Trends of Air Temperature, Precipitation and Potential Evapotranspiration in Southeastern United States and East-central China

THESIS

Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University

By

Yiming Zhao

Graduate Program in Environmental Science

The Ohio State University

2015

Master's Examination Committee:

Dr. Rattan Lal, Advisor

Dr. Brian Slater

Dr. Jialin Lin
Abstract

Human beings are increasing emissions of greenhouse gases, inducing the anthropogenic climate change. Climate change influences the air temperature as well as the hydrological cycle globally. In the background of climate change, previous research indicated different trends of air temperature, precipitation and evapotranspiration in the southeastern United States (SUS) and east-central China (ECC). This study’s objective is to compare the trends of air temperature, precipitation and potential evapotranspiration in the SUS and the ECC, and the impacts of climatic variables on these two regions. The data for analyzing the trends of air temperature, precipitation and potential evapotranspiration are from 6 stations in 3 states (Fairhope 2 NE, AL; Mobile Regional Airport, AL; Montgomery Airport, AL; Alma Bacon Co Airport, GA; Toccoa, GA; Meridian Key Field, MS) in the SUS and 6 stations in 3 provinces (Lushi, Henan; Xinyang, Henan; Anqing, Anhui; Wuhan, Hubei; Yichang, Hubei; Bengbu, Anhui) in the ECC. The results from observed data of these 12 stations indicated that: most of the stations in the SUS did not show significantly decreased trends of air temperature during 1931–2013, while most of the stations in the ECC showed significantly increased trends of air temperature during 1951–2013; no significant trend was found in the SUS during 1931–2013 or in the ECC during 1951–2013. Very few stations in the SUS showed significant potential evapotranspiration trend during 1931–2013 but most of the stations in the ECC showed significantly increased trends of potential evapotranspiration during 1951–2013.
To analyze the different impacts of large-scale climatic variables on the air temperature, precipitation and potential evapotranspiration in the SUS and the ECC, 7 climatic variables (North Atlantic Oscillation, Arctic Oscillation, North Pacific Index, Southern Oscillation Index, Atlantic Multidecadal Oscillation, Pacific Decadal Oscillation, Niño 3.4 SST Index) were selected to obtain their correlations in these two regions. No significant cooling trend is found in the weather stations selected in the southeastern United States during 1951–2013. Stepwise multiple linear regression (SMLR) models are employed to reveal the impacts of the large-scale climatic variables on the variance of the monthly air temperature in these two regions. All 7 climatic variables selected for the regression models are linked to more than 75% of the variance in both the SUS and the ECC. In both regions, the North Pacific Index, the Atlantic Multidecadal Oscillation and the Niño3.4 Index explain most of the variance, in which North Pacific Index contributes to the variance most. The predicted annual air temperature in the SUS also shows no significant trend in cooling during 1950–2013, however, in both the SUS and the ECC, a rapidly increasing trend in predicted annual air temperature is significant (0.041 °C/yr in the SUS and 0.056 °C/yr in the ECC, with 95% confidence) over the 40 years between 1974 and 2013.

Scarcely significant trend of annual total precipitation is observed in the weather stations selected in the SUS and the ECC during 1951–2013. The weather stations selected in the ECC are more likely to have increasing potential evapotranspiration trends than those in the SUS during 1949–2013. SMLR models can’t explain most of the variance of the monthly total precipitation in both regions (1.3% in the SUS and 24.5% in the ECC).
Conversely, all 7 climatic variables selected for the regression models are linked to more than 72% of the variance of monthly total potential evapotranspiration in both regions. The North Pacific Index, the Atlantic Multidecadal Oscillation and the Niño3.4 Index explain most of the variance in both regions. The predicted annual total potential evapotranspiration in the SUS during 1950–2014 and ECC during 1951–2014 shows no significant trend, however, a rapidly increasing trend in predicted annual total potential evapotranspiration is significant in both regions (3.975 mm/yr in the SUS and 4.312 mm/yr in the ECC, with 95% confidence) during 1974–2013.

To minimize the potential threats of increased air temperature and potential evapotranspiration predicted in this research, mitigation and adaptation measurements should be taken to protect the ecology in these two regions, especially the forestry in the SUS and agricultural production in the ECC.
Acknowledgments

I want to thank Dr Rattan Lal, my advisor, for his advice he gave during these two years I worked as an MS student here in the Ohio State University. Also, I would like to thank Dr Jialin Lin and Dr Brian Slater, whose suggestions helped me much in my thesis. My gratitude also goes to Dr Jeffery Rogers for his help in providing the dataset of NPI and other helps in regression analysis. I also appreciate Dr Jiangyong Yin for his helpful advice in statistical analysis.

Thanks to National Climatic Data Center and China Meteorological Data Sharing Service System for the data used in this thesis.

I also want to thank all the members in the CMASC, I feel like being in a family in these two years here. Thanks to my family, without your help, I will not be myself today.
Vita

January 11, 1991....................................................Born in Zibo, China

July 2005..............................................................B.S. (Agricultural Resources and Environment), Zhejiang University

Fields of Study

Major Field: Environmental Science
Table of Contents

Abstract ........................................................................................................................................ ii
Acknowledgments ....................................................................................................................... v
Vita ................................................................................................................................................. vi
List of Tables ................................................................................................................................... viii
List of Figures ............................................................................................................................... xi
Chapter 1: Introduction .................................................................................................................. 1
Chapter 2: Air Temperature Trends in the SUS and the ECC ......................................................... 21
Chapter 3: Precipitation Trends in the SUS and the ECC .............................................................. 44
Chapter 4: Potential Evapotranspiration Trends in the SUS and the ECC ................................. 67
Chapter 5: The Recent Temperature Trends and Variance in the SUS and the ECC .............. 91
Chapter 6: The Recent Precipitation and Potential Evapotranspiration Trends and Variance in the SUS and the ECC ......................................................................................... 114
Chapter 7: Discussion and Conclusion ....................................................................................... 143
Bibliography ................................................................................................................................. 158
Appendix : List of Acronyms ....................................................................................................... 178
List of Tables

Table 1. Basic information of the weather stations selected in the SUS for air temperature ................................................................................................................................. 25

Table 2. Basic information of the weather stations selected in the ECC for air temperature ................................................................................................................................. 26

Table 3. Trends of air temperature of the weather stations selected in the SUS and the ECC ................................................................................................................................. 41

Table 4. Basic information of the weather stations selected in the SUS for precipitation 48

Table 5. Basic information of the weather stations selected in the ECC for precipitation 49

Table 6. Trends of precipitation of the weather stations selected in the SUS and the ECC ................................................................................................................................. 64

Table 7. Basic information of the weather stations selected in the SUS for potential evapotranspiration ................................................................................................................................. 72

Table 8. Basic information of the weather stations selected in the ECC for potential evapotranspiration ................................................................................................................................. 73

Table 9. Trends of potential evapotranspiration of the weather stations selected in the SUS and the ECC ................................................................................................................................. 87

Table 10. Basic information of the weather stations selected in the SUS for air temperature analysis ................................................................................................................................. 95
Table 11. Basic information of the weather stations selected in the ECC for air temperature analysis

Table 12. Large-scale climatic variables used in air temperature analysis

Table 13. The annual average mean air temperature trends for the 12 weather stations in the SUS and the ECC during 1951–2013

Table 14. Constants, regression coefficients and adjusted variance ($R^2$) from the SMLR for the monthly average mean air temperature in the SUS and the ECC

Table 15. Correlation coefficients between the predicted and observed values and the residual and observed values of the monthly average mean air temperature from the SMLR results for the SUS and the ECC

Table 16. Basic information of the weather stations selected in the SUS for precipitation and potential evapotranspiration analysis

Table 17. Basic information of the weather stations selected in the ECC for precipitation and potential evapotranspiration analysis

Table 18. Large-scale climatic variables used in precipitation and potential evapotranspiration analysis

Table 19. The annual total precipitation trends for the 12 weather stations in the SUS and the ECC during 1951–2013

Table 20. The annual total potential evapotranspiration trends for the 12 weather stations in the SUS during 1949-2013 and the ECC during 1951–2013

Table 21. Constants, regression coefficients and adjusted variance ($r^2$) from the SMLR for the monthly total precipitation in the SUS and the ECC
Table 22. Constants, regression coefficients and adjusted variance (r^2) from the SMLR for the monthly total potential evapotranspiration in the SUS and the ECC .......... 128

Table 23. Correlation coefficients between the predicted and observed values and the residual and observed values of the monthly total precipitation from the SMLR results for the SUS and the ECC ........................................................................................................................................... 130

Table 24. Correlation coefficients between the predicted and observed values and the residual and observed values of the monthly total potential evapotranspiration from the SMLR results for the SUS and the ECC ........................................................................................................................................... 130
List of Figures

Figure 1. Locations of the weather stations selected in the SUS for air temperature ...... 25
Figure 2. Locations of the weather stations selected in the ECC for air temperature ...... 26
Figure 3. Trends in temperature in Fairhope 2 NE ......................................................... 27
Figure 4. Trends in temperature in Mobile Regional Airport ............................................ 28
Figure 5. Trends in temperature in Montgomery Airport ................................................. 29
Figure 6. Trends in temperature in Alma Bacon Co Airport ............................................ 30
Figure 7. Trends in temperature in Toccoa ........................................................................ 31
Figure 8. Trends in temperature in Meridian Key Field .................................................... 32
Figure 9. Trends in temperature in Lushi .......................................................................... 33
Figure 10. Trends in temperature in Bengbu ...................................................................... 34
Figure 11. Trends in temperature in Anqing ...................................................................... 35
Figure 12. Trends in temperature in Wuhan ...................................................................... 36
Figure 13. Trends in temperature in Yichang .................................................................... 37
Figure 14. Trends in temperature in Xinyang .................................................................... 38
Figure 15. Locations of the weather stations selected in the SUS for precipitation and potential evapotranspiration ................................................................................. 48
Figure 16. Locations of the weather stations selected in the ECC for precipitation and potential evapotranspiration ................................................................................. 49
Figure 17. Trends in precipitation in Fairhope 2 NE .......................................................... 50
Figure 18. Trends in precipitation in Mobile Regional Airport........................................ 51
Figure 19. Trends in precipitation in Montgomery Airport........................................ 52
Figure 20. Trends in precipitation in Alma Bacon Co Airport.................................... 53
Figure 21. Trends in precipitation in Toccoa............................................................... 54
Figure 22. Trends in precipitation in Meridian Key Field.......................................... 55
Figure 23. Trends in precipitation in Lushi ................................................................. 56
Figure 24. Trends in precipitation in Bengbu.............................................................. 57
Figure 25. Trends in precipitation in Anqing............................................................... 58
Figure 26. Trends in precipitation in Wuhan.............................................................. 59
Figure 27. Trends in precipitation in Yichang............................................................. 60
Figure 28. Trends in precipitation in Xinyang............................................................. 61
Figure 29. Locations of the weather stations selected in the SUS for potential evapotranspiration................................................................. 72
Figure 30. Locations of the weather stations selected in the ECC for potential evapotranspiration................................................................. 73
Figure 31. Trends in potential evapotranspiration in Fairhope 2 NE ......................... 74
Figure 32. Trends in potential evapotranspiration in Mobile Regional Airport ............. 75
Figure 33. Trends in potential evapotranspiration in Montegomery Airport................. 76
Figure 34. Trends in potential evapotranspiration in Alma Bacon Co Airport............... 77
Figure 35. Trends in potential evapotranspiration in Toccoa....................................... 78
Figure 36. Trends in potential evapotranspiration in Meridian Key Field.................... 79
Figure 37. Trends in potential evapotranspiration in Lushi......................................... 80
Figure 38. Trends in potential evapotranspiration in Bengbu................................. 81
Figure 39. Trends in potential evapotranspiration in Anqing................................. 82
Figure 40. Trends in potential evapotranspiration in Wuhan ................................ 83
Figure 41. Trends in potential evapotranspiration in Yichang ............................... 84
Figure 42. Trends in potential evapotranspiration in Xinyang ............................... 85
Figure 43. Locations of the weather stations selected in the SUS for air temperature analysis........................................................................................................... 95
Figure 44. Locations of the weather stations selected in the ECC for air temperature analysis....................................................................................................... 96
Figure 45. a Diagnosed annual average mean air temperature for the SUS (1950–2013) and the ECC (1951–2013); b same as a, but for the 1974–2013 in the SUS and the ECC ........................................................................................................................................ 105
Figure 46. Locations of the weather stations selected in the SUS for precipitation and potential evapotranspiration analysis........................................................................ 118
Figure 47. Locations of the weather stations selected in the ECC for precipitation and potential evapotranspiration analysis........................................................................ 119
Figure 48. a Diagnosed annual total potential evapotranspiration for the SUS (1950–2013) and the ECC (1951–2013); b same as a, but for the 1974–2013 in the SUS and the ECC ........................................................................................................................................ 132
Figure 49. Diagnosed annual total potential evapotranspiration for the SUS (1950–1989) and the ECC (1951–1990) ........................................................................................................... 135
1.1 Anthropogenic Impacts on Global Climate

Human activities are changing the atmospheric concentration of radiatively important gases and aerosols by increasing emissions and altering land surface properties, thus affecting the Earth’s energy budget (Stocker et al., 2013). Greenhouse gases such as carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}), and nitrous oxide (N\textsubscript{2}O) are transparent to solar shortwave radiation, but they absorb longwave radiation emitted from Earth, thus keeping heat in the atmosphere. CH\textsubscript{4} and N\textsubscript{2}O have the values of a global warming potential of 28 and 265 for 100 years, respectively (Stocker et al., 2013). With no greenhouse gas in the atmosphere, the Earth’s surface temperature would be about -19° C, which is 33° C colder than the current average of roughly 14° C (Le Treut et al., 2007).

The concentration of greenhouse gases in the atmosphere is profoundly influenced by human activities. Ruddiman (2003) stated that the natural cyclic variations of CO\textsubscript{2} and CH\textsubscript{4} have been changed over the past 8,000 and 5,000 years, respectively, when humans increased their concentrations by deforestation and early agricultural development like rice irrigation. Ruddiman (2003) suggested that the increased concentrations of CO\textsubscript{2} and CH\textsubscript{4} in the atmosphere before the industrial era were about 40 ppm and 250 ppb, respectively. The hypothesis that the Anthropocene began 8,000 years ago is, however, challenged by Broecker and Stocker (2006) who claim that the increasing CO\textsubscript{2}
concentration was induced by a natural process of the ocean carbonate chemistry rather than deforestation and development in agriculture before the industrial era. Thus, the statement that the advent of the Anthropocene was 8,000 years ago is in question. But one thing is certain: the influence of human beings on Earth’s system has dramatically increased since the Industrial Revolution. The wide use of coal, oil, and natural gas; the vast construction of infrastructure; heavy deforestation; rapid urbanization; and the advanced development of the agriculture and livestock sector have all led to a greater emission of greenhouse gases. The concentration of CO$_2$ in the atmosphere rose by about 50 ppm during from 1830 to 1980 (Etheridge et al., 1996) and is still rapidly increasing. The N$_2$O concentration also reached approximately 293 ppb around 1965 compared with the pre-industrial value of about 276 ppb on average (Machida et al., 1995). The CH$_4$ concentration increased from roughly 741 ppb at 1800 to more than 1700 ppb at the end of the twentieth century (Etheridge et al., 1998). Air temperature has increased since the late nineteenth century and accelerated since the 1970s globally (Stocker et al., 2013). The late twentieth century was the warmest among the past four centuries (Brumfiel, 2006), and with the evidence above, it is reasonable to say that anthropogenic factors are important to the warming Earth.

The impacts of anthropogenic climate change on climatic phenomena are apparent. For instance, the tropical easterly trade winds have weakened in the Pacific region (Collins et al., 2010). The anthropogenic climate change also influences the global hydrological cycle because more water vapor is in the air with warmer air temperatures under the Clausius-Clapeyron relation (Huntington, 2006). The global land-based hydrological
cycle is expected to intensify due to the impacts of the greenhouse effect (Wild et al., 2008). A model study based on the IS92a scenario showed that by 2050, global mean precipitation and evapotranspiration would both increase by 5.2% (Wetherald and Manabe, 2002). Observations show that both precipitation and evaporation increased at a rate of 6% K⁻¹ with the increasing air temperature (Wentz et al., 2007).

The mean annual air temperature of the Arctic is increasing at a rate two times as large as the global mean annual air temperature increasing rate from 1970 to 2008 (Chylek et al., 2009). The warming air temperature also induces the glaciers to melt, which has significant impacts, including a rise in sea level. Complete melting of ice sheets would cause a 70m worldwide sea level rise (Rahmstorf, 2007). The global mean sea level rose at a rate of 3.4 mm/yr from 1993 to 2008 (Ablain et al., 2009). Rahmstorf (2007) predicted that by 2100 the sea level would rise between 0.5m to 1.4m compared to the 1990 level.

In addition to ice melting, other impacts will occur in Arctic areas due to climate change. Around the Arctic region, the permafrost zone stores approximately 1700 Pg of soil carbon, a carbon pool with more than twice the amount of carbon of that of the atmosphere (Schuur et al., 2008). Increasing air temperature is significantly and positively correlated with the global increase of soil respiration, which means more soil carbon degradation and more soil CO₂ emission (Bond-Lamberty and Thomson, 2010). In addition, water-saturated soils are common in the permafrost areas around the Arctic, and these soils have abundant soil carbon and are prone to anaerobic organic matter processes and CH₄ production (Knoblauch et al., 2008). Olefeldt et al. (2013) suggested
that CH₄ flux was significantly promoted by warmer soil temperatures, and the wetter ecosystems in the permafrost zone were more sensitive to changing temperatures than drier ecosystems. Another research on CH₄ fluxes in Alaska demonstrated that soil temperature was the best predictor of CH₄ emission, explaining 89% of the variability in CH₄ flux (Zona et al., 2009). The increasing CH₄ production in permafrost areas is associated with the methanogenic archaea, increasing overall abundance and biodiversity with increasing temperature (Høj et al., 2008). Generally, increasing temperatures in Arctic soils, having synergistic effects with moisture, promote methane emission, and an 80–300% seasonal increase could be observed with wetter soils and more moisture (Turetsky et al., 2008). Koven et al. (2011) predicted that CH₄ emission in the near Arctic permafrost soils would increase by 7 to 36 Tg CH₄/yr at the end of the twenty-first century. The anthropogenic climate change will be exacerbated if more soil carbon in the permafrost areas around the Arctic is released to the atmosphere in the form of CO₂ or CH₄.

