2010

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Recommended Citation

Wu, Chenjie, "Long-term climate trend in Mid-Atlantic Region, USA" (2010). *Graduate Theses, Dissertations, and Problem Reports*. 4674.
https://researchrepository.wvu.edu/etd/4674

Long-Term Climate Trend in Mid-Atlantic Region, USA

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Thesis submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Civil Engineering

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Morgantown, West Virginia

2010

Keywords: Trend analysis; Mid-Atlantic Region; Climate variability; Air temperature; Precipitation extremes

Abstract

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Chenjie Wu

Climate change on global scale has been studied by many researchers while regional studies are limited. The most recent international summary of climate change science (IPCC 2007) suggested a remarkable trend of increasing global surface temperature but no statistically significant trend in precipitation on a global average due to large variability in both space and time. Thus, this study focused on detecting climate changes and effects in the Mid-Atlantic Region, an important ecological system in the US and the world. Climate data from 25 stations with daily measurements for more than 100 years from the National Climate Data Center were analyzed.

The primary aim of this study was to examine the trends of the air temperature and precipitation time series for all the available stations in the region using the Mann Kendall statistical test. The Z statistic for each season as well as for the whole time period was calculated. The median slope of trends was estimated by Sen’s method. Regional trends were formed by statistically combining the results of the Mann Kendall test for each individual trend. Extreme event indices were developed to study the trends of severe conditions. Winter and summer seasons were selected to study seasonal effects.

The secondary objective of this study was to detect relations between landscape attributes (e.g., elevation, altitude, forestry) and the long-term trend. The analyses were expected to provide information that can help answer questions related to regional climate changes such as elevation-dependent climate changes in this region. Stations were divided into three groups—low, medium, high according to their elevation. Kruskal-Wallis test was performed to detect the differences among the three groups.

All statistical analyses were conducted using SAS software 9.1 and SYSTAT 12. Results indicated variations between stations. Both negative and positive trends for all parameters were detected. Homogeneous trend was not found for the whole region. Our results showed coastal stations and inland stations have opposite results. One of the possible reasons could be the bigger cities and faster population growth rate at the coastal area which urbanization effect was more pronounced. Annual trends and seasonal trends were consistent for most parameters. The only differences was the increasing rate of warm days in winter compared with decreasing rate at most stations for summer and annual trends. Due to the insignificant of the differences among our three elevation groups, the dependency was not well established. Our study is the first look of the available data, more work are needed to justify the results.

Acknowledgement

I thank my advisor Dr. Lian-Shin Lin who made great efforts in supervising me through my master project. His profound knowledge and nice personality enabled me a smooth and joyful journey of study. Also I thank Dr. Donald Gray and Dr. James Anderson for their support and guidance. I appreciate their time on serving on my committee and also I benefited a lot from their classes.

The same thanks go to all the other faculty and staff members at WVU, Dr. Xinchao Wei, Dr. Karen Buzby, and Research Assistant Will Ravenscroft. Life is always easier when others offer their warm hands.

Also, I thank my parents and my twin sister. They supported me unconditionally with their love. I could not have the strength without them.

In addition, I thank my friends and fellow students: Dongyang Deng, Isabel Cardona, Jinyan Sun, Khaled, Lina Cui, Ning Zhang, and Yushun Chen.

Table of content

Abstract ii
Acknowledgement iii
Table of content iv
List of Tables v
List of Figures vii
Chapter 1 Introduction 1
Chapter 2: Literature Review 3
2.1 Mid-Atlantic Region 3
2.2 Climate Change 4
  2.2.1 Evidence of Climate Change 4
  2.2.2 Elevation Dependence of Climate Change 7
  2.2.3 Climate Change Effects 8
2.3 Trend Analysis 12
  2.3.1 Quality Control for Climate Data 12
  2.3.2 Statistical Methods 15
Chapter 3 Materials and Methods 18
3.1 Study Area and Data Quality 18
  3.1.1 Study Area 18
  3.1.2 Data Source and Quality 18
  3.1.3 Software 19
  3.1.3 Data Preparation 19
  3.1.5 Statistic Analysis 21
Chapter 4 Results 27
4.1 Temperature Trends 27
  4.1.1 Annual Trends 27
  4.1.2 Seasonal Trends 30
  4.1.3 Homogenous Test 33
4.2 Precipitation Trends 33
  4.2.1 Annual Trends 33
  4.2.2 Seasonal Trends 34
  4.2.3 Homogenous Test 35
Chapter 5 Discussion and Conclusion 92
Reference 97

List of Tables

Table 3-1 List of climate stations in the four states (Land cover results are from NLCD 2001). 24

Table 3-2 Temperature and Precipitation Indices..26

Table 4-1 Slopes and P values for annual temperature. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends. 37

Table 4-2 Slopes and P values for the difference between annual maximum and annual minimum temperature. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends. 38

Table 4-3 Slopes and P values for warm days and cool days. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends. 39

Table 4-4 Slopes and P values for warm nights and cool nights. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends. 40

Table 4-5 Slopes and P values for maximum annual maximum temperature and annual minimum temperature. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends. 41

Table 4-6 Slopes and P values for minimum annual maximum temperature and annual minimum temperature. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends. 42

Table 4-7 Slopes and P values for annual temperature for the summer season. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends................43

Table 4-8 Slopes and P values for annual temperature for the winter season. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends................44

Table 4-9 Slopes and P values for annual temperature for summer and winter season. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends. 45

Table 4-10 Slopes and P values for TX90 (warm days) and TX10 (cool days) during the summer season. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends. 46

Table 4-11 Slopes and P values for TX90 (warm days) and TX10 (cool days) during the winter season. Significant tends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends...47

Table 4-12 Slopes and P values for TN90 (warm nights) and TN10 (cool nights) during the summer season. Significant tends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends. 48
Table 4-13 Slopes and P values for TN90 (warm nights) and TN10 (cool nights) during the winter season. Significant tends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends. 49
Table 4-14 Slopes and P values for wet day precipitation and wet days. Significant tends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends. 50
Table 4-15 Slopes and P values maximum number of consecutive days with no precipitation and maximum annual precipitation intensity in in/day. Significant tends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends. 51
Table 4-16 Slopes and P values maximum number of consecutive days with no precipitation and maximum annual precipitation intensity in in/day during summer season. Significant tends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends. 52
Table 4-17 Slopes and P values maximum number of consecutive days with no precipitation and maximum annual precipitation intensity in in/day during winter season. Significant tends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends. 53
Table 4-18 Slopes and P values for wet day precipitation during summer and winter season. Significant tends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends. 54

List of Figures

Figure 3-1The Mid-Atlantic Region of the United States (National Land Cover Data 2001 are used.) 23
Figure 4-1 Slopes of TX10 (cool days) in different elevation groups. 55
Figure 4-2 Slopes of TX10 (cool days) during summer season in different elevation groups. 56
Figure 4-3 Slopes of TX10 (cool days) during winter season in different elevation groups. 57
Figure 4-4 Slopes of TXN (minimum annual maximum temperature) in different elevation groups. 58
Figure 4-5 Slopes of TXN in different elevation groups. 59
Figure 4-6 Slopes of annual maximum temperature during summer season in different elevation groups. 60
Figure 4-7 Slopes of annual maximum temperature during winter season in different elevation groups. 61
Figure 4-8 Slopes of TX90 (Warm days) in different elevation groups. 62
Figure 4-9 Slopes of TX90 (Warm days) during summer season in different elevation groups. 63
Figure 4-10 Slopes of TX90 (Warm days) during winter season in different elevation groups. 64
Figure 4-11 Slopes of P95 (Annual total precipitation exceeding 95th percentile) in different elevation groups. 65
Figure 4-12 Slopes of P95 (Annual total precipitation exceeding 95th percentile) during summer season in different elevation groups. 66
Figure 4-13 Slopes of P95 (Annual total precipitation exceeding 95th percentile) during winter season in different elevation groups. 67
Figure 4-14 Slopes of PX (maximum precipitation intensity) in different elevation groups. 68
Figure 4-15 Slopes of PX (maximum precipitation intensity) during summer season in different elevation groups. 69
Figure 4-16 Slopes of PX (maximum precipitation intensity) during winter season in different elevation groups. 70
Figure 4-17 Slopes of P95D (numbers of days with precipitation exceeding 95th percentile) during in different elevation groups. 71
Figure 4-18 Graphic view of trends for station 185111, a. annual mean temperature, b. annual maximum temperature, c. annual minimum temperature d. T_{RANGE} 72
Figure 4-19 Graphic view of trends for station 185111, a. Tmax90, b. Tmin90, c. Tmax10 d. Tmin10..73
Figure 4-20 Graphic view of trends for station 185111, a. P95, b. P95D, c. CDD d. PX. 74
Figure 4-21 Graphic view of trends for station 185111, a. TXX, b. TXN, c. TNX d. TNN. 75

Figure 4-22 Spatial distribution of trends for annual mean temperature. 76
Figure 4-23 Spatial distribution of trends for annual maximum temperature....... 77
Figure 4-24 Spatial distribution of trends for annual minimum temperature. 78
Figure 4-25 Spatial distribution of trends for binaural temperature range. 79
Figure 4-26 Spatial distribution of trends for TX90 (warm days). 80
Figure 4-27 Spatial distribution of trends for TX10 (cool days). 81
Figure 4-28 Spatial distribution of trends for TN90 (warm nights)...................... 82
Figure 4-29 Spatial distribution of trends for TN10 (cool nights). 83
Figure 4-30 Spatial distribution of trends for maximum annual maximum temperature. 84
Figure 4-31 Spatial distribution of trends for minimum annual maximum temperature. 85
Figure 4-32 Spatial distribution of trends for maximum annual minimum temperature. 86
Figure 4-33 Spatial distribution of trends for minimum annual minimum temperature. 87
Figure 4-34 Spatial distribution of trends for annual total precipitation exceeding 95th percentile.. 88
Figure 4-35 Spatial distribution of trends for annual total days with precipitation exceeding 95th percentile. 89
Figure 4-36 Spatial distribution of trends for consecutive dry days. 90
Figure 4-37 Spatial distribution of trends for maximum annual precipitation intensity. 91

Chapter 1 Introduction

It is obvious to us all that the earth's climate has been changing over time from ice age to present. Changes in climate may involve just single parameter such as temperature or precipitation, but usually it is the shift of meteorology conditions. Lots of evidences supported the fact that the earth is facing different climate conditions along time. Study revealed that the rate of sea level raise in the last decade was nearly double that of the last century (Church et al. 2006). Totally, they reported that global sea level had risen about 17 centimeters. Synthesis and Assessment Product (SAP) 3.4 report summarized an acceleration of flow and thinning with the velocity of some glaciers increasing more than twofold at the edges of the Greenland and West Antarctic ice sheets. Data from National Snow and Ice Data Center (NSIDC) showed a decline of 2.9% per decade of arctic sea ice extent. Levitus, Antonov et al. (2009) showed warming of 0.168 ºC of the top 701 meters of the oceans. Global mean surface temperatures have risen by 0.74°C over the last 100 years (1906–2005). The rate of warming over the last 50 years is almost double that over the last 100 years (0.13°C vs. 0.07°C per decade) (Intergovernmental Panel on Climate Change, IPCC 2007).

Work done by climatologists showed evidence that the past climate change on the earth was caused by a limited number of factors (Pidwirny and Sidney, 2010). Changes may be caused by the variability of nature itself such as volcanoes, sunspots and solar activities, continental drift and other factors. However, debate over current climate change caused by human activities has been going on all over the world. Vincent (2008) considered that global warming was man-made. The top concern was greenhouse gas emissions. Data from National Oceanic & Atmospheric Administration (NOAA) showed that atmospheric CO_2 has increased since the industrial revolution. The amount of atmospheric CO_2 had never been above 300ppm until 1950. The current level is above 380ppm and there is a continuous increase. The discovery of ozone hole in the 1980s provided dramatic evidence of the global impacts of human activates towards the atmosphere as well. Daily maximum area in 2009 was reported to be 24 million square km (NASA). In addition, desertification and deforestation and dust and aerosols can also be the causes of climate change (Burroughs 2007).

Scientists are making efforts towards uncovering the mystery of climate variations. “The essential point is, in considering climate change; we are concerned about the statistics of the weather phenomena that provide evidence of longer term changes.” says Burroughs (2007). Lots of studies have been done to find trends of climate using historical data as well as predicting future climate using model approaches. Other scientists also tried to discover the effects of the changing climate on the environment and human society. The primary objective of this study is to examine the trends of climatic parameters of Mid-Atlantic Region to see the regional responses of the changes on earth. Secondly, find correlations between the landscape attributes and climatic trends in order to aid future study of the impacts of such changes in climate.

Chapter 2: Literature Review

2.1 Mid-Atlantic Region

The Mid-Atlantic Region (MAR) includes all parts of West Virginia, Virginia, Maryland, Pennsylvania, New Jersey, Delaware and part of North Carolina, and New York which makes 200,000 km^2 in area with diverse landscape and landforms (Herlihy, Stoddard et al. 1998). With a wide range of physiographic characters such as Blue Ridge Mountains, Ridge and Valley, Coastal Plain, Appalachian Plateau, MAR composes one of the most diverse physical and ecological regions in the nation.

The two most dominant land-cover types in the Mid-Atlantic Region are forest and agriculture which covers about 70% and 25% of the area, respectively. Most of the watersheds are primarily forested with some approaching complete forest cover. Forest ecosystems of the MAR plays an import role in providing crucial habitats for wildlife, and communities such as limestone and dolomite glades that are home to endangered plant species (Jones, Riitters et al. 1997). On the coastal plain, pine-oak forest form unique habitats for rare plants and animals. Despite the significant role that wetlands play in nutrient cycling, crucial fish and wildlife habitats, and pollutants removal from water, MAR is also the home to one of the most critically endangered ecosystems in the United States the distinctive Atlantic white-cedar *Chamaecyparis thyoides* swamp forest. There are also important coastal ecosystems within the region. The Chesapeake Bay is considered the largest and most productive estuary in the United States; and the Delaware Bay is an extremely important habitat for migratory shorebirds. The importance of freshwater ecosystems to residents of MAR is blatantly obvious as people are deeply attached to water (Rogers and McCarty 2000).

2.2 Climate Change

2.2.1 Evidence of Climate Change

Concerns for climate change caused by anthropogenic activities have attracted global attention towards its potential effects on the environment. Enormous efforts by international researchers have been directed to seeking evidence of climate changes, such as analyzing historical data for notable trends in temperature and precipitation. The fourth Intergovernmental Panel on Climate Change report (IPCC 2007) suggested a warming of 0.74 ºC in global surface temperature over the years of 1906 to 2005 with a more rapid warming trend during the second half of the century. Alexander et al. (2006) reported a significant warming throughout the 20th century with over 70% of the global land area sampled, a significant increase in the annual occurrence of cold nights, and a significant increase in the annual occurrence of warm nights. Precipitation trend on a global scale was hard to predict due to large variability in both space and time (IPCC 2007).

Over Europe, the average indices of precipitation extremes was found to increased during the 1946-1999 period, although the spatial patterns were not coherent (Tank et al. 2003). The indices of temperature extremes indicated ‘‘symmetric’’ warming of the cold and warm tails of the distributions of daily minimum and maximum temperature during the same period. A general tendency towards more intense precipitation extremes during the 20th century in winter and a warming trend for all temperature indices over western and Central Europe was confirmed by Moberg et al. (2006). Other scholars from different parts of Europe have found similar trends either warming in temperature or increasing in precipitation (Brunetti, Buffoni et al. 2004; Hundecha and Bárdossy, 2005; De Toffol, Laghari et al. 2009; Tecer and Cerit 2009). Contradictorily, a study in Bulgaria showed an overall decrease in annual precipitation in the area (Alexandrov et al. 2004). It was stated that the country has experienced several drought episodes during the 20th century, most notably in the 1940s and 1980s. No significant warming trend in the country was found in spite of the warming observed during the last two decades. Increases in the magnitude of dryness and pronounced trends were found over most of southern Portugal in the 1955-1999 periods, highlighting the fact that large areas are threatened by drought and desertification (Costa et al. 2008). In Greece, study showed a cooling trend in winter for the period of 1955–2001 and an overall warming trend in summer. However, both trends were not statistically significant (Feidas et al. 2004).

In Asia, researchers (Jung et al. 2002) have saw an increase in the annual mean temperature at a rate of 0.23 °C per decade in the past four to five decades in South Korea. The occurrence frequency of extreme maximum temperature events showed an increasing trend, with higher values in the 1980s and 1990s. Minimum temperature showed opposite result with a decreasing trend in magnitude. In the Tibetan Plateau in China, temperature during the last several decades showed a long-term warming trend and precipitation amount exhibiting a decreasing trend in the western part and an increasing trend in the eastern and central part (Xu et al. 2008). Upward trend in annual precipitation was found in the same region by other researchers as well (Zhao et al. 2009). Moreover, statistically significant positive trends in annual mean air temperature and negative trend in precipitation were detected by another group (Zhao et al. 2008) studying the Yellow River basin. In southeast China, enhanced precipitation extremes defined as the largest 1- and 5-day precipitation total were detected after the early 1990s (Zhang et al. 2009a). They also investigated moisture flux variations to further explore the possible causes behind the changes in precipitation extremes. Cumulative departure analysis results confirmed the influences of moisture flux on the variations of precipitation extremes in the study region. Another study covering a larger study area substantiated the increases of precipitation maxima in this part of China (Zhang et al. 2009b).

A study in ten Asia-Pacific Network (APN) countries on the changes of spatial and temporal patterns in extreme events of temperature and precipitation and their associations with changes in climate means was conducted for the 1955–2007 period (Choi et al. 2009). Averaged over the APN region, annual frequency of cool nights (days) had decreased by 6.4 days/decade (3.3 days/decade), and the frequency of warm nights (days) has increased by 5.4 days/decade (3.9 days/decade). Additionally, they concluded that most rates of changes in extreme temperature events were generally less than that of mean temperatures. Regional trends over the study period in total precipitation, or in the frequency and duration of extreme precipitation events were not discovered in their research. Correspondingly, study done by Manton et al. (2001) in the same region gave consistent results.

Across the United States, nearly two-thirds of the trends in the 2-, 5-, and 10-yr return-period rainfall amounts, as well as the GEV (generalized extreme value) distribution location parameter, were positive. Significant positive trends in these values tend to cluster in the Northeast, western Great Lakes, and Pacific Northwest. Slopes were more evident in the 1960–2007 period when compared with the 1950–2007 interval (DeGaetano 2009). Intense warming was found by Robeson (2004) in the lowest minimum temperatures as well as daily maximum air temperature over western and central North America during the months through January to March. Other times of year in western North America, as well as much of eastern North America, showed little change in either minimum or maximum air temperature during the last half-century. Study region extending from the border areas of New Mexico and Texas southward into the altiplano of north central Mexico was investigated for maximum and minimum temperature records (1941-2000) by Englehart and Douglas (2003). They used data collected at 21 stations located in a variety of land-use environments ranging from large urban settings to rural areas and suggested rapid urbanization influence based on positive linear trend of minimum temperatures at stations in urban areas. A similar, but comparatively minor, urban effect was also apparent in the maximum temperature records during the warm seasons (June-September). A simple linear analysis indicated that the overall trend of the occurrence of short duration extreme precipitation events covering the period of 1931–96 was statistically significant upward over the southwest United States and in a broad region from the central Great Plains across the middle Mississippi River and southern Great Lakes basins. The national trend for the United States is upward at a rate of 3% per decade for period 1931–96, while the annual trend for Canada is upward for the period of 1951–93, which was not statistically significant (Kunkel et al. 1999).

Seasonal temperature trends in the Mediterranean region were reported to be negative trends during winter and spring and no significant trends for the summer and fall season (El Kenawy et al. 2009). Elmallah and Elsharkawy (2009) studied summer temperature anomalies in Egypt during the 20th century. The temperature in the North of Egypt was elevated by 1.05 °C during the summer seasons in the last century, comparing to non-significant changes with very low warming trend in the southern part of Egypt.

2.2.2 Elevation Dependence of Climate Change

One interesting finding of researchers is elevation dependency of climate change. Beniston and Rebetez (1996) proposed that surface climate change associated with global warming might show an elevation signal. Their analysis of wintertime minimum temperature anomalies from 88 Swiss stations revealed a significant altitudinal dependency. They suggested that the warming at high elevation sites would be more pronounced than those at low elevations which implied that an amplified response at high elevations could be utilized as an early climate change detection tool. A later study (Giorgi et al. 1997) also showed an evident elevation signal in the simulated temperature and precipitation changes with more manifested changes at higher elevations. They gave several possible reasons to explain the phenomenon. They argued that high elevation stations were less affected by ameliorating anthropogenic factors for they were more directly in contact with the free troposphere than the low elevation stations. The snow-albedo feedback was considered as a strong force towards elevation dependency. More solar radiation is absorbed at the surface as snow is depleted at high altitudes resulting in a decrease in surface albedo which could lead to an enhancement of surface warming at higher elevation. The dominant contribution for the elevation dependency of precipitation stated in the article is associated with the gradient of topography.

The elevation dependency of warming in Tibetan Plateau was also observed (Liu et al. 2009). Enhancement of warming trend with increasing elevation was shown after summarizing linear trends of temperature by elevation zones. They also pointed out that snow-albedo and cloud-radiation feedbacks could be one of the reasons for the amplification of warming trends. You et al. (2008) examined the correlation between elevation and climate extremes in Tibetan Plateau. Seventy one stations was classified into three topography types (summit, flat and valley) and two land use types (urban and rural) to investigate the influence of topography and/or urbanization towards climate changing rates. The significant relation between trend magnitudes and elevation in their analysis might be superseded by the strong influence of both topographic type and degree of urbanization. Analysis of maximum temperature data from 49 stations in Nepal for the period of 1971–94 revealed warming trends after 1977 ranging from 0.068 to 0.128 °C/yr in most of the Mountain regions (Shrestha et al. 1999). The southern plains regions showed warming trends less than 0.038 °C /yr which confirmed that high elevation areas could be more sensitive.

Pepin and Lundquist (2008) studied records from 1000 high elevation stations around the globe to examine free atmospheric change and topography feedback as the causes of the changing temperature trend with elevation. Although no global relation between elevation and warming trends were observed, data still showed that high elevation stations could be a good indicator of the plant climate for they are free from the effects of urbanization and topographic sheltering.

2.2.3 Climate Change Effects

2.2.3.1 Water and Climate Change

Many modeling studies of the impact of climate change and water quality have been conducted by different groups of researchers. Using meteorological input calculated by a GCM A2 scenario with averaged 3 ºC temperature increase and 200 mm precipitation increase by the year 2090 resulted in an increase of surface water temperature by 3.8 ºC and the water temperature of the hypolimnion by 2.8 ºC for Shimajigawa reservoir (Komatsu et al. 2007). This change might expand the thermal stratification period and deepen the thermocline of the reservoir. In addition, the higher surface water temperature could greatly increase algae growth. Cruise, Limaye et al. (1999) predicted dissolved oxygen problems and high nitrogen levels in basins in the southeast United States under conditions based on the United Kingdom Hadley Center climate model. In addition, the stream flow was projected to decline over the next 30-50 years which would exacerbate these water quality problems. Similar conclusions were found by various researchers (Mimikou et al. 2000; Arheimer et al. 2005; Wilby et al. 2006).

Chang et al. (2001) used GWLF (Generalized Watershed Loading Function) to simulate stream flow and nutrient loading in the Mid-Atlantic region under future climate scenario. Under the prediction of increasing temperature and precipitation for future climate, their results suggested that nitrogen loads increase in winter (January and February) for all watersheds and decreased in some months (e.g., April, July, and August) as a result of the reduction in stream flow during this period for most watersheds. Eutrophication problems might be weakened during spring and late summer. Neff et al. (2000) reported that nutrient loads could be expected to increase in winter and spring because of the expected increase in stream flow and ameliorate problems associated with estuarine stratification and eutrophication in late summer in the same region.

By rewetting the dried acid sulfate soils with Murray River water after a drought period in south-eastern Australia et al. (2010) found the concentrations of dissolved Al, Cu and Zn were greater than 100 times the Australian water quality guidelines. A high level of land and water management should be required to counter the effects of such climate change events.

Hydrology of water not only impact water quality but also affects water quantity. Scientists also paid great attention to the relation of its changes with climate. Using climate change scenarios based on GCM A2 and B2 scenarios, the overall results showed that runoff in the Tarim River basin showed a slight decreasing trend; while evapotranspiration exhibited an increasing trend which implied that water availability in the area is likely to become more critical in the future (Chen et al. 2008).

Using Parallel Climate Model for climate scenarios, results showed increase for temperature but the annual averaged precipitation remained equivalent for the years of 2000 to 2100 in the San Joaquin River Basin. A number of water resource management factors were affected. Spring snow water equivalent (SWE) and basin-average monthly stream flow would decrease during the whole period (VanRheenen et al. 2004).

Whitfield and Cannon (2000) analyzed climatic and hydrologic variations between 1976 and 1995 in Canada. Significant increases in temperatures during spring and fall was found for most stations. On the contradictory, significant decreases in temperature were found during winter in eastern Canada. The amount of precipitation decreased in the north part of Canada while increased in the south. Observed hydrographs showed an early spring flood and increased winter mean discharge as well as smaller summer flows. Similar study was done by Regonda et al. (2005) in the United States. Attributed to climate change, an advancing trend in the timing of peak spring flows was observed. Results also suggested that the precipitation trend was offset by higher temperatures and increased winter seasonal melt and more liquid precipitation .for not translating into higher spring discharges while winter precipitations increased.

