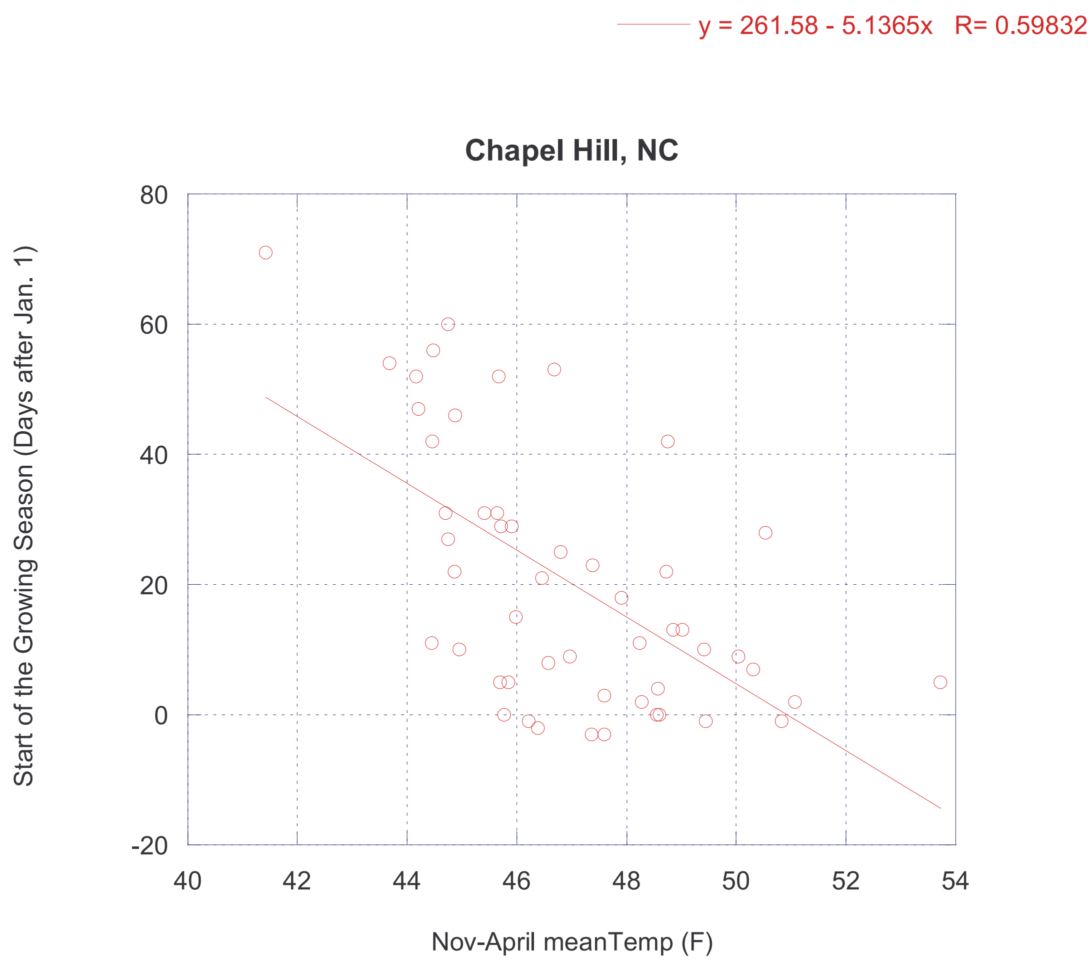

Figure 23a

Correlation between the Freeze Free Period and Warm Period Minimum Temperatures

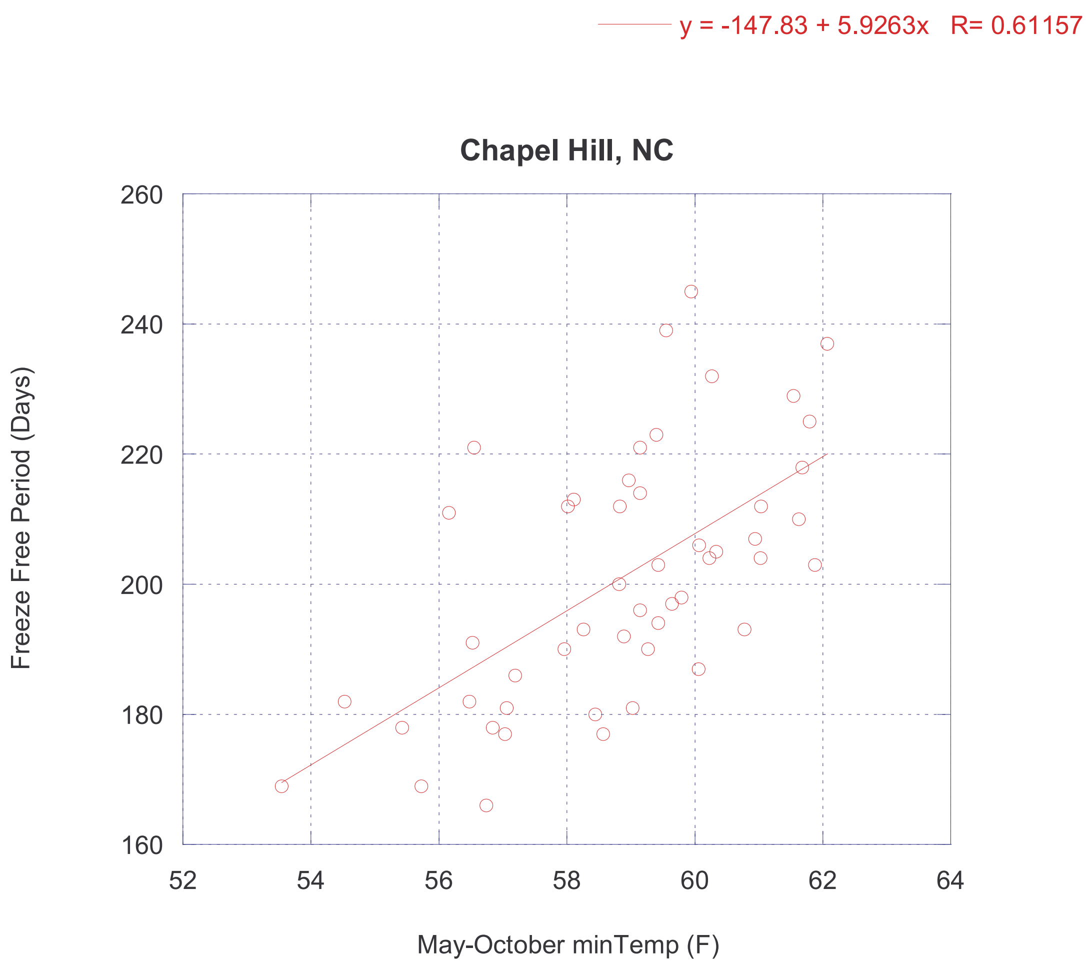

Figure 24a

Correlation between the Start of the Growing Season the End of Snow Cover (Red)