1.2 Agriculture in China and the United States in the Background of Climate Change

East Asian monsoons are also influenced by global warming. Both summer and winter monsoons in East Asia are expected to weaken under the conditions of global warming (Hu et al., 2000; Hori and Ueda, 2006; Ueda et al., 2006). The climate in China is characterized by East Asian monsoons (Qian and Zhu, 2001). In this way, global warming has impacted the climate in China. Climate variations have played an important role in the history of China. The demise of the Tang, Yuan, and Ming Dynasties were marked by weak summer monsoons, linking
the falls of the dynasties to climate shifts (Zhang et al., 2008). Changes in climate, which adversely affect the agricultural production in China, caused famine. Historically, hungry people rose up and overthrew the government, a common phenomenon during the last years of a dynasty. Agriculture, associated significantly with climate, influences the stability of human civilization economically and politically. It is expected that climate change will favor the agricultural production in developed countries while hurting the agricultural production in developing countries, thus widening the disparities between the First and Third World (Fischer et al., 2005; Parry et al., 2004; Rosenzweig and Parry, 1994). By 2050, millions of additional people will be at risk of hunger (Parry et al., 2004). People who lack food will be an important source of waves of popular unrest in the future. Extreme climate events once were an important trigger of general global crises with more and prolonged revolts, wars, and conflicts during the seventeenth century (Parker, 2008).

The conditions for agricultural production in China are vulnerable. Approximately 20% of the world’s population is fed by 7% of the world’s cultivated land in China (Yao, et al., 2007). China’s agriculture is under the stress of land problems, water shortages, and increasing food demands (Smit and Cai, 1996). The effects of climate change on agricultural production in China are diverse and complicated. Lin et al. (2005) suggested that up to 37% of the corn, wheat, and rice production would diminish without the effect of CO\(_2\) fertilization in response to climate change. Chavas et al. (2009) stated that rice, rapeseed, corn, potatoes, and winter wheat yields will suffer 2.5%-12% declines under climate change conditions without CO\(_2\) fertilization in China.
Increasing CO₂ concentration in the atmosphere increases the rates of photosynthesis and suppresses stomatal openings, enhancing both photosynthesis and water use, and is therefore beneficial to plant growth (Parry et al., 2004). Rice yields in China are expected to increase with CO₂ fertilization (Yao et al., 2007). Chavas et al. (2009) suggested that potential yields in eastern China will increase by 24.9%, 8.3%, 18.6%, 6.5%, and 22.9% for winter wheat, rapeseed, corn, rice, and potatoes, respectively, considering the effect of expanded CO₂ fertilization.

Water availability, another important parameter in agricultural production in China, is also influenced by climate change. The drier North China has been suffering from decreasing precipitation since 1960, but precipitation has risen in the more moist South China, and the area exposed to floods increased by 88% from the 1970s to the 2000s (Piao et al., 2010). Wang et al. (2009) say global warming is expected to favor irrigated farms while harming rain fed farms. Tao et al. (2003) demonstrated that climate change would reduce water demand in agricultural production in South China; in contrast, North China agricultural water demand would increase, thus water stress in North China would be exacerbated. Moreover, the growing demand of non-agricultural uses of water as a consequence of economic development will also place a heavy burden on China’s water supply (Xiong et al., 2009; 2010).

Pests and plant diseases are also booming due to the impact of climate change. From the early 1970s to the mid-2000s, the area of cultivated land affected by pests increased from 100 Mha to 345 Mha, and the yearly grain damage caused by pests and plant diseases increased by more than 100% in China (Piao et al., 2010).
The effects of warming on crop yields are controversial. Liu et al. (2004) suggested that more rainfall and warmer temperatures would be generally beneficial to agricultural production in China, although regional disparities would occur—East China and South China would be favored by climate change while Southwest and Northwest China would be harmed. In the Huang-Hai Plain of China, higher nighttime temperatures and precipitation are expected to raise the winter wheat yield by 0.2 Mg ha\(^{-1}\) in the short term and by 0.8 Mg ha\(^{-1}\) in the long run (Thomson et al., 2006). However, Piao et al. (2010) suggested that nighttime warming would hurt winter wheat yield but be beneficial to the rice yield. Peng et al. (2004), on the other hand, suggested that a 10% decline of rice yield would follow each 1° C increase of minimum temperature in growing season. Adaptation measurements on sustainable techniques in agriculture could help limit the negative effects of climate change in China (Fischer et al., 2005; Xiong et al., 2009).

Agriculture in the United States is also influenced by climate change. Agricultural production in the United States is important to the world’s food supply with yields of 41% of the corn and 38% of the soybeans production worldwide (Schlenker and Roberts, 2009). The changes in yields of staple foods in the United States will lead to fluctuations of food prices in the global food market.

Warmer air temperatures affect the spread, reproduction, activities, and life span of pests and weeds. Damage caused by pests, plant diseases, and weeds is associated with climate change. Faster growth rates and fewer days between generations of insects could be induced by warmer temperatures (Rosenzweig et al., 2001). An increase of 2° C higher than normal temperatures is expected to alter the mountain pine beetle (Dendroctonus
ponderosae) from semivoltine to univoltine. In spring, the mountain pine beetle also has earlier activity in response to climate change in the United States (Tubiello et al., 2007). The geographical areas exposed to damage of pests, weeds, and plant diseases may expand with higher temperatures (Bentz et al., 2010; Rosenzweig et al., 2001; Patterson, 1995). From 1971 to 1998, the frontier of fields affected by soybean cyst nematode (Heterodera glycines) and soybean sudden death syndrome (Fusarium solani f. sp. glycines) moved greatly northwards (Rosenzweig et al., 2001). Bentz et al. (2010) suggested that climate change would facilitate bark beetles of appropriate air temperatures to move to higher latitudes. Some aggressive tropical or subtropical weed species, once limited to the southern United States, may spread northward due to warming temperatures, as Patterson suggested (1995). The important agricultural regions in the Great Plains were exposed to wheat scab, which, according to Rosenzweig et al. (2001), is associated with climate change.

The temporal and spatial distribution of water in the United States is also affected by climate change. Compared to the early twenty-first century, nationwide precipitation is predicted to increase between 17% to 23% by the end of the twenty-first century (Reilly et al., 2003). Corn yield would increase with more precipitation in the growing season, as Rosenzweig et al. suggested (2001). However, increasing precipitation could cause problems such as erosion and excessive soil moisture. The runoff in the midwestern United States is predicted to rise by 10% to 310% following a soil loss increase by 33% to 274% during the mid-2000s, compared to the late 1900s (O’Neal et al., 2005). Excessive moisture content in soil could negatively affect agricultural production. The
increased soil moisture, providing more water films and pores with water, promotes the spread of nematodes (Rosenzweig et al., 2001). By the 2030s, soil moisture excess is expected to induce an estimated 3 billion dollars in losses per year, according to Rosenzweig et al. (2002).

The overall effect of anthropogenic climate change on agriculture in the United States is opaque. The increased CO$_2$ concentration in the atmosphere favors forests and crops, but also weeds that could cause huge damage, which could lead to an increased use of chemicals in agriculture along with heavy economic and ecological losses (Kirilenko and Sedjo, 2007; Patterson, 1995; Rosenzweig et al., 2001; Tubiello et al., 2007). Yields of corn, soybean, and cotton rise with warming temperatures up to 29° C, 30° C, and 32° C, respectively, whereas temperatures in excess of such thresholds hurt these plants (Schlenker and Roberts, 2009). Lower yields of crops are the result of higher temperatures accelerating their growth and decreasing their water use efficiency (Brown and Rosenberg, 1997). Lobell and Field (2007) suggested that increasing temperatures led to an estimated global annual loss of $5 billion per year from 1981 to 2002 for maize, wheat, and barley.

Yield of rain-fed winter wheat is expected to decrease by 4%–30%, while irrigated winter wheat grain yield is expected to increase by 6%–25% by the 2090s relative to the late twentieth century in the United States; the trends in yields of maize are anticipated to be in reverse of those in yields of winter wheat—yields of rain-fed maize would rise while those of irrigated maize may drop (Tubiello et al., 2002). In California, research by Lobell, Field, Cahill, and Bonfils (2006) on the impact of climate change on wine grapes,
oranges, walnuts, almonds, table grapes, and avocados showed that with no CO$_2$

ergization effect or adaptation, the yields of these crops will suffer a 0-40% loss by the

2060s. Izaurralde et al. (2003) suggested that the yields of both winter wheat and corn

would increase by the end of the twenty-first century.

1.3 Objectives and Hypotheses

This thesis focuses on the trends of air temperatures, precipitation, and evapotranspiration

in the southeastern United States (SUS) and east-central China (ECC) in the last century,

attempting to compare the trends in these two regions for air temperature, precipitation

and evapotranspiration, and to analyze the roles large-scale climatic variables play in

these two regions in the trends of air temperature, precipitation, and evapotranspiration.

The hypotheses of this thesis are:

1. the trends of air temperatures in the SUS and ECC are different;

2. the trends of precipitation in the SUS and ECC are different;

3. the trends of evapotranspiration in the SUS and ECC are different;

4. differences lie in the SUS and the ECC between the impacts of the climatic variables

   on the air temperature during 1951–2013; and

5. differences lie in the SUS and the ECC between the impacts of the climatic variables


The objectives of this thesis are:

1. to compare the trends of air temperatures in the SUS and ECC, as demonstrated in

   Chapter 2;

2. to compare the trends of precipitation in the SUS and ECC, shown in Chapter 3;
3. to compare the trends of evapotranspiration in the SUS and ECC, as described in Chapter 4;

4. to identify climatic variables associated with the air temperature in the SUS and ECC, to compare the roles they play in the air temperature in these two regions, and to predict the overall trends of the air temperatures in the SUS and ECC from 1951 to 2013, which is shown in Chapter 5; and

5. to identify climatic variables associated with the precipitation and evapotranspiration in the SUS and ECC, to compare the roles they play in the precipitation and evapotranspiration in these two regions, and to predict the overall trends of the precipitation and evapotranspiration in the SUS and ECC from 1951 to 2013, which is shown in Chapter 6.
References


Environmental Change, 6(3), 205–214.

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., . . .


activity to water table and soil warming manipulations in an Alaskan peatland. 


Chapter 2: Air Temperature Trends in the SUS and the ECC

2.1 Introduction

Global warming caused by greenhouse gases has exceeded the variations of solar irradiance, and is the leading force of anthropogenic climate change (Hansen and Lacis, 1990). The global land surface air temperature was estimated to rise at a rate of 0.175-0.197°C per decade during 1951–2012 (Stocker et al., 2013). An overall increasing trend of global air temperature is obvious.

Hansen et al. (2001) showed simultaneous trends of air temperature in the United States and the whole world: the temperature increased during 1900–1940, then dropped during 1940–1965, and rose again during 1965–2000. According to the estimates based on 969 stations around the United States with an average record length of 103 years, Lu et al. (2005) suggested that the air temperature in Northeast, West, and northern Midwest of United States was increasing, while southeastern United States (SUS) was cooling in the background of climate change. The trends of air temperature demonstrated by Lund et al. (2001) was also decreasing for spring, summer, autumn and winter in southeastern United States.

In China, since most weather stations of the country were established after 1951, the record length is quite short. Yatagai and Yasunari (1994) demonstrated that during 1951–
1990 most parts of China were warming except for the Southwest China. Wang et al. (2004) estimated that annual mean temperature in China heated at a rate of 0.058°C per decade, which is similar to the global rate of 0.060°C per decade during the same time period. According to the estimation of Tang et al. (2010), during the 100 years between 1906 and 2005 the annual mean temperature in China rose by 0.78±0.27°C. The annual mean temperature in the east-central China (ECC), which is at the similar latitude with the SUS, had an overall slightly increased trend during 1951–1990 according to Yatagai and Yasunari (1994).

The increased trend of the air temperature in the ECC is in accordance with the global increased trend while the air temperature in the SUS seems to have a reverse trend (Lu et al., 2005; Wang et al., 2004; Yatagai and Yasunari, 1994). Pan et al. (2004) demonstrated that the Great Plains low level jet occurred more frequently in the south-central United States, leading to replenishment of seasonally depleted soil moisture, caused more summer evapotranspiration and suppressed daytime temperatures. Robinson et al. (2002) linked this cooling trend to tropical Pacific sea-surface temperatures, demonstrated that warmer tropical Pacific led to more cloud cover suppressing solar heating and thus decreased air temperature. Yu et al. (2001) compared data from stations in the southeastern United States and eastern China, suggested that both these two regions had decreased annual mean maximum temperature and increased annual mean minimum temperature, and both experienced decreased temperature after Pinatubo eruption, while the annual mean daily temperature of these two regions had different trends: the eastern China became warmer but southeastern United States tended to be colder.
Many researches focused on the decreasing trend of the air temperature in the SUS last century in the background of global warming (Lu et al., 2005; Lund et al., 2001; Pan et al., 2004; Robinson et al., 2002; Yu et al., 2001). It remains questionable whether the SUS is still cooling in the 21 century. This chapter focuses on the trends of air temperature in the SUS and ECC, and the trends of air temperature in these two regions are compared. The hypothesis of this chapter is: the air temperature in the SUS during 1931–2013 is different from that in the ECC during 1951–2013. The objective of this chapter is to analyze the trend of air temperature in the SUS during 1931–2013 and that in the ECC during 1951–2013.

2.2 Data and Methodology

Monthly average mean, average maximum and average minimum air temperature data for six stations from 3 states (Alabama, Mississippi and Georgia) in the SUS were analyzed in this chapter. Six stations from 3 provinces in the ECC (Henan, Hubei and Anhui) were also used to analyze their air temperature trends based on their monthly average mean, average maximum and average minimum air temperature data. The stations selected for the study are located in 3 states across the SUS – Meridian Key Field (Mississippi), Fairhope 2 NE (Alabama), Mobile Regional Airport (Alabama), Montgomery Airport (Alabama), Alma Bacon Co Airport and Toccoa (Georgia); and 3 provinces across the ECC – Lushi (Henan), Xinyang (Henan), Bengbu (Anhui), Anqing (Anhui), Wuhan and Yichang (Hubei), as shown in Figs 1 and 2 and Tables 1 and 2.

These 12 stations were selected to analyze the temperature trends, based on the accuracy of data, length of period, availability, and on the least missing data since the historical
climate records have begun. The data of monthly air temperature are scrutinized to remove the data of mistake, and after the data are averaged into annual air temperature data, the sites with less than 10% of the missing data are chosen. Monthly average mean, average maximum and average minimum air temperature data were collected from the National Climatic Data Center (www.ncdc.noaa.gov) for the 6 stations in the SUS and China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/home.do) for the 6 stations in the ECC. The monthly air temperature data from these stations were averaged into annual values when analyzing the annual mean air temperature, annual average maximum and annual average minimum air temperature trends of these two regions. Regression analysis was processed to analyze the linear correlation between the annual data of air temperature and the years, and find out the annual mean air temperature, annual average maximum and annual average minimum air temperature trends of these stations by using MS Office Excel (2007) and SPSS 22. The confidence interval of 95% was chosen to calculate p value and the significance of the regression models.
Figure 1. Locations of the weather stations selected in the SUS for air temperature

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2, NE, AL</td>
<td>30°33’S</td>
<td>87°53’W</td>
<td>7</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL</td>
<td>30°41’S</td>
<td>88°15’W</td>
<td>65.5</td>
</tr>
<tr>
<td>Montgomery Airport, AL</td>
<td>32°18’S</td>
<td>86°24’W</td>
<td>61.6</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA</td>
<td>31°32’S</td>
<td>82°30’W</td>
<td>58.8</td>
</tr>
<tr>
<td>Toccoa, GA</td>
<td>34°35’S</td>
<td>83°20’W</td>
<td>308.5</td>
</tr>
<tr>
<td>Meridian Key Field, MS</td>
<td>32°20’S</td>
<td>88°45’W</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Table 1. Basic information of the weather stations selected in the SUS for air temperature
Figure 2. Locations of the weather stations selected in the ECC for air temperature

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lushi, Henan</td>
<td>34°03’N</td>
<td>111°02’E</td>
<td>568.8</td>
</tr>
<tr>
<td>Xinyang, Henan</td>
<td>32°08’N</td>
<td>114°03’E</td>
<td>114.5</td>
</tr>
<tr>
<td>Anqing, Anhui</td>
<td>30°32’N</td>
<td>117°03’E</td>
<td>19.8</td>
</tr>
<tr>
<td>Wuhan, Hubei</td>
<td>30°37’N</td>
<td>114°08’E</td>
<td>23.1</td>
</tr>
<tr>
<td>Yichang, Hubei</td>
<td>30°42’N</td>
<td>111°18’E</td>
<td>133.1</td>
</tr>
<tr>
<td>Bengbu, Anhui</td>
<td>32°55’N</td>
<td>117°23’E</td>
<td>21.9</td>
</tr>
</tbody>
</table>

Table 2. Basic information of the weather stations selected in the ECC for air temperature
2.3 Results

2.3.1 Fairhope 2 NE (Alabama)

The temperature data in Fairhope 2 NE dates back to 1931. The annual mean and average minimum air temperature in Fairhope 2 NE decreased significantly (p=0.01 for annual mean air temperature and 0.02 for annual average minimum air temperature) during 1931–2013 at the average rate of 0.006°C/year (Fig. 3). The annual average maximum air temperature in Fairhope 2 NE decreased at the average rate of 0.005 °C/year, but not significantly.

![Figure 3. Trends in temperature in Fairhope 2 NE](image-url)

\[
y = -0.006x + 19.90 \\
p = 0.02
\]

\[
y = -0.005x + 25.65 \\
p = 0.07
\]

\[
y = -0.006x + 14.11 \\
p = 0.01
\]
2.3.2 Mobile Regional Airport (Alabama)

The earliest temperature record in Mobile Regional Airport goes back to 1948. No significant trend is shown in the annual mean, average maximum and average minimum air temperature in Mobile Regional Airport during 1948–2013 (Fig. 4). The annual mean and average minimum air temperature in Mobile Regional Airport decreased at the average rates of 0.001 and 0.005 ºC/year, respectively, while average maximum air temperature here increased at the average rate of 0.002 ºC/year.