Using a spatially distributed hydrology model (the Distributed Hydrology-Soil-Vegetation Model, DHSVM)，Cuo et al. (2009) studied the effects of changing climate (primarily temperature) and land cover in the Puget Sound basin. In the lowlands, land cover signal dominated temperature change. In the uplands, both land cover and temperature change played important roles. Warmer temperatures reduced the occurrence of snowfall and increased rainfall occurrences, resulting in substantial shifts in runoff from spring and summer to winter. A secondary effect was that winter ET was increased.

Groisman et al. (2001) discovered a significant relationship in the eastern half of the United States between the frequency of heavy precipitation and high streamflow events both annually and during the months of maximum streamflow. An increase of spring heavy precipitation events over the eastern United States indicated with high probability that during the twentieth century an increase of high streamflow conditions has also occurred.

Study by Hodgkins et al. (2003) suggested that the geophysical and biological changes in the New England area were caused by a common mechanism, temperature increase. Winter/spring center of volume (WSCV) dates have become significantly earlier where snowmelt runoff has the most effect on spring river flows.

Olsen et al. (1999) studied the correlation between flood frequency and precipitation. Although the there was no direct relation between the both, large and statistically significant upward trends for flood frequency were found in many gauge which challenged the traditional assumption that flood series are independent and identically distributed random variables and suggested that flood risk changes over time.

2.2.3.2 Ecological System and Climate Change

Walther et al. (2002) listed numbers of ecological responses to recent climate change. Changes to phenology were one of the simplest processes to reflect the responses of ecology of species to climate change. Studies revealed common changes in the timing of spring activities include earlier breeding or first singing of birds, earlier arrival of migrant birds, earlier appearance of butterflies, earlier choruses and spawning in amphibians and earlier shooting and powering of plants (Bradley et al. 1999; Inouye et al. 2000; Chmielewski 2001; Both et al. 2006; Menzel et al. 2006; etc).

Many studies of the biological impacts of climate change also focused on abundances and distributions of species. It is well known that species' distribution is influenced by climatic parameters through the thresholds of temperature and precipitation tolerance. Studies were done by various researchers on difference specie behaviors (Murawski 1993; Condit et al. 1996; Pearson and Dawson 2003; Perry et al. 2005).

Mulholland et al. (1997) listed 8 ecological effects of climate change on freshwaters of Gulf of Mexico which included a general increase in rates of primary production, organic matter decomposition and nutrient cycling as a result of higher temperatures and longer growing seasons, reduction in habitat for cool water species in Appalachian streams, reduction in water quality and in suitable habitat in summer owing to lower baseflows and intensification of the temperature-dissolved oxygen squeeze, reduction in organic matter storage and loss of organisms during more intense flushing events, shorter periods of inundation of riparian wetlands and greater drying of wetland soils, particularly in northern and inland areas, expansion of subtropical species northwards, expansion of wetlands in Florida and coastal Mexico, but increase in eutrophication of Florida lakes, changes in the flushing rate of estuaries that would alter their salinity regimes, stratification and water quality as well as influence productivity in the Gulf of Mexico.

2.3 Trend Analysis

2.3.1 Quality Control for Climate Data

For long-term climate analyses to be accurate, the climate data used must be homogeneous. Conrad (2007) defined a homogeneous climate time series as data variations caused only by variations in weather and climate. Unfortunately, most long-term climatological time series had been affected by a number of non-climatic factors such as changes in instruments, observing practices, station locations, formulae used to calculate means and station environment that made these data unrepresentative of the actual climate variation occurring over time. Direct and indirect methodologies for homogeneity testing were reviewed by Peterso et al. (1998). Three direct and four indirect methods are discussed in the followings.

Station history metadata files could provide valuable information on station moves, changes in instrumentation, problems with instrumentation, new formulae used, changes in the nearby environment such as buildings, vegetation and etc.

Variations caused by instrument changes can be tested either by side by side comparisons of different instruments or a statistical study of the effects of an instrument change. A graphic view of time series could also show abrupt changes by comparing one station with another.

Reference time series could be developed to isolate the effects of station discontinuities from regional climate change using nearby stations as a reference. Alexandersson (2007) described three techniques to create reference data using arithmetic mean of the homogeneous and complete stations, arithmetic mean of normalized data or a weighted mean of normalized data where the weighting was based on a distance function that was determined by spatial correlation. Brunetti et al. (2001) adopted an procedure consists of the following steps: carrying out cross checks among the stations; considering as possible errors the data which may be very different from the rainfall records of all other stations; checking these data by means of comparison with precipitation data of nearby stations. After these checks, monthly precipitation series were calculated for each station and then the monthly dataset was tested for homogeneity by means of the Craddock homogeneity test (Craddock 1979). Parallel cumulative sums of seasonally adjusted series from neighboring stations were used by Rhoades and Salinger (1993) as a useful exploratory tool for recognizing site-change effects at a station that has a number of near neighbors.

Several scientists came up with methods to test homogeneity when stations were isolated with each other or lack of information from nearby stations. Lazaro et al. (2001) described a Thom test for testing homogeneity. The theory was that code ‘a’ was assigned to values greater than median and code ‘b’ was assigned to values smaller than median value. For sample size larger than 25, the data series was considered homogenous when the numbers of ‘a’ and ‘b’ follow a normal distribution. On the other hand, Zurbenko et al. (1996) illustrated the use of an adaptive moving average filter in detecting systematic biases.

Data gaps were another issue for climate analyses as incomplete data was unavoidable while dealing with real world data sources. A number of methods had been chosen by experts to deal with this matter. The simplest way was perhaps to ignore the missing instances. Alternatively, researchers chose the most common feature values or mean value to replace all the missing values.

A more sophisticated approach is to use regression or classification model for substituting missing values. Seven functions were divided into three groups in a study by Kemp et al. (1983) to estimate missing values. The first group defined as within-station techniques contained linear regression and moving averages. A between-station additive procedure used the average of the estimates of the between station predictions to form a replacement value. The remaining four functions were correlative procedures which were similar to each other.

A yearly temperature equation developed by Kouremenos and Antonopoulos (1993) was selected in Kotsiantis, Kostoulas et al. (2006)'s paper to replace the missing values for each year. Approximation of temperature increasing from spring to summer was simulated by sin function.

$$\mathrm{T}(\mathrm{D}) = \mathrm{A} + \mathrm{B}\sin\left(\frac{360}{365}\mathrm{D} - \mathrm{f}\right) \qquad (2.1)$$

where *D* is the day of the year, *A* is the mean yearly temperature in ºC, *B* is the width of the yearly temperature variation in ºC and *f* is the phase shift expressed in degrees or days.

Schneider (2001) proposed regularized expectation maximization (EM) algorithm to estimate and exploit the imputation of missing values, both synchronic and diachronic covariance matrices. They claimed that the regularized EM algorithm was applicable to typical sets of climate data and that it led to more accurate estimates of the missing values than a conventional non-iterative imputation technique.

The method described by Twala (2009) built decision trees to determine the missing values of each attribute, and then filled the missing values of each attribute by using its corresponding tree. Separate trees were built using a reduced training set for each attribute. The original class was treated as another attribute, while the value of the attribute becomes the "class" to be determined. The attributes used to grow the respective trees are unordered. These trees were then used to determine the unknown values of that particular attribute.

2.3.2 Statistical Methods

Various methods for detecting the existence of trends in time series of random variables have been used by different groups of researchers. Both parametric and non-parametric statistical tests could be used to decide whether there was a statistically significant trend.

The most common parametric test is the simple linear regression to explore the (linear) relationship between random variable *Y* (dependent variable) and time *X* (independent variable):

$$Y = \beta_1 X + \beta_0 + \varepsilon \tag{2.2}$$

The regression coefficient b_1 or the Pearson correlation coefficient r was computed from the data to measure the global fit of the model.

$$r = \frac{1}{n-1} \sum_{i=1}^{n} \left(\frac{(x_i - \bar{x})}{S_x}\right) \left(\frac{y_i - \bar{y}}{S_y}\right) \tag{2.3}$$

where $S_x = \sum_{i=1}^{n} (x_i - \bar{x})^2$, $S_y = \sum_{i=1}^{n} (y_i - \bar{y})^2$

The student’s t test with degree of freedom of n-2 was used to test if the slope is statistically significant:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} = \frac{b1}{s/\sqrt{SS_x}} \tag{2.4}$$

where n is the sample size, s is the standard deviation of residuals, and SS_x is the sums of squares of independent variable (Önöz and Bayazit 2003).

The nonparametric test Spearman’s rho can be used to testify trends as well. The null hypothesis H_0 can be stated as that the data series, X_i’s, were independent and identically distributed; the alternate hypothesis H_1 is that X_i‘s increased or decreased with i. The test statics was given by:

$$D = 1 - \frac{6 \sum_{i=1}^{n} [R(Xi) - i]^2}{n(n^2 - 1)} \tag{2.5}$$

where $R(X_i)$ is the rank of i^{th} observation X_i. The distribution of D followed the normal distribution.

$$Z = \frac{D}{\sqrt{V(D)}} \quad (2.6)$$

$$V(D) = \frac{1}{n-1} \quad (2.7)$$

One of the most command nonparametric methods used is the Mann-Kendall test. The test describe by Mann is a particular application of Kendall's test for correlation (Hirsch, Slack et al.). The null hypothesis of H_0 was that the data (x_1, $x_2 \ldots x_n$) are a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 of a two sided test is that the distribution of data is not identical. Each pair of observed values X_i, X_j of the random variable was compared. The test static S is defined as:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} \mathrm{sgn}(Xi - Xj) \quad (2.8)$$

where

$$\mathrm{sgn}(Xi - Xj) = \begin{cases} 1 & \text{if } Xi > Xj \\ 0 & \text{if } Xi = Xj \\ -1 & \text{if } Xi < Xj \end{cases} \quad (2.9)$$

Normal approximation is used for the distribution of S. Z is calculated as:

$$Z = \begin{cases} \frac{S-1}{\sigma_s} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma_s} & \text{if } S < 0 \end{cases} \quad (2.10)$$

$$\sigma_s = \sqrt{\frac{n(n-1)(2n+5)}{18}} \quad (2.11)$$

For the two nonparametric tests abovementioned, the magnitudes of the slopes can be estimated by methods described by Sen (1968):

$$\text{slope} = \text{median} \frac{Xi - Xj}{i - j} \quad j < i \quad (2.12)$$

Shrestha et al. (1999) computed seasonal and annual temperature trends for all stations in Nepal using linear regression for the period 1971–1994. Vuille and Bradley (2000), Zhang et al. (2000), Böhm et al. (2001) also chose the regression method to study the trend of temperature. Studying precipitation trends using linear regression methods were reported by various groups of scholars (Suppiah and Hennessy 1998; Frei and Schär 2001; Gemmer et al. 2004; Schmidli and Frei 2005; Wang and Zhou 2005).

Spearman’s rho test was another method for detecting trends in the metrology data. Neelin et al. (2006) used it to examine tropical drying trends in global warming models and observations. The method was also used to study trends in other water quality and stream flow (Lettenmaier et al. 1999; Kahya and Kalayc 2004).

Most paper cited in this article used Mann-Kendall test for studying temperature and precipitation trends. Yue and Pilon (2004) compared the power of *t*-test and Mann-Kendall for trend detection and the results showed only slight difference between the two tests. The power of *t*-test is slightly higher than MK for normally distributed data. Another study by the same group indicated that p-values computed by Mann-Kendall test and Spearman’s rho test were almost identical (Yue et al. 2002).

Chapter 3 Materials and Methods

3.1 Study Area and Data Quality

3.1.1 Study Area

The four states located in Mid-Atlantic Region including West Virginia, Pennsylvania, Virginia and Maryland spread cross the domain of 75ºW - 82ºW, 36ºN - 42ºN (Fig. 3.1). The most common climate in this region is humid subtropical climate according to the Köppen climate classification which covers the southwestern part of West Virginia, most of Pennsylvania, Virginia and Maryland (McKnight et at. 2000). Humic subtropical climate is chacterized by hot, humid summers and cold winters. The rest part of West Virginia falls into the category of humid continental climate. The total study area is approximately 200,000 km^2. Elevation ranges from 3 to 900 meters above mean sea level.

Twenty five stations in the region were selected for our study for precipitation and twenty four were selected for temperature. Weston, WV station was excluded from the analysis involving maximum and minimum temperature. Of the twenty five stations, eight stations are in West Virginia and Pennsylvania and Virginia each has six stations. The other five stations are located in Maryland. The criterion for selecting the stations was stations with more than 100 years of climate data. Information about the stations is summarized in Table 3.1.

3.1.2 Data Source and Quality

The climate data were obtained from the National Climate Data Center (NCDC). According to the metadata, NCDC has made numerous efforts to ensure the quality of the data (NCDC data document for data set 3200). The observing equipments used were calibrated and maintained by National Weather Service (NWS) field representatives, Cooperative Program Managers and Hydro-Meteorological

Technicians for the purpose of accurate and consistent measurement. The data collected have received a high measure of quality control through computer and manual edits. Data have gone through internal consistency checks, and been compared against climatological limits and evaluated against surrounding stations. Suspicious values were flagged and excluded from the analysis.

Several steps were taken before using the data for analysis: (1) flagged values using alphabetic letters or unique numbers such as 999.99 or 99999 were replaced as missing values; (2) percentage of missing values was calculated and only stations with less than 10% missing values were selected for the study; (3) a quick scan of the whole data set for each station was occupied to see if the missing data were randomly distributed; (4) data entirety was computed by counting the months in each year; and (5) inventory informing which months were missing in a year was developed for decision making in the latter part of the study.

3.1.3 Software

Statistical software SYSTAT (SYSTAT Software, Inc., ver. 12) and SAS 9.1.2 (SAS Institute Inc.) were used for analyses in the study. For data points less than 1,000, SYSTAT was chosen as primary option for analysis. Due to its memory capacity, larger data sets were analyzed using SAS 9.1.2. Climate station maps were prepared using ArcGIS 9.3 (ESRI Inc.).

3.1.3 Data Preparation

Sixteen indices of temperature and precipitation listed in Table 3.2 were selected in our study. Annual mean, maximum and maximum were calculated for each station using daily temperature. To avoid biased results caused by incomplete data set, years with less than 300 days were excluded from our analysis, which resulted in one missing year per station on average. In addition to annual average, the difference between maximum temperature and minimum temperature for each year was calculated and termed as T_{RANGE}. The 90th and 10th percentiles were used to define extreme temperature events. Total number of days in a year with temperature value greater than the 90th percentile for each station was counted as warm days or nights and temperature value less than the 10th percentile was counted as cool days or nights (Choi et al. 2009).

Precipitation intensity of a rainfall event was quantified by dividing total amount of rainfall (inches) during the event by the number of consecutive days. In addition, consecutive days without rainfall were counted and the maximum number of the consecutive days was used to indicate drought condition. Rainfall amount exceeding the 95th percentile value was defined as extreme precipitation (Choi et al. 2009). Wet day precipitation was calculated by adding up the total amount of rainfall (inches) which exceeded the 95th percentile. The total number of days per year was counted for the extreme events. Separate computer programs were written in Visual Basic (VB) language for each task.

Missing values were interpolated by local quadratic smoothing during the analysis process incorporated in SYSTAT. Results presented in Duffy et al. (2001) suggested that the observed near-surface temperature trend of about 0.6 ºC over 1900~1998 was unlikely to have been significantly overestimated by incomplete and time-varying observed data coverage. Another paper studied the impact of missing data on calculated monthly mean temperature by randomly removing 1–10 consecutive days of data from the stations with complete data (Stooksbury et al. 1999). This represented 3%-30% missing data and the consequent temperature deviations from the true value varied from 0.18 ºC to 2.28 ºC. Most researchers chose a threshold for missing data at around 20% as (Brunetti, et al. 2000; Manton, et al. 2001; Klein 2002; Knowles, et al. 2006). In this study, 10% missing data was used as a criterion for non-biased results as better quality.

Zhai et al. (1999) considered a year was missing for having 20 days or more missing data and a station was rejected with more than 5 years of random missing or 3 years of consecutive missing data. In our study, there were only few days of data were missing in one year and thus no action was taken on the precipitation data.

The missing value analysis in SYSTAT suggested that our data met the criteria of MCAR (Missing complete at random), thus neglecting the missing value from the analysis was adaptable.

Winter and summer season were selected to study seasonal trend. If warming were primarily a phenomenon during summer which represented the warmest air masses, social cost and energy consumption would be more stressed than winter. Winter warming might be benefitial in some circumstances than concerns (Balling 1998). However mild winter would increase the survival of diseases since winter season was the major period of pathogen mortality (Harvell and Mitchell 2002). It is reported that summer temperature as well as winter temperature have significant effect on plant distribution as well (Naurzbaev et al. 2002; Kirdyanov et al. 2003).

3.1.5 Statistic Analysis

Shapiro–Wilk test was chosen to test the normality of the climate data used in the study (Shapiro and Wilk 1965). The test statistic was defined as:

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{3.1}$$

where $x_{(i)}$ is the ranked i^{th} order x and $\bar{x}$ is the sample mean. The coefficient a_i is given by

$$(a_1, \ldots, a_n) = \frac{m^T V^{-1}}{(m^T V^{-1} V^{-1} m)^{1/2}} \tag{3.2}$$

where $m = (m_1, \ldots, m_n)^T$ and $m_1, \ldots, m_n$ are the expected values of the order statistics of independent and identically-distributed random variables sampled from the standard normal distribution. V is the covariance matrix of those order statistics.

A non-parametric test, Mann-Kendall, was selected for trend analysis in our study. The advantages of non-parametric tests over parametric methods include no requirement for data normality and resistance to outliers. In the trend analysis, time variable was set as year.

Regional trends were calculated using the trends at individual climate stations and a method presented in Helsel and Frans (2006). Data from different stations were expressed as the following matrixes:

$$X = \begin{pmatrix} X_{11} & \cdots & X_{1q} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nq} \end{pmatrix} \tag{3.3}$$

where q is the number of stations, and n is the number of years.

The Mann-Kendall test statistic for each station is given as:

$$S_g = \sum_{i<j} \operatorname{sgn}(X_{jg} - X_{ig}) \quad g = 1,2 \ldots, q \tag{3.4}$$

The regional Kendall test statistic is:

$$S' = \sum_{g=1}^{q} S_g \tag{3.5}$$

The same estimate standard as Mann-Kendall test was used to compute the statistic and p value of the normal approximation for the overall regional Kendall test.

$$Z = \begin{cases} \frac{S' - 1}{\sigma_{s'}} & \text{if } S' > 0 \\ 0 & \text{if } S' = 0 \\ \frac{S' + 1}{\sigma_{s'}} & \text{if } S' < 0 \end{cases} \tag{3.6}$$

$$\sigma_{s'} = \sqrt{\sum_{g=1}^{q} \left(\frac{n_g}{18}\right)(n_g - 1)(2n_g + 5)} \tag{3.7}$$

where n_g is the number of data at the g^{th} of q locations.

The statistic Z_g^2 was used instead of Z_g to test the homogeneity of the regional trend (Van Belle and Hughes 1984). Given the null H_0: $\tau = 0$, each Z^2 has approximately a chi-square distribution with 1 degree of freedom.

The overall statistic is

$$\chi^2_{total} = \sum_{g=1}^{p} Z_g^2 \tag{3.8}$$

$$\chi^2_{homogenous} = \chi^2_{total} - \chi^2_{trend} \tag{3.9}$$

where $\chi^2_{\text{trend}} = mZ^2$

To examine if the climate trends are elevation-dependent, of the climate stations were divided into three groups based on their elevation — low, medium and high equally from lowest value to largest value. Krusal-Wallis test was used to compare the different groups. The null hypothesis is the populations from which the *k* data sets have been drawn have the same mean; the alternative hypothesis is at least one population has a mean larger or smaller than at least one other population. The test statistic is given by:

$$K = (\frac{12}{N(N+1)} \sum_{j=1}^{k} n_j \left[\overline{R}_j - \frac{N+1}{2}\right]^2 \tag{3.10}$$

N is the total number of variables in j groups,$\overline{R}_j = \frac{\sum_{i=1}^{n_j} R_{ij}}{n_j}$, R_{ij} is the rank of variables in each group according the whole variables in j groups.

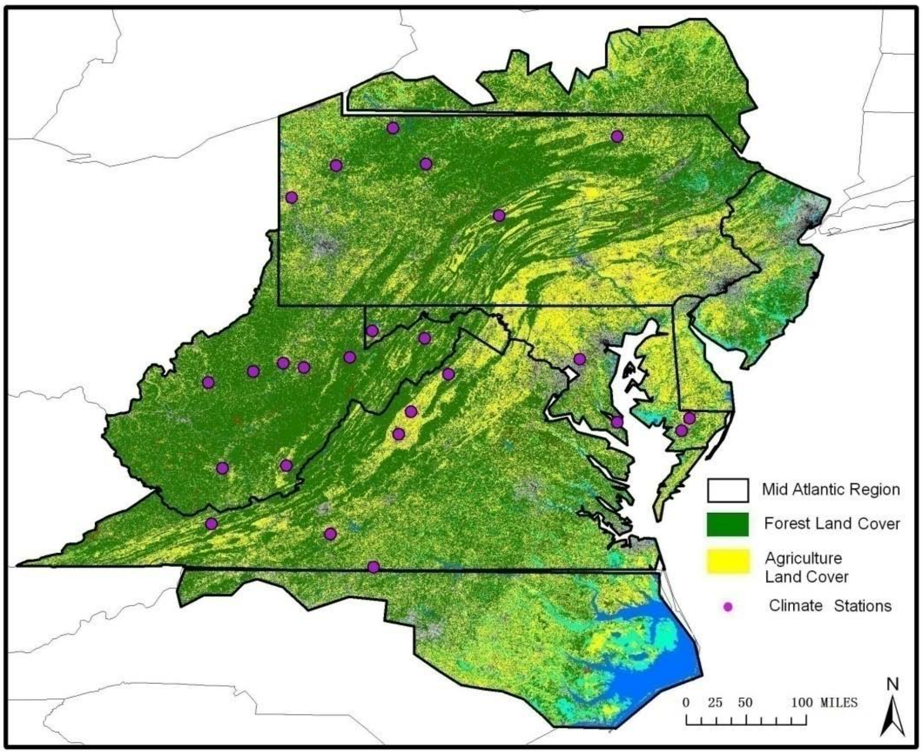

Figure 3-1The Mid-Atlantic Region of the United States (National Land Cover Data 2001 are used.)

Table 3-1 List of climate stations in the four states (Land cover results are from NLCD 2001).

Station ID	Name	State	Land cover	Elevation(m)	Data range
185111	Laurel 3 W	MD	Urban	121.9	1890s~present
186620	Oakland 1 SE	MD	Urban	737.6	1890s~present
187330	Princess Anne	MD	Agriculture (distance to urban less than 1 mile)	6.1	1890s~present
188000	Salisbury	MD	Urban	3.0	1900s~present
188405	Solomons	MD	Urban	3.7	1890s~1983
363028	Franklin	PA	Urban	309.4	1890s~present
366233	New Castle 1 N	PA	Urban	251.5	1890s~present
367477	Ridgway	PA	Urban	414.5	1900s~present
368449	State College	PA	Urban	356.6	1890s~present
368905	Towanda 1 S	PA	Forest (distance to urban less than 1 mile)	231.6	1890s~present
369298	Warren	PA	Urban	368.8	1890s~present
441209	Burkes Garden	VA	Agriculture	935.1	1890s~present
442208	Dale Enterprise	VA	Agriculture (distance to urban less than 1 mile)	426.7	1890s~present
442245	Danville	VA	Urban	125	1900s~present
447338	Rocky Mt	VA	Urban	400.8	1890s~present
448062	Staunton Water Trmtmt Plt	VA	Urban	499.9	1890s~present
449263	Woodstock	VA	Urban	271.0	1890s~present
460580	Beckley Va Hospital	WV	Urban	710.2	1890s~present
461220	Buckhannon	WV	Urban	443.5	1890s~present
463544	Glenville	WV	Agriculture (distance to urban less than 1 mile)	216.4	1890s~present
465224	Lewisburg	WV	Urban	686.1	1900s~present

Table 3-1 Continue

Station ID	Name	State	Land cover	Elevation(m)	Data range
466867	Parsons 1 NE	WV	Urban	556.6	1900s~present
467730	Romney	WV	Forest (distance to urban less than 1 mile)	284.1	1890s~present
468384	Spencer	WV	Urban	287.4	1890s~present
469436	Weston	WV	Urban	311.8	1890s~present

Table 3-2 Temperature and Precipitation Indices.

Abbreviation	Term	Definition
Tmean(TM)	Mean temperature	Annual average mean temperature in degree Fahrenheit
Tmax(TX)	Maximum temperature	Annual average maximum temperature in degree Fahrenheit
Tmin(TN)	Minimum temperature	Annual average minimum temperature in degree Fahrenheit
TRANGE	Difference of Tmax and Tmin	Difference of annual average maximum and minimum temperature
TX90(TX10)	Warm days (Cool days)	Annual counts of days when TX>90th (TX<10th) percentile
TN90(TN10)	Warm nights (Cool nights)	Annual counts of days when TN>90th (TN<10th) percentile
TXX(TNX)	Maximum maximum(minimum) temperature	Annual maximum maximum(minimum) temperature in degree Fahrenheit
TXN(TNN)	Minimum maximum(minimum) temperature	Annual minimum maximum (minimum) temperature in degree Fahrenheit
CDD	Consecutive dry days	Maximum number of consecutive days with no precipitation
PX	Maximum precipitation intensity	Maximum annual precipitation intensity in in/day
P95	Wet day precipitation	Annual total PRCP when PRCP>95th percentile
P95D	Wet days	Annual counts of days when PRCP>95th percentile

Chapter 4 Results

4.1 Temperature Trends

4.1.1 Annual Trends

Statistical significance of the trends was determined using the alpha (α) value of 0.05. The results for trends of annual temperatures are shown in Table 4.1. Fourteen out of twenty five stations had decreasing trends in annual mean temperature with 9 being statistically significant. The magnitude of the decreasing slopes ranged from -0.002 to -0.028 ºF/yr for all the stations and -0.009 to -0.028 ºF/yr for stations with p values less than 0.05. All stations in West Virginia experienced decreasing trends, and 6 of them were statistically significant. The average slope for the 6 stations was -0.017 ºF/yr. Three significant decreasing trends were found in Virginia with average slope of -0.02 ºF/yr. The 5 stations in Maryland all occurred to have significant increasing trends for annual mean temperature. The average slope was 0.02 ºF/yr. Increasing trends were also found in Pennsylvania but none were statistically significant.

Annual maximum temperature and annual minimum temperature exhibited similar trends as the annual average temperature. Sixteen decreasing trends were found with 8 being statistically significant. The slopes ranged from -0.001 to -0.042 ºF/yr for all the decreasing trends and the significant trends ranged from -0.013 to -0.042 ºF/yr. Consistently, the 7 stations in West Virginia showed a decreasing trend as the annual mean temperature did. Four out of the six stations which showed statistically significant trends for annual mean temperature also had p values less than 0.05 for annual maximum temperature. Nevertheless, 3 significant decreasing trends were found in Virginia with average slope of -0.017 ºF/yr. The average slope of significant increasing trends was 0.028 ºF/yr, two of the stations were located in Maryland and one in Pennsylvania. There were total of four stations with an increasing trend in Maryland.

Twelve stations exhibited a decreasing trend in annual minimum temperature and 7 of them were significant. On the other hand, 7 statistically significant increasing trends were found. Except for one station, all West Virginia stations showed a decreasing trend (4 of them were significant), similar to annual mean temperature and annual maximum temperature. Range of the decreasing slopes in West Virginia was -0.009 - -0.034 ºF/yr for all decreasing trends. Three significant decreasing trends were found in Virginia with an averaged slope of -0.026 ºF/yr. All the Maryland stations showed an increasing trend and 3 of them were significant (average slope was 0.033 ºF/yr). One significant increasing trend (0.02 ºF/yr) was found in Virginia, and 3 increasing trends (two slopes being 0.012 ºF/yr and 1 being 0.014 ºF/yr) in Pennsylvania. The remaining trends were not significant.

The trends for the differences between annual maximum temperature and annual minimum temperature also varied among differently stations (Table 4.2). The number of decreasing trends and increasing trends both were found at nearly half of the stations (13 decreasing trends and 10 increasing trends). Nine out of the 13 decreasing trends were significant and 6 out of the 10 increasing trends were significant. Three (3) stations in West Virginia showed significant increasing trends (0.011 ºF/yr, 0.011 ºF/yr, and 0.018 ºF/yr) and two showed significant decreasing trends (-0.031 ºF/yr and -0.037 ºF/yr). There were 3 significant decreasing trends (-0.021 ºF/yr, -0.018 ºF/yr, and -0.016 ºF/yr) and 1 significant increasing trend (0.013 ºF/yr) in Pennsylvania. One (1) station in Virginia showed a significant decreasing trend (-0.028 ºF/yr) and 2 increasing trends (0.013 ºF/yr and 0.016 ºF/yr). Three (3) stations in Maryland showed a significant decreasing trend (-0.033 ºF/yr, -0.028 ºF/yr, and -0.026 ºF/yr) and 1 increasing trend (0.057 ºF/yr).

Tables 4.3, 4.4, 4.5 and 4.6 listed the results for extreme temperature events. Seventeen stations showed decreasing trend for TX90 (warm days) with 11 of them being statistically significant. All the stations in Virginia had a decreasing trend and 4 of them were significant (-0.10 d/yr, -0.11 d/yr, -0.22 d/yr, and -0.14 d/yr). Except for one station, the remainder stations in West Virginia also exhibited a decreasing trend for TX90. The magnitude of the slopes was larger than the stations in Virginia with the highest value of -0.37 d/yr and the lowest value of -0.12 d/yr. Two significant decreasing trends were also observed at Pennsylvania stations (-0.077 d/yr and -0.2 d/yr). Alternatively, 2 significant increasing trends were detected in Maryland. The values for the slope were 0.199 d/yr and 0.087 d/yr respectively.

Among the 8 significant trends found for TX10 (cool days), 4 of them were increasing trends and 3 decreasing trends. Those stations spread out the whole region. Although all of the 7 stations in West Virginia showed an increasing trend, only 2 of them were significant (0.114 d/yr and 0.128 d/yr). One (1) significant increasing trend was spotted in Pennsylvania (0.1 d/yr) and 1 in Virginia (0.109 d/yr). No trend was found for 3 stations in Pennsylvania and 1 significant decreasing trend with a slope of -0.098 d/yr. Two (2) remaining significant decreasing trends were found in Maryland (-0.284 d/yr and -0.197 d/yr). The total number decreasing trends identified was 7 regardless of the statistical significance. The number of the increasing trends was two times of the decreasing ones.

Trends for TN90 (warm nights) and TN10 (cool nights) also varied from stations to stations. The number of stations showed a decreasing trend was 13 which exceeded the number of increasing trends by 5 for warm nights. Six (6) out of 7 stations in West Virginia showed a decreasing trend but only 1 of them was statistically significant (-0.091 d/yr). Three (3) stations in Virginia showed significant a decreasing trend (-0.111 d/yr, -0.165 d/yr, and -0.067 d/yr) and 1 in Maryland (-0.164 d/yr) which made a total of 6 significant decreasing trends among the 25 stations. The single station had a statistically significant increasing trend in West Virginia (0.098 d/yr). The only two significant trends found in Pennsylvania were increasing trends (0.067 d/yr and 0.095 d/yr). The 4 remaining significant increasing trends all had a p value less than 0.001. One (1) station was located in Virginia (0.172 d/yr) and 3 were located in Maryland (0.273 d/yr, 0.138 d/yr, and 0.160 d/yr).

Results for TN10 were slightly different from those for TN90. Both 11 decreasing trends and 11 increasing trends were detected. Half of the trends were significant. All stations in Maryland experienced a decreasing trend and 4 of them were significant. The average slope was -0.115 d/yr for the 4 stations. Pennsylvania had 1 station with a significant decreasing trend (-0.083 d/yr). Regardless of the station that showed no trend, all West Virginia stations showed an increasing trend and 2 were statistically significant (0.125 d/yr and 0.094 d/yr). The slopes for the significant increasing trends were 0.084 d/yr in Pennsylvania and 0.108 d/yr and 0.130 d/yr for stations in Virginia.

In addition to the frequency of extreme temperature events, the magnitude was also studied. Nearly half of the stations showed no trend for all the four parameters (TXX, TNX, TXN, and TNN). Eight (8) significant decreasing trends were found for TNX (3 in WV, 1 in PA, 3 in VA, 2 in MD). The average slope of the decreasing trends was -0.028 ºF/yr and 0.03 ºF/yr for the increasing trends. All TXX trends were decreasing. The average slope for the 11 significant decreasing trends was -0.025 ºF/yr. The significant trends for TNN were all increasing (3 in Pennsylvania, 2 in Virginia, and 1 in Maryland) and the average slope was 0.055 ºF/yr. Only 2 significant trends were found for TXN, 1 was decreasing and the other increasing. The station with a decreasing trend located in West Virginia had slope of -0.042 ºF/yr. The station with increasing trend was located Maryland (0.049 ºF/yr).

4.1.2 Seasonal Trends

Winter (December to February) and summer (June to August) were picked to study the seasonal trend for all parameters.

Most stations showed consistency in the seasonal trends and annual trends of annual mean temperature, annual maximum temperature and annual minimum temperature (Tables 4.7 and 4.8). However, some stations showed mixed trends. At station Warren, in Pennsylvania, annual mean temperature exhibited opposite trends for winter season (positive, not significant) and summer season (-0.009 ºF/yr, significant). Two stations in West Virginia (Romeny and Spencer) showed discrepancy between the seasonal trends and annual trends for annual maximum temperature. The station at Romeny (ID 467730) had a significant decreasing trend (-0.013 ºF/yr) for summer but a non-significant increasing trend for winter was detected. The climate station at Spencer (ID 468384) had a significant decreasing trend (-0.065 ºF/yr) for summer season was and a significant increasing trend (0.037 ºF/yr) for the winter season. Two incompatible trends were also discovered for annual minimum temperature. Both significant decreasing trends were found for station at Woodstock (ID 449263, -0.096 ºF/yr) and Princess Anne (ID 187330, -0.017 ºF/yr) for the summer season and significant increasing trends (0.076 ºF/yr and 0.017 ºF/yr) for the winter season.

Except for three stations, trends for the differences between annual maximum temperature and annual minimum temperature were similar for the seasonal trends and annual trends (Table 4.9). Two stations (Glenville ID463544 and Spencer ID 468384) showed significant decreasing trends for the summer season (-0.021 ºF/yr and -0.059 ºF/yr) but significant increasing trends for the winter season (0.016 ºF/yr and 0.046 ºF/yr). At station (Woodstock, ID 449263), a significant increasing trend occurred in summer (0.094 ºF/yr) but a significant decreasing trend occurred in winter (-0.068 ºF/yr).

The criterion of greater than the 95th percentile or less than 95th Percentile of individual season instead of the whole year was used to define extreme temperature events at individual climate stations for summer and winter seasons to study severe conditions. Tables 4.10~4.13 showed the results for the two seasons. Seven (7) significant decreasing trends were found for TX90 (warm nights) for summer season and 7 significant increasing trends were found for winter season. Three (3) out of the 7 stations with a significant decreasing trend for TX90 during summer season were located in West Virginia (-0.067 d/yr, -0.056 d/yr, and -0.053 d/yr), 1 station was in Pennsylvania (-0.067 d/yr), and 3 were in Virginia (-0.053 d/yr, -0.036 d/yr, and -0.057 d/yr). One (1) out of the 7 stations showed a significant increasing trend for TX90 during winter season was located in West Virginia (0.024 d/yr), 3 in Pennsylvania (0.028 d/yr, 0.034 d/yr, and 0.029 d/yr), 1 in Virginia (0.032 d/yr) and 1 in Maryland (0.042 d/yr). Overall 63% of the stations showed a negative trend for warm nights during summer season and only 12% showed a positive trend with one being statistically significant. Exclude all the stations where no trends were found, during the winter season, all the trends were positive for TX90. The average negative slope was -0.04 d/yr for the summer season and the average positive slope was 0.025 d/yr for the winter season.

Ten stations showed no trends for TX10 (cool days) for the summer season and 8 showed no trends for the winter season. A total of 6 increasing trends were detected with only 1 being significant (0.029 d/yr) and 8 decreasing trends were detected with 5 being significant for summer. All the stations in Maryland showed a negative trend for summer and 4 of them were statistically significant. The average slope of the decreasing trend was 0.037d/yr. On the other hand, 5 decreasing trends were detected with 2 being significant (-0.038 d/yr and -0.069 d/yr) and 9 increasing trends were detected with 3 being significant (0.03 d/yr, 0.03 d/yr and 0.047 d/yr) for winter.

Ten decreasing trends were found for TN90 (warm nights) for summer time and 8 of them were significant - 3 in West Virginia (-0.04 d/yr, -0.026 d/yr, and -0.025 d/yr), 1 in Pennsylvania (-0.043 d/yr), 3 in Virginia (-0.036 d/yr, -0.038 d/yr, and -0.019 d/yr) and 1 in Maryland (-0.028 d/yr). A total of 6 significant increasing trends were found. Pennsylvania and Virginia each had one station and Maryland had four. The average slope of the increasing trends was 0.056 d/yr. Eight (8) negative trends (5 significant) and 6 positive trends (4 significant) were found for the winter season. The average negative slope was 0.029 d/yr and the average positive slope was 0.032 d/yr. Fourteen decreasing trends were found for TN10 (cool nights) during summer time and 11 of them were significant. All the stations in Pennsylvania and Maryland (except for one) showed a decreasing trend. Only 4 increasing trends were found with 2 being significant. Ten decreasing trends (3 significant) and 5 increasing trends (none significant) were found for TN10 for winter.

4.1.3 Homogenous Test

The χ^2 homogeneous test showed significant heterogeneous trends for the 25 (24) stations for all parameters. This suggested that a homogeneous regional trend cannot be formed given the individual trends.

The stations were divided into three groups (low, medium and high) according to their elevation with each group covering a third of the elevation range of the climate stations. Figure 4.1 shows that the slopes of TX10 (cool days) at lower elevation stations tended to be negative and positive at higher elevations. Kruskal-Wallis test indicated significant statistical differences among the three groups (K = 10.13, p = 0.006). Similar results were found for the summer (K = 5.012, p = 0.082, Figure 4.2) and winter seasons (K = 5.687, p = 0.058, Figure 4.3). Decreasing distributions from low elevation stations to high elevation stations were found for minimum annual maximum temperature (K = 6.906, p= 0.032, Figures 4.4). Graphic view showed decreasing trend from low elevation to high elevation for both annual trends and seasonal trends for maximum temperature (Figure 4.5~4.7). However, only winter season showed statistically difference (K = 7.835, p= 0.02). Similar conclusion was drawn for TX90 (Figure 4.8~4.10). Trends for winter season for parameter TX90 were all greater or equal to zero, and the magnitude tend to decreasing from low elevation to high elevation (K = 7.536, p= 0.023).

4.2 Precipitation Trends

4.2.1 Annual Trends

Most of the stations (21 out 25) showed an increasing trend for wet day precipitation and half of them were statistically significant (Table 4.14). There was 1 significant positive trend in West Virginia; the magnitude of the slope was 0.039 in/yr. Four stations in Pennsylvania showed significant positive trend, and the slopes were 0.026 in/yr, 0.029 in/yr, 0.033 in/yr, and 0.024 in/yr. The remaining 5 significant trends, 2 of them were located in Virginia (0.042 in/yr and 0.025 in/yr) and 3 of them were located in Maryland (0.031 in/yr, 0.035 in/yr, and 0.102 in/yr). One (1) significant negative trend (-0.087 in/yr) was detected in West Virginia.

More than half of the stations showed no trend for the number of days with precipitation greater than 95th percentile (Table 4.14). Nine (9) positive trends were found. A total of 7 significant positive trends included 1 in West Virginia (0.025 d/yr), 3 in Pennsylvania (0.018 d/yr and 0.022 d/yr), and 2 in Virginia (0.015 d/yr and 0.009 d/yr) and 1 in Maryland (0.049 d/yr).

Table 4.15 shows the results for severe dry days and severe precipitation intensity. Thirteen out of 25 trends were negative for consecutive dry days (CDD). There were 5 significant negative trends in West Virginia, and the slopes were -0.076 d/yr, -0.029 d/yr, -0.088 d/yr, -0.058 d/yr, and -0.060 d/yr. Three stations in Pennsylvania experienced significant decreasing trends with the slopes being -0.054 d/yr, -0.025 d/yr and -0.015 d/yr. The remaining significant trends were located in Virginia (-0.075 d/yr and -0.047 d/yr). Beside the stations where no trend was found, all the stations in Maryland experienced increasing trends. The magnitude of the one significant trend was 0.031 d/yr.

Eight significant trends were found for maximum precipitation intensity, mostly decreasing. Seven stations in West Virginia showed a decreasing trend and 2 of them were statistically significant (-0.003 in/d/yr and -0.012 in/d/yr). The remaining station in West Virginia showed a significant increasing trend with slope of 0.005 in/d/yr. The other 4 stations had a significant decreasing trend with 1 in Pennsylvania (-0.003 in/d/yr) and 3 in Virginia (-0.004 in/d/yr, -0.004 in/d/yr and -0.003 in/d/yr). Including the 1 station located in West Virginia, 3 showed significant increasing trends. Both of the 2 trends were located in Maryland (0.006 in/d/yr and 0.011 in/d/yr).

4.2.2 Seasonal Trends

Trends for maximum annual intensity showed moderate discrepancy between annual trends and seasonal trends. Only two stations showed a difference. Negative slope was detected for station Glenville, WV (ID 463544) during winter but positive slope was detected during summer. Negative slope was detected for station Franklin, PA (ID 363028) for winter but no trend was found for summer. Several stations accouter the condition that trends of CDD were detected in one season but not the other. Four stations had significant increasing trends for summer but no trends were detected for winter. Four stations had significant decreasing trends for winter season but no trends were detected for summer season.

The criteria for P95 and P95D were defined individually for each season to study severe conditions. Only 1 significant trend was found during the summer season for P95 and 3 during the winter season (Table 4.18). The significant trend in summer had a decreasing slope of -0.03 in/yr. The 3 significant slopes were detected in winter with 1 decreasing trend (-0.03 in/yr) and 2 increasing trends (0.008 in/yr and 0.012 in/yr). No trend was found for P95D during both seasons at any station.

4.2.3 Homogenous Test

The χ^2 homogeneous test showed significant heterogeneous trends among the 25 stations for all parameters. This suggested that a homogeneous regional trend cannot be formed given the individual trends.

After dividing the station into three groups, results showed the trends tend to decreasing from low elevation stations to high elevations for P95 and PX (Figures 4.11~4.16).

Figure 4.11 shows that the slopes of annual precipitation amount exceeding 95th percentile at lower elevation stations tended to be positive and negative at higher elevations. Kruskal-Wallis test indicated significant statistical differences among the three groups ($K = 14.17$, $p < 0.001$). Similar results were found for the summer ($K = 7.465$, $p = 0.024$, Figure 4.12). The difference for winter season was not statistically significant. Similar decreasing distributions from low elevation stations to high elevation stations were found for annual maximum precipitation intensity ($K = 10.617$, p=0.005, Figures 4.14). Although graphic view showed differences among the three groups, Kruska-Wallis test results showed no significant differences between the groups for summer seasonal maximum precipitation intensity (K = 4.946, p=0.084, Figure 4.15), and winter seasonal maximum precipitation intensity (K = 3.162, p=0.206, Figure 4.16). Only the medium elevation group showed discrepancy with the other two with median value being zero (K =9.540, p=0.008, Figure 4.17).

Table 4-1 Slopes and P values for annual temperature. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Tmean		Tmax		Tmin	
	Slope(°F/yr)	P	Slope(°F/yr)	P	Slope(°F/yr)	P
WV						
460580	**-0.028**	**<0.001**	**-0.042**	**<0.001**	**-0.013**	**0.034**
461220	-0.005	0.249	*0.005*	*0.363*	**-0.013**	**0.006**
463544	**-0.016**	**0.006**	**-0.023**	**0.015**	**-0.014**	**0.004**
465224	-0.008	0.06	-0.007	0.228	-0.009	0.064
466867	**-0.014**	**0.005**	**-0.033**	**<0.001**	*0.005*	*0.367*
467730	**-0.009**	**0.043**	-0.004	0.442	**-0.009**	**0.042**
468384	**-0.015**	**0.007**	**-0.013**	**0.024**	-0.011	0.131
469436	**-0.022**	**0.003**	**-0.016**	**0.036**	**-0.034**	**<0.001**
PA						
363028	No trend		-0.006	0.219	***0.012***	***0.004***
366233	*0.01*	*0.064*	*0.005*	*0.407*	***0.012***	***0.021***
367477	-0.011	0.059	**-0.02**	**0.006**	-0.005	0.429
368445	*0.006*	*0.108*	*0.009*	*0.057*	*0.007*	*0.125*
368905	*0.005*	*0.177*	***0.011***	***0.017***	-0.001	0.806
369298	*0.007*	*0.105*	-0.001	0.746	***0.014***	***0.005***
VA						
441209	-0.002	0.646	-0.004	0.364	No trend	
442208	*0.004*	*0.253*	**-0.014**	**0.002**	***0.02***	***<0.001***
442245	**-0.022**	**<0.001**	**-0.02**	**0.002**	**-0.028**	**<0.001**
447338	**-0.017**	**0.003**	-0.01	0.101	**-0.021**	**0.001**
448062	**-0.023**	**<0.001**	**-0.018**	**<0.001**	**-0.029**	**<0.001**
449263	-0.002	0.65	*0.002*	*0.668*	-0.002	0.601
MD						
185111	***0.024***	***<0.001***	*0.006*	*0.168*	***0.041***	***<0.001***
186620	***0.012***	***0.006***	-0.004	0.482	***0.026***	***<0.001***
187330	***0.029***	***<0.001***	***0.055***	***<0.001***	*0.002*	*0.617*
188000	***0.017***	***0.001***	*0.004*	*0.523*	***0.032***	***<0.001***
188405	***0.014***	***0.013***	***0.019***	***0.004***	*0.01*	*0.092*

Table 4-2 Slopes and P values for the difference between annual maximum and annual minimum temperature. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	TRANGE	
	Slope (°F/yr)	P
WV		
460580	**-0.031**	**0.001**
461220	***0.011***	***0.017***
463544	-0.003	0.622
465224	No trend	
466867	**-0.037**	**<0.001**
467730	***0.011***	***0.048***
468384	-0.001	0.925
469436		
PA		
363028	**-0.021**	**<0.001**
366233	-0.002	0.566
367477	**-0.018**	**0.017**
368445	*0.002*	*0.515*
368905	***0.013***	***0.001***
369298	**-0.016**	**0.003**
VA		
441209	-0.003	0.427
442208	**-0.028**	**<0.001**
442245	*0.008*	*0.153*
447338	***0.013***	***0.027***
448062	***0.016***	***0.032***
449263	*0.005*	*0.362*
MD		
185111	**-0.033**	**<0.001**
186620	**-0.028**	**<0.001**
187330	***0.057***	***<0.001***
188000	**-0.026**	**<0.001**
188405	*0.006*	*0.151*

Table 4-3 Slopes and P values for warm days and cool days. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	TX90(Warm Days)		TX10(Cool Days)	
	Slope(d/yr)	P	Slope(d/yr)	P
WV Stations				
460580	**-0.367**	**<0.001**	***0.114***	***0.017***
461220	*0.016*	*0.666*	*0.034*	*0.265*
463544	**-0.253**	**<0.001**	*0.017*	*0.593*
465224	-0.031	0.427	*0.06*	*0.106*
466867	**-0.25**	**<0.001**	***0.128***	***0.001***
467730	**-0.124**	**0.002**	*0.016*	*0.652*
468384	**-0.348**	**<0.001**	*0.016*	*0.572*
469436				
PA Stations				
363028	**-0.077**	**0.029**	No trend	
366233	-0.057	0.275	No trend	
367477	**-0.2**	**0.002**	***0.1***	***0.014***
368445	*0.024*	*0.474*	-0.036	0.186
368905	No trend		**-0.098**	**0.004**
369298	*0.014*	*0.697*	No trend	
VA Stations				
441209	-0.028	0.484	*0.061*	*0.052*
442208	**-0.1**	**0.024**	*0.043*	*0.192*
442245	**-0.111**	**0.021**	***0.109***	***0.017***
447338	-0.074	0.143	*0.059*	*0.112*
448062	**-0.222**	**<0.001**	*0.048*	*0.097*
449263	**-0.143**	**0.006**	-0.023	0.550
MD Stations				
185111	*0.067*	*0.080*	-0.042	0.201
186620	-0.089	0.058	*0.039*	*0.187*
187330	***0.199***	***<0.001***	**-0.284**	**<0.001**
188000	-0.026	0.544	-0.064	0.124
188405	***0.087***	***0.003***	**-0.197**	**<0.001**

Table 4-4 Slopes and P values for warm nights and cool nights. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	TN90(Warm Nights)		TN10(Cool Nights)	
	Slope(d/yr)	P	Slope(d/yr)	P
WV Stations				
460580	-0.074	0.056	***0.125***	***<0.001***
461220	No trend		***0.094***	***0.004***
463544	**-0.091**	**0.006**	*0.047*	*0.168*
465224	-0.039	0.295	*0.059*	*0.079*
466867	***0.098***	***0.006***	No trend	
467730	-0.014	0.645	*0.053*	*0.150*
468384	-0.044	0.243	*0.061*	*0.075*
469436				
PA Stations				
363028	*0.022*	*0.396*	-0.051	0.157
366233	*0.063*	*0.061*	-0.038	0.328
367477	-0.048	0.194	***0.084***	***0.048***
368445	***0.067***	***0.033***	-0.031	0.332
368905	-0.012	0.551	-0.028	0.409
369298	***0.095***	***0.003***	-0.030	0.370
VA Stations				
441209	No trend		No trend	
442208	***0.172***	*<**0.001***	**-0.083**	**0.016**
442245	-0.054	0.285	***0.108***	***0.011***
447338	**-0.111**	**0.009**	*0.057*	*0.092*
448062	**-0.165**	**<0.001**	***0.130***	***<0.001***
449263	**-0.067**	**0.038**	*0.012*	*0.671*
MD Stations				
185111	***0.273***	*<**0.001***	**-0.162**	**<0.001**
186620	***0.138***	*<**0.001***	-0.031	0.235
187330	**-0.164**	**<0.001**	**-0.090**	**0.012**
188000	***0.160***	*<**0.001***	**-0.128**	**0.001**
188405	-0.050	0.079	**-0.080**	**0.005**