Figure 4. Trends in temperature in Mobile Regional Airport
2.3.3 Montgomery Airport (Alabama)

The recorded data of air temperature in Montgomery Airport date back to 1948. The annual average maximum air temperature in Montgomery Airport increased significantly during 1948–2013 at the average rate of 0.010 °C/year (Fig. 5). No significant trend is shown in annual mean air temperature and average minimum air temperature in Montgomery Airport during the same time period. Annual mean air temperature increased at the rate of 0.003°C/year, while average minimum air temperature decreased at the same rate of the annual mean air temperature.

Figure 5. Trends in temperature in Montgomery Airport
2.3.4 Alma Bacon Co Airport (Georgia)

The recorded air temperature in Alma Bacon Co Airport lasts from 1939 to 2013. The annual mean, average maximum and average minimum air temperature in Alma Bacon Co Airport increased significantly during 1939–2013 at the average rate of 0.013, 0.006 and 0.020 °C/year, respectively, as shown in Fig. 6.

![Graph showing temperature trends](image_url)

Figure 6. Trends in temperature in Alma Bacon Co Airport
2.3.5 Toccoa (Georgia)

The records in Toccoa date back to 1931. During 1931–2013, the annual average maximum and mean air temperature in Toccoa decreased at the average rates of 0.008 and 0.003 °C/year, respectively, the former significantly (p=0.005) while the latter insignificantly (p=0.20), as shown in Fig. 7. However, average minimum air temperature in Toccoa increased at the rate of 0.001 °C/year insignificantly.

Figure 7. Trends in temperature in Toccoa
2.3.6 Meridian Key Field (Mississippi)

The recorded air temperature in Meridian Key Field lasts from 1950 to 2013, indicating no strong trends among the annual mean, average maximum or average minimum air temperature. During 1950–2013, the annual average maximum air temperature in Meridian Key Field decreased at the average rate of 0.003 °C/year insignificantly, while minimum air temperature increased at the same rate of average maximum air temperature insignificantly (Fig. 8). On average, the annual mean air temperature in Meridian Key Field did not significantly change.

Figure 8. Trends in temperature in Meridian Key Field
2.3.7 Lushi (Henan)

The recorded air temperature in Lushi lasts from 1953 to 2013. The annual mean, average maximum and average minimum air temperature in Lushi all show increased trends during 1953–2013, though the increased tendency of annual mean air temperature is insignificant at a rate of 0.004°C/year ($p=0.21$), as shown Fig. 9. The annual average maximum and average minimum air temperature increased significantly at the rates of 0.018 and 0.008°C/year, respectively.

![Figure 9. Trends in temperature in Lushi](image)

Figure 9. Trends in temperature in Lushi
2.3.8 Bengbu (Anhui)

The air temperature records in Bengbu date back to 1952. The annual mean, average maximum and average minimum air temperature in Bengbu increased during 1952–2013 at the average rates of increase of 0.021, 0.008 and 0.032°C/year, respectively (Fig. 10). Only the increase of annual average maximum air temperature is insignificant (p=0.11).

![Graph showing temperature trends in Bengbu](image)

Figure 10. Trends in temperature in Bengbu
2.3.9 Anqing (Anhui)

The records of data from Anqing began at 1951, indicating very significant increased trends of the annual mean, average maximum and average minimum air temperature. The annual mean, average maximum and average minimum air temperature in Anqing increased significantly during 1951–2013 at the average rates of increase of 0.023, 0.014 and 0.027°C/year, respectively (Fig. 11).

Figure 11. Trends in temperature in Anqing
2.3.10 Wuhan (Hubei)

The data from Wuhan, dating back to 1951, indicate strong increased trends in the annual mean, average maximum and average minimum air temperature. The annual mean, average maximum and average minimum air temperature in Wuhan increased significantly during 1951–2013 at the average rates of 0.026, 0.018 and 0.034°C/year, respectively (Fig. 12).

Figure 12. Trends in temperature in Wuhan

\[
\begin{align*}
\text{Avg Temp: } & \quad y = 0.026x + 15.91 \quad p < 0.0001 \\
\text{Avg Max Temp: } & \quad y = 0.018x + 20.76 \quad p < 0.0001 \\
\text{Avg Min Temp: } & \quad y = 0.034x + 12.08 \quad p < 0.0001
\end{align*}
\]
2.3.11 Yichang (Hubei)

The air temperature records in Yichang go back to 1952. Significant trends are shown in the annual mean and average minimum air temperature data. The annual mean, average maximum and average minimum air temperature in Yichang increased during 1952–2013 at the average rates of increase of 0.012, 0.007 and 0.016 °C/year, respectively (Fig. 13). Only the annual average maximum air temperature increased insignificantly (p=0.099).

Figure 13. Trends in temperature in Yichang
2.3.12 Xinyang (Henan)

The data from Xinyang last from 1951 to 2013. The annual mean, average maximum and average minimum air temperature in Xinyang increased during 1951–2013 at the average rates of 0.019, 0.006 and 0.026, respectively (Fig. 14). Although the increase rate of the annual average maximum air temperature is greater than those of the annual mean and average minimum air temperature, it is not significant (p=0.17).

Figure 14. Trends in temperature in Xinyang
2.3 Discussion and Conclusions

The correlations of air temperature and years in these 12 stations are summarized in Table 3. The annual mean air temperature decreased in Fairhope 2 NE, Mobile Regional Airport and Toccoa, in which only Fairhope 2 NE has a significant decreased tendency. Increased annual mean air temperature rates are shown in Montgomery Airport and Alma Bacon Co Airport, and the increased trend is significant in Alma Bacon Co Airport. No increase or decrease in the annual mean air temperature is found in Meridian Key Field during 1950–2013. The annual mean air temperature increased in all six stations in the ECC. Lushi is the only station which increased insignificantly in the annual mean air temperature in the ECC.

Annual average maximum air temperature decreased in 3 stations (Fairhope 2 NE, Toccoa and Meridian Key Field) in the SUS, but increased in another three stations. The annual average maximum air temperature in Toccoa decreased significantly during 1931–2013, while Montgomery Airport and Alma Bacon Co Airport have significant increased trends in annual average maximum air temperature. In contrast, annual average maximum air temperature increased in all six stations in the ECC show trends, in which Lushi, Anqing and Wuhan have significant trends.

Annual average minimum air temperature decreased in 3 stations in Alabama (Fairhope 2 NE, Mobile Regional Airport, and Montgomery Airport), while increased in other 3 stations in the SUS. Only the decrease in Fairhope 2 NE and the increase in Alma Bacon Co Airport are significant. In the ECC, the annual average minimum air temperature increased significantly in all six stations.
The decreased trends in air temperature in the SUS are ambiguous in this chapter, which is not in accordance with the previous researches (Lu et al., 2005; Lund et al., 2001; Pan et al., 2004; Robinson et al., 2002; Yu et al., 2001). This result may be due to the influence of recent trends, especially the years in the twenty-first century that former research could not cover. Air temperature trends in the ECC are inclined to increase in the background of climate change. Since the records from the ECC date back to the years no earlier than 1951, the record lengths of the stations in the SUS are longer. The comparison of air temperature trends with similar time period (1950-2013 for the SUS and 1951-2013 for the ECC) of these two regions and the analysis of the roles climate variables play in the air temperature in these two regions are shown in Chapter 5.
<table>
<thead>
<tr>
<th>Stations</th>
<th>Temperature</th>
<th>P values</th>
<th>Significant</th>
<th>Rate of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL (1931 - 2013)</td>
<td>Average</td>
<td>0.01</td>
<td>✓</td>
<td>-0.006</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.07</td>
<td>×</td>
<td>-0.005</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.02</td>
<td>✓</td>
<td>-0.006</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL (1948-2013)</td>
<td>Average</td>
<td>0.65</td>
<td>×</td>
<td>-0.001</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.46</td>
<td>×</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.12</td>
<td>×</td>
<td>-0.005</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.34</td>
<td>×</td>
<td>0.003</td>
</tr>
<tr>
<td>Montgomery Airport, AL (1948-2013)</td>
<td>Maximum</td>
<td>0.03</td>
<td>✓</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.42</td>
<td>×</td>
<td>-0.003</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA (1939-2013)</td>
<td>Average</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.038</td>
<td>✓</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.02</td>
</tr>
<tr>
<td>Toccoa, GA (1931-2013)</td>
<td>Average</td>
<td>0.2</td>
<td>×</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.005</td>
<td>✓</td>
<td>-0.008</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.69</td>
<td>×</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.96</td>
<td>×</td>
<td>0</td>
</tr>
<tr>
<td>Meridian Key Field, MS (1950-2013)</td>
<td>Maximum</td>
<td>0.53</td>
<td>×</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.46</td>
<td>×</td>
<td>0.003</td>
</tr>
<tr>
<td>Lushi, Henan (1953-2013)</td>
<td>Average</td>
<td>0.21</td>
<td>×</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.002</td>
<td>✓</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0.002</td>
<td>✓</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.021</td>
</tr>
<tr>
<td>Bengbu, Anhui (1952-2013)</td>
<td>Maximum</td>
<td>0.11</td>
<td>×</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.023</td>
</tr>
<tr>
<td>Anqing, Anhui (1951-2013)</td>
<td>Maximum</td>
<td>0.002</td>
<td>✓</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.026</td>
</tr>
<tr>
<td>Wuhan, Hubei (1951-2013)</td>
<td>Maximum</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.0002</td>
<td>✓</td>
<td>0.012</td>
</tr>
<tr>
<td>Yichang, Hubei (1952-2013)</td>
<td>Maximum</td>
<td>0.099</td>
<td>×</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.019</td>
</tr>
<tr>
<td>Xinyang, Henan (1951-2013)</td>
<td>Maximum</td>
<td>0.17</td>
<td>×</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>&lt; 0.0001</td>
<td>✓</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Table 3. Trends of air temperature of the weather stations selected in the SUS and the ECC
References


Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., ... Midgley, P. M. (2013). Climate change 2013: The physical science basis.
Intergovernmental Panel on Climate Change, Working Group I Contribution to the IPCC Fifth Assessment Report (AR5). Retrieved from 
http://www.ipcc.ch/pdf/assessment-
report/ar5/wg1/WG1AR5_Chapter02_FINAL.pdf


Chapter 3: Precipitation Trends in the SUS and the ECC

3.1 Introduction

The global temperature increased about 0.63±0.2°C during the 100 years after 1880s (Hansen and Lebedeff, 1988). Warmer temperature implies a more dynamic hydrological cycle and a more moistured atmosphere inclines to more precipitation (Dore, 2005). Accelerated global hydrological cycle will increase the average precipitation, inducing the river discharge increase (Oki and Kanae, 2006).

Karl and Knight (1998) suggested that from 1910 to late 1990s the contiguous United States generally experienced a 10% increase of precipitation. Increased precipitation was observed in the SUS during 1900 –1994 (Karl et al., 1996). The river discharge of lower Mississippi also increased significantly during 1948 –1988 (Lettenmaier et al., 1994). The increased precipitation in the United States is reflected primarily in the heavy and extreme daily precipitation events, with more than 50% of the increase in precipitation distributed in the upper 10 percentiles of the precipitation (Karl and Knight, 1998).

Kunkel (2002) demonstrated that the frequency of extreme precipitation events increased since 1920s. Crop production suffered huge damage from heavy precipitation in the United States, for instance, impacts of excessive soil moisture on maize yields caused about 3% loss per year on average (Rosenzweig et al., 2002). The waterborne disease outbreaks are also associated with the extreme precipitation (Curriero et al., 2001).
The annual precipitation showed an overall decreased trend in the ECC during 1951–2000 (Zhai et al., 2005). According to Ding et al. (2008), the precipitation anomalies showed 20 and 30–40-year oscillations: peak values of precipitation happened in the 1910s, 1950s and 1990s, with a decreasing trend from the mid-1950s to the late 1970s. The precipitation in China depends heavily on the summer monsoons. Zhao et al. (2010) suggested that the warming over the tropical Indian Ocean and the western North Pacific reduced the air temperature contrast between the oceans and East Asia, thus the activity of East Asian summer monsoon was weakened. The winter and spring snow in Tibetan Plateau increased the soil moisture there and thus decreased the spring and summer air temperature in Tibetan Plateau, which also caused the decrease of the thermal contrast between the oceans and East Asia (Ding et al., 2009; Zhao et al., 2010). The moisture from oceans was more difficult to be transported northwards due to weakened summer monsoon, leading to more precipitation in the ECC and less precipitation in higher latitude areas (Ding et al., 2009; Zhao et al., 2010). Ding et al. (2009) showed that winter snow cover over Tibetan Plateau was positively correlated with the precipitation in the ECC while was negatively correlated with the precipitation in the higher latitude areas in China.

In this chapter, the trends in precipitation through the previous years of the twenty-first century in the SUS and ECC are scrutinized. The hypothesis of this chapter is: the precipitation in the SUS during 1931–2013 is different from that in the ECC during 1951–2013. The objective of this chapter is to analyze the trend of precipitation in the SUS during 1931–2013 and that in the ECC during 1951–2013.
3.2 Data and Methodology

In this chapter, six stations from 3 states (Alabama, Mississippi and Georgia) in the SUS were chosen to analyze their monthly precipitation data. Monthly precipitation data for six stations from 3 provinces in the ECC (Henan, Hubei and Anhui) were also used to analyze their air precipitation trends. The stations selected for the study are located in 3 states across the SUS - Meridian Key Field (Mississippi), Fairhope 2 NE (Alabama), Mobile Regional Airport (Alabama), Montgomery Airport (Alabama), Alma Bacon Co Airport and Toccoa (Georgia); and 3 provinces across the ECC – Lushi (Henan), Xinyang (Henan), Bengbu (Anhui), Anqing (Anhui), Wuhan and Yichang (Hubei), as shown in Figs 15 and 16 and Tables 4 and 5.

These 12 stations were selected to analyze the precipitation trends due to the accuracy of data, length of period, availability online, and on the least missing data since the historical climate records have begun. The data of monthly precipitation are scrutinized to remove the data of mistake, and after the data are added into annual or seasonal air temperature data, the sites with less than 10% of the missing data are chosen. Monthly precipitation data were collected from the National Climatic Data Center (www.ncdc.noaa.gov) for the 6 stations in the SUS and China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/home.do) for the 6 stations in the ECC. The monthly precipitation data from these stations were added into annual values, summer (June, July and August, JJA) values, and winter (December, January and February, DJF) values when analyzing the annual precipitation, summer precipitation and winter precipitation trends of these two regions, respectively. Regression analysis was
processed to analyze the linear correlation between the annual or seasonal data of precipitation and the years, and find out their annual precipitation, summer precipitation and winter precipitation trends by using MS Office Excel (2007) and SPSS 22. The confidence interval of 95% was chosen to calculate p value and the significance of the regression models.
Figure 15. Locations of the weather stations selected in the SUS for precipitation and potential evapotranspiration

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL</td>
<td>30°33’N</td>
<td>87°53’W</td>
<td>7</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL</td>
<td>30°41’N</td>
<td>88°15’W</td>
<td>65.5</td>
</tr>
<tr>
<td>Montgomery Airport, AL</td>
<td>32°18’N</td>
<td>86°24’W</td>
<td>61.6</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA</td>
<td>31°32’N</td>
<td>82°30’W</td>
<td>58.8</td>
</tr>
<tr>
<td>Toccoa, GA</td>
<td>34°35’N</td>
<td>83°20’W</td>
<td>308.5</td>
</tr>
<tr>
<td>Meridian Key Field, MS</td>
<td>32°20’N</td>
<td>88°45’W</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Table 4. Basic information of the weather stations selected in the SUS for precipitation
Figure 16. Locations of the weather stations selected in the ECC for precipitation and potential evapotranspiration

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lushi, Henan</td>
<td>34°03’N</td>
<td>111°02’E</td>
<td>568.8</td>
</tr>
<tr>
<td>Xinyang, Henan</td>
<td>32°08’N</td>
<td>114°03’E</td>
<td>114.5</td>
</tr>
<tr>
<td>Anqing, Anhui</td>
<td>30°32’N</td>
<td>117°03’E</td>
<td>19.8</td>
</tr>
<tr>
<td>Wuhan, Hubei</td>
<td>30°37’N</td>
<td>114°08’E</td>
<td>23.1</td>
</tr>
<tr>
<td>Yichang, Hubei</td>
<td>30°42’N</td>
<td>111°18’E</td>
<td>133.1</td>
</tr>
<tr>
<td>Bengbu, Anhui</td>
<td>32°55’N</td>
<td>117°23’E</td>
<td>21.9</td>
</tr>
</tbody>
</table>

Table 5. Basic information of the weather stations selected in the ECC for precipitation
3.3 Results

3.3.1 Fairhope 2 NE (Alabama)

The annual precipitation in Fairhope 2 NE increased during 1931–2013 at the average rate of increase of 1.414 mm/year insignificantly (p=0.36), as shown in Fig. 17. The summer and winter precipitation in Fairhope 2 NE also insignificantly increased during the same time period, at the rates of 0.393 and 0.559 mm/year, respectively (Fig. 17).

Figure 17. Trends in precipitation in Fairhope 2 NE
3.3.2 Mobile Regional Airport (Alabama)

For Mobile Regional Airport, the monthly precipitation data date back to 1948. During 1948–2013, the annual, summer and winter precipitation decreased at the average rate of 0.825, 0.290 and 0.423 mm/year, respectively (Fig. 18). However, the decreases of the annual, summer and winter precipitation are not significant (Fig. 18).

Figure 18. Trends in precipitation in Mobile Regional Airport
3.3.3 Montgomery Airport (Alabama)

The recorded data of precipitation in Montgomery Airport date back to 1948. During 1948–2013, the annual, summer and winter precipitation increased at the average rate of 1.001, 0.528 and 0.050 mm/year, respectively (Fig. 19). However, the increases of the annual, summer and winter precipitation are not significant (Fig. 19).

Figure 19. Trends in precipitation in Montgomery Airport
3.3.4 Alma Bacon Co Airport (Georgia)

For Alma Bacon Co Airport, the monthly precipitation data last from 1938 to 2013. During 1938–2013, the annual precipitation decreased at the average rate of 0.293 mm/year insignificantly, as shown in Fig. 20. The summer precipitation in Alma Bacon Co Airport insignificantly increased at the rates of 0.064 mm/year during the same time period. The winter precipitation increased very insignificantly and slightly (0.001 mm/year) (Fig. 20).