Table 4-5 Slopes and P values for maximum annual maximum temperature and annual minimum temperature. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	TNX		TXX	
	Slope (°F/yr)	P	Slope (°F/yr)	P
WV				
460580	**-0.024**	**0.001**	**-0.025**	**0.01**
461220	No trend		No trend	
463544	No trend		**-0.021**	**0.024**
465224	No trend		**-0.013**	**0.029**
466867	No trend		**-0.034**	**<0.001**
467730	**-0.043**	**<0.001**	-0.012	0.078
468384	No trend		No trend	
469436				
PA				
363028	No trend		**-0.024**	**0.006**
366233	No trend		**-0.022**	**0.013**
367477	**-0.029**	**<0.001**	**-0.05**	**<0.001**
368445	No trend		**-0.011**	**0.037**
368905	No trend		No trend	
369298	No trend		No trend	
VA				
441209	No trend		**-0.02**	**0.006**
442208	No trend		No trend	
442245	**-0.017**	**0.013**	**-0.029**	**0.002**
447338	**-0.029**	**<0.001**	-0.01	0.075
448062	No trend		**-0.024**	**0.003**
449263	**-0.025**	**<0.001**	No trend	
MD				
185111	***0.04***	***<0.001***	No trend	
186620	*0.01*	*0.052*	No trend	
187330	No trend		No trend	
188000	***0.02***	***<0.001***	-0.011	0.065
188405	No trend		No trend	

Table 4-6 Slopes and P values for minimum annual maximum temperature and annual minimum temperature. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	TNN		TXN	
	Slope (ºF/yr)	P	Slope (ºF/yr)	P
WV				
460580	No trend		-0.028	0.179
461220	No trend		No trend	
463544	*0.038*	*0.088*	*0.013*	*0.348*
465224	No trend		**-0.042**	**0.018**
466867	-0.032	0.08	-0.029	0.133
467730	No trend		-0.023	0.129
468384	*0.021*	*0.289*	*0.02*	*0.274*
469436				
PA				
363028	***0.048***	***0.016***	-0.013	0.288
366233	*0.034*	*0.096*	No trend	
367477	No trend		-0.02	0.289
368445	***0.037***	***0.01***	No trend	
368905	*0.034*	*0.063*	*0.026*	*0.121*
369298	***0.063***	***0.001***	No trend	
VA				
441209	No trend		-0.024	0.155
442208	***0.054***	***0.007***	No trend	
442245	No trend		-0.027	0.141
447338	No trend		No trend	
448062	No trend		No trend	
449263	***0.08***	***<0.001***	*0.022*	*0.203*
MD				
185111	***0.047***	***0.014***	*0.018*	*0.194*
186620	*0.04*	*0.107*	No trend	
187330	No trend		***0.049***	***0.001***
188000	*0.023*	*0.183*	No trend	
188405	*0.022*	*0.104*	*0.03*	*0.056*

Table 4-7 Slopes and P values for annual temperature for the summer season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Summer					
	Tmean		Tmax		Tmin	
	Slope(°F/yr)	P	Slope(°F/yr)	P	Slope(°F/yr)	P
WV						
460580	**-0.03**	**<0.001**	**-0.054**	**<0.001**	-0.005	0.405
461220	No trend		*0.011*	*0.114*	-0.006	0.378
463544	**-0.017**	**0.003**	**-0.032**	**0.001**	-0.005	0.258
465224	No trend		*0.001*	*0.89*	-0.002	0.769
466867	-0.004	0.454	**-0.027**	**<0.001**	***0.022***	***<0.001***
467730	**-0.009**	**0.027**	**-0.013**	**0.037**	-0.004	0.369
468384	**-0.015**	**0.011**	**-0.065**	**<0.001**	-0.006	0.286
469436	**-0.017**	**0.008**				
PA						
363028	*0.001*	*0.838*	-0.005	0.493	***0.012***	***0.014***
366233	*0.004*	*0.414*	-0.006	0.341	***0.014***	***0.01***
367477	**-0.013**	**0.04**	**-0.027**	**0.004**	-0.006	0.493
368445	***0.015***	***0.004***	*0.009*	*0.118*	***0.019***	***<0.001***
368905	***0.01***	***0.017***	*0.011*	*0.079*	***0.009***	***0.045***
369298	**-0.195**	**<0.001**	-0.001	0.85	***0.02***	***0.001***
VA						
441209	*0.003*	*0.473*	-0.001	0.872	*0.009*	*0.1*
442208	***0.009***	***0.024***	-0.005	0.397	***0.026***	***<0.001***
442245	-0.007	0.169	-0.012	0.086	-0.001	0.913
447338	-0.002	0.771	-0.001	0.854	-0.011	0.069
448062	**-0.019**	**<0.001**	**-0.016**	**0.003**	**-0.021**	**<0.001**
449263	-0.004	0.464	-0.004	0.61	**-0.096**	**<0.001**
MD						
185111	***0.036***	***<0.001***	***0.023***	***<0.001***	***0.048***	***<0.001***
186620	***0.016***	***<0.001***	-0.002	0.804	***0.035***	***<0.001***
187330	***0.022***	***<0.001***	***0.057***	***<0.001***	**-0.017**	**0.001**
188000	***0.018***	***<0.001***	*0.005*	*0.403*	***0.033***	***<0.001***
188405	***0.013***	***0.006***	***0.018***	***0.002***	*0.007*	*0.09*

Table 4-8 Slopes and P values for annual temperature for the winter season. Significant trends are indicated in bold characters ($P<0.05$). Italic stands for increasing trend and normal format stands for decreasing trends.

	Winter					
	Tmean		Tmax		Tmin	
	Slope(°F/yr)	P	Slope(°F/yr)	P	Slope(°F/yr)	P
WV						
460580	**-0.034**	**0.004**	**-0.052**	**<0.001**	**-0.024**	**0.026**
461220	-0.009	0.353	-0.001	0.89	-0.015	0.146
463544	-0.009	0.303	-0.007	0.593	-0.017	0.081
465224	-0.01	0.239	-0.011	0.28	-0.012	0.221
466867	-0.014	0.175	**-0.023**	**0.041**	-0.002	0.8
467730	*0.003*	*0.81*	*0.007*	*0.466*	-0.004	0.668
468384	-0.009	0.337	***0.037***	***0.017***	-0.013	0.341
469436	**-0.02**	**0.049**				
PA						
363028	*0.008*	*0.424*	-0.004	0.667	***0.02***	***0.043***
366233	*0.01*	*0.365*	*0.006*	*0.542*	*0.014*	*0.186*
367477	-0.012	0.308	-0.014	0.216	-0.009	0.416
368445	*0.015*	*0.091*	***0.016***	***0.047***	*0.014*	*0.142*
368905	***0.016***	***0.046***	***0.023***	***0.005***	*0.009*	*0.307*
369298	***0.245***	***<0.001***	-0.001	0.892	*0.018*	*0.099*
VA						
441209	-0.008	0.451	-0.006	0.466	-0.006	0.421
442208	*0.005*	*0.552*	-0.009	0.308	***0.02***	***0.019***
442245	**-0.028**	**0.006**	-0.021	0.077	**-0.038**	**0.001**
447338	-0.009	0.299	-0.003	0.807	-0.017	0.053
448062	**-0.023**	**0.01**	-0.013	0.196	**-0.034**	**<0.001**
449263	*0.007*	*0.449*	*0.015*	*0.219*	***0.076***	***<0.001***
MD						
185111	***0.028***	***0.002***	*0.017*	*0.1*	***0.042***	***<0.001***
186620	*0.008*	*0.463*	No trend		*0.016*	*0.1*
187330	***0.031***	***<0.001***	***0.042***	***<0.001***	***0.017***	***0.047***
188000	***0.023***	***0.016***	*0.013*	*0.203*	***0.035***	***<0.001***
188405	***0.022***	***0.026***	***0.032***	***0.003***	*0.01*	*0.241*

Table 4-9 Slopes and P values for annual temperature for summer and winter season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	TRANGE			
	Winter		Summer	
	Slope(°F/yr)	P	Slope(°F/yr)	P
WV				
460580	-0.017	0.073	**-0.052**	**<0.001**
461220	*0.01*	*0.076*	*0.005*	*0.523*
463544	***0.016***	***0.05***	**-0.021**	**0.013**
465224	*0.001*	*0.846*	*0.001*	*0.903*
466867	**-0.023**	**<0.001**	**-0.046**	**<0.001**
467730	*0.009*	*0.189*	-0.004	0.563
468384	***0.046***	***0.001***	**-0.059**	**<0.001**
469436				
PA				
363028	**-0.024**	**<0.001**	**-0.017**	**0.013**
366233	**-0.01**	**0.042**	**-0.018**	**0.006**
367477	-0.009	0.283	**-0.03**	**0.007**
368449	*0.002*	*0.58*	-0.008	0.109
368905	***0.013***	***0.004***	*0.003*	*0.656*
369298	**-0.018**	**0.008**	**-0.017**	**0.01**
VA				
441209	*0.002*	*0.721*	-0.007	0.226
442208	**-0.033**	**<0.001**	**-0.029**	**<0.001**
442245	***0.019***	***0.003***	-0.011	0.208
447338	***0.018***	***0.01***	*0.016*	*0.074*
448062	***0.031***	***<0.001***	*0.002*	*0.742*
449263	**-0.068**	**<0.001**	***0.094***	***<0.001***
MD				
185111	**-0.026**	**<0.001**	**-0.024**	**<0.001**
186620	**-0.018**	**0.001**	**-0.036**	**<0.001**
187330	***0.024***	***<0.001***	***0.074***	***<0.001***
188000	**-0.02**	**<0.001**	**-0.028**	**<0.001**
188405	***0.014***	***0.012***	*0.007*	*0.104*

Table 4-10 Slopes and P values for TX90 (warm days) and TX10 (cool days) during the summer season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Summer			
	TX90(Warm Days)		TX10(Cool Days)	
	Slope(d/yr)	P	Slope(d/yr)	P
WV				
460580	**-0.067**	**0.006**	***0.065***	***<0.001***
461220	No trend		-0.013	0.224
463544	**-0.056**	**0.035**	***0.029***	***0.026***
465224	-0.015	0.369	No trend	
466867	**-0.053**	**0.004**	*0.02*	*0.121*
467730	-0.029	0.108	*0.011*	*0.212*
468384	-0.036	0.13	No trend	
469436				
PA				
363028	-0.012	0.345	No trend	
366233	-0.037	0.071	No trend	
367477	**-0.067**	**0.002**	*0.017*	*0.226*
368445	No trend		No trend	
368905	No trend		**-0.026**	**0.028**
369298	No trend		No trend	
VA				
441209	-0.023	0.155	No trend	
442208	No trend		No trend	
442245	**-0.053**	**0.026**	No trend	
447338	**-0.036**	**0.026**	No trend	
448062	**-0.057**	**0.002**	*0.017*	*0.128*
449263	-0.022	0.181	-0.018	0.138
MD				
185111	*0.013*	*0.299*	**-0.033**	**0.003**
186620	-0.022	0.248	-0.012	0.151
187330	***0.063***	***0.004***	**-0.113**	**<0.001**
188000	-0.013	0.372	**-0.037**	**0.005**
188405	No trend		**-0.049**	**<0.001**

Table 4-11 Slopes and P values for TX90 (warm days) and TX10 (cool days) during the winter season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Winter			
	TX90(Warm Days)		TX10(Cool Days)	
	Slope(d/yr)	P	Slope(d/yr)	P
WV				
460580	No trend		*0.022*	*0.144*
461220	**0.024**	**0.024**	No trend	
463544	*0.01*	*0.375*	No trend	
465224	No trend		***0.03***	***0.036***
466867	No trend		***0.03***	***0.026***
467730	*0.023*	*0.121*		
468384	*0.031*	*0.064*	-0.02	0.213
469436				
PA				
363028	No trend		No trend	
366233	*0.014*	*0.292*	*0.013*	*0.359*
367477	No trend		*0.033*	*0.111*
368445	***0.028***	***0.032***	No trend	
368905	***0.034***	***0.008***	**-0.038**	**0.01**
369298	***0.029***	***0.024***	No trend	
VA				
441209	No trend		*0.021*	*0.09*
442208	No trend		No trend	
442245	No trend		***0.047***	***0.028***
447338	*0.016*	*0.257*	*0.019*	*0.151*
448062	No trend		*0.011*	*0.351*
449263	***0.032***	***0.04***	-0.029	0.07
MD				
185111	***0.035***	***0.016***	No trend	
186620	*0.02*	*0.179*	No trend	
187330	*0.019*	*0.086*	**-0.069**	**<0.001**
188000	*0.027*	*0.065*	No trend	
188405	***0.042***	***0.012***	-0.032	0.054

Table 4-12 Slopes and P values for TN90 (warm nights) and TN10 (cool nights) during the summer season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Summer			
	TN90(Warm Nights)		TN10(Cool Nights)	
	Slope(d/yr)	P	Slope(d/yr)	P
WV				
460580	**-0.04**	**0.012**	-0.016	0.218
461220	-0.012	0.345	*0.013*	*0.344*
463544	-0.014	0.173	No trend	
465224	No trend		No trend	
466867	*0.016*	*0.053*	**-0.051**	**0.001**
467730	**-0.026**	**0.041**	No trend	
468384	**-0.025**	**0.046**	No trend	
469436				
PA				
363028	No trend		**-0.055**	**<0.001**
366233	No trend		-0.026	0.055
367477	**-0.043**	**0.036**	-0.028	0.094
368445	No trend		**-0.043**	**<0.001**
368905	No trend		**-0.037**	**<0.001**
369298	***0.039***	***0.005***	**-0.056**	**<0.001**
VA				
441209	No trend		**-0.026**	**0.044**
442208	***0.042***	***0.009***	**-0.05**	**<0.001**
442245	No trend		No trend	
447338	**-0.036**	**0.015**	No trend	
448062	**-0.038**	**0.002**	*0.018*	*0.152*
449263	**-0.091**	**<0.001**	***0.077***	***<0.001***
MD				
185111	***0.1***	***<0.001***	**-0.103**	**<0.001**
186620	***0.071***	***<0.001***	**-0.069**	**<0.001**
187330	**-0.028**	**0.044**	***0.047***	***0.002***
188000	***0.065***	***<0.001***	**-0.091**	**<0.001**
188405	***0.019***	***0.031***	-0.019	0.111

Table 4-13 Slopes and P values for TN90 (warm nights) and TN10 (cool nights) during the winter season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Winter			
	TN90(Warm Nights)		TN10(Cool Nights)	
	Slope(d/yr)	P	Slope(d/yr)	P
WV				
460580	-0.018	0.117	*0.015*	*0.283*
461220	No trend		No trend	
463544	**-0.036**	**0.001**	No trend	
465224	-0.012	0.316	No trend	
466867	No trend		No trend	
467730	No trend		No trend	
468384	-0.011	0.312	*0.011*	*0.379*
469436				
PA				
363028	*0.017*	*0.052*	-0.005	0.446
366233	No trend		-0.012	0.351
367477	No trend		*0.028*	*0.148*
368445	*0.01*	*0.287*	No trend	
368905	No trend		No trend	
369298	No trend		-0.02	0.142
VA				
441209	**-0.021**	**0.047**	No trend	
442208	No trend		**-0.048**	**0.002**
442245	**-0.069**	**<0.001**	No trend	
447338	**-0.025**	**0.022**	No trend	
448062	**-0.042**	**0.001**	*0.034*	*0.097*
449263	***0.053***	***0.003***	**-0.091**	**<0.001**
MD				
185111	***0.041***	***0.001***	**-0.057**	**0.004**
186620	No trend		-0.017	0.145
187330	No trend		-0.014	0.316
188000	***0.043***	***0.003***	-0.035	0.075
188405	***0.029***	***0.045***	-0.03	0.062

Table 4-14 Slopes and P values for wet day precipitation and wet days. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	P95		P95D	
	Slope(in/yr)	P	Slope(d/yr)	P
WV Stations				
460580	-0.021	0.223	No trend	
461220	*0.006*	*0.63*	No trend	
463544	*0.013*	*0.32*	No trend	
465224	*0.003*	*0.8*	No trend	
466867	**-0.087**	**<0.001**	**-0.041**	**0.001**
467730	*0.003*	*0.754*	No trend	
468384	*0.022*	*0.145*	*0.013*	*0.081*
469436	***0.039***	***0.011***	***0.025***	***0.007***
PA Stations				
363028	***0.026***	***0.024***	*0.013*	*0.059*
366233	***0.029***	***0.02***	***0.018***	***0.026***
367477	***0.033***	***0.016***	***0.022***	***0.01***
368445	*0.01*	*0.376*	No trend	
368905	***0.024***	***0.016***	***0.015***	***0.017***
369298	*0.007*	*0.557*	No trend	
VA Stations				
441209	-0.02	0.124	No trend	
442208	*0.005*	*0.633*	No trend	
442245	***0.042***	***0.004***	***0.015***	***0.011***
447338	*0.011*	*0.43*	No trend	
448062	No trend		No trend	
449263	***0.025***	***0.03***	***0.009***	***0.047***
MD Stations				
185111	*0.024*	*0.075*	No trend	
186620	*0.005*	*0.652*	No trend	
187330	***0.031***	***0.043***	No trend	
188000	***0.035***	***0.046***	No trend	
188405	***0.102***	***<0.001***	***0.049***	***<0.001***

Table 4-15 Slopes and P values maximum number of consecutive days with no precipitation and maximum annual precipitation intensity in in/day. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Drought		Intensity	
	Slope(days/yr)	P	Slope(in/day/yr)	P
WV Stations				
460580	**-0.076**	**<0.001**	-0.002	0.092
461220	**-0.029**	**0.018**	-0.002	0.096
463544	-0.019	0.055	-0.001	0.516
465224	No trend		**-0.003**	**0.031**
466867	**-0.088**	**<0.001**	**-0.012**	**<0.001**
467730	**-0.058**	**<0.001**	-0.001	0.681
468384	**-0.06**	**<0.001**	-0.003	0.062
469436	No trend		***0.005***	***0.001***
PA Stations				
363028	**-0.054**	**<0.001**	No trend	
366233	-0.019	0.082	*0.001*	*0.417*
367477	**-0.025**	**0.02**	-0.003	0.066
368445	No trend		*0.001*	*0.3*
368905	No trend		-0.001	0.482
369298	**-0.015**	**0.044**	**-0.003**	**0.026**
VA Stations				
441209	**-0.075**	**<0.001**	**-0.004**	**0.011**
442208	-0.011	0.262	**-0.004**	**<0.001**
442245	*0.026*	*0.053*	*0.002*	*0.215*
447338	**-0.047**	**0.001**	**-0.003**	**0.05**
448062	*0.017*	*0.131*	-0.004	**0.017**
449263	*0.018*	*0.207*	No trend	
MD Stations				
185111	*0.012*	*0.297*	*0.001*	*0.645*
186620	No trend		-0.001	0.437
187330	*0.025*	*0.063*	***0.006***	***0.001***
188000	***0.031***	***0.026***	*0.001*	*0.525*
188405	*0.011*	*0.319*	***0.011***	***<0.001***

Table 4-16 Slopes and P values maximum number of consecutive days with no precipitation and maximum annual precipitation intensity in in/day during summer season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Summer			
	Drought		Intensity	
	Slope(days/yr)	P	Slope(in/day/yr)	P
WV				
460580	**-0.023**	**0.019**	-0.002	0.21
461220	-0.015	0.141	**-0.003**	**0.003**
463544	No trend		*0.001*	*0.647*
465224	*0.017*	*0.037*	-0.001	0.485
466867	**-0.057**	**<0.001**	**-0.009**	**<0.001**
467730	**-0.026**	**0.008**	-0.001	0.322
468384	**-0.03**	**<0.001**	-0.002	0.166
469436	No trend		*0.003*	*0.048*
PA				
363028	**-0.019**	**0.031**	No trend	
366233	No trend		No trend	
367477	No trend		-0.002	0.352
368445	No trend		*0.002*	*0.085*
368905	No trend		No trend	
369298	No trend		-0.001	0.299
VA				
441209	No trend		-0.001	0.726
442208	***0.019***	***0.006***	-0.001	0.313
442245	***0.028***	***0.012***	*0.001*	*0.522*
447338	No trend		-0.002	0.259
448062	***0.031***	***0.003***	*0.001*	*0.549*
449263	*0.01*	*0.165*	-0.001	0.589
MD				
185111	***0.019***	***0.05***	*0.001*	*0.635*
186620	No trend		No trend	
187330	***0.024***	***0.006***	***0.005***	***0.007***
188000	No trend		*0.001*	*0.603*
188405	***0.034***	***0.005***	*0.004*	*0.129*

Table 4-17 Slopes and P values maximum number of consecutive days with no precipitation and maximum annual precipitation intensity in in/day during winter season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	Winter			
	Drought		Intensity	
	Slope(days/yr)	P	Slope(in/day/yr)	P
WV				
460580	**-0.038**	**<0.001**	-0.001	0.388
461220	**-0.032**	**<0.001**	**-0.002**	**0.029**
463544	**-0.012**	**0.026**	**-0.002**	**0.038**
465224	-0.014	0.086	-0.001	0.249
466867	**-0.058**	**<0.001**	**-0.012**	**<0.001**
467730	**-0.031**	**0.011**	-0.002	0.092
468384	No trend		**-0.002**	**0.022**
469436	No trend		No trend	
PA				
363028	No trend		**-0.002**	**<0.001**
366233	No trend		No trend	
367477	No trend		**-0.002**	**0.037**
368445	**-0.014**	**0.001**	-0.001	0.114
368905	No trend		No trend	
369298	**-0.019**	**<0.001**	-0.001	0.208
VA				
441209	**-0.025**	**0.002**	**-0.003**	**0.001**
442208	No trend		-0.001	0.281
442245	No trend		*0.001*	*0.642*
447338	-0.014	0.125	-0.003	0.059
448062	*0.012*	*0.228*	No trend	
449263	*0.013*	*0.274*	No trend	
MD				
185111	No trend		No trend	
186620	No trend		-0.001	0.241
187330	***0.034***	***0.002***	***0.004***	***<0.001***
188000	No trend		No trend	
188405	No trend		***0.005***	***<0.001***

Table 4-18 Slopes and P values for wet day precipitation during summer and winter season. Significant trends are indicated in bold characters (P<0.05). Italic stands for increasing trend and normal format stands for decreasing trends.

	P95			
	Summer		Winter	
	Slope(in/yr)	P	Slope(in/yr)	P
WV				
460580	-0.008	0.431	-0.007	0.147
461220	-0.009	0.243	*0.01*	*0.059*
463544	*0.004*	*0.460*	-0.006	*0.102*
465224	*0.003*	*0.492*	*0.001*	*0.472*
466867	**-0.02**	**0.01**	**-0.03**	**<0.001**
467730	-0.001	0.830	-0.002	0.539
468384	-0.004	0.422	-0.003	0.41
469436	*0.003*	*0.743*	*0.002*	*0.654*
PA				
363028	*0.003*	*0.433*	No trend	
366233	-0.001	0.867	*0.001*	*0.505*
367477	*0.005*	*0.248*	*0.004*	*0.322*
368445	*0.001*	*0.719*	*0.002*	*0.402*
368905	-0.002	0.647	No trend	
369298	*0.008*	*0.120*	No trend	
VA				
441209	-0.001	0.723	-0.002	0.594
442208	-0.003	0.561	-0.001	0.431
442245	-0.002	0.651	-0.001	0.775
447338	0.003	0.722	-0.002	0.351
448062	-0.001	0.723	No trend	
449263	*0.004*	*0.296*	*0.003*	*0.475*
MD				
185111	*0.001*	*0.875*	*0.002*	*0.522*
186620	*0.002*	*0.673*	-0.009	0.075
187330	*0.007*	*0.224*	***0.008***	***0.015***
188000	*0.01*	*0.172*	*0.013*	*0.055*
188405	*0.018*	*0.058*	***0.012***	***0.048***

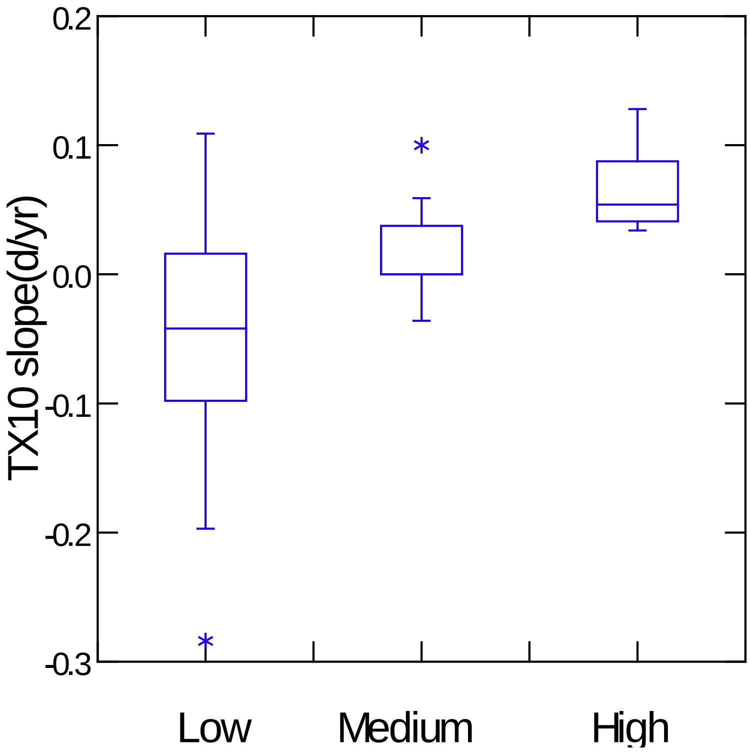

Figure 4-1 Slopes of TX10 (cool days) in different elevation groups.

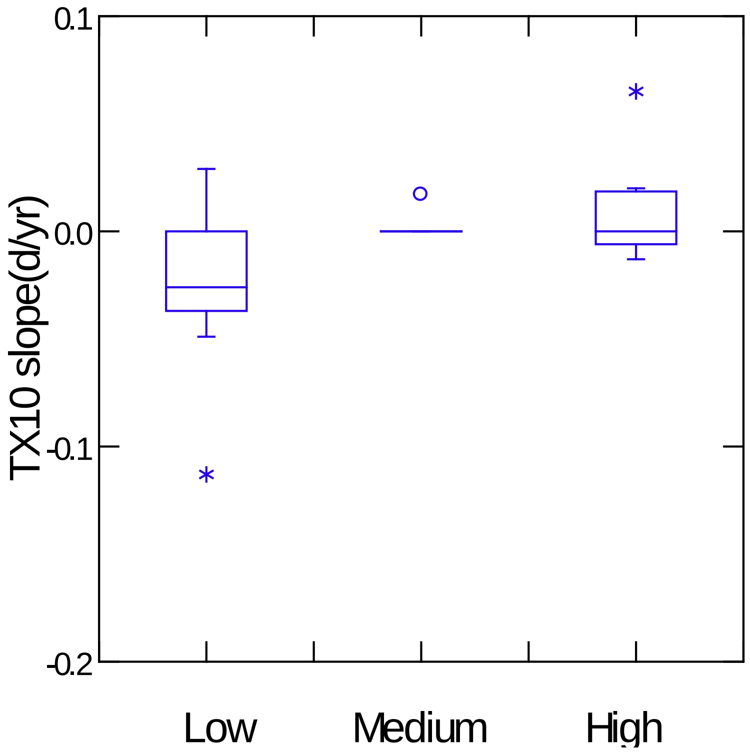

Figure 4-2 Slopes of TX10 (cool days) during summer season in different elevation groups.

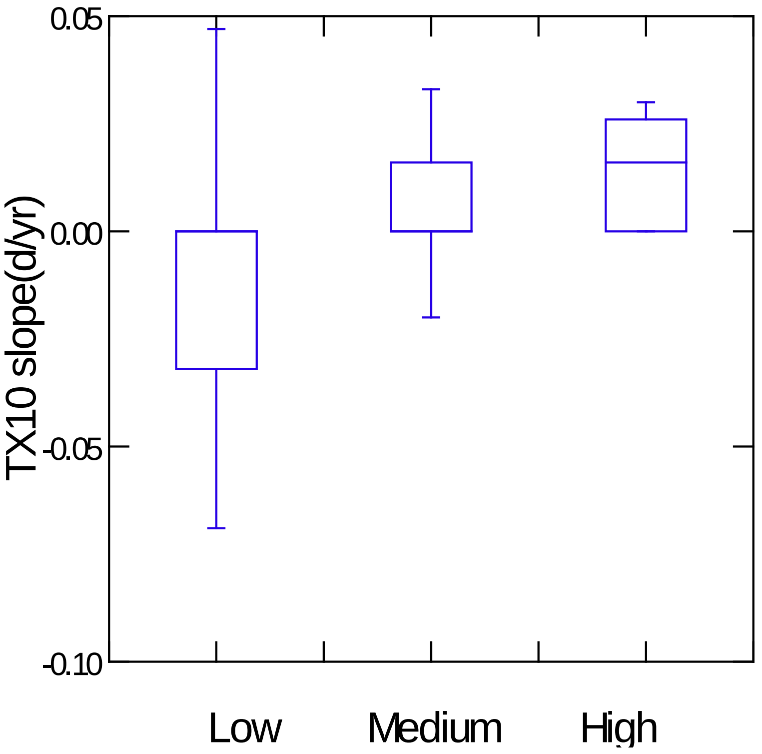

Figure 4-3 Slopes of TX10 (cool days) during winter season in different elevation groups.

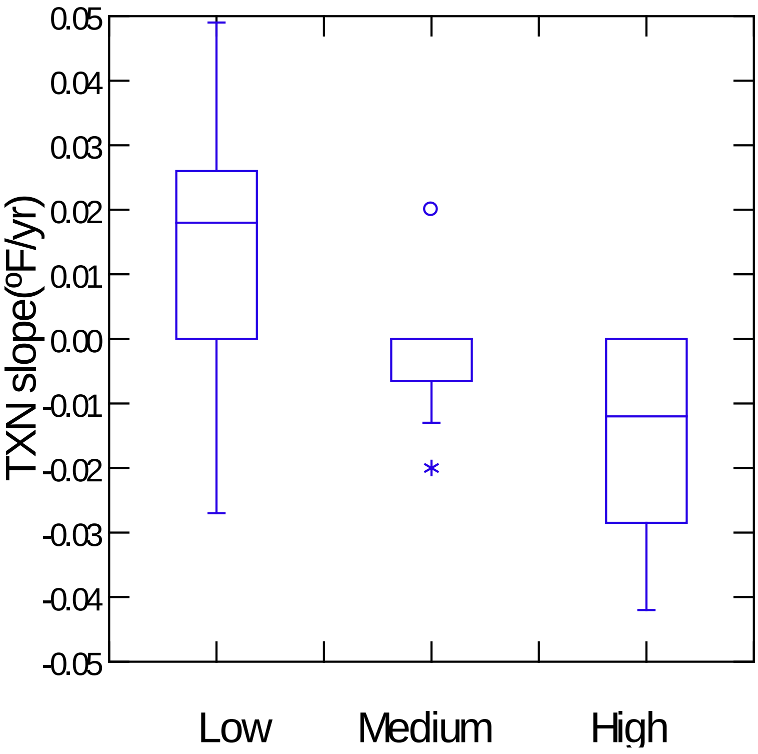

Figure 4-4 Slopes of TXN (minimum annual maximum temperature) in different elevation groups.

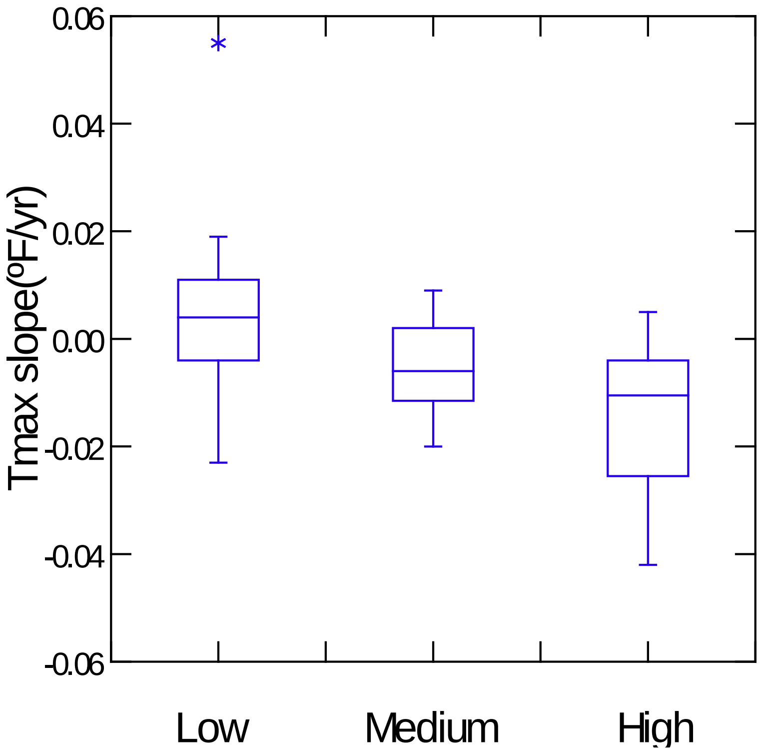

Figure 4-5 Slopes of TXN in different elevation groups.

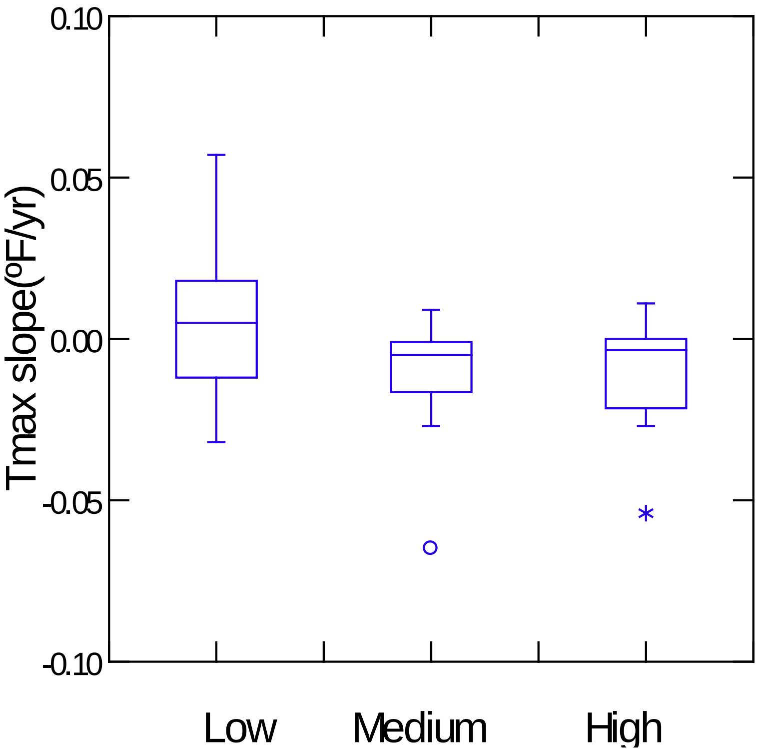

Figure 4-6 Slopes of annual maximum temperature during summer season in different elevation groups.

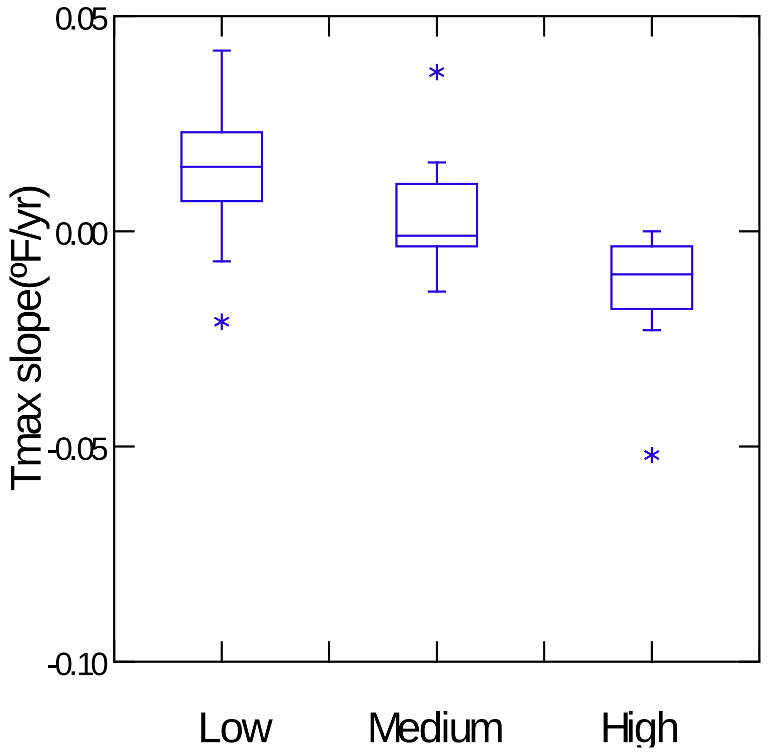

Figure 4-7 Slopes of annual maximum temperature during winter season in different elevation groups.

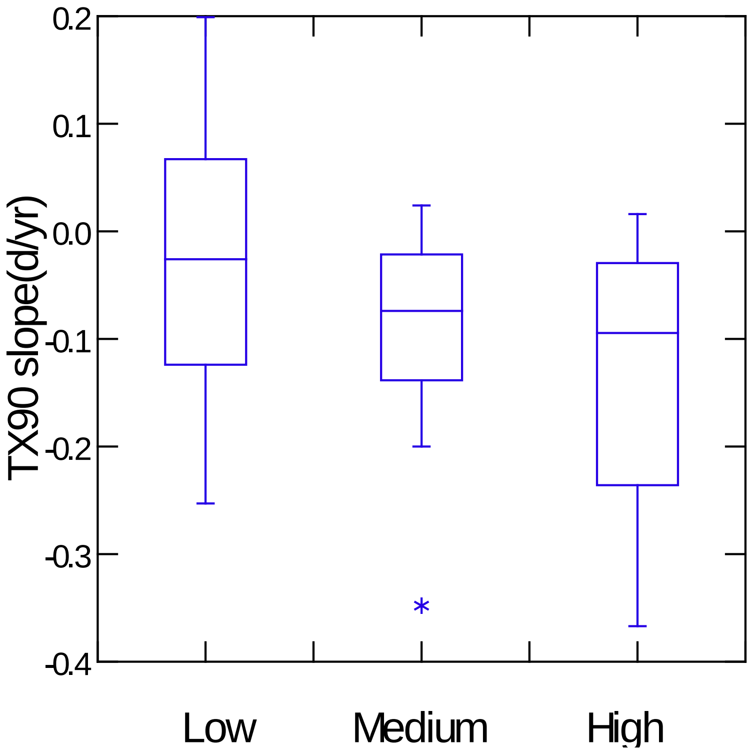

Figure 4-8 Slopes of TX90 (Warm days) in different elevation groups.

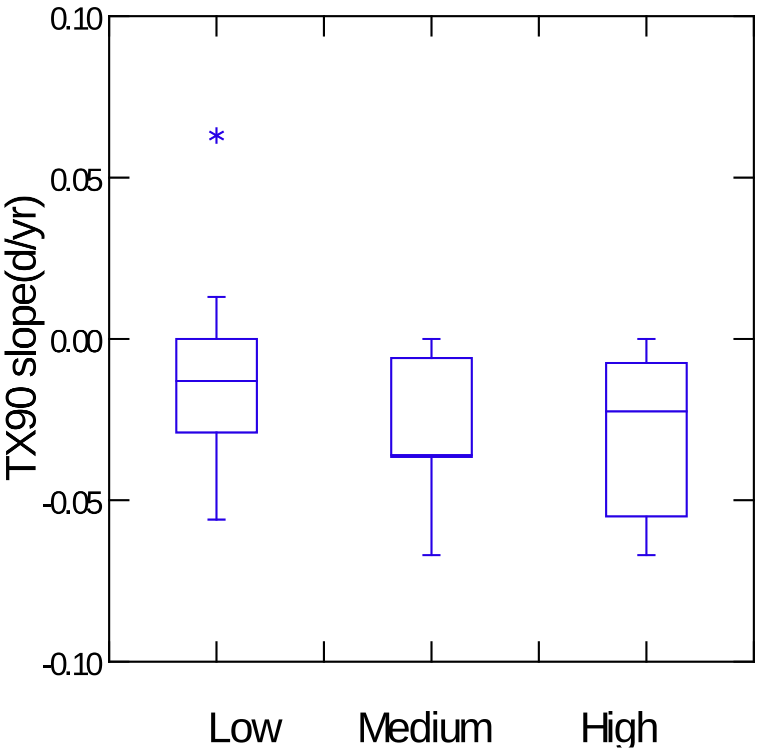

Figure 4-9 Slopes of TX90 (Warm days) during summer season in different elevation groups.

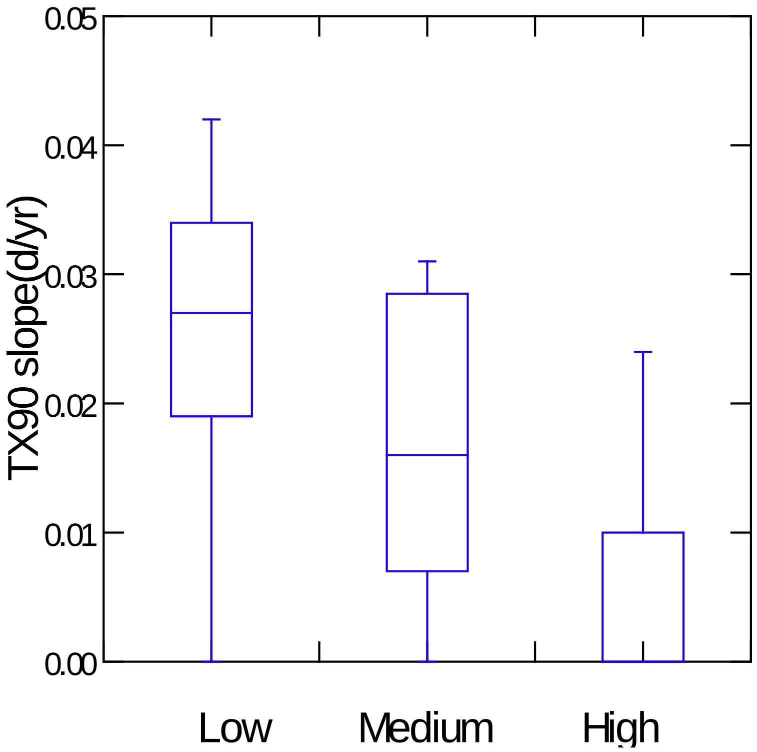

Figure 4-10 Slopes of TX90 (Warm days) during winter season in different elevation groups.

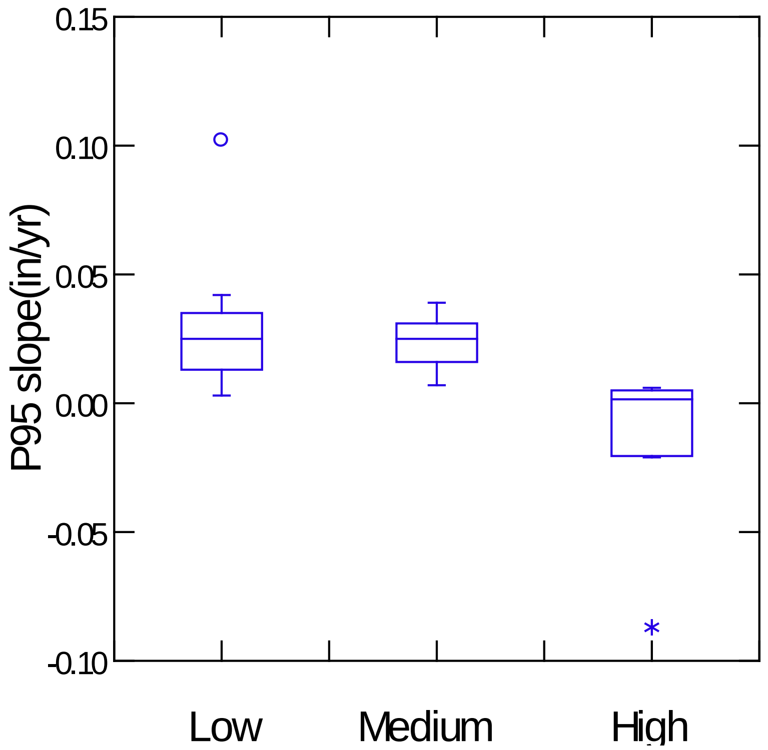

Figure 4-11 Slopes of P95 (Annual total precipitation exceeding 95th percentile) in different elevation groups.

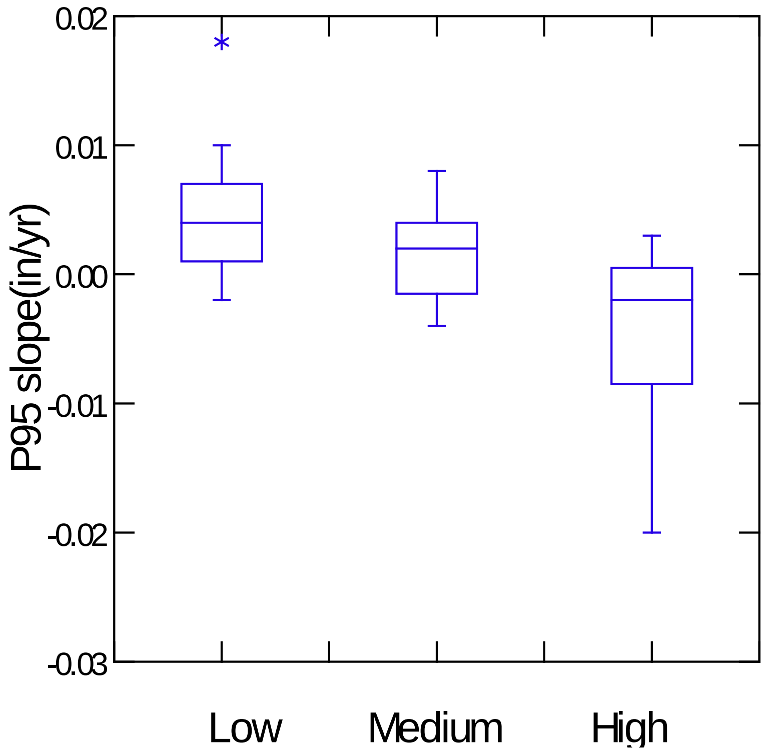

Figure 4-12 Slopes of P95 (Annual total precipitation exceeding 95th percentile) during summer season in different elevation groups.

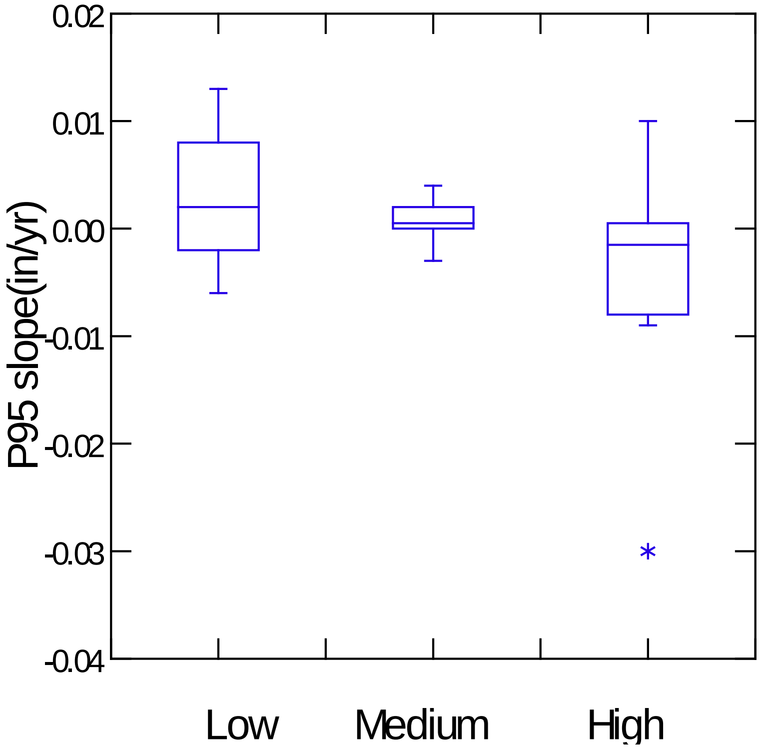

Figure 4-13 Slopes of P95 (Annual total precipitation exceeding 95th percentile) during winter season in different elevation groups.

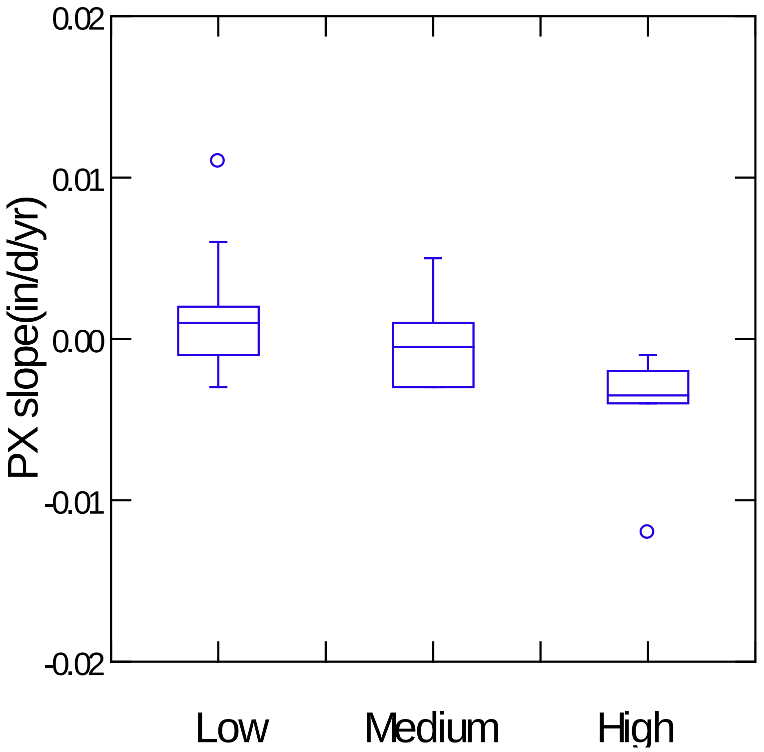

Figure 4-14 Slopes of PX (maximum precipitation intensity) in different elevation groups.

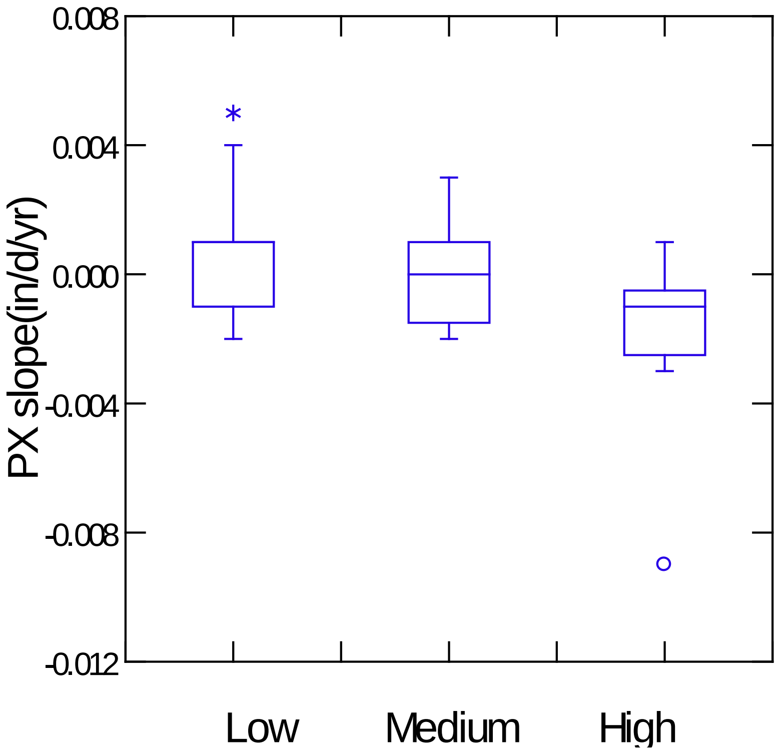

Figure 4-15 Slopes of PX (maximum precipitation intensity) during summer season in different elevation groups.