Figure 20. Trends in precipitation in Alma Bacon Co Airport
3.3.5 Toccoa (Georgia)

The records in Toccoa go back to 1931. During 1931–2013, the annual, summer and winter precipitation in Toccoa decreased at the average rates of 0.248, 0.034 and 1.059 mm/year, respectively (Fig. 21). However, the decreases of the annual, summer and winter precipitation are insignificant in Toccoa.

Figure 21. Trends in precipitation in Toccoa
3.3.6 Meridian Key Field (Mississippi)

The recorded precipitation data in Meridian Key Field last from 1950 to 2013. During 1950–2013, the annual, summer and winter precipitation in Meridian Key Field increased at the average rates of 3.152, 0.991 and 0.263 mm/year, respectively (Fig. 22). The increases of the annual, summer and winter precipitation are insignificant in Meridian Key Field.

Figure 22. Trends in precipitation in Meridian Key Field
3.3.7 Lushi (Henan)

The recorded monthly precipitation data in Lushi date back to 1952. The annual and summer precipitation insignificantly decreased at rates of 0.739 and 0.752 mm/year, respectively (Fig. 23). The winter precipitation increased at the rate of 0.022 mm/year, insignificantly (Fig. 23).

Figure 23. Trends in precipitation in Lushi
3.3.8 Bengbu (Anhui)

The recorded monthly precipitation data in Bengbu last from 1951 to 2013. During 1951–2013, the annual, summer and winter precipitation in Bengbu increased at the average rates of 0.897, 1.012 and 0.203 mm/year, respectively (Fig. 24). The increases of the annual, summer and winter precipitation are insignificant in Bengbu.

Figure 24. Trends in precipitation in Bengbu
3.3.9 Anqing (Anhui)

The recorded monthly precipitation data in Anqing go back to 1951. During 1951–2013, the annual precipitation in Anqing decreased at the average rate of 0.199 mm/year, insignificantly (Fig. 25). In contrast, both the summer and winter precipitation insignificantly increased at the average rates of 1.518 and 0.574 mm/year, respectively.

Figure 25. Trends in precipitation in Anqing
3.3.10 Wuhan (Hubei)

The recorded precipitation data in Wuhan go back to 1951. During 1951–2013, the annual, summer and winter precipitation in Wuhan increased at the average rates of 0.845, 1.128 and 0.352 mm/year, respectively (Fig. 26). The increases of the annual, summer and winter precipitation are insignificant in Wuhan.

Figure 26. Trends in precipitation in Wuhan
3.3.11 Yichang (Hubei)

The recorded monthly precipitation data in Yichang date back to 1951. During 1951–2013, the annual and summer precipitation in Yichang insignificantly decreased at the average rates of 0.851 and 0.614 mm/year, respectively (Fig. 27). The winter precipitation increased during the same time period at the rate of 0.114 mm/year, insignificantly.

Figure 27. Trends in precipitation in Yichang
3.3.12 Xinyang (Henan)

The recorded monthly precipitation data in Xinyang last from 1951 to 2013. During 1951–2013, the annual, summer and winter precipitation in Xinyang decreased at the average rates of 0.797, 0.049 and 0.273 mm/year, respectively (Fig. 28). The decreases of the annual, summer and winter precipitation are insignificant in Xinyang.

![Trends in precipitation in Xinyang](image)

Figure 28. Trends in precipitation in Xinyang
3.3 Discussion and Conclusions

Table 6 summarizes the trends of precipitation in these 12 stations. None of these 12 stations in these 2 regions showed any significant trends in annual, summer or winter precipitation.

The annual precipitation decreased in Alma Bacon Airport, Mobile Regional Airport and Toccoa. Increased annual precipitation rates were shown in Montgomery Airport, Meridian Key Field and Fairhope 2 NE. The insignificant precipitation changes in the SUS do not agree with the increased trends in annual precipitation demonstrated by Karl et al. (1996). This result may be due to the influence of recent precipitation records not covered by previous researches. The records from the recent decade opaqued the increased trends.

The annual precipitation decreased in four stations (Lushi, Anqing, Yichang, Xinyang) in the ECC. This result partly agrees with the decreased trends in the ECC in annual precipitation during 1951–2000 by Zhai et al. (2005). The records in the twenty-first century also shadowed the strength of the decreased trends in annual precipitation in the ECC.

Both summer and winter precipitation increased in 4 stations (Montgomery Airport, Meridian Key Field and Fairhope 2 NE and Alma Bacon Airport) in the SUS. Summer precipitation increased in 3 stations (Bengbu, Anqing and Wuhan) in the ECC. The winter precipitation increased in 5 stations (Lushi, Wuhan, Anqing, Bengbu, and Yichang). The winter precipitation in the ECC is generally in small amounts, thus the
variability of winter precipitation in the ECC cannot influence the annual precipitation greatly.

Since the records from the ECC date back to the years no earlier than 1951, the record history of the stations in the SUS is longer. The comparison of precipitation trends with similar time period (1950-2013 for the SUS and 1951-2013 for the ECC) of these two regions and the analysis of the roles climate variables play in the precipitation in these two regions are shown in Chapter 6.
<table>
<thead>
<tr>
<th>Stations</th>
<th>Precipitation</th>
<th>P values</th>
<th>Significant</th>
<th>Rate (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL (1931 - 2013)</td>
<td>Annual</td>
<td>0.36</td>
<td>×</td>
<td>1.414</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.65</td>
<td>×</td>
<td>0.393</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.35</td>
<td>×</td>
<td>0.559</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL (1948-2013)</td>
<td>Annual</td>
<td>0.66</td>
<td>×</td>
<td>-0.825</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.78</td>
<td>×</td>
<td>-0.29</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.63</td>
<td>×</td>
<td>-0.423</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td>0.56</td>
<td>×</td>
<td>1.001</td>
</tr>
<tr>
<td>Montgomery Airport, AL (1948-2013)</td>
<td>Summer</td>
<td>0.43</td>
<td>×</td>
<td>0.528</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.95</td>
<td>×</td>
<td>0.05</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA (1938-2013)</td>
<td>Annual</td>
<td>0.81</td>
<td>×</td>
<td>-0.293</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.91</td>
<td>×</td>
<td>0.064</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>1</td>
<td>×</td>
<td>0.001</td>
</tr>
<tr>
<td>Toccoa, GA (1931-2013)</td>
<td>Annual</td>
<td>0.86</td>
<td>×</td>
<td>-0.248</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.96</td>
<td>×</td>
<td>-0.034</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.084</td>
<td>×</td>
<td>-1.059</td>
</tr>
<tr>
<td>Meridian Key Field, MS (1950-2013)</td>
<td>Annual</td>
<td>0.12</td>
<td>×</td>
<td>3.152</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.78</td>
<td>×</td>
<td>0.991</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.21</td>
<td>×</td>
<td>0.263</td>
</tr>
<tr>
<td>Lushi, Henan (1952-2013)</td>
<td>Annual</td>
<td>0.48</td>
<td>×</td>
<td>-0.739</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.34</td>
<td>×</td>
<td>-0.752</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.83</td>
<td>×</td>
<td>0.022</td>
</tr>
<tr>
<td>Bengbu, Anhui (1951-2013)</td>
<td>Annual</td>
<td>0.57</td>
<td>×</td>
<td>0.897</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.42</td>
<td>×</td>
<td>1.012</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.48</td>
<td>×</td>
<td>0.203</td>
</tr>
<tr>
<td>Anqing, Anhui (1951-2013)</td>
<td>Annual</td>
<td>0.93</td>
<td>×</td>
<td>-0.199</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.42</td>
<td>×</td>
<td>1.518</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.23</td>
<td>×</td>
<td>0.574</td>
</tr>
<tr>
<td>Wuhan, Hubei (1951-2013)</td>
<td>Annual</td>
<td>0.67</td>
<td>×</td>
<td>0.845</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.5</td>
<td>×</td>
<td>1.128</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.37</td>
<td>×</td>
<td>0.352</td>
</tr>
<tr>
<td>Yichang, Hubei (1951-2013)</td>
<td>Annual</td>
<td>0.61</td>
<td>×</td>
<td>-0.851</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.62</td>
<td>×</td>
<td>-0.614</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.64</td>
<td>×</td>
<td>0.114</td>
</tr>
<tr>
<td>Xinyang, Henan (1951-2013)</td>
<td>Annual</td>
<td>0.66</td>
<td>×</td>
<td>-0.797</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.97</td>
<td>×</td>
<td>-0.049</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>0.39</td>
<td>×</td>
<td>-0.273</td>
</tr>
</tbody>
</table>

Table 6. Trends of precipitation of the weather stations selected in the SUS and the ECC
References


Chapter 4: Potential Evapotranspiration Trends in the SUS and the ECC

4.1 Introduction

Greenhouse gases emitted by human beings, causing anthropogenic climate change, are profoundly influencing the global climate. Jones and Moberg (2002) stated that the estimated rate of annual air temperature increase for land areas worldwide during the last century was 0.07°C per decade. Increased concentrations of greenhouse gases in the atmosphere have major effects on the land water and energy cycles, especially on evapotranspiration, as suggested by climate models (Teuling et al., 2009). Zeng et al. (2012) suggested that global annual land evapotranspiration increased at a rate of 1.10 mm per year during 1982–2009. Global land evapotranspiration increased from the early 1980s to the late 1990s, but lacking moisture availability in Southern Hemisphere land regions has played a role as limit to further increase of global land evapotranspiration (Stocker et al., 2013).
Szilagyi et al. (2001) estimated that annual evapotranspiration increased by 3% during 1948–1996 in conterminous United States. Similarly, Walter et al. (2004) showed that the evapotranspiration calculated from precipitation and streamflow data over the conterminous United States had increased trends over the period 1950–2000. Tian et al. (2010) suggested that the southern United States, much of which covered by forests, experienced slight changes of evapotranspiration during 1895–2007. Golubev et al. (2001) indicated that the pan evapotranspiration increased in the SUS at an average rate of 0.8% per decade insignificantly during 1957–1998, but the actual evaporation showed a decreased trend during the same time period.

Gao et al. (2006) showed that potential evapotranspiration was decreasing in most parts of China except for Northeast China during 1956–2000. Comparing the annual pan evaporation and potential evaporation trends in China, the decreased annual potential evapotranspiration happened in the East, Southeast, South China and parts of the Northwest China during 1960–2002; for annual actual evapotranspiration, the decreased trends occurred in the Southeast and Southwest China, while the Northeast and Northwest China experienced increased trends during the same time period (Gao et al., 2007). Liu et al. (2004) also observed that pan evaporation decreased significantly in most parts of China except Northeast China during 1955–2000. The decreased trends of potential and pan evapotranspiration in the Yangtze River basin during 1960–2000 were suggested by Xu et al. (2006). For the ECC, Gao et al. (2007) showed that both the annual actual evapotranspiration and potential evapotranspiration during 1960–2002 had decreased trends.
The trends of annual potential evapotranspiration in the SUS and the ECC need investigation. The hypothesis of this chapter is: the potential evapotranspiration trend in SUS during 1949–2013 is different from that in the ECC during 1951–2013. The objective of this chapter is to analyze the trend of potential evapotranspiration in the SUS during 1949–2013 and that in the ECC during 1951–2013.

4.2 Data and Methodology

Potential evapotranspiration data were analyzed for six stations from 3 states (Alabama, Mississippi and Georgia) in the SUS in this chapter. Six stations from 3 provinces in the ECC (Henan, Hubei and Anhui) were also used to analyze their potential evapotranspiration trends. The stations selected for the study are located in 3 states across the SUS – Meridian Key Field (Mississippi), Fairhope 2 NE (Alabama), Mobile Regional Airport (Alabama), Montgomery Airport (Alabama), Alma Bacon Co Airport and Toccoa (Georgia); and 3 provinces across the ECC – Lushi (Henan), Xinyang (Henan), Bengbu (Anhui), Anqing (Anhui), Wuhan and Yichang (Hubei), as shown in Figs 29 and 30 and Tables 7 and 8.

Based on the accuracy of data, length of period, availability, and on the least missing data since the historical climate records have begun, these 12 stations in these two regions were selected to analyze the potential evapotranspiration trends. The data of monthly potential evapotranspiration are scrutinized to remove the data of mistake, and after the data are added into annual potential evapotranspiration data, the sites with less than 10% of the missing data are chosen. The potential evapotranspiration is calculated in the Thornthwaite method improved by Willmott et al. (1985).
The monthly unadjusted potential evapotranspiration is:

Equation 1 \[ e (\text{mm per month}) = \begin{cases} 0, & t < 0^\circ \text{C} \\ 16 \left(\frac{10t}{t+1}\right)^a, & 0 \leq t < 26.5^\circ \text{C} \\ -415.85 + 32.24t - 0.43t^2, & t \geq 26.5^\circ \text{C} \end{cases} \]

where \( t \) is the mean monthly air temperature in \(^\circ\text{C}\),

Equation 2 \[ i = \left(\frac{1}{5}\right)^{1.514} \]

Equation 3 \[ I = \sum_{j=1}^{12} i_j \]

in which \( I \) is the annual heat index, \( i \) is the monthly heat index for the month \( j \) (which is zero when the mean monthly temperature is 0 \(^\circ\text{C}\) or less) (Thornthwaite, 1948; Willmott et al., 1985; Xu and Singh, 2001)

Monthly potential evapotranspiration should be adjusted with daytime length and the length of a month, the final potential evapotranspiration is:

Equation 4 \[ E(\text{mm} \cdot \text{month}^{-1}) = e(\theta/30)(N/12) \]

where \( \theta \) is the length of the month (in days) and \( N \) is the daytime length (in hours) of a day.

Equation 5 \[ N = \frac{24}{\pi} \omega_s \]

\( \omega_s \) is the sunset hour angle in radians, it is taken as:

Equation 6 \[ \omega_s = \cos^{-1}[-\tan(\phi)\tan(\delta)] \]

where \( \phi \) is the latitude of the station in radians, \( \delta \) is solar declination in radians given by

Equation 7 \[ \delta = 0.409 \sin\left(\frac{2\pi J}{365} - 1.39\right) \]

and \( J \) is Julian day number.

Data representing the air temperature measurements were collected from the National Climatic Data Center (www.ncdc.noaa.gov) and China Meteorological Data Sharing
Service System (http://cdc.cma.gov.cn/home.do). Monthly potential evapotranspiration data calculated from the monthly air temperature data were added into annual potential evapotranspiration data to process the regression between annual potential evapotranspiration and years. Regression analysis was performed to analyze the linear correlation between the annual data of potential evapotranspiration and the years by using MS Office Excel (2007) and SPSS 22. Confidence interval of 95% was used while calculating p value of the models.
Figure 29. Locations of the weather stations selected in the SUS for potential evapotranspiration

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL</td>
<td>30°33’N</td>
<td>87°53’W</td>
<td>7</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL</td>
<td>30°41’N</td>
<td>88°15’W</td>
<td>65.5</td>
</tr>
<tr>
<td>Montgomery Airport, AL</td>
<td>32°18’N</td>
<td>86°24’W</td>
<td>61.6</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA</td>
<td>31°32’N</td>
<td>82°30’W</td>
<td>58.8</td>
</tr>
<tr>
<td>Toccoa, GA</td>
<td>34°35’N</td>
<td>83°20’W</td>
<td>308.5</td>
</tr>
<tr>
<td>Meridian Key Field, MS</td>
<td>32°20’N</td>
<td>88°45’W</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Table 7. Basic information of the weather stations selected in the SUS for potential evapotranspiration
Figure 30. Locations of the weather stations selected in the ECC for potential evapotranspiration

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lushi, Henan</td>
<td>34°03’N</td>
<td>111°02’E</td>
<td>568.8</td>
</tr>
<tr>
<td>Xinyang, Henan</td>
<td>32°08’N</td>
<td>114°03’E</td>
<td>114.5</td>
</tr>
<tr>
<td>Anqing, Anhui</td>
<td>30°32’N</td>
<td>117°03’E</td>
<td>19.8</td>
</tr>
<tr>
<td>Wuhan, Hubei</td>
<td>30°37’N</td>
<td>114°08’E</td>
<td>23.1</td>
</tr>
<tr>
<td>Yichang, Hubei</td>
<td>30°42’N</td>
<td>111°18’E</td>
<td>133.1</td>
</tr>
<tr>
<td>Bengbu, Anhui</td>
<td>32°55’N</td>
<td>117°23’E</td>
<td>21.9</td>
</tr>
</tbody>
</table>

Table 8. Basic information of the weather stations selected in the ECC for potential evapotranspiration
4.3 Results

4.3.1 Fairhope 2 NE (Alabama)

The annual potential evapotranspiration in Fairhope 2 NE decreased, but not significantly (p=0.24) during 1949–2013 at the average rate of 0.264 mm/yr (Fig. 31).

![Figure 31. Trends in potential evapotranspiration in Fairhope 2 NE](image)

4.3.2 Mobile Regional Airport (Alabama)

The annual potential evapotranspiration in Mobile Regional Airport decreased insignificantly (p=0.60) at the average rate of 0.115 mm/yr (Fig. 32).
4.3.3 Montegomery Airport (Alabama)

The annual potential evapotranspiration in Montegomery Airport increased insignificantly ($p=0.29$) during 1949–2013 at the average rate of 0.253 mm/yr (Fig. 33).

Figure 32. Trends in potential evapotranspiration in Mobile Regional Airport

$$y = -0.115x + 1039.$$  
$p = 0.60$

Mean $= 1036.2 \pm 31.5$
Figure 33. Trends in potential evapotranspiration in Montgomery Airport

4.3.4 Alma Bacon Co Airport (Georgia)

The annual potential evapotranspiration in Alma Bacon Co Airport increased significantly (p<0.0001) during 1949–2013 at the average rate of 0.893 mm/yr (Fig. 34).
Figure 34. Trends in potential evapotranspiration in Alma Bacon Co Airport

4.3.5 Toccoa (Georgia)

The annual potential evapotranspiration in Toccoa increased at the average rate of 0.257 mm/yr insignificantly (Fig. 35).
4.3.6 Meridian Key Field (Mississippi)

The annual potential evapotranspiration in Meridian Key Field decreased at the average rate of 0.043 insignificantly (Fig. 36).
Figure 36. Trends in potential evapotranspiration in Meridian Key Field

4.3.7 Lushi (Henan)

The annual potential evapotranspiration in Lushi decreased during 1953–2013 at the average rate of 0.029 mm/yr insignificantly (Fig. 37).
4.3.8 Bengbu (Anhui)

The annual potential evapotranspiration in Bengbu increased during 1951–2013 at the average rate of 0.853 mm/yr significantly (p<0.0001), as shown in Fig. 38.