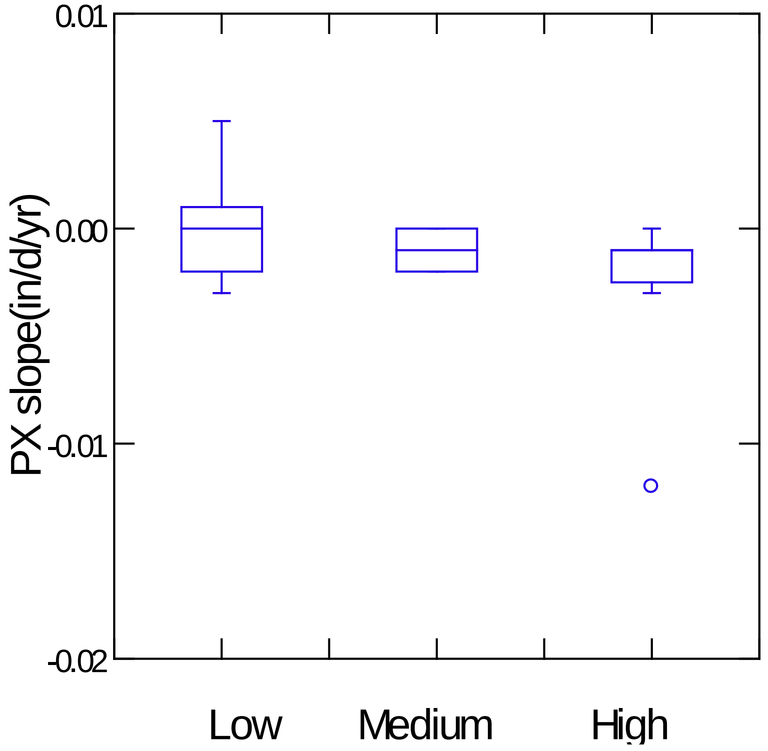

Figure 4-16 Slopes of PX (maximum precipitation intensity) during winter season in different elevation groups.

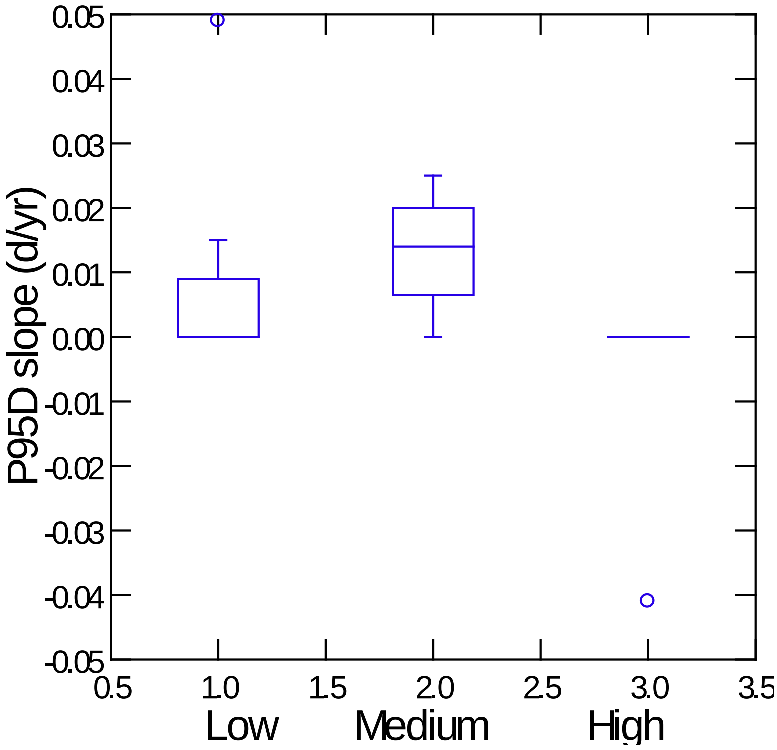

Figure 4-17 Slopes of P95D (numbers of days with precipitation exceeding 95th percentile) during in different elevation groups.

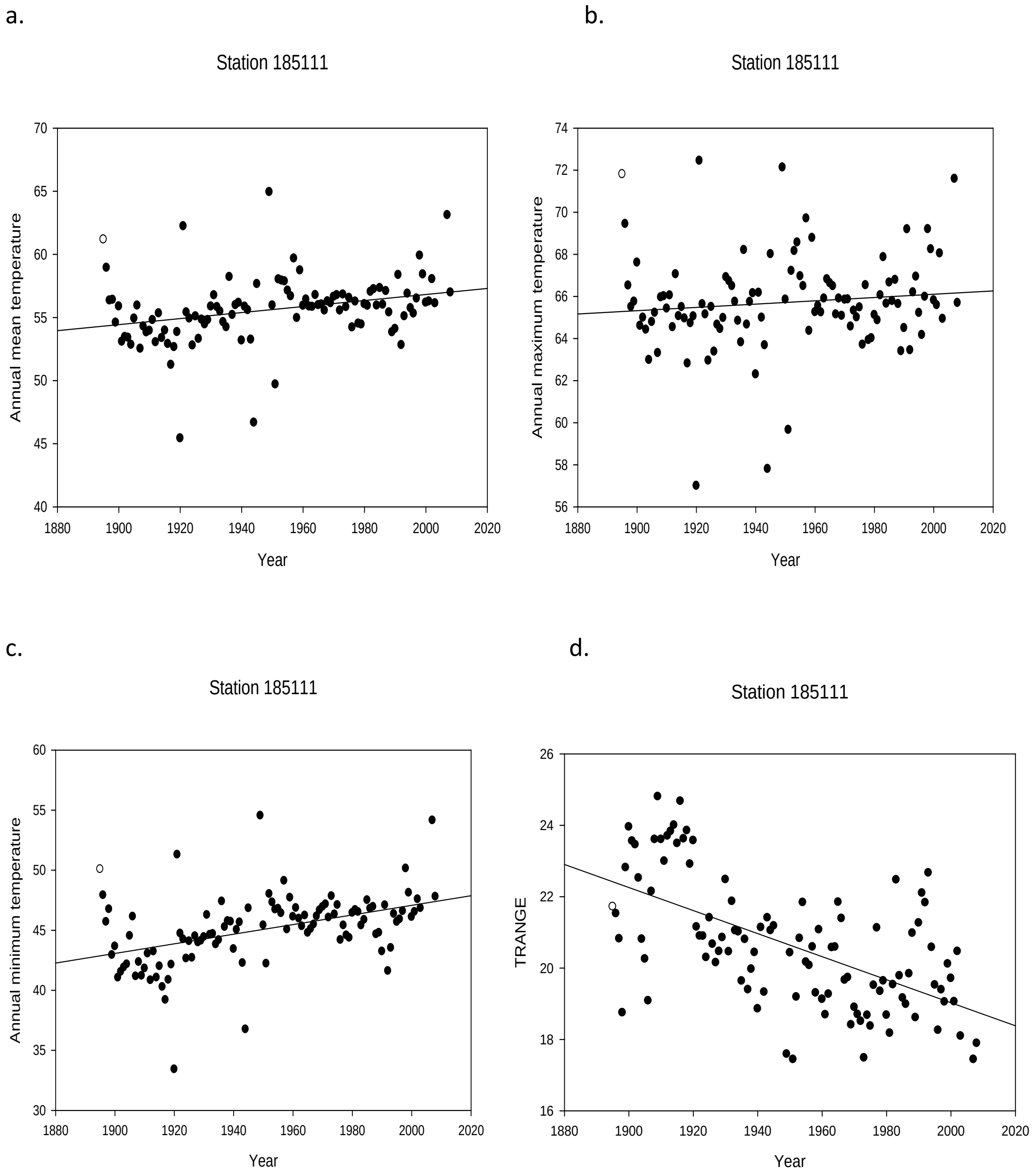

Figure 4-18 Graphic view of trends for station 185111, a. annual mean temperature, b. annual maximum temperature, c. annual minimum temperature d. T_{RANGE}

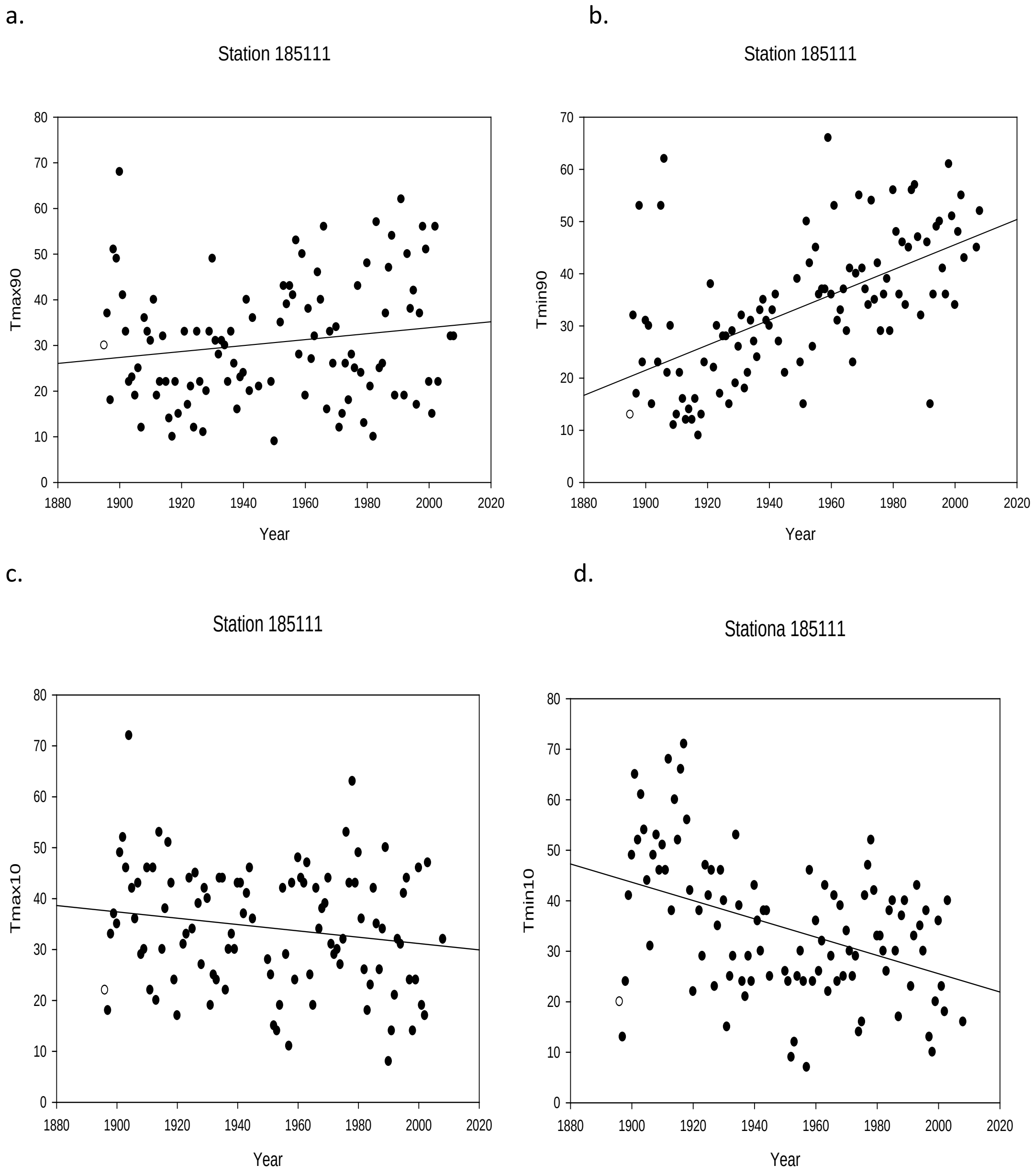

Figure 4-19 Graphic view of trends for station 185111, a. Tmax90, b. Tmin90, c. Tmax10 d. Tmin10.

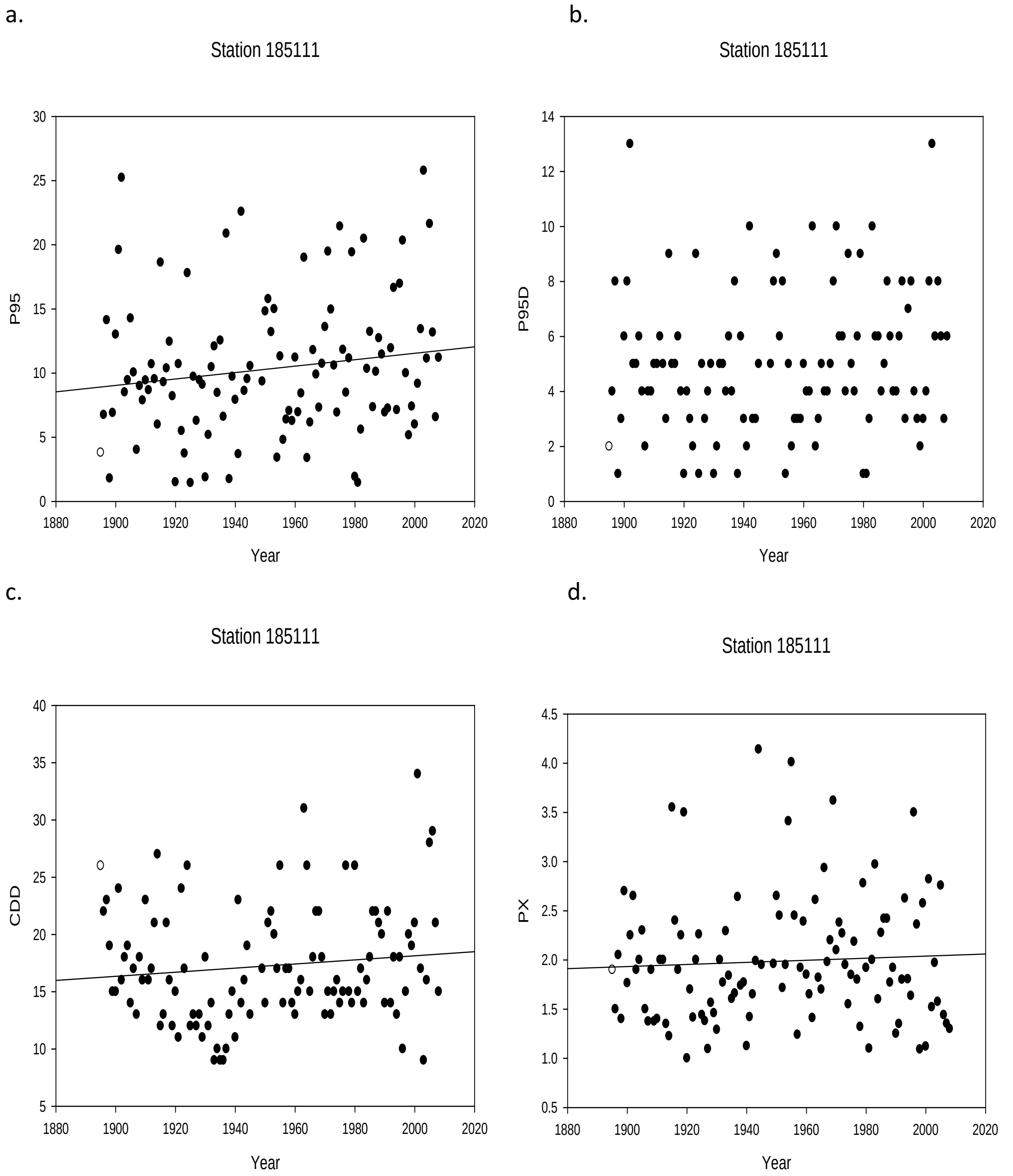

Figure 4-20 Graphic view of trends for station 185111, a. P95, b. P95D, c. CDD d. PX.

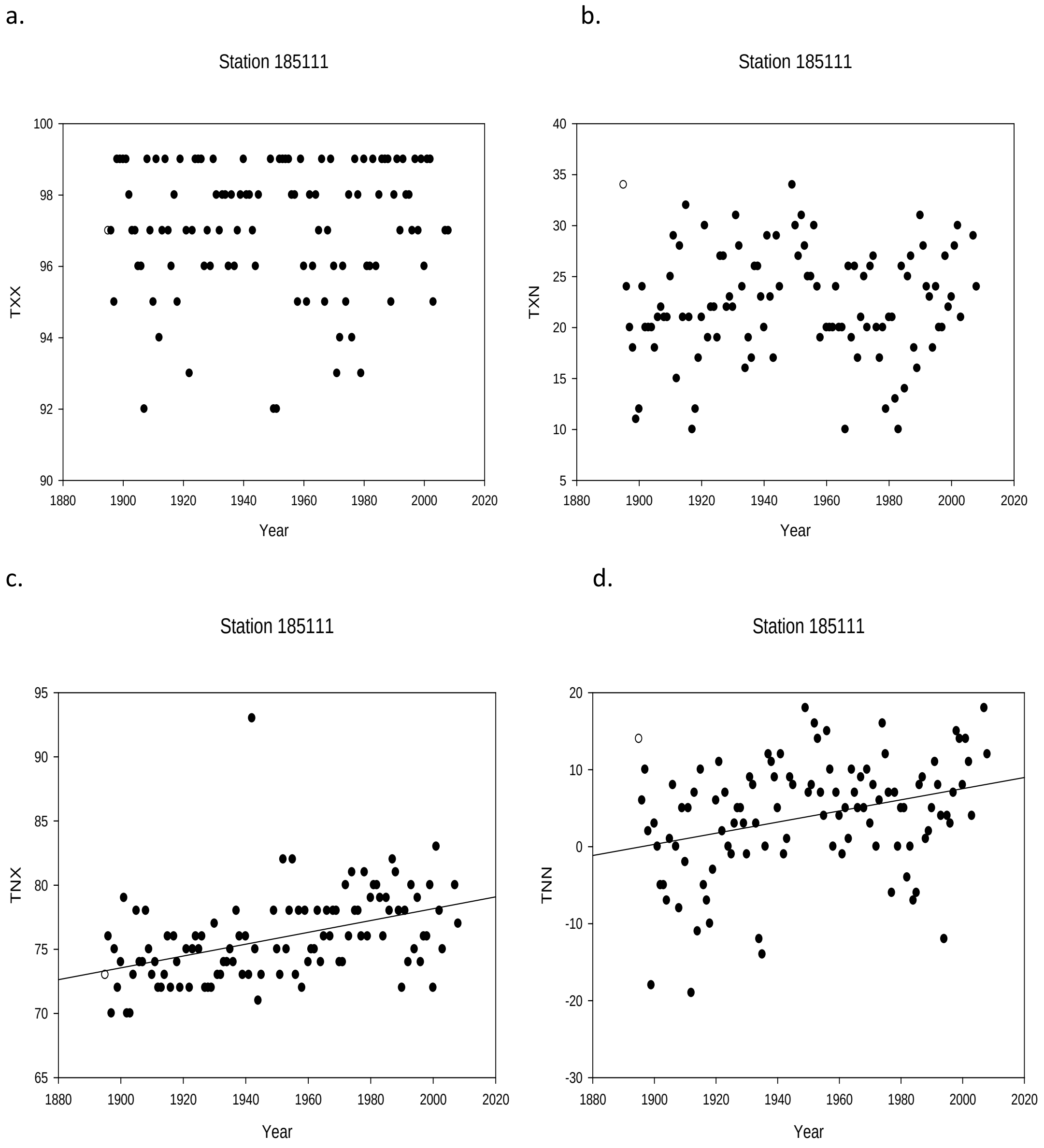

Figure 4-21 Graphic view of trends for station 185111, a. TXX, b. TXN, c. TNX d. TNN.

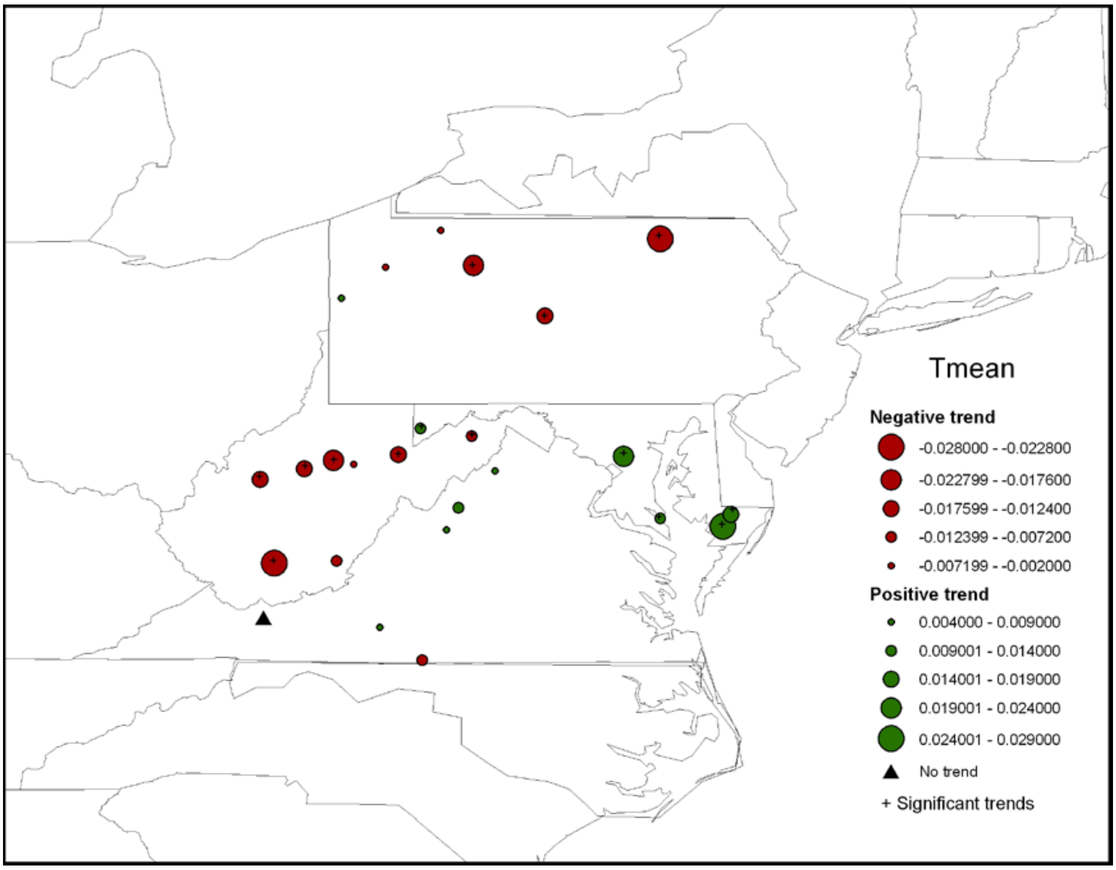

Figure 4-22 Spatial distribution of trends for annual mean temperature.

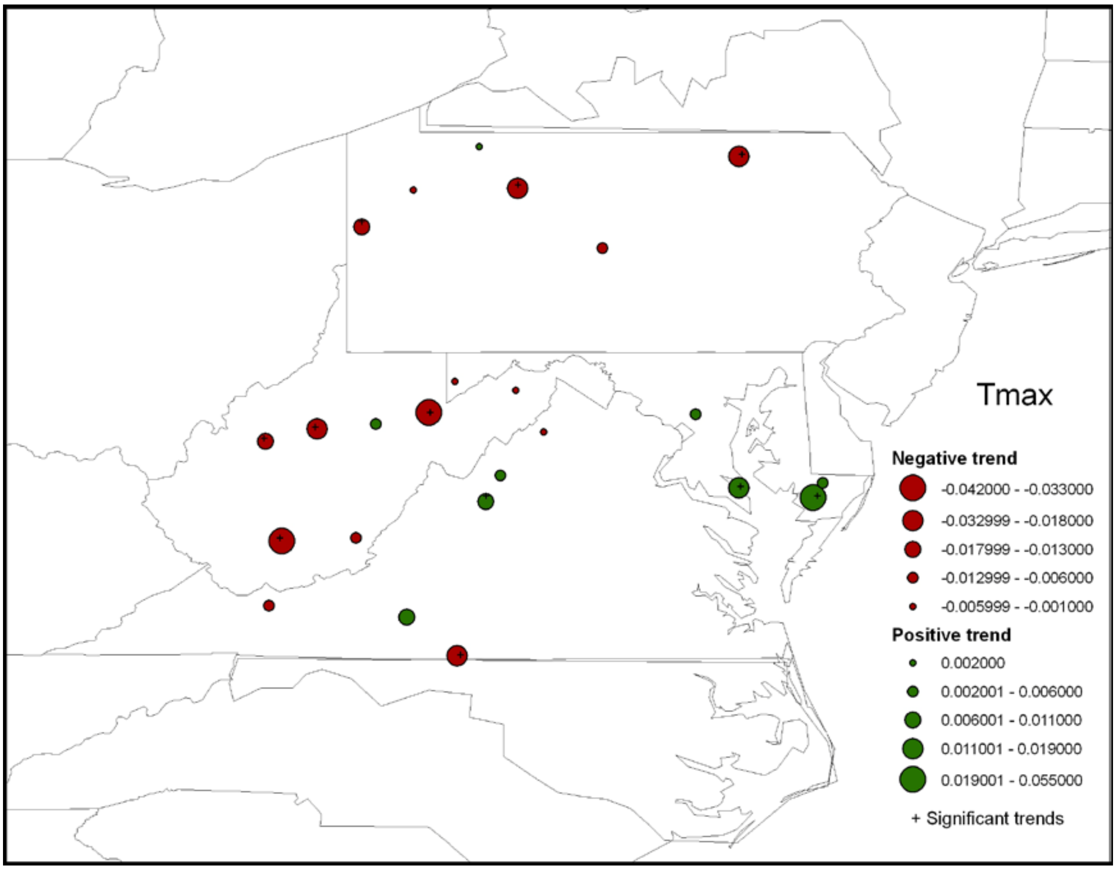

Figure 4-23 Spatial distribution of trends for annual maximum temperature.

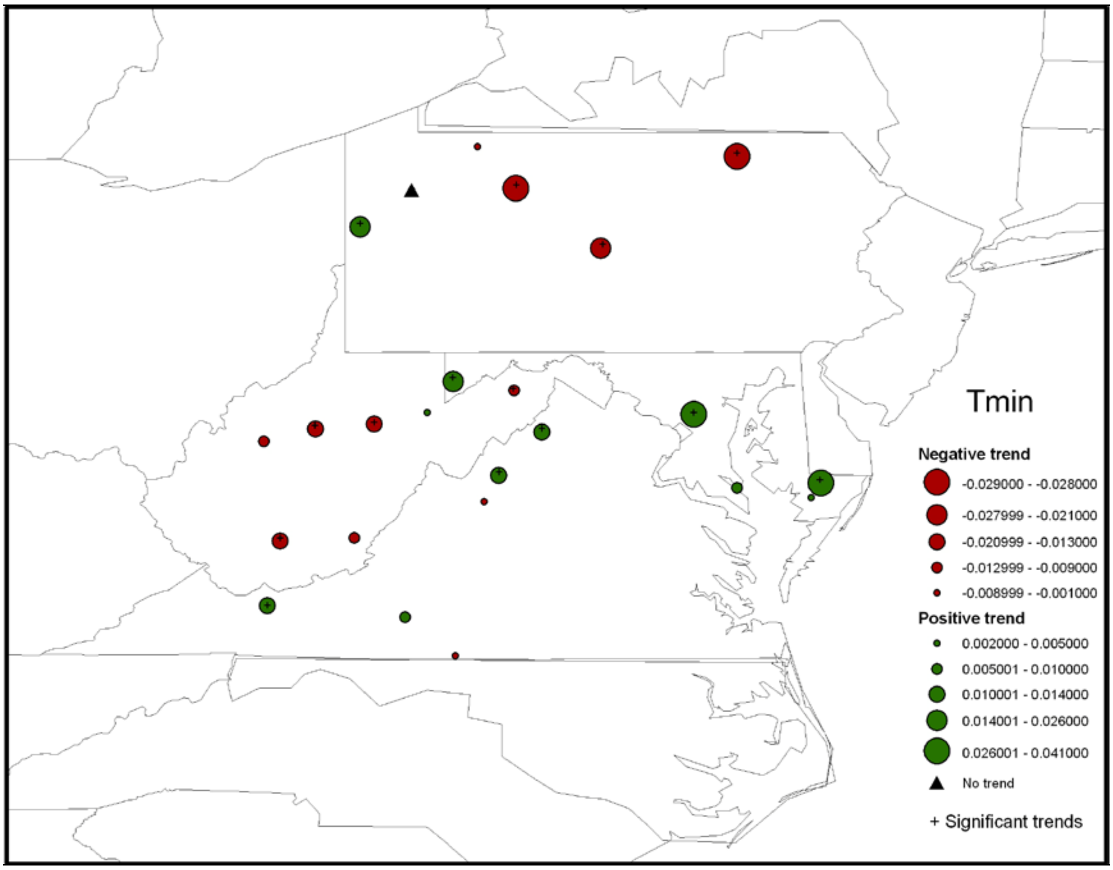

Figure 4-24 Spatial distribution of trends for annual minimum temperature.

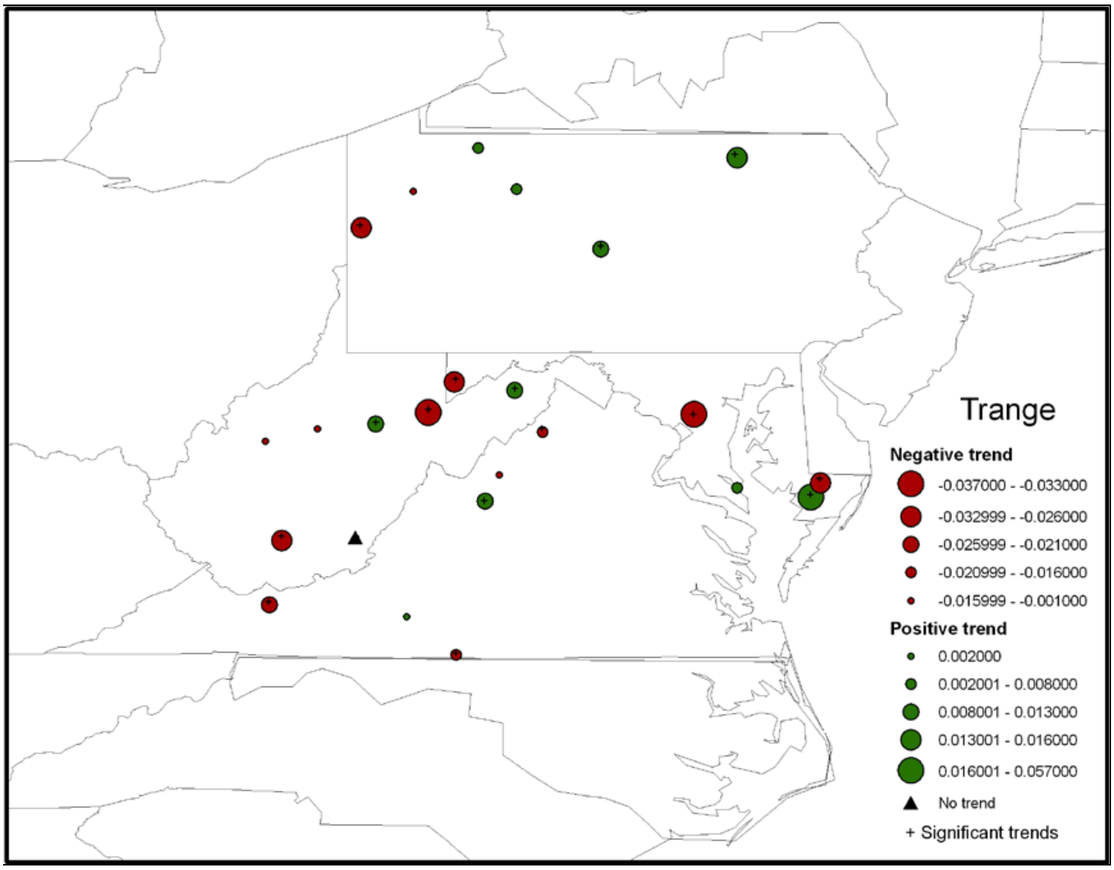

Figure 4-25 Spatial distribution of trends for binaural temperature range.

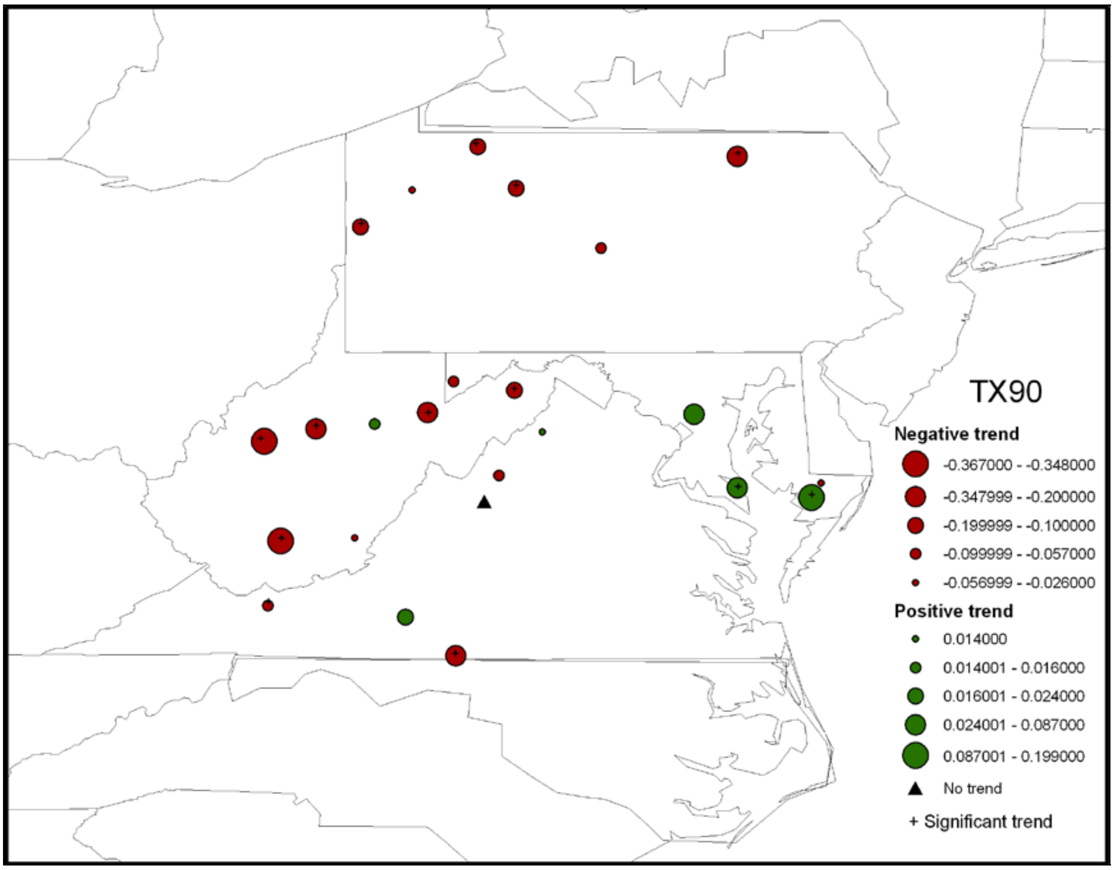

Figure 4-26 Spatial distribution of trends for TX90 (warm days).

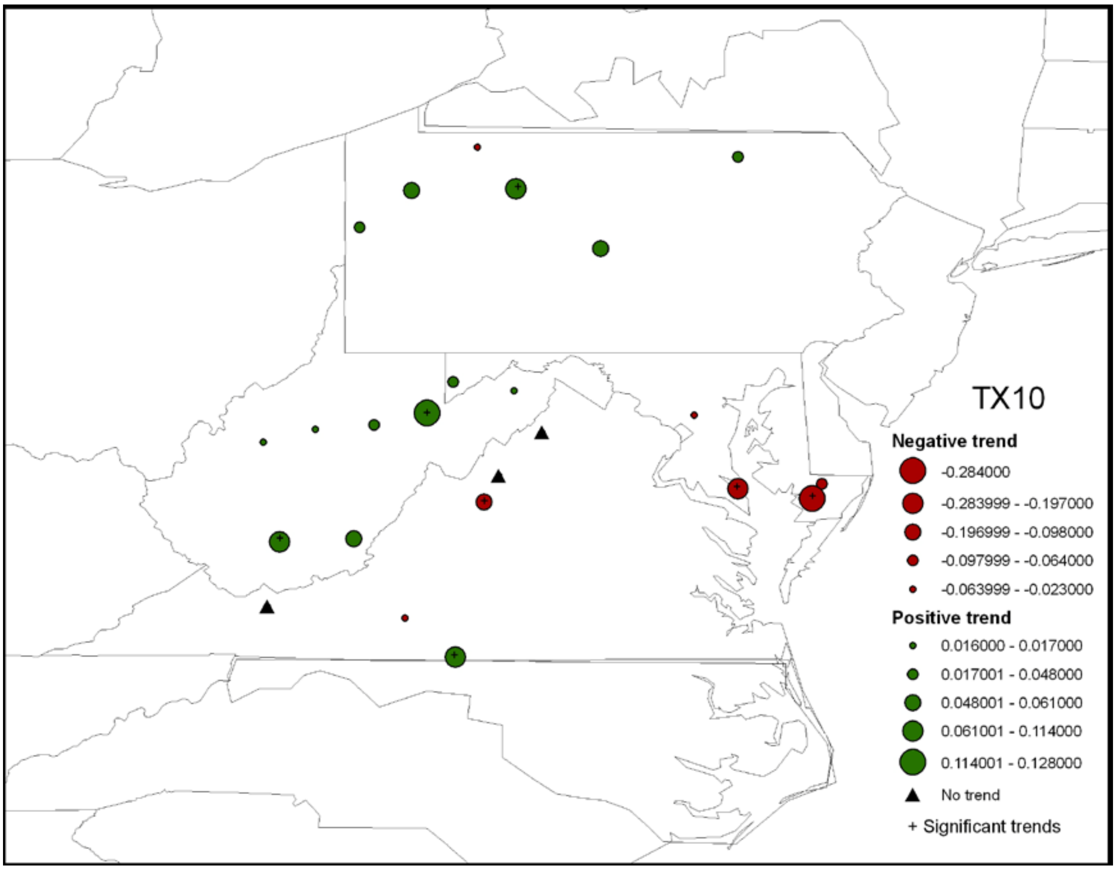

Figure 4-27 Spatial distribution of trends for TX10 (cool days).

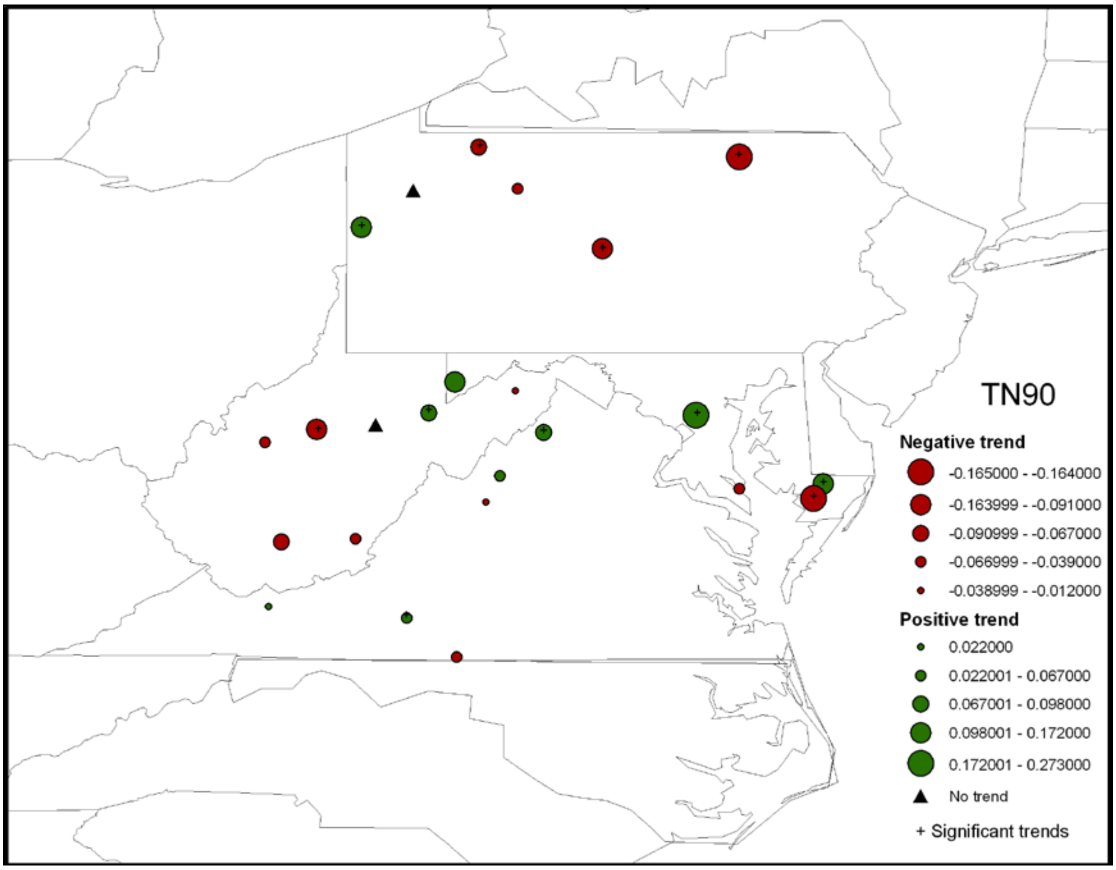

Figure 4-28 Spatial distribution of trends for TN90 (warm nights).

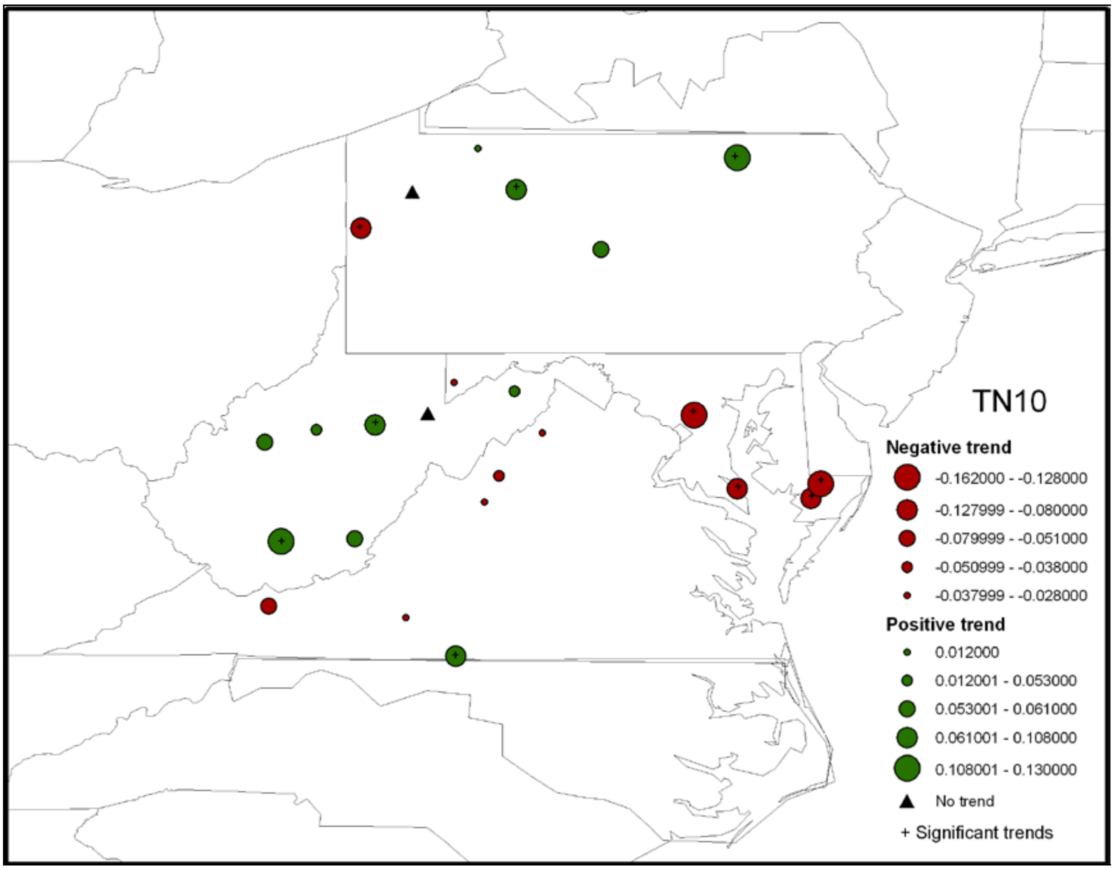

Figure 4-29 Spatial distribution of trends for TN10 (cool nights).

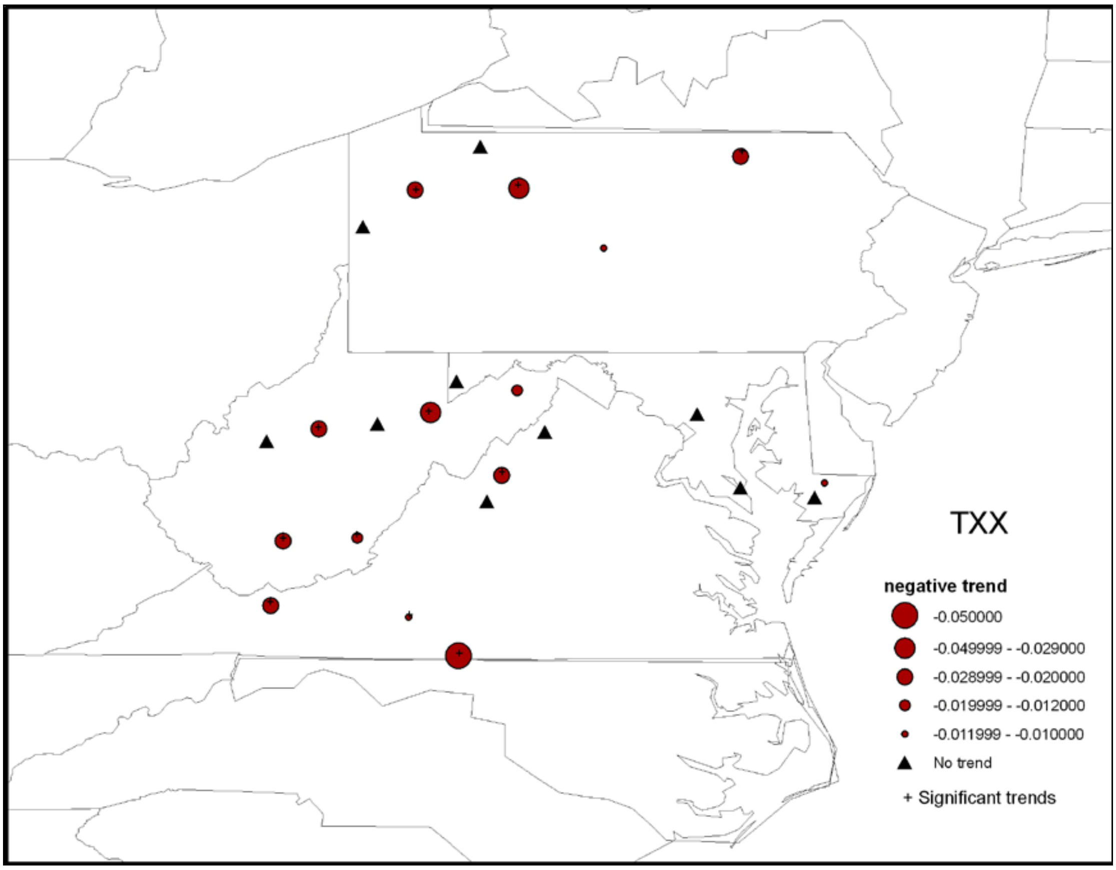

Figure 4-30 Spatial distribution of trends for maximum annual maximum temperature.

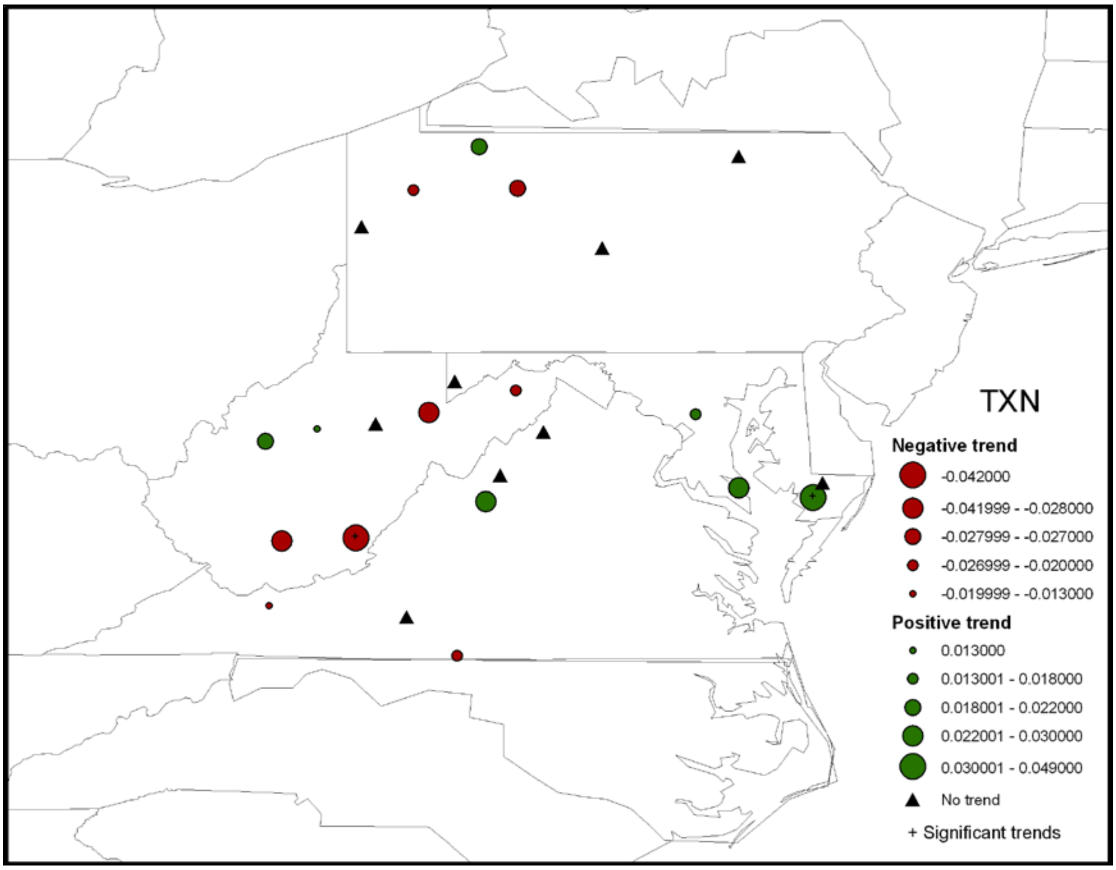

Figure 4-31 Spatial distribution of trends for minimum annual maximum temperature.