Figure 37. Trends in potential evapotranspiration in Lushi
4.3.9 Anqing (Anhui)

The annual potential evapotranspiration in Anqing increased significantly (p<0.0001) during 1951–2013 at the average rate of 1.250 mm/yr (Fig. 39).
4.3.10 Wuhan (Hubei)

The potential evapotranspiration in Wuhan increased significantly (p<0.0001) during 1951–2013 at the average rate of 1.405 (Fig. 40).
4.3.11 Yichang (Hubei)

The potential evapotranspiration in Yichang increased during 1952–2013 at the average rate of 0.621 significantly (p=0.002), as shown in Fig. 41.
4.3.12 Xinyang (Henan)

The potential evapotranspiration in Xinyang increased significantly (p=0.0001) during 1951–2013 at the average rate of 0.733 mm/yr (Fig. 42).
4.4 Discussion and Conclusions

The trends of potential evapotranspiration in these 12 stations are summarized in Table 9. The annual potential evapotranspiration in Montegomery Airport, Alma Bacon Co Airport and Toccoa decreased insignificantly. The annual potential evapotranspiration in Fairhope 2 NE, Mobile Regional Airport and Meridian Key Field increased, in which only the increased trend in Alma Bacon Co Airport is significant. The overall annual potential evapotranspiration trends during 1949–2013 in the SUS are ambiguous, which is in accordance with the contradiction between pan and actual evaporation in the SUS suggested by Golubev et al. (2001).
5 out of 6 stations in the ECC (Anqing, Wuhan, Bengbu, Yichang, Xinyang) showed significantly increased annual potential evapotranspiration, and only Lushi insignificantly decreased in annual potential evapotranspiration. This overall increased trend does not agree with the decreased annual potential evapotranspiration trend suggested by Gao et al. (2007) during 1960–2002. In this chapter, the potential evapotranspiration is calculated with the Thornthwaite method, different from the Penman-Monteith method used by Gao et al. (2007). The Thornthwaite method depends more on the air temperature data than the Penman-Monteith method, and the ECC showed overall increased trends in annual air temperature, as depicted in Chapter 2, which may cause the different result of this chapter compared with the result by Gao et al. (2007). Another reason for different trends of annual potential evapotranspiration between the result of this chapter and the result by Gao et al. (2007) is that longer length of years is used (1951–2013) in this chapter. The analysis of the roles climate variables play in the potential evapotranspiration in these two regions is shown in Chapter 6.
<table>
<thead>
<tr>
<th>Weather station</th>
<th>p value</th>
<th>Significant</th>
<th>Rate (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL US (1949-2013)</td>
<td>0.24</td>
<td>N</td>
<td>-0.264</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL (1949-2013)</td>
<td>0.6</td>
<td>N</td>
<td>-0.115</td>
</tr>
<tr>
<td>Montgomery Airport, AL (1949-2013)</td>
<td>0.29</td>
<td>N</td>
<td>0.253</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA (1949-2013)</td>
<td>&lt; 0.0001</td>
<td>Y</td>
<td>0.893</td>
</tr>
<tr>
<td>Toccoa, GA (1949-2013)</td>
<td>0.27</td>
<td>N</td>
<td>0.257</td>
</tr>
<tr>
<td>Meridian Key Field, MS (1940-2013)</td>
<td>0.86</td>
<td>N</td>
<td>-0.043</td>
</tr>
<tr>
<td>Anqing, Anhui (1951-2013)</td>
<td>&lt; 0.0001</td>
<td>Y</td>
<td>1.25</td>
</tr>
<tr>
<td>Bengbu, Anhui (1951-2013)</td>
<td>&lt; 0.0001</td>
<td>Y</td>
<td>0.853</td>
</tr>
<tr>
<td>Lushi, Henan (1953-2013)</td>
<td>0.85</td>
<td>N</td>
<td>-0.029</td>
</tr>
<tr>
<td>Xinyang, Henan (1951-2013)</td>
<td>0.0001</td>
<td>Y</td>
<td>0.733</td>
</tr>
<tr>
<td>Wuhan, Hubei (1951-2013)</td>
<td>&lt; 0.0001</td>
<td>Y</td>
<td>1.405</td>
</tr>
<tr>
<td>Yichang, Hubei (1952-2013)</td>
<td>0.002</td>
<td>Y</td>
<td>0.621</td>
</tr>
</tbody>
</table>

Table 9. Trends of potential evapotranspiration of the weather stations selected in the SUS and the ECC
References


Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., … Midgley, P. M. (2013). Climate change 2013: The physical science basis. 88


Chapter 5: The Recent Temperature Trends and Variance in the SUS and the ECC

5.1 Introduction

Globally averaged land-surface air temperature increased in the last century (Stocker et al., 2013). In China, mean air temperature has increased since the instrumental records began in 1950s (Wang and Gong, 2000; Liu et al., 2004). In the ECC including Henan, Hubei and Anhui Provinces, the general trend of mean air temperature was increasing during 1955–2000 (Liu et al., 2004). However, at similar latitude, a slightly cooling trend was observed during the twentieth century in the SUS, albeit the warming trend in other parts of the United States (Lu et al, 2005; Roger, 2013). Rogers (2013) used stepwise multiple linear regression (SMLR) models to determine the correlation between the various climatic oscillations, natural forcings and the air temperature in the SUS. The author noted that the Palmer Drought Severity (PDSI) and the Tropical Pacific SST Index (TrPac) decreased the annual temperature in the SUS significantly, while the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO) weakly increased the annual temperature in the SUS.

Large-scale climatic variables such as the AMO and the NAO are important determinants of the climate variations globally. The NAO significantly influenced the ice breakup
dates for Lake Mendota, and the El Niño Southern Ocean Index (ENSO) impacted the timing of ice breakup in Lakes Mendota and Monona during 1905–2004 (Sharma et al., 2013). The AMO and the Pacific Decadal Oscillation (PDO) explained over half of the variance of the multidecadal drought frequency in the last century in the United States (McCabe et al., 2004). The influence of the AMO is not limited to the Atlantic Ocean. Indeed, it has a global effect on the climate variability, especially over northern Hemisphere with switches between positive and negative phases (Li, 2004; Sutton and Hodson, 2005; Knight et al., 2006; Wyatt et al., 2012). Sutton and Hodson (2005) demonstrated the significant increasing impact of the AMO on the summer air temperature in the SUS, which also agrees with the results reported by Rogers (2013). The AMO also influenced the hydrological cycle of the SUS with an interaction with the ENSO (Enfield et al., 2001; Mo et al., 2009). The PDO strongly influenced the climate variance in China associated with the ENSO (Zhu and Yang, 2003). Li and Bates (2007) used three different atmospheric general circulation models (AGCM) to investigate the AMO impact on the climate in eastern China. Results from all three models agreed with the observational composite analyses that the positive (negative) AMO phase is associated with warm (cold) winters in the ECC. In winter, the positive AMO induces negative surface air pressure anomalies over Eurasia. These negative surface anomalies reduce the Mongolian Cold High, weakening the East Asian Winter Monsoon, thus heat the winter in the ECC (Li and Bates, 2007). In summer, the warm AMO induces a positive tropospheric temperature anomaly, thus increases temperature in Eurasia (Wang et al., 2009).
The different annual air temperature trends between the SUS and the ECC necessitate additional researches. Although the large-scale climatic variables influenced the climate variance in both of these regions, there might be different impacts on the SUS and the ECC. Thus, the tested hypotheses are: 1) the air temperature is keeping cooling after 2007 in the SUS; 2) different trends of air temperature occurred in these two regions during 1951–2013; and 3) the impacts of climatic variables on the air temperature differ among SUS and the ECC. The specific objectives of this study are to identify climatic variables associated with the air temperature and to identify the trends of the air temperature during 1950–2013 in these two regions.

5.2 Data and Methodology

5.2.1 Data

The analysis used the monthly average mean air temperature for 6 weather stations from 3 states (Alabama, Mississippi and Georgia) in the SUS and 6 stations from 3 provinces in the ECC (Henan, Hubei and Anhui). These weather stations were selected on the basis of the data availability online, the accuracy of data, and the least missing data. The data of monthly air temperature are scrutinized to remove the data of mistake, and after the data are averaged into annual air temperature data, the sites with less than 10% of the missing data are chosen.

The stations selected for the study are located in 3 states across the SUS – Meridian Key Field (Mississippi), Fairhope 2 NE (Alabama), Mobile Regional Airport (Alabama), Montgomery Airport (Alabama), Alma Bacon Co Airport and Toccoa (Georgia); and 3 provinces across the ECC – Lushi (Henan), Xinyang (Henan), Bengbu (Anhui), Anqing
(Anhui), Wuhan and Yichang (Hubei), as shown in Tables 10 and 11, and Figs 43 and 44. The data of air temperature were collected from the National Climatic Data Center (www.ncdc.noaa.gov) and China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/home.do).
Figure 43. Locations of the weather stations selected in the SUS for air temperature analysis

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL US</td>
<td>30°33’N</td>
<td>87°53’W</td>
<td>7</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL</td>
<td>30°41’N</td>
<td>88°15’W</td>
<td>65.5</td>
</tr>
<tr>
<td>Montgomery Airport, AL</td>
<td>32°18’N</td>
<td>86°24’W</td>
<td>61.6</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA</td>
<td>31°32’N</td>
<td>82°30’W</td>
<td>58.8</td>
</tr>
<tr>
<td>Toccoa, GA</td>
<td>34°35’N</td>
<td>83°20’W</td>
<td>308.5</td>
</tr>
<tr>
<td>Meridian Key Field, MS</td>
<td>32°20’N</td>
<td>88°45’W</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Table 10. Basic information of the weather stations selected in the SUS for air temperature analysis
Figure 44. Locations of the weather stations selected in the ECC for air temperature analysis

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lushi, Henan</td>
<td>34°03’N</td>
<td>111°02’E</td>
<td>568.8</td>
</tr>
<tr>
<td>Xinyang, Henan</td>
<td>32°08’N</td>
<td>114°03’E</td>
<td>114.5</td>
</tr>
<tr>
<td>Anqing, Anhui</td>
<td>30°32’N</td>
<td>117°03’E</td>
<td>19.8</td>
</tr>
<tr>
<td>Wuhan, Hubei</td>
<td>30°37’N</td>
<td>114°08’E</td>
<td>23.1</td>
</tr>
<tr>
<td>Yichang, Hubei</td>
<td>30°42’N</td>
<td>111°18’E</td>
<td>133.1</td>
</tr>
<tr>
<td>Bengbu, Anhui</td>
<td>32°55’N</td>
<td>117°23’E</td>
<td>21.9</td>
</tr>
</tbody>
</table>

Table 11. Basic information of the weather stations selected in the ECC for air temperature analysis
Large-scale climatic variables influencing both the SUS and the ECC (e.g., NAO) were involved in the SMLR analysis as predictors; and their sources are shown in Table 12. The AMO is a 65–80 year sea surface temperature oscillation in the North Atlantic Ocean (Enfield et al., 2001). The PDO is a recurring ocean-atmosphere climate anomaly over the midlatitude North Pacific basin (Mantua, 1997). The NAO is the raw sea level pressure (SLP) anomaly between the Ponta Delgadas, Azores and Akureyri, Iceland, and is comprised of the Azores High and Icelandic Low (Rogers, 1984). The Arctic Oscillation (AO) is an Arctic analogy of the NAO (Thompson and Wallace, 1998). The Southern Oscillation Index (SOI) is the SLP anomaly difference between Tahiti and Darwin, Australia, a dominant atmospheric variability pattern in central Pacific (Chen, 1982). The North Pacific Index (NPI) stretches from 30° N to 65° N and 160° E to 140° W, and is an area-weighted SLP (hPa) (Trenberth and Hurrell, 1994). The Niño3.4 Index (N34) is a sea surface temperature (SST) for the region 5°N–5°S, 120°–170°W (Trenberth, 1997).
<table>
<thead>
<tr>
<th>Index name</th>
<th>Abbreviation</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic Oscillation</td>
<td>AO</td>
<td><a href="http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao_index.b50.current.ascii">http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao_index.b50.current.ascii</a></td>
</tr>
<tr>
<td>Southern Oscillation Index</td>
<td>SOI</td>
<td><a href="http://www.cgd.ucar.edu/cas/catalog/climind/SOI.signal.ascii">http://www.cgd.ucar.edu/cas/catalog/climind/SOI.signal.ascii</a></td>
</tr>
<tr>
<td>Atlantic Multidecadal Oscillation</td>
<td>AMO</td>
<td><a href="http://www.esrl.noaa.gov/psd/data/timeseries/AMO">http://www.esrl.noaa.gov/psd/data/timeseries/AMO</a></td>
</tr>
<tr>
<td>Niño 3.4 SST Index</td>
<td>N34</td>
<td><a href="http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino34/">http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino34/</a></td>
</tr>
</tbody>
</table>

Table 12. Large-scale climatic variables used in air temperature analysis

5.2.2 Methodology

The linear correlation analysis was done to analyze the linear correlations between the annual data of air temperature and the years in the SUS and the ECC, and the linear regression is used to assess the impacts of the climatic variables on the air temperature in both regions. Linear regression is widely used to study the relationships between climate anomalies and the climatic variables (McCabe et al., 2004; Sharma et al., 2013; Rogers, 2013; Zhou and Tung, 2013; Mikšovský et al., 2014), and it helps to understand how much variance could be explained by the climatic variables and how significantly the...
climate anomalies and the climatic variables are associated, although the physical
mechanisms behind these relationships are not studied.

In this paper, linear correlation is established to assess the annual average mean air
temperature correlations with years for the 12 weather stations of these two regions with
a 95% confidence interval. The SMLR is applied to evaluate the variance of the monthly
average mean air temperature that the large-scale climatic variables explained, and to
understand the different roles these predictors play in these two regions. The predictand
and the predictors in SMLR are depicted as:

Equation 8 \[ Y = a + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n \]

where, \( Y \) is the predictand value of the monthly average mean air temperature of these
two regions, \( a \) is the constant and \( x_1 \ldots x_n \) are predictor variables for which \( b_1 \ldots b_n \) are the
regression coefficients for the climatic variables shown in Table 12. Predictors are
selected step-by-step in SMLR. The predictor explaining the most predictand variance is
chosen first, and then the predictor explaining the most remaining predictand variance is
chosen, until the rest climatic variables fail to explain the predictand variance with 95%
confidence as a predictor. In this way, the multiple coefficient of determination \( (R^2) \) with
the predictand value \( Y \) reaches the highest values. After the selection of the predictors,
the regression coefficients for the predictors are recalculated and the number of degrees
of freedom is reduced step-by-step, and an ultimate \( R^2 \) value is attained for the reduction
in degrees of freedom (Rogers, 2013). Since the instrumental records of most weather
stations in China began after 1951, there are gaps when the records from the weather
stations in the SUS exist while the records from the ECC are absent. Thus, the annual
average mean air temperature used for linear correlation was started from 1951 in these two regions and the monthly average mean air temperature of the SUS for SMLR began from 1950. After the SMLR models for these two regions came out, the trends of the predicted values of the annual average mean air temperature are regressed against years to diagnose the air temperature correlations with years for these two regions in recent years. Correlation and regression analysis were performed by using MS Office Excel (2007) and SPSS 22.

5.3 Results

5.3.1 The annual average mean air temperature trends for the 12 weather stations in the SUS and the ECC

The annual average mean air temperature trends for the 12 weather stations in the SUS and the ECC are shown in Table 1. No significant trend is observed in 5 out of 6 weather stations in the SUS for the annual average mean air temperature with a 95% confidence interval. Only the annual average mean air temperature for Alma Bacon Co Airport increased significantly during 1951–2013 at the rate of 0.015 ºC/yr. In contrast, 5 weather stations in the ECC demonstrated significant increased annual average mean air temperature trends, most of them at the rate > 0.015 ºC/yr. The stations in the ECC showed strengthened, more significantly increased trends in annual average mean air temperature, compared with those in the SUS. Since 1951, the annual average mean air temperature trends in the SUS did not decrease significantly, and this trend differs from that observed in the last century (Rogers, 2013).
<table>
<thead>
<tr>
<th>Weather station</th>
<th>Rate of change (°C/yr)</th>
<th>p value</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL US</td>
<td>-0.007</td>
<td>0.07</td>
<td>N</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL</td>
<td>0</td>
<td>0.88</td>
<td>N</td>
</tr>
<tr>
<td>Montgomery Airport, AL</td>
<td>0.005</td>
<td>0.14</td>
<td>N</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA</td>
<td>0.015</td>
<td>0.0001</td>
<td>Y</td>
</tr>
<tr>
<td>Toccoa, GA</td>
<td>0.003</td>
<td>0.43</td>
<td>N</td>
</tr>
<tr>
<td>Meridian Key Field, MS</td>
<td>0</td>
<td>0.87</td>
<td>N</td>
</tr>
<tr>
<td>Anqing, Anhui</td>
<td>0.023</td>
<td>&lt;</td>
<td>Y</td>
</tr>
<tr>
<td>Bengbu, Anhui</td>
<td>0.021</td>
<td>0.0001</td>
<td>Y</td>
</tr>
<tr>
<td>Lushi, Henan</td>
<td>0.004</td>
<td>0.21</td>
<td>N</td>
</tr>
<tr>
<td>Xinyang, Henan</td>
<td>0.019</td>
<td>&lt;</td>
<td>Y</td>
</tr>
<tr>
<td>Wuhan, Hubei</td>
<td>0.026</td>
<td>&lt;</td>
<td>Y</td>
</tr>
<tr>
<td>Yichang, Hubei</td>
<td>0.012</td>
<td>0.0002</td>
<td>Y</td>
</tr>
</tbody>
</table>

Table 13. The annual average mean air temperature trends for the 12 weather stations in the SUS and the ECC during 1951–2013

5.3.2 Relationships of large-scale climatic variables and mean air temperature

The SMLR models of the mean air temperature in the SUS and the ECC are established with monthly data of the large-scale climatic variables shown in Table 14, and the monthly average mean air temperature for the 12 weather stations from the SUS and the ECC, respectively. Table 14 summarizes the constant of the prediction equation, the regression coefficients of the predictors and the adjusted variance (R²) of the predictands explained by the predictors.