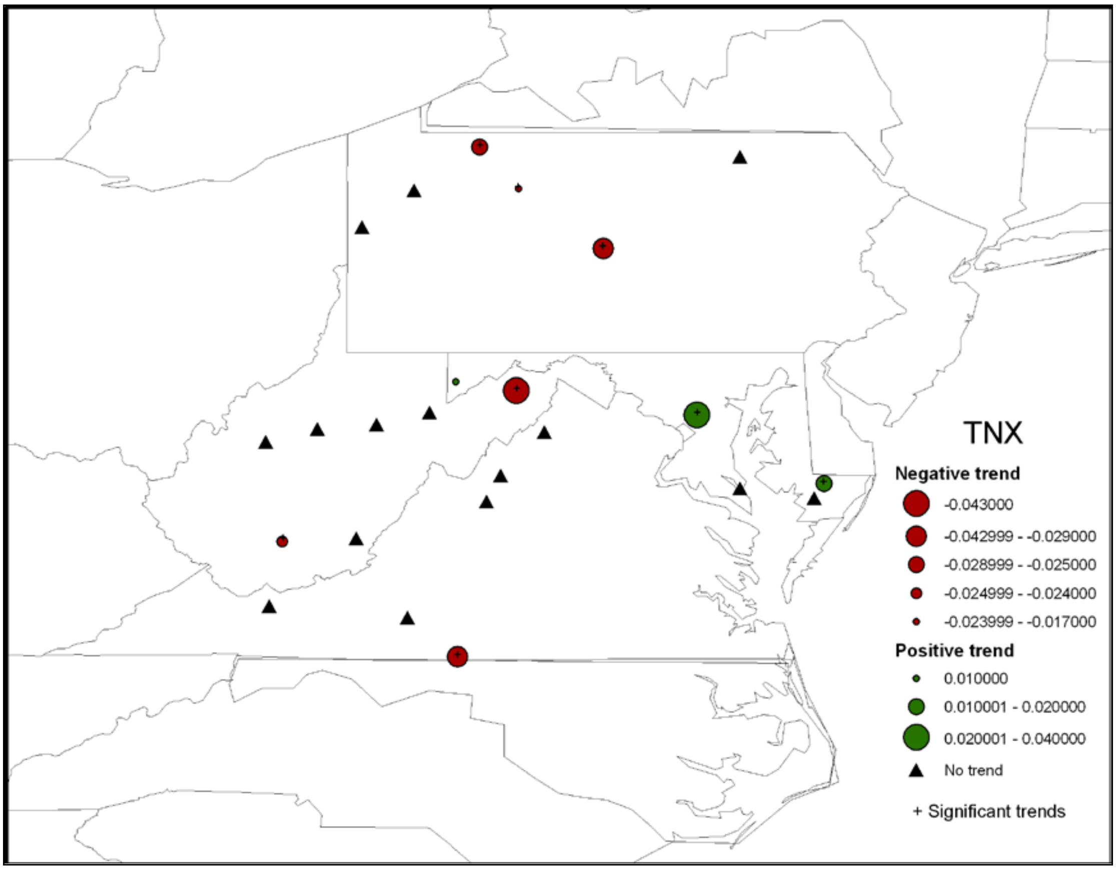

Figure 4-32 Spatial distribution of trends for maximum annual minimum temperature.

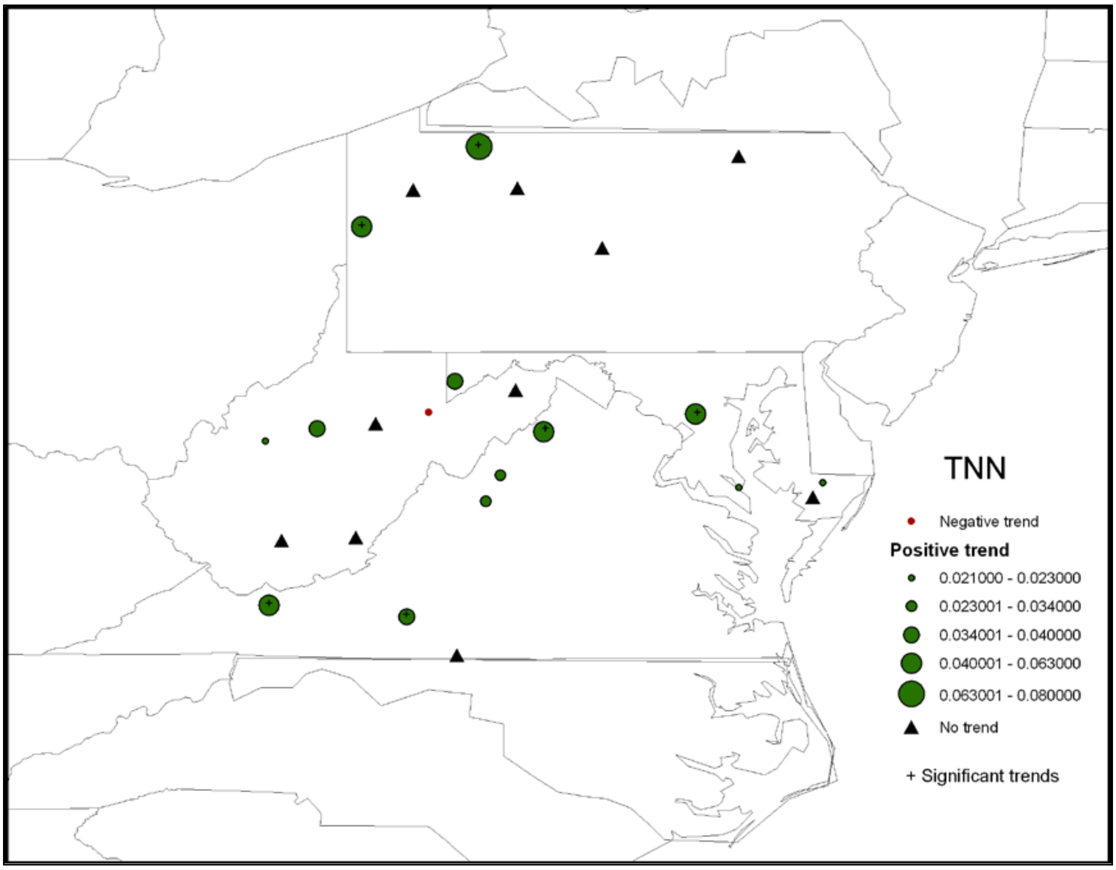

Figure 4-33 Spatial distribution of trends for minimum annual minimum temperature.

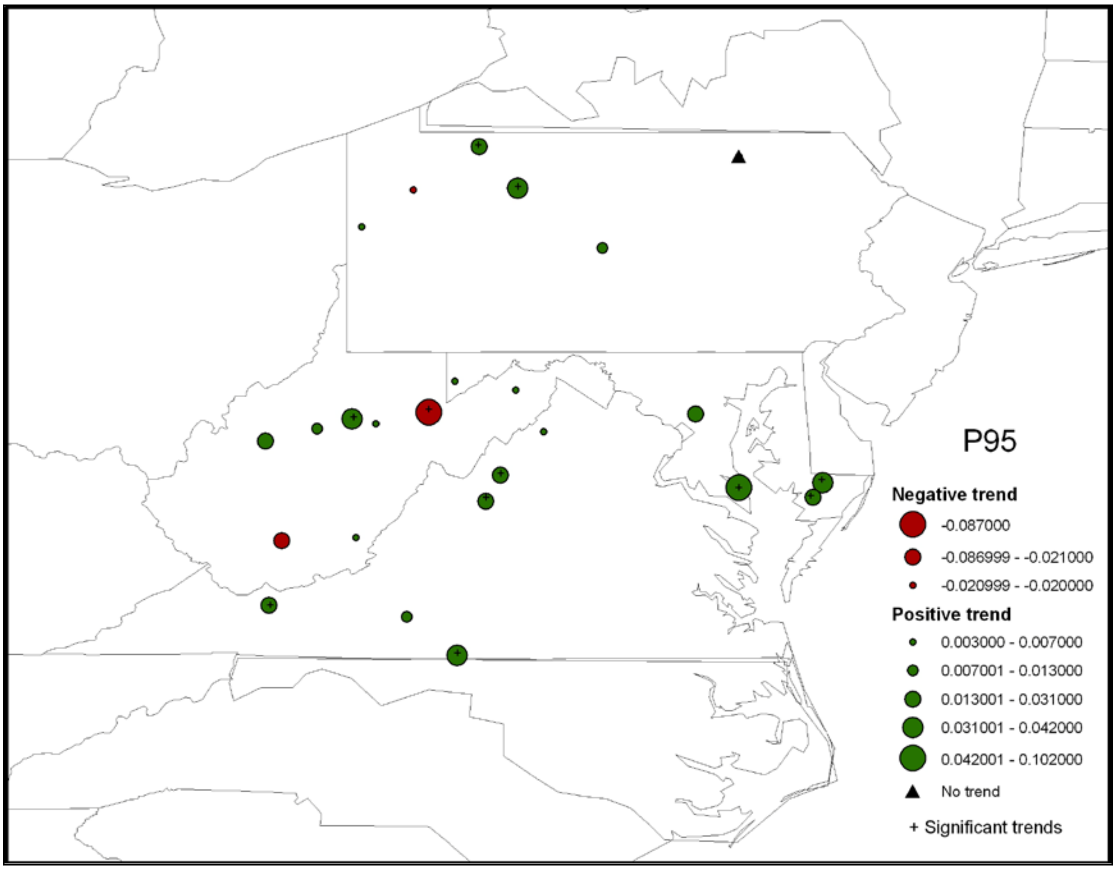

Figure 4-34 Spatial distribution of trends for annual total precipitation exceeding 95th percentile.

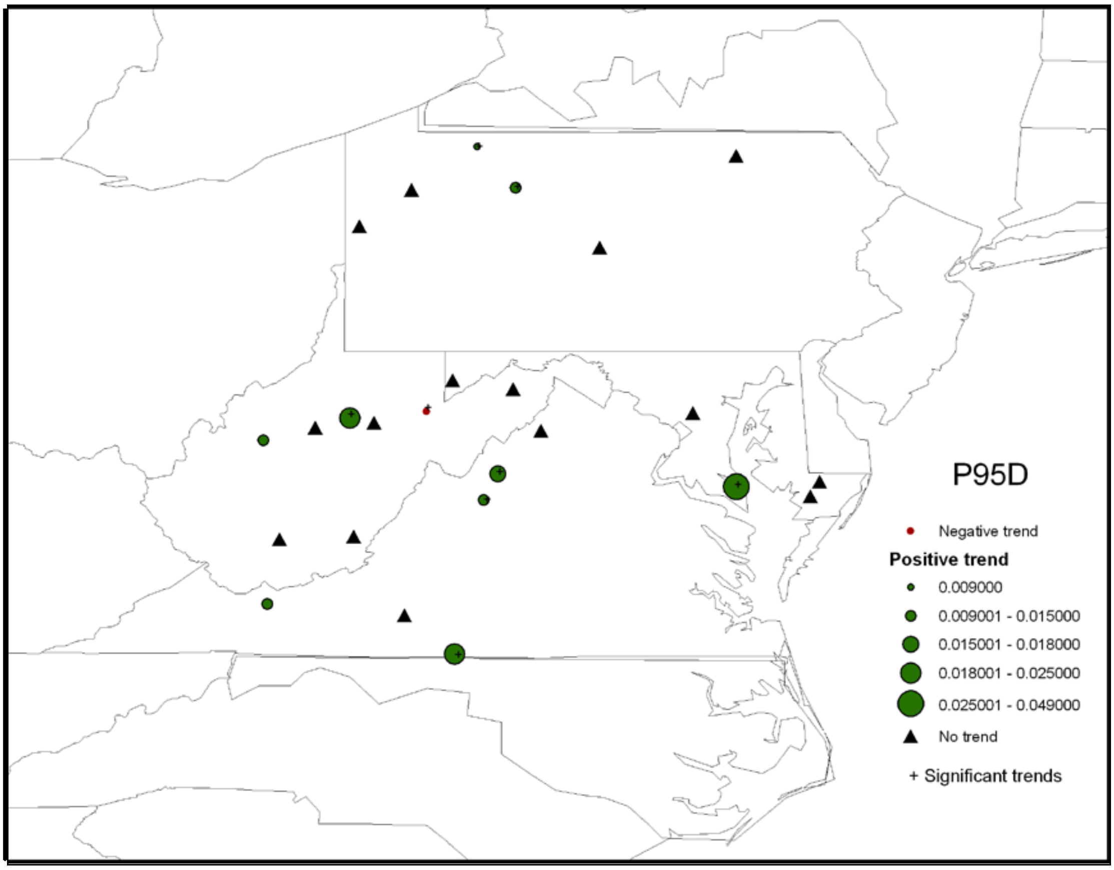

Figure 4-35 Spatial distribution of trends for annual total days with precipitation exceeding 95th percentile.

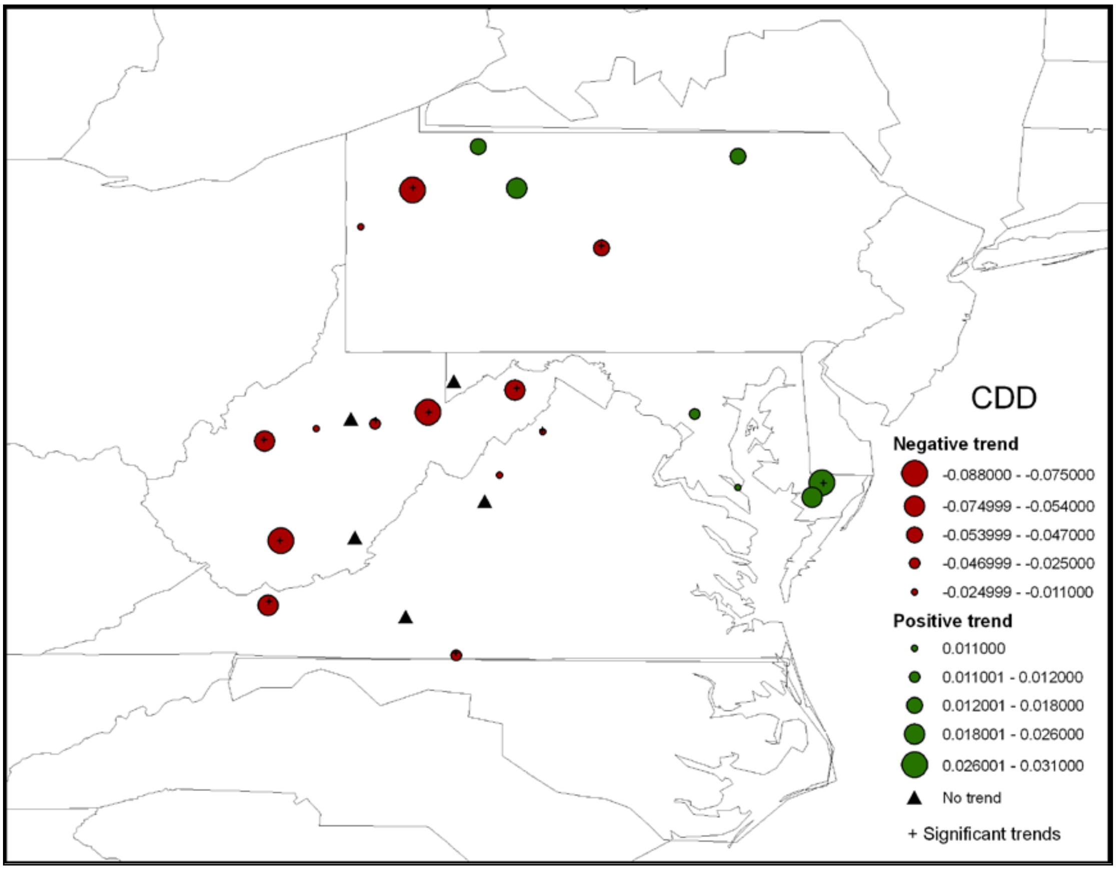

Figure 4-36 Spatial distribution of trends for consecutive dry days.

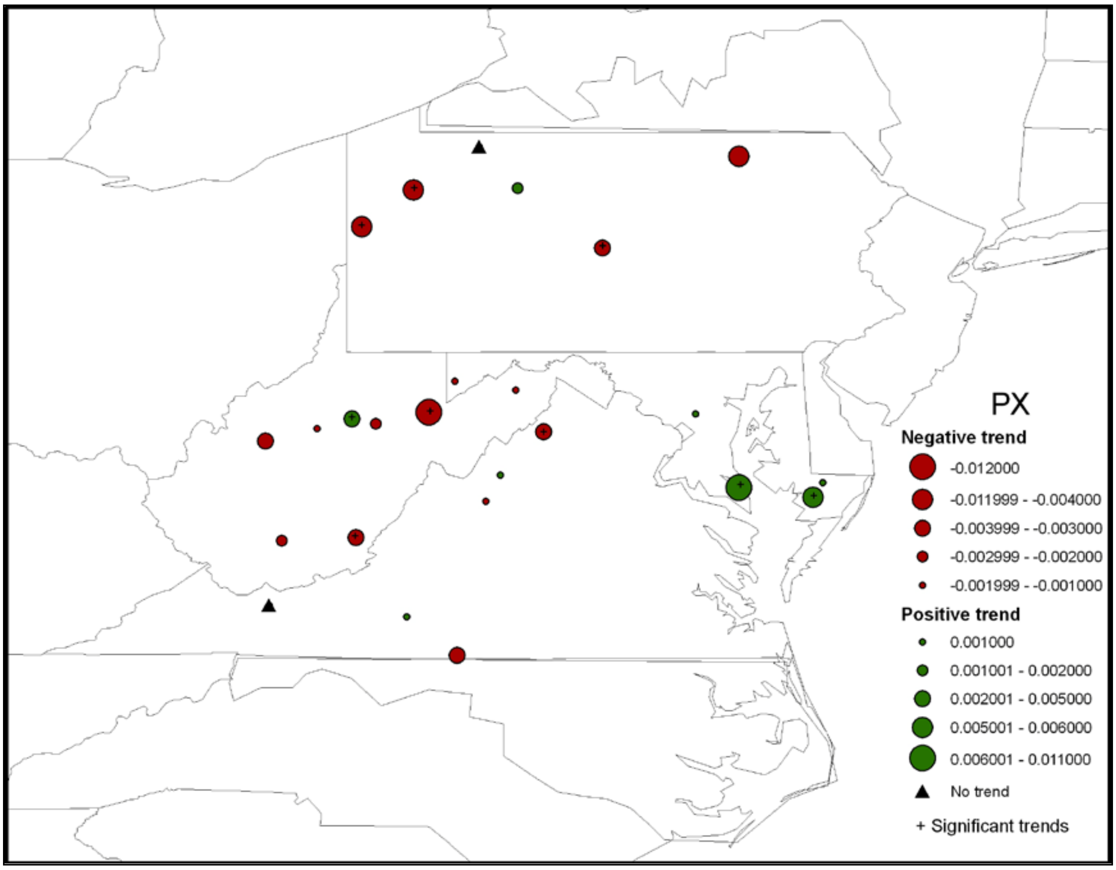

Figure 4-37 Spatial distribution of trends for maximum annual precipitation intensity.

Chapter 5 Discussion and Conclusion

To summarize, a focus has been placed on analyzing the long-term trend (100 years) of climate variables for the Mid-Atlantic Region. Average slope of -0.015 ºF/yr in changes for annual mean temperature was detected for inland stations and 0.021 ºF/yr for coastal stations. Average slope for annual maximum temperature and annual minimum temperature are -0.019 ºF/yr and -0.006 ºF/yr for inland stations and 0.037 ºF/yr and 0.037 ºF/yr for coastal stations. Although the frequency of extreme temperature events did not show significant increase, the magnitude increased 5.5 ºF over the century for all stations for parameter TNN and 3.5 ºF for coastal stations for parameter TNX. Annual precipitation exceeding the 95th percentile increased 0.028 inch per year with a more pronounced increases in the coastal area of 0.056 inch per year. The number of days with precipitation exceeding the 95th percentile also increased by a rate of 0.014 d/yr.

The results showed great variation among stations. There was a clear discrepancy between coastal stations and inland stations. For most parameters, coastal stations showed opposite results with the stations away from the coast. We could see clearly increasing trends for annual temperatures for the four stations located in Maryland. As well as for the extreme temperature events, the stations showed increased warm days/nights corresponding with decreased cool days/nights. Increasing maximum intensity is observed in coastal stations also compared with negative trends or no trends for the inland stations. Increasing trends in cumulative dry days were also shown in the coastal stations while not much of a change in the inlands. One of the possible reasons of the results could the larger population and faster growth rate at the coastal stations than inland stations. Study suggested rapid urbanization could influence linear trend of temperatures (Englehart and Douglas 2003). Other authors also found this kind of discrepancy between coastal areas and inlands (El Kenawy et al. 2009). They suggested a close relation between air temperature near the coastal with sea surface temperature. Trends for sea surface temperature found in the Northwest Atlantic: between 1961 and 1990 warmed as much as 2.6°C off the mouth of the Chesapeake Bay, and cooled as much as 5°C north of Newfoundland. The Gulf Stream and the North Atlantic Current carry water warmer than average, as indicated by positive anomalies (Lemos and Sanso 2009).

Our seasonal results were consistent with our annual results. Significant difference was only found for warm days during winter season. Annual trends and summer trends mostly showed decreasing trends while winter showed increasing trends. This might indicated milder winter. Correspondingly, temperature for coldest nights which mainly occur in winter time showed no decreasing trends as well. One of the possible explanations for milder winter could be the North Atlantic Oscillation. The greatest climatic influence of the NAO is in the winter half of the year. Positive NAO pushes mild air across Europe and into Russia as well as the strong westerly flow tends to bring mild winter to much of North America (Burroughs 2007).

The changing rate for cool days seemed to be more dramatic at higher elevations as well as for the annual minimum maximum temperature. At stations with higher elevation, results showed more cool days and lower night temperature. Researchers also found similar results at the northwest of America. Largest warming trends rates occurred at lower elevations and smallest warming rates occurs in the Rockies (Mote 2003). Slopes of annual precipitation amount exceeding 95th percentile at lower elevation stations tended to be positive and negative at higher elevations. Similar decreasing distributions from low elevation stations to high elevation stations were found for annual maximum precipitation intensity. The difference between each elevation group could be partly explained by the warming trend in coastal area and cooling trends in inland area. Our study condition differed from other researches in Europe and China. They have much higher elevation level, more than 1000 m. As snow cover is a much import factor there, snow-albedo is used to explain the trend from low elevation to high elevation.

It would be inappropriate to state that the observed trends in air temperature and precipitation in the Mid-Atlantic Region have occurred as a consequence of climate change. Moreover, although both temperature and precipitation trends showed dependency on elevation to some degree, other factors might also have influences on trend attribution. Future study must be done to include influences of all possible factors.

In accordance with the global trends, most studies found significant warming trend during the second half of the 20th century. Studies showed two main periods of significant changes from 1900 to 1940 and 1970 to 2000. Differences between each period may compensate each other which results in no trend or none significant trend over the 100-year period. Cumulative deviation approach can be included in future study to detect different changing periods from the entire time frame (Tecer et al. 2009). Furthermore, in future study, all four seasons will be analyzed to get complete understanding of seasonal trends and which season is mainly exposed to changes in climatic parameters.

Regional trends were not found in this study. One of the possible reasons for failing the χ^2 test is that the number of the stations is not sufficient enough to cover the whole region. In order to study regional trend in the future, increased density of stations are required to get convincing results. Our study is the first look of the available data, more work are needed to justify the results.

For future study, we also plan to develop the relation between climate change and water resources. In particular, a systematic examination of how water availability in terms of both quantity and quality change with climate. Recent studies have been using dynamical downscaling with a regional climate model (RCM) driven by a general circulation models (GCMs) to simulate climate change scenarios. The simulated results were used to drive hydrology models or water quality models to study the impacts of climate. Results showed that most water parameters including physicochemical basic parameters, micropollutants and biological parameters has been affected by changing in temperature as well as precipitation. We would like to use historical data of hydrology and water quality together with climatic data to develop more direct relations. Numerical relations could be developed between temperature and precipitation trends with water quality trends excluding other affecting factor. Paired correlation test could be done to study the relationship between water quality parameters and climatic parameters. Water quality data could be compared after and before the indentified extreme weather events. Sensitivity of the response of the water body to climate change could also be studied using Structure Equation Model (SEM). Two latent growth curves, one for changes in climatic parameters and the other for changes for water quality can be used to test the hypothesis of the relationship between these two types of variables. All these approaches could be used to develop conceptual model for climate change impacts on water availability and quality.

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