Both prediction equations for the SUS and the ECC explain more than 75% of the variance of the monthly average mean air temperature (76.2% for the SUS and 78.7% for
The seven large-scale climatic variables involved in the analysis all contribute to the two prediction equations. NPI, AMO and N34 explain most of the variance both in the SUS and in the ECC, in which NPI accounts for more than half of the variance in these two regions (56.2% in the SUS and 53.1% in the ECC).

There exist negative correlations between the AO and the monthly average mean air temperature in the SUS and the ECC, as indicated by their negative regression coefficients. These correlations indicate that the monthly average mean air temperature in the SUS and the ECC is low (high) during the positive (negative) phase of the AO. The other large-scale climatic variables involved in the SMLR as predictors have positive regression coefficients for the predictands.
### Table 14. Constants, regression coefficients and adjusted variance ($R^2$) from the SMLR for the monthly average mean air temperature in the SUS and the ECC

<table>
<thead>
<tr>
<th></th>
<th>Coefficient ($b_a$)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUS</td>
<td>$a=18.355$</td>
<td></td>
</tr>
<tr>
<td>NPI</td>
<td>3.507</td>
<td>0.562</td>
</tr>
<tr>
<td>AMO</td>
<td>3.388</td>
<td>0.728</td>
</tr>
<tr>
<td>N34</td>
<td>1.233</td>
<td>0.756</td>
</tr>
<tr>
<td>PDO</td>
<td>0.423</td>
<td>0.759</td>
</tr>
<tr>
<td>SOI</td>
<td>0.273</td>
<td>0.761</td>
</tr>
<tr>
<td>NAO</td>
<td>0.19</td>
<td>0.762</td>
</tr>
<tr>
<td>AO</td>
<td>-0.304</td>
<td>0.762</td>
</tr>
<tr>
<td>ECC</td>
<td>$a=15.363$</td>
<td></td>
</tr>
<tr>
<td>NPI</td>
<td>4.201</td>
<td>0.531</td>
</tr>
<tr>
<td>AMO</td>
<td>4.841</td>
<td>0.724</td>
</tr>
<tr>
<td>N34</td>
<td>2.191</td>
<td>0.770</td>
</tr>
<tr>
<td>SOI</td>
<td>0.587</td>
<td>0.777</td>
</tr>
<tr>
<td>PDO</td>
<td>0.669</td>
<td>0.782</td>
</tr>
<tr>
<td>AO</td>
<td>-0.864</td>
<td>0.786</td>
</tr>
<tr>
<td>NAO</td>
<td>0.248</td>
<td>0.787</td>
</tr>
</tbody>
</table>

The results of linear correlations between the predicted and observed values and the residual and observed values of the SMLR for the SUS and the ECC are shown in Table 15. The predicted and observed correlation is strong (0.873, significant at 99%) relative to the predicted and observed analogy (0.487, significant at 99%) in the SUS. Similar correlations are observed in the ECC (0.887, significant at 99% vs. 0.462, significant at 99%). The predicted values of the monthly average mean air temperature are well correlated with the observed ones in both the ECC and the SUS. Thus, these functions can be used to diagnose the air temperature trends for the SUS and the ECC.
<table>
<thead>
<tr>
<th>Region</th>
<th>predicted vs. observed values</th>
<th>residual vs. observed values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>correlation coefficient</td>
<td>p value</td>
</tr>
<tr>
<td>SUS</td>
<td>0.873</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ECC</td>
<td>0.887</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Table 15. Correlation coefficients between the predicted and observed values and the residual and observed values of the monthly average mean air temperature from the SMLR results for the SUS and the ECC

5.3.3 The annual average mean air temperature trends diagnosed for the SUS and the ECC

The annual average mean air temperature trends diagnosed for the SUS during 1950–2013 and the ECC during 1951–2013 are shown in Fig. 45. No significant trend is observed for the diagnosed annual average mean air temperature (Fig. 45a). During 1974–2013, however, the diagnosed values of the annual average mean air temperature for both regions showed significant (at 99%) and rapidly increased trends. The diagnosed trend in the ECC during 1974–2013 is 0.056 °C/yr, which is higher than the diagnosed trend during the same period in the SUS (0.041 °C/yr) (Fig. 45b).
Figure 45. a Diagnosed annual average mean air temperature for the SUS (1950–2013) and the ECC (1951–2013); b same as a, but for the 1974–2013 in the SUS and the ECC.
5.4 Discussion

5.4.1 The air temperature trends in the SUS and the ECC

The observed annual average mean air temperature trends for the 6 weather stations in the SUS indicated no decreased trends of the air temperature during 1950–2013. These results do not agree with those reported by Rogers (2013) for the SUS during 1895–2007. The absence of the decreased trend might be attributed to the increased temperature in recent years. Rogers (2013) observed that the cooling trend in the SUS would not exist under the condition of the warming beginning in the late 1990s and it persisted beyond 2007. More weather stations in the ECC selected showed a significantly increased air temperature trend during the 1951–2013 than those in the SUS. In contrast to the SUS, the ECC is more likely to undergo a warming period in the last 60 years.

The annual average mean air temperature diagnosed by the large-scale climatic variables in the SUS and the ECC indicated a similar insignificant increase during 1950–2013. The diagnosed annual average mean air temperature increased in both regions, but not statistically significantly. When analyzing the trends of predicted annual average mean air temperature in the SUS and the ECC during the last 40 years since 1970s, the results indicate acceleratingly increased and significant trends for SUS (0.41 °C per decade) and ECC (0.56 °C per decade). These trends are much higher than the 0.254–0.273 °C per decade increase in the global land-surface air temperature during 1979–2012 predicted by climate models (Stocker et al., 2013). The accelerating warming happened in the SUS during the last 40 years is in accord with the indication that the cooling trend in the SUS
last century disappears as a result of the continuous warming from the late 1990s. The ECC became warmer more rapidly than the SUS during 1979–2013.

5.4.2 The impacts of the climatic variables on the air temperature in the SUS and the ECC

The SMLR results demonstrate that the NPI explains most of the variance, and has positive correlation with the monthly average mean air temperature for the SUS and the ECC. However, Rogers (2013) suggested that the NPI had no significant impact on the annual and seasonal average mean air temperature for the SUS during 1895–2007. Differences in Rogers’ result and this SMLR trial might be attributed to the differences between the locations and numbers of the weather stations, the period of time and the differences between monthly, seasonal and annual scales. The NPI turned into a positive phase after 2005 (Hurrell et al., 2014), thus contributed to the warming of the positively correlated air temperature in the SUS and the ECC.

The AMO also has a positive correlation with the monthly average mean air temperature for these two regions, which is in accord with the data of Rogers (2013) and Wang et al. (2009). Rogers (2013) predicted that the SUS would stop cooling if the AMO, positively correlated with the annual air temperature in the SUS, continues its positive phase after 2007. Since the AMO has been in the positive phase these years (Wang et al., 2013), our results are in accord with those of Rogers’ (2013).

The positive correlations of N34 with the monthly average mean air temperature for these two regions disagree with the results reported by Liu and Ding (1995) and Mo (2010). The results are interesting and may need additional research. There are more large-scale
climatic variables involved in the SMLR for the SUS than reported by Rogers (2013), which may be attributed to the different time periods, weather stations selected and the different time scales (monthly vs. annual).

5.5 Conclusions

Results obtained in this study support the following conclusions:

1) Compared with the weather stations in the ECC, those selected in the SUS did not show a significant cooling trend during 1951–2013. This disproves the hypothesis that the SUS is still cooling after 2007.

2) The diagnosed values of the annual mean air temperature based on the SMLR results for the SUS during 1950–2013 and the ECC for 1951–2013 increased insignificantly. However, the diagnosed values of the annual mean air temperature for these two regions in recent 40 years indicated significant and rapidly increased trends. Similar insignificant increases of air temperature in these two regions during 1950–2013 do not support hypothesis 2 that there are different trends of air temperature in these two regions during 1951–2013.

3) All seven large-scale climatic variables selected in the study (NPI, AMO, N34, PDO, SOI, NAO and AO) explain more than 75% of the variance of the monthly average mean air temperature for the SUS during 1950–2013 and the ECC for 1951–2013, in which NPI, AMO and N34 contribute to the most variance in both of the two regions. The overall influences of these climatic variables are similar in these two regions, which does not support hypothesis 3.
The results from linear regression models can only imply the possible correlation of the climatic variables with the temperature in certain regions, and the roles of several climatic variables in this study differ from those of other researches. The predictors chosen in the research have correlations with each other, such as the NAO and AO, N34 and SOI. A flaw of this research is the absence of making the data series of the predictors orthogonal to each other. This may also explain that only three predictors contribute to most of the explained variance of monthly mean air temperature. The future researches could use rotated principal component analysis to resolve the multicollinearity problem of the predictors. Also the time period in this research is so short that the limited data points may result in overfitting of the data. To understand the physical mechanisms governing the relationships of the temperature and the climatic variables, results based on AGCMs are needed to compare with those from the linear regression models.
References


Chapter 6: The Recent Precipitation and Potential Evapotranspiration Trends and Variance in the SUS and the ECC

6.1 Introduction

In the twentieth century, globally averaged land-surface air temperature followed an increased trend (Stocker et al., 2013), which may impact the global hydrologic cycle. In the mid-latitude areas of the Northern Hemisphere, it is likely that precipitation has been increasing since 1951 (Stocker et al., 2013). However, in most parts of the east-central China (ECC) (i.e. Henan, Hubei and Anhui Provinces), a decreased trend was observed in precipitation between 1961 and 2001 (Wang and Zhou, 2005). Similar trends in annual precipitation in most parts of the ECC, except for areas along the Yangtze River, were observed during 1961–1990 (Zhai et al., 2005). In contrast, the precipitation increased during 1900–1994 in most parts of the southeastern United States (SUS) (Karl et al., 1996). The annual potential evapotranspiration in the ECC had a declining trend during 1956 to 2000 (Gao et al., 2006). In the SUS, the pan evapotranspiration decreased but the actual evapotranspiration increased during 1957–1998 (Golubev et al., 2001). There are notable differences in climate between the SUS and the ECC, despite two regions being at similar latitudes. For example, the mean air temperature increased during
1955–2000 in the ECC (Liu et al., 2004) while the SUS experienced a slightly cooling trend during the twentieth century (Lu et al., 2005; Rogers, 2013). Global climate variations are associated with large-scale climatic variables such as the Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO). The impacts of the AMO, not limited to the Atlantic Ocean, are reported all over the world, especially over northern Hemisphere (Li, 2004; Sutton and Hodson, 2005; Knight et al., 2006; Wyatt et al., 2012). Knight et al. (2006) demonstrated that AMO anomalies influence the precipitation in the northeastern Brazil and the Sahel by shifts in the mean inter-tropical convergence zone (ITCZ), while the broad cyclonic pressure anomalies induced by those of AMO influence the precipitation in the northwestern Europe. Positive (negative) AMO anomalies are also observed to warm (cool) the Eurasia by inducing warm (cold) tropospheric temperature anomalies. Consequently, a late (early) withdrawal of summer monsoon happens in India, increasing (decreasing) the summer precipitation (Goswami et al., 2006). The PDO influences the climate variance in China associated with the ENSO remarkably (Zhu and Yang, 2003). For the hydrological factors in the SUS, Enfield et al. (2001) reported that the AMO itself is negatively correlated with the rainfall in most of the Mississippi Basin. Such impacts of AMO also interact with the ENSO (Enfield et al., 2001; Mo et al., 2009). More than half of the variance of the multidecadal drought frequency in the last century can be explained by the AMO and the PDO in the United States (McCabe et al., 2004).

Although the large-scale climatic variables have influences on the climate variance in both of these regions, there might be differences between the impacts on the SUS and the
ECC. Thus, the differences in precipitation and potential evapotranspiration trends differ among the SUS and the ECC warrant further research. The hypotheses tested in this study are: 1) trends in precipitation differ among the SUS and the ECC regions during 1951–2013; 2) the impacts of climatic variables on the precipitation differ among the SUS and the ECC; 3) the trends of potential evapotranspiration differ in the SUS and in the ECC during 1951–2013; and 4) impacts of the climatic variables on the potential evapotranspiration differ in the SUS and the ECC. Thus, the objectives of this study are to identify the trends of the precipitation and the climatic variables associated with the precipitation during 1950–2013 in the SUS and the ECC, and to identify the trends of the potential evapotranspiration and the climatic variables associated with the potential evapotranspiration during 1949–2013 in these two regions.

6.2 Data and Methodology

6.2.1 Data

Monthly average mean air temperature and monthly total precipitation data of 6 weather stations from 3 states (Alabama, Mississippi and Georgia) in the SUS, and 6 stations from 3 provinces (Henan, Hubei and Anhui) in the ECC are used in the analysis. These weather stations were selected on the basis of the data availability online, the accuracy of data, and the least missing data. The data are scrutinized to remove the data of mistake, and after the data are added or converted into annual precipitation or potential evapotranspiration data, the sites with less than 10% of the missing data are chosen. The calculation of potential evapotranspiration used the revised Thornthwaite method (Thornthwaite, 1948; Willmott et al., 1985; Xu and Singh, 2001) with the monthly
average mean air temperature. Annual total potential evapotranspiration is the sum of the monthly values.

The stations selected for the study are located in 3 states across the SUS – Meridian Key Field (Mississippi), Fairhope 2 NE (Alabama), Mobile Regional Airport (Alabama), Montgomery Airport (Alabama), Alma Bacon Co Airport and Toccoa (Georgia); and 3 provinces across the ECC – Lushi (Henan), Xinyang (Henan), Bengbu (Anhui), Anqing (Anhui), Wuhan and Yichang (Hubei), as shown in Figs 46 and 47, and Tables 16 and 17. Data representing the air temperature and precipitation measurements were collected from the National Climatic Data Center (www.ncdc.noaa.gov) and China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/home.do).
Figure 46. Locations of the weather stations selected in the SUS for precipitation and potential evapotranspiration analysis

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL US</td>
<td>30°33'N</td>
<td>87°53'W</td>
<td>7</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL</td>
<td>30°41'N</td>
<td>88°15'W</td>
<td>65.5</td>
</tr>
<tr>
<td>Montgomery Airport, AL</td>
<td>32°18'N</td>
<td>86°24'W</td>
<td>61.6</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA</td>
<td>31°32'N</td>
<td>82°30'W</td>
<td>58.8</td>
</tr>
<tr>
<td>Toccoa, GA</td>
<td>34°35'N</td>
<td>83°20'W</td>
<td>308.5</td>
</tr>
<tr>
<td>Meridian Key Field, MS</td>
<td>32°20’N</td>
<td>88°45’W</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Table 16. Basic information of the weather stations selected in the SUS for precipitation and potential evapotranspiration analysis
Figure 47. Locations of the weather stations selected in the ECC for precipitation and potential evapotranspiration analysis

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m above sea level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lushi, Henan</td>
<td>34°03’N</td>
<td>111°02’E</td>
<td>568.8</td>
</tr>
<tr>
<td>Xinyang, Henan</td>
<td>32°08’N</td>
<td>114°03’E</td>
<td>114.5</td>
</tr>
<tr>
<td>Anqing, Anhui</td>
<td>30°32’N</td>
<td>117°03’E</td>
<td>19.8</td>
</tr>
<tr>
<td>Wuhan, Hubei</td>
<td>30°37’N</td>
<td>114°08’E</td>
<td>23.1</td>
</tr>
<tr>
<td>Yichang, Hubei</td>
<td>30°42’N</td>
<td>111°18’E</td>
<td>133.1</td>
</tr>
<tr>
<td>Bengbu, Anhui</td>
<td>32°55’N</td>
<td>117°23’E</td>
<td>21.9</td>
</tr>
</tbody>
</table>

Table 17. Basic information of the weather stations selected in the ECC for precipitation and potential evapotranspiration analysis
Stepwise multiple linear regression (SMLR) models are used to determine any association between large-scale climatic variables and the precipitation and potential evapotranspiration in the SUS and the ECC. The climatic variables involved in the analysis are from the sources shown in Table 18. The North Atlantic Oscillation (NAO) is the raw sea level pressure (SLP) anomaly between the Ponta Delgadas, Azores and Akureyri, Iceland, and is comprised of the Azores High and Icelandic Low (Rogers, 1984), and the Arctic Oscillation (AO) is an Arctic analogy of the NAO (Thompson and Wallace, 1998). The AMO is a 65–80 year sea surface temperature oscillation in the North Atlantic Ocean (Enfield et al., 2001). For the climatic variables in the Pacific, the Southern Oscillation Index (SOI) as the SLP anomaly difference between Tahiti and Darwin, Australia, is a dominant atmospheric variability pattern in central Pacific (Chen, 1982). The PDO is a recurring ocean-atmosphere climate anomaly over the midlatitude North Pacific basin (Mantua, 1997). The North Pacific Index (NPI) stretches from 30° N to 65° N and 160° E to 140° W, and is an area-weighted mean SLP (hPa) (Trenberth and Hurrell, 1994). The Niño3.4 Index (N34) is a sea surface temperature (SST) for the region 5°N–5°S, 120°–170°W (Trenberth, 1997).
Table 18. Large-scale climatic variables used in precipitation and potential evapotranspiration analysis

<table>
<thead>
<tr>
<th>Index name</th>
<th>Abbreviation</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic Oscillation</td>
<td>AO</td>
<td><a href="http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly_ao_index.b50.current.ascii">http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly_ao_index.b50.current.ascii</a></td>
</tr>
<tr>
<td>Southern Oscillation Index</td>
<td>SOI</td>
<td><a href="http://www.cgd.ucar.edu/cas/catalog/climind/SOI.signal.ascii">http://www.cgd.ucar.edu/cas/catalog/climind/SOI.signal.ascii</a></td>
</tr>
<tr>
<td>Atlantic Multidecadal Oscillation</td>
<td>AMO</td>
<td><a href="http://www.esrl.noaa.gov/psd/data/timeseries/AMO/">http://www.esrl.noaa.gov/psd/data/timeseries/AMO/</a></td>
</tr>
<tr>
<td>Pacific Decadal Oscillation</td>
<td>PDO</td>
<td><a href="http://jisao.washington.edu/pdo/PDO.latest">http://jisao.washington.edu/pdo/PDO.latest</a></td>
</tr>
<tr>
<td>Niño 3.4 SST Index</td>
<td>N34</td>
<td><a href="http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino34/">http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino34/</a></td>
</tr>
</tbody>
</table>

6.2.2. Methodology

The potential evapotranspiration is calculated in the Thornthwaite method modified by Willmott et al. (1985). The monthly unadjusted potential evapotranspiration is shown in Eq 9 to 11:

\[ e \text{ (mm per month)} = \begin{cases} 
0, & t < 0\degree C \\
16\left(\frac{10t}{9}\right)^a, & 0 \leq t < 26.5\degree C \\
-415.85 + 32.24t - 0.43t^2, & t \geq 26.5\degree C 
\end{cases} \]

where, \( t \) is the mean monthly air temperature in \( \degree C \),
Equation 10 \[ i = \left( \frac{t}{5} \right)^{1.514} \]

Equation 11 \[ I = \sum_{j=1}^{12} i_j \]

in which \( I \) is the annual heat index, \( i \) is the monthly heat index for the month \( j \) (which is zero when the mean monthly temperature is 0 °C or less) (Thornthwaite, 1948; Willmott et al., 1985; Xu and Singh, 2001).

Monthly potential evapotranspiration should be adjusted with daytime length and the length of a month, and the final potential evapotranspiration is shown in Eq 12:

Equation 12 \[ E(\text{mm} \cdot \text{month}^{-1}) = e(\theta/30)(N/12) \]

where, \( \theta \) is the length of the month (in days) and \( N \) is the daytime length (in hours).

Linear regression models have been widely used to establish the relationships between climate variances and the climatic variables (McCabe et al., 2004; Sharma et al., 2013; Rogers, 2013; Zhou and Tung, 2013; Mikšovský et al., 2014). The linear regression can assess how much variance the climatic variables could explain and the significance of the associations between the climate anomalies and the climatic variables, albeit not directly linking to the physical reality behind these associations. For the SUS and the ECC in this article, linear correlation is computed to assess the annual total precipitation and potential evapotranspiration correlations with years for the 12 weather stations of these two regions with a 95% confidence interval. The SMLR is used to evaluate the variance of the monthly total precipitation and potential evapotranspiration that the large-scale climatic variables explained, assess the roles these predictors play in these two regions, and determine the significance of the relationships between the monthly total precipitation and...
and potential evapotranspiration and the climatic variables. The predictand and the predictors in SMLR were depicted as shown in Eq 13:

Equation 13 \[ Y = a + b_1x_1 + b_2x_2 + \cdots + b_nx_n \]

where, \( Y \) is the predictand values representing the monthly total precipitation or potential evapotranspiration of these two regions. \( a \) is the constant. \( b_1 \ldots b_n \) are the regression coefficients and \( x_1 \ldots x_n \) are predictor variables for the climatic variables shown in Table 18. Predictors are chosen step-by-step in SMLR. First, the predictor explaining the most predictand variance is selected; and then the predictor explaining the most remaining predictand variance is selected. This process continues until the rest of climatic variables cannot explain the predictand variance with 95% confidence as a predictor. The multiple coefficient of determination (\( R^2 \)) with the predictand value \( y \) reaches the maximum value in this process. After the selection of the predictors, the regression coefficients of the predictors chosen are recalculated and the number of degrees of freedom is reduced step-by-step, thus the final \( R^2 \) value is attained for the reduction in degrees of freedom (Rogers, 2013).

The instrumental records of most weather stations in China began after 1951. The records for years prior to 1951 from the weather stations in the SUS exist while those from the ECC are absent. Thus, the annual total precipitation and potential evapotranspiration used for linear regression began from 1951 and 1949, respectively, and the data on monthly total precipitation and potential evapotranspiration of the SUS for SMLR was started from 1950. Correlation and regression analysis were performed by using MS Office Excel (2007) and SPSS 22.
6.3 Results

6.3.1 The annual total precipitation and annual total potential evapotranspiration trends for the 12 weather stations in the SUS and the ECC

Table 19 shows the annual total precipitation trends for the 12 weather stations in the SUS and the ECC. No significant trend is observed in 5 out of 6 weather stations in the SUS for the annual total precipitation with a 95% confidence interval. The only exception is Toccoa, GA which had a significantly decreased annual total precipitation trend during 1951–2013 at the rate of -0.073mm/yr. Similarly, all stations selected in the ECC did not show any significant trend in annual total precipitation during the same time period. For both of these two regions, significant trends were rare for the annual total precipitation during the 1951–2013.
<table>
<thead>
<tr>
<th>Weather station</th>
<th>Rate of change (mm/yr)</th>
<th>p value</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL US</td>
<td>2.842</td>
<td>0.238</td>
<td>N</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL</td>
<td>0.7</td>
<td>0.728</td>
<td>N</td>
</tr>
<tr>
<td>Montgomery Airport, AL</td>
<td>1.405</td>
<td>0.449</td>
<td>N</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA</td>
<td>-0.147</td>
<td>0.924</td>
<td>N</td>
</tr>
<tr>
<td>Toccoa, GA</td>
<td>-0.073</td>
<td>0.974</td>
<td>Y</td>
</tr>
<tr>
<td>Meridian Key Field, MS</td>
<td>3.214</td>
<td>0.12</td>
<td>N</td>
</tr>
<tr>
<td>Anqing, Anhui</td>
<td>-0.199</td>
<td>0.93</td>
<td>N</td>
</tr>
<tr>
<td>Bengbu, Anhui</td>
<td>0.897</td>
<td>0.57</td>
<td>N</td>
</tr>
<tr>
<td>Lushi, Henan</td>
<td>-0.739</td>
<td>0.48</td>
<td>N</td>
</tr>
<tr>
<td>Xinyang, Henan</td>
<td>-0.797</td>
<td>0.66</td>
<td>N</td>
</tr>
<tr>
<td>Wuhan, Hubei</td>
<td>0.845</td>
<td>0.67</td>
<td>N</td>
</tr>
<tr>
<td>Yichang, Hubei</td>
<td>-0.851</td>
<td>0.61</td>
<td>N</td>
</tr>
</tbody>
</table>

Table 19. The annual total precipitation trends for the 12 weather stations in the SUS and the ECC during 1951–2013

The annual total potential evapotranspiration trends for the 12 weather stations in the SUS and the ECC are shown in Table 20. Only the annual total potential evapotranspiration for Alma Bacon Co Airport increased significantly during 1951–2013 at the rate of 0.893 mm/yr with a 95% confidence interval. However, 5 out of 6 weather stations in the ECC showed significant increased annual total potential evapotranspiration trends. In contrast to the weather stations in the SUS, those in the ECC demonstrated stronger and more significantly increased trends in annual total potential evapotranspiration.
<table>
<thead>
<tr>
<th>Weather station</th>
<th>Rate of change (mm/yr)</th>
<th>p value</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairhope 2 NE, AL US</td>
<td>-0.264</td>
<td>0.24</td>
<td>N</td>
</tr>
<tr>
<td>Mobile Regional Airport, AL</td>
<td>-0.115</td>
<td>0.6</td>
<td>N</td>
</tr>
<tr>
<td>Montgomery Airport, AL</td>
<td>0.253</td>
<td>0.29</td>
<td>N</td>
</tr>
<tr>
<td>Alma Bacon Co Airport, GA</td>
<td>0.893</td>
<td>&lt; 0.0001</td>
<td>Y</td>
</tr>
<tr>
<td>Toccoa, GA</td>
<td>0.257</td>
<td>0.27</td>
<td>N</td>
</tr>
<tr>
<td>Meridian Key Field, MS</td>
<td>-0.043</td>
<td>0.86</td>
<td>N</td>
</tr>
<tr>
<td>Anqing, Anhui</td>
<td>1.25</td>
<td>&lt; 0.0001</td>
<td>Y</td>
</tr>
<tr>
<td>Bengbu, Anhui</td>
<td>0.853</td>
<td>&lt; 0.0001</td>
<td>Y</td>
</tr>
<tr>
<td>Lushi, Henan</td>
<td>-0.029</td>
<td>0.85</td>
<td>N</td>
</tr>
<tr>
<td>Xinyang, Henan</td>
<td>0.733</td>
<td>0.0001</td>
<td>Y</td>
</tr>
<tr>
<td>Wuhan, Hubei</td>
<td>1.405</td>
<td>&lt; 0.0001</td>
<td>Y</td>
</tr>
<tr>
<td>Yichang, Hubei</td>
<td>0.621</td>
<td>0.002</td>
<td>Y</td>
</tr>
</tbody>
</table>

Table 20. The annual total potential evapotranspiration trends for the 12 weather stations in the SUS during 1949-2013 and the ECC during 1951–2013

6.3.2 Relationships of precipitation and potential evapotranspiration with large-scale climatic variables

The SMLR models of the precipitation and potential evapotranspiration in the SUS and the ECC were established with monthly data of the large-scale climatic variables shown in Table 18 and the monthly total precipitation and potential evapotranspiration for the 12 weather stations from the SUS and the ECC, respectively.

The constant of the prediction equation, the regression coefficients of the predictors and the adjusted variance (R²) of the monthly total precipitation explained by the climatic variables are summarized in Table 21. Similar equation for monthly total potential evapotranspiration is shown in Table 22.

The SMLR models could not explain much of the variance of precipitation in these two regions. Neither prediction equations for the SUS or the ECC explain more than 25% of
the variance of the monthly total precipitation. Seven climatic variables could only explain low fraction of total variance of the monthly total precipitation in the ECC with \( R^2 = 0.245 \). In the SUS, only N34 and NAO could explain mere 0.013 of the variance. In the ECC, NPI explains 0.2 of the variance; and negative correlation exists between the AO and the monthly total precipitation.

Contributions from all seven climatic variables account for more than 72% of total variance of the monthly total potential evapotranspiration in both the SUS and the ECC (73% for the SUS and 72.6% for the ECC). In both SUS and ECC regions, more than 70% of the variance is attributed to NPI, AMO and N34. The NPI accounts for more than half of the variance (51.1%) in the SUS, while the AMO explains most of the variance (48.6%) in the ECC. Most of the large-scale climatic variables involved in the SMLR as predictors have positive regression coefficients for the predictands, except for AO for the SUS and PDO for the ECC.
Table 21. Constants, regression coefficients and adjusted variance ($r^2$) from the SMLR for the monthly total precipitation in the SUS and the ECC

<table>
<thead>
<tr>
<th></th>
<th>Coefficient ($b_n$)</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUS</td>
<td>$a=115.314$</td>
<td></td>
</tr>
<tr>
<td>N34</td>
<td>73.051</td>
<td>0.01</td>
</tr>
<tr>
<td>NAO</td>
<td>-2.233</td>
<td>0.013</td>
</tr>
<tr>
<td>ECC</td>
<td>$a=81.021$</td>
<td></td>
</tr>
<tr>
<td>NPI</td>
<td>35.308</td>
<td>0.2</td>
</tr>
<tr>
<td>PDO</td>
<td>7.053</td>
<td>0.219</td>
</tr>
<tr>
<td>AMO</td>
<td>12.636</td>
<td>0.227</td>
</tr>
<tr>
<td>N34</td>
<td>131.821</td>
<td>0.235</td>
</tr>
<tr>
<td>SOI</td>
<td>3.673</td>
<td>0.238</td>
</tr>
<tr>
<td>NAO</td>
<td>6.079</td>
<td>0.24</td>
</tr>
<tr>
<td>AO</td>
<td>-9.382</td>
<td>0.245</td>
</tr>
</tbody>
</table>

Table 22. Constants, regression coefficients and adjusted variance ($r^2$) from the SMLR for the monthly total potential evapotranspiration in the SUS and the ECC

<table>
<thead>
<tr>
<th></th>
<th>Coefficient ($b_n$)</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUS</td>
<td>$a=72.05$</td>
<td></td>
</tr>
<tr>
<td>NPI</td>
<td>28.041</td>
<td>0.511</td>
</tr>
<tr>
<td>AMO</td>
<td>28.577</td>
<td>0.679</td>
</tr>
<tr>
<td>N34</td>
<td>116.42</td>
<td>0.715</td>
</tr>
<tr>
<td>PDO</td>
<td>4.415</td>
<td>0.72</td>
</tr>
<tr>
<td>SOI</td>
<td>3.145</td>
<td>0.725</td>
</tr>
<tr>
<td>AO</td>
<td>-5.702</td>
<td>0.729</td>
</tr>
<tr>
<td>NAO</td>
<td>1.642</td>
<td>0.73</td>
</tr>
<tr>
<td>ECC</td>
<td>$a=72.05$</td>
<td></td>
</tr>
<tr>
<td>AMO</td>
<td>28.041</td>
<td>0.486</td>
</tr>
<tr>
<td>NPI</td>
<td>28.577</td>
<td>0.665</td>
</tr>
<tr>
<td>N34</td>
<td>116.42</td>
<td>0.706</td>
</tr>
<tr>
<td>AO</td>
<td>4.415</td>
<td>0.714</td>
</tr>
<tr>
<td>SOI</td>
<td>3.145</td>
<td>0.719</td>
</tr>
<tr>
<td>PDO</td>
<td>-5.702</td>
<td>0.724</td>
</tr>
<tr>
<td>NAO</td>
<td>1.642</td>
<td>0.726</td>
</tr>
</tbody>
</table>
The SMLR results show that the correlation of the predicted and observed values of the monthly total precipitation in the SUS (0.114, significant at 99%) is much less than that of the residual and observed values (0.993, significant at 99%) (Table 23). Similar results are observed by comparing the correlation of the predicted and observed values of the monthly total precipitation in the ECC (0.496, significant at 99%) and that of the residual and observed values (0.868, significant at 99%). The observed monthly total precipitation is not well correlated with the predicted values of the SMLR models in the SUS and the ECC. Therefore, the predicted values cannot be used to diagnose the precipitation trends for the SUS and the ECC.

In contrast, the predicted values of the monthly total potential evapotranspiration are strongly correlated with the observed ones in both the ECC and the SUS (Table 24). The predicted and observed correlation is strong (0.854, significant at 99%) relative to the observed and residual correlation (0.519, significant at 99%) in the SUS. The correlations in the ECC follow a similar pattern for the predicted and observed values and the observed and residual ones (0.852, significant at 99% vs. 0.523, significant at 99%). Thus, predicted potential evapotranspiration values can be applied for the diagnosis of the potential evapotranspiration trends for the SUS and the ECC.
### Table 23. Correlation coefficients between the predicted and observed values and the residual and observed values of the monthly total precipitation from the SMLR results for the SUS and the ECC

<table>
<thead>
<tr>
<th>Region</th>
<th>predicted vs. observed values</th>
<th>residual vs. observed values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>correlation coefficient</td>
<td>p value</td>
</tr>
<tr>
<td>SUS</td>
<td>0.114</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ECC</td>
<td>0.496</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

### Table 24. Correlation coefficients between the predicted and observed values and the residual and observed values of the monthly total potential evapotranspiration from the SMLR results for the SUS and the ECC

<table>
<thead>
<tr>
<th>Region</th>
<th>predicted vs. observed values</th>
<th>residual vs. observed values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>correlation coefficient</td>
<td>p value</td>
</tr>
<tr>
<td>SUS</td>
<td>0.854</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ECC</td>
<td>0.852</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

6.3.3 The annual total potential evapotranspiration diagnosed for the SUS and the ECC

Since the predicted potential evapotranspiration values are strongly correlated with the observed data in SUS and ECC (Table 23), these values are used to analyze and compare the overall potential evapotranspiration for these two regions. No significant trend was observed for the diagnosed annual total potential evapotranspiration during 1950–2013 in the SUS and 1951–2013 in the ECC (Fig. 48a). However, during the last 40 years, the diagnosed values of the total potential evapotranspiration for both regions increased significantly (significant at 99%). The diagnosed trend in the ECC during 1974–2013 (4.312 mm/yr) is higher than the diagnosed trend during the same period in the SUS.
(3.975 mm/yr). In this period, the diagnosed annual total potential evapotranspiration in the ECC increased more rapidly than that in the SUS (Fig. 48b).
Figure 48. a Diagnosed annual total potential evapotranspiration for the SUS (1950–2013) and the ECC (1951–2013); b same as a, but for the 1974–2013 in the SUS and the ECC.
6.4 Discussion

6.4.1 The precipitation trends and impacts of the climatic variables on the precipitation in the SUS and the ECC

The observed annual total precipitation for most of the weather stations selected in the SUS indicated no significant trend in the SUS during 1950–2013. Similarly, none of the weather stations selected in the ECC showed a significant trend in total precipitation during the 1951–2013. The SMLR models for the total precipitation indicate that only the N34 and the NAO explain a small fraction (1.3%) of the variance of total precipitation in the SUS among the seven climatic variable. Enfield et al. (2001) reported that the N34 is negatively correlated with the rainfall during the AMO positive phase but is not correlated during the AMO negative phase in the Mississippi basin. The significant positive effects of the N34 on the precipitation in the SUS observed in the present study are not in accord with Enfield et al. (2001). In the ECC, all seven climatic variables selected contribute to the variance of the monthly total precipitation, but they also explain only a small fraction of the variance (24.5%). Overall, the SMLR models for the monthly total precipitation explain a small fraction of the variance in both regions. Predicted values of the SMLR models for the precipitation in these two regions do not fit well with the observed values (Table 23). Thus, many other factors might be associated with the precipitation in the SUS and the ECC, and the precipitation trend is not mostly attributed to the climatic variables used in this study.

6.4.2 The potential evapotranspiration trends and impacts of the climatic variables on the potential evapotranspiration in the SUS and the ECC
The observed annual total potential evapotranspiration data for the weather stations selected in the SUS rarely followed any significant trend during 1950–2013. More weather stations in the ECC selected showed significantly increased trends in total potential evapotranspiration during 1951–2013 than those in the SUS. Compared with the SUS, the ECC is more likely to have an increased potential evapotranspiration trend during 1951–2013.

The SMLR results can explain more variance of the potential evapotranspiration than that of the precipitation in both SUS and ECC. In these regions, the NPI, AMO and N34 contribute to more than 0.7 of the variance of the monthly total potential evapotranspiration. The NPI explains most of the variance in the SUS (51.1%); and AMO (48.6%) in the ECC.

The annual total potential evapotranspiration data diagnosed by the large-scale climatic variables in the SUS and the ECC indicate similar increases during 1950–2013. The diagnosed annual total potential evapotranspiration increased, but did not show any significant trend in these regions. However, during the last 40 years, the results indicated acceleratingly and significantly increased trends for SUS (3.975mm/yr) and ECC (4.312mm/yr). Conversely, the annual total potential evapotranspiration was declining in SUS during 1950–1989 and ECC during 1951–1990, although not significantly (Fig. 49). Gao et al. (2006) suggested that the annual total potential evapotranspiration in the ECC was decreasing during 1956–2000. In this paper, however, the trend of the annual total potential evapotranspiration has changed when analyzing the years after 2000. Decrease happened during 1951–1990 in the ECC (Fig. 49), which agrees with the result reported
by Gao et al. (2006). In contrast, during 1974–2013, the annual total potential evapotranspiration increased significantly, which altered the overall trend during the last 60 years to an insignificant increasing track. The annual total potential evapotranspiration trend in the SUS is similar to that in the ECC.

![Figure 49. Diagnosed annual total potential evapotranspiration for the SUS (1950–1989) and the ECC (1951–1990)](image)

\[
y = -1.671x + 4250. \\
p = 0.170
\]

\[
y = -2.028x + 4856. \\
p = 0.143
\]
6.5 Conclusions

Results obtained in this study support the following conclusions:

1) The weather stations selected in the SUS and ECC rarely indicated any significant trend for the annual total precipitation during 1951–2013. The observed results from selected stations in these regions do not support the hypothesis that trends in precipitation differ in SUS and ECC during 1951–2013. However, lack of trends in diagnosed precipitation from SMLR undermines this evidence.

2) Only N34 and NAO explain 0.013 of the variance of the monthly total precipitation in the SUS during 1950–2013, and all seven large-scale climatic variables selected in the study (NPI, AMO, N34, PDO, SOI, NAO and AO) explain less than 0.25 of the variance of the monthly total precipitation in the ECC for 1951–2013. The SMLR results also indicate that there are differences between the impacts of the climatic variables on the precipitation in the SUS and the ECC, although the SMLR models fail to explain most of the variance in precipitation in these two regions.

3) More than 72% of the variance of the monthly total potential evapotranspiration is attributed to these seven climatic variables in the SUS during 1950–2013 and the ECC for 1951–2013; in which NPI, AMO and N34 contribute to the most variance in both these regions. The NPI explains more variance (0.511) than other climatic variables in SUS, and AMO (0.486) in ECC. The SMLR results show that there are differences between the impacts of the climatic variables on the potential evapotranspiration in the SUS and ECC.

4) 5 out of 6 stations selected in the SUS showed no significant trend for the annual total potential evapotranspiration during 1949–2013 while same number of stations selected in
the ECC demonstrated significantly increased trends during 1949–2013. The diagnosed values of the annual total potential evapotranspiration on the basis of the SMLR models for the SUS during 1950–2013 and the ECC for 1951–2013 showed insignificant increases. Both regions observed insignificant decreases in the annual total potential evapotranspiration during 1950–1989 and 1951–1990, respectively. However, the diagnosed values of the annual total potential evapotranspiration for both regions indicated significantly increased trends (3.975mm/yr in the SUS and 4.312 mm/yr in the ECC) since 1970s. Thus, the hypothesis that there are differences between the trends of potential evapotranspiration in the SUS and ECC during 1951–2013 is not proved. Finally, results from the linear regression models can only indicate the possible associations of the climatic variables with the precipitation and potential evapotranspiration in specific regions. Results of linear regression do not indicate any cause-effect relationship based on physical controls of the precipitation and potential evapotranspiration and the climatic variables. The predictors chosen in the research have correlations with each other, such as the NAO and AO, N34 and SOI. A flaw of this research is the absence of making the data series of the predictors orthogonal to each other. The future researches could use rotated principal component analysis to resolve the multicollinearity problem of the predictors. Also the time period in this research is so short that the limited data points may result in overfitting of the data. Data based on results based on atmospheric general circulation models (AGCMs) are needed to understand the results from linear regression models. The present study used the Thornthwaite method to calculate the potential evapotranspiration in these two regions.
Therefore, additional research is needed to use to access potential and actual evapotranspiration.
References


142
Chapter 7: Discussion and Conclusion

7.1 Air Temperature Trends in the Six Stations in the SUS and Six Stations in the ECC

As shown in chapter 2, the air temperature in the six stations in the SUS does not show an overwhelmingly significant trend of decrease from 1931 to 2013. The lack of significant trends is not in accordance with the previous research stating that the SUS was cooling during the last century (Hansen et al., 2001; Lu et al., 2005; Lund et al., 2001; Pan et al., 2004; Robinson et al., 2002; Yu et al., 2001).

The difference between the result in chapter 2 and the previous research may lie in the time the data were chosen. Hansen et al. (1999) demonstrated that the global air temperatures experienced 0.1°C decrease from the early 1930s to the late 1970s. However, the decrease of air temperature in the United States during the same time period is 0.5°C, with the greatest decline in the SUS. The decreased trend of air temperature during the 20th century in the previous research is due to the great decrease in air temperatures in the SUS from the early 1930s to the late 1970s. However, after 1975, the rapid increase of global air temperatures at a rate of 0.2°C per decade changed the decreasing trend, and the rapidly increasing trend continues in the 21st century (Hansen et al., 2006). After 1965, the air temperatures in the United States also began to
rise, along with global temperatures (Hansen et al., 2001), and the result in chapter 2 shows that the continued increasing trend of air temperatures in the 21st century blurs the former cooling trend in the SUS.

Compared with the air temperature trends in the six stations in the SUS, most of the six stations in the ECC experienced increasing trends of air temperatures during 1951–2013. The result is in accordance with the results from Tang et al. (2010) and Yatagai and Yasunari (1994).

Similar to the air temperature trends in the United States and the whole world, the warming trend in China was interrupted during the 1950s and 1960s, and then has continuously increased since 1969 (Wang et al., 2001). All stations in the ECC showed 0.04–0.26°C decade$^{-1}$ trends, which is also in accordance with the $<0.4°C$ decade$^{-1}$ trend shown in the results from Yatagai and Yasunari (1994).

7.2 Precipitation and Potential Evapotranspiration Trends in the Six Stations in the SUS and Six Stations in the ECC

None of the stations in the SUS shows any significant trend of precipitation from 1931 to 2013. Similarly, no significant trend of precipitation is found in the ECC from 1951 to 2013. The lack of significant trend in the SUS does not agree with the increasing trend in the SUS shown by Karl et al. (1996). The difference may lie in the time period of the research: Karl et al. (1996) focused on the SUS from 1900 to 1994, while chapter 3 focuses on the SUS from 1931 to 2013. For the ECC, the 20- to 40-year oscillations were dominant from 1880 to 2002, according to Wang et al. (2004). Therefore, no significant trends of precipitation in the ECC could be found in the six stations from 1951 to 2013.
Only Alma Bacon County Airport shows a significant trend of potential evapotranspiration in the SUS. The result is in accordance with the results by Golubev et al. (2001). Most of the stations in the ECC demonstrate significant trends of potential evapotranspiration. The potential evapotranspiration is calculated by the Thornthwaite method, in which air temperature plays an important role. Increased air temperature increases potential evapotranspiration directly in the Thornthwaite method. The air temperature in stations in the ECC showed increasing trends, thus the result of this research on potential evapotranspiration in the ECC is different from the decreasing trends of potential evapotranspiration in the ECC shown by Gao et al. (2007) and Thomas (2000) with the Penman-Monteith method.

7.3 The Overall Recent Temperature Trends and Variance in the SUS and ECC
For the same time period in the SUS and the ECC, 1951–2013, the comparison of the annual mean air temperature trends in the six stations in the SUS and the six stations in the ECC also shows no significant cooling trends in the stations in the SUS. Even Alma Bacon Co Airport shows a significant increasing trend of the annual mean air temperature.

For the SMLR results shown in chapter 5, the NPI is the most important predictor for the monthly mean air temperatures in both the SUS and the ECC, accounting for 56.2% and 53.2% of the total variance, respectively (Table 14). The AMO proves to be the second predictor, explaining 16.6% of the variance in the SUS and 19.3% of the variance in the ECC (Table 14). The top three key predictors in both the SUS and the ECC are NPI, AMO, and N34, which are responsible for 75.6% of the variance in the SUS and 77.0%
of the variance in the ECC (Table 14). All seven climatic variables chosen contribute to the variance of monthly mean air temperatures in these two regions, and AO has negative correlations with the monthly mean air temperatures in both regions with tiny impact (Table 14). Therefore, the correlations of the climatic variables and the monthly mean air temperatures are very similar in the two regions, which does not support the hypothesis that the impact of climatic variables on the air temperatures differ among SUS and the ECC. Li and Bates (2007) indicated that global warming would mitigate thermohaline circulation (THC) and thus would have a negative feedback on the AMO. With anthropogenic global warming, the El Niño events were expected to become more frequent, which means that N34 is more likely to exceed 1.5 standard deviations (Toniazzo, 2006). Since N34 is positively correlated with the annual mean air temperatures in these two regions, the more extreme positive N34 may have more positive effects on the annual mean air temperatures in the SUS and the ECC. The impact of the climatic variables on air temperatures in these two regions might be influenced or even transferred by global warming, and more research in the future is needed to track such transfers.

With the overall annual mean air temperatures diagnosed by the climatic variables in the SUS and the ECC, insignificant increases from 1950 to 2013 in both regions are demonstrated (Fig. 45a). Thus, the result does not support the hypothesis that different trends of air temperatures occurred in these two regions from 1951 to 2013. The global air temperature, as well as air temperatures in the United States and China, experienced decreasing trends from the 1940s to the 1960s and began to rise again after 1975 (Hansen
et al., 2001, 2006; Wang et al., 2001). These fluctuations in air temperature are also in accordance with the results of an accelerating increase in air temperatures in the SUS and the ECC after 1974 in this research. From 1974 to 2013, the diagnosed annual mean air temperature data indicate significantly increasing trends for the SUS (0.41°C per decade) and the ECC (0.56°C per decade; Fig. 45b).

7.4 The Overall Recent Precipitation and Potential Evapotranspiration Trends and Their Variance in the SUS and the ECC

From 1951 to 2013, the time period that is recorded in both the ECC and the SUS, only Toccoa in the SUS had a significant decreasing trend of annual total precipitation. No significant trend of annual total precipitation is shown in the six stations in the ECC.

For the SUS, only N34 and NAO explain 1.3% of the total variance of monthly precipitation (Table 21). In the ECC, all seven climatic variables account for only 24.5% of the total variance of monthly precipitation (Table 21). The results from SMLR analysis on the impact of the climatic variables in these two regions agree with the hypothesis that the impact of climatic variables on the precipitation differ among the SUS and the ECC. However, the seven climatic variables could not cover most of the variance of precipitation in these two regions because many factors influence the local precipitation, such as the long-term precipitation analysis in Czech lands by Mikšovský et al. (2014). Considering the various impacts on precipitation by factors such as soil moisture and precipitation (Koster, 2004; Pielke and Avissar, 1990), it is reasonable that the prediction by the climatic variables could not cover most of the variance of monthly precipitation in these two regions. Because the climatic variables could not explain most of the total
variance of monthly precipitation in the SUS and the ECC, the correlations of observed and predicted annual total precipitation are weaker than those of observed and residual annual total precipitation. Thus, the overall annual total precipitation trends in these two regions could not be diagnosed by these seven climatic variables.

Based on the observed results of the selected stations in the SUS and the ECC, the hypothesis that trends in precipitation differed in SUS and ECC from 1951 to 2013 is not supported. However, the absence of the overall trends in diagnosed precipitation from SMLR undermines the rejection of this hypothesis.

From 1949 to 2013, only Alma Bacon County Airport in the SUS experienced a significant increasing trend of annual potential evapotranspiration. In contrast, only Lushi shows an insignificant decrease of annual potential evapotranspiration, with the other five stations experiencing a significant increase in annual potential evapotranspiration.

All seven climatic variables contribute to the potential evapotranspiration in these two regions. In the SUS, the top three key predictors—NPI, AMO, and N34—account for 51.1%, 16.8%, and 3.6% of the total variance of monthly potential evapotranspiration, respectively, with all seven climatic variables explaining 73.0% of the total variance (Table 22). The top three key predictors in the ECC are AMO, NPI, and N34, explaining 48.6%, 17.9%, and 4.1% of the total variance of monthly potential evapotranspiration, respectively (Table 22). The seven climatic variables account for 72.6% of the total variance of monthly potential evapotranspiration in China (Table 22). The results of the impact of climatic variables on the potential evapotranspiration in these two regions
confirms the hypothesis that the impact of the climatic variables on the potential
evapotranspiration differ in the SUS and the ECC.

The annual total potential evapotranspiration in the ECC was expected to decrease from
1956 to 2000 by the results of Gao et al. (2006). However, in this research, the diagnosed
annual total potential evapotranspiration in the SUS and the ECC from 1950 to 2013 were
both insignificantly increased (Fig. 48a). The differences between the results in this
research and the results of Gao et al. (2006) might be due to the different time periods
because the annual total potential evapotranspiration showed an insignificant decrease
trend in both of these regions. The insignificant trend of the overall predicted annual
potential evapotranspiration in the SUS is in accordance with the ambiguous trends of
evapotranspiration in this region reported by Golubev et al. (2001). The insignificantly
increases of the predicted annual total potential evapotranspiration in both the SUS and
the ECC do not support the hypothesis that the trends of potential evapotranspiration
differ in the SUS and in the ECC from 1951 to 2013. The increased annual potential
evapotranspiration during the recent years changed the former decreasing trend in these
two regions. Both the SUS and the ECC showed significant increasing trends of the
overall diagnosed annual potential evapotranspiration from 1974 to 2013, with the
increased rates of 3.975 mm/yr for the SUS and 4.312 mm/yr for the ECC (Fig. 48b). The
predicted air temperature showed significant increasing trends during the same time
period in these two regions as shown in chapter 5 and in much other research (Hansen et
al., 2001, 2006; Wang et al., 2001), and the Thornthwaite method adopted in this research

149
is based on the air temperature data, thus it is reasonable that the overall predicted annual 
potential evapotranspiration increased significantly from 1974 to 2013.

From the accelerating increase in the overall air temperature trends in the SUS and the 
ECC shown in the research, these two regions should prepare for the impact of increasing 
air temperatures with both mitigation and adaptation measurements.

For the mitigation measurements in China, Cheng et al. (2013) indicated that the 
technically attainable potential of China’s cropland was 0.62 Pg C for conservation 
tillage plus straw return and 0.98 Pg C for recommended fertilizer applications, 
respectively, which accounted for 40–60% of China’s total energy production CO₂ 
emissions in 2007. Pan et al. (2004) suggested that 0.675 Pg of total C sequestration 
could be achieved with the scenario of commonly observed SOC (soil organic carbon) 
levels in high-yielding paddies in China. In the United States, the technical sink capacity 
of soils is 0.288 Pg C per year (Lal, 2010).

Moreover, the development of China’s renewable energy is quite rapid and will help the 
country in response to the mitigation of the impact of climate change. In the area of solar 
energy, China was the largest manufacturer and the largest user of solar water heaters in 
the world, and covered 30% of the world’s Photovoltaic (PV) market share by 2011 (Liu 
et al., 2011). China also performed well in the field of hydroelectric power—the installed 
capacity of hydroelectric power reached 145.26 GW, and the energy generation was 
486.7 TWh by 2007 (Huang and Yan, 2009). By the same time, cumulative wind power 
installations in China exceeded 5 GW (Wang, 2010). The renewable energy contributed 
to 8.5% of the primary energy consumption in China by 2007 (Liu et al., 2011). China
promised that by 2020, it would reduce its CO₂ emissions per unit of GDP by 40–45% on the basis of 2005 levels, and the total accumulated traded volume of the seven pilot sites for emission trading reached 12,900,000 tCO₂e by August, 2014, after their start-up no earlier than June 2013 (Yu and Lo, 2015). Similarly, the renewable energy in the United States shows a growing tendency, with 342 MW of solar PV electric power installed in 2007 in the United States (Solangi et al., 2011). In 2001 the United States installed about 1700 MW of wind energy capacity (Bird et al., 2005). Hydroelectric power contributed to 6.6% of total electricity production in the United States in 2002 (Menz, 2005).

The ECC accounts for a large amount of crop yields in China. With predicted increased air temperatures and potential evapotranspiration, adaptation measurements are necessary for the ECC, especially for the agricultural production there. China launched “Water Agenda 21” in 1998 to face the challenges of national economic reconstruction and development under water stress in the 21st century (Yang and Pang, 2006). A series of laws has been issued in China to improve the agricultural use of water, and the regional water storage and management infrastructure is also emphasized (Piao et al., 2010). The SUS is mostly covered by forests, thus neutralizing the impact of increased air temperatures and potential evapotranspiration on forests is the key problem for the SUS. Dale et al. (2001) indicated that the disturbances challenging the forests should be coped with using these measures: managing the system before the disturbance, managing the disturbance, managing recovery, and monitoring for adaptive management. Considering the adaptation measurements to the predicted changes, Millar et al. (2007) suggested that
to create resistance to change, resilience to change should be promoted to enable forests to respond to predicted changes.
References


158


Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., . . . Wotton, B. M. (2001). Climate change and forest disturbances: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire,


Policy, 33(18), 2398–2410.


Ruddiman, W. F. (2003). The anthropogenic greenhouse era began thousands of years


impact of climate change on China’s agriculture. *Agricultural Economics, 40*(3), 323–337.


socio-economic scenarios. *Global Environmental Change, 19*(1), 34–44.


Appendix: List of Acronyms

southeastern United States — SUS
east-central China — ECC
stepwise multiple linear regression — SMLR
Palmer Drought Severity — PDSI
Tropical Pacific SST Index — TrPac
El Niño Southern Ocean Index — ENSO
atmospheric general circulation models — AGCM
North Atlantic Oscillation — NAO
Arctic Oscillation — AO
North Pacific Index — NPI
Southern Oscillation Index — SOI
Atlantic Multidecadal Oscillation — AMO
Pacific Decadal Oscillation — PDO
Niño 3.4 SST Index — N34
sea level pressure — SLP
sea surface temperature — SST
inter-tropical convergence zone — ITCZ
Thermohaline Circulation — THC
Photovoltaic — PV