TEMPERATURE AND PRECIPITATION TRENDS IN THE U.S. FROM 1931–2000

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Abstract: Climatic trends of mean annual temperature and annual precipitation from 1931 to 2000 are analyzed for four regions of the United States: Northeast, South Atlantic, North Central, and Pacific West regions. Climatic variations are known to obscure trend detection. To reduce the impact of outliers and variation, five-year moving averages are calculated for the trend analysis. Simple regression analysis was performed to evaluate the level of significance for each trend line. A trend with $P < 0.0001$ is considered statistically significant throughout the study. The data of five–year moving average temperature show a significant positive trend in the Pacific West with a R2 of 0.36 and significance F equal to 1.07E-07. Mean annual temperature of the Pacific West has increased by 0.62oC from 1931 to 2000. No significant trend is observed in any of the other three regions. The data of five-year moving average precipitation show a significant increasing trend in North Central Region of the U.S. with a R2 of 0.35 and significance F value of 2.87E-07. Annual precipitation of North Central Region has increased by 10.4 centimeters from 1931 to 2000, which is 10% higher than the long term average of the region. No precipitation trend is evident in any other region studied. Although 0.62oC of temperature increase may not be dramatic, it suggests that Pacific West may be experiencing the effect of global warming because this finding is consistent with the result of the Canadian climatic trend study by Zhang et al. (2000). They found that the temperature of southwest region of Canada has increased between 0.5 and 1.5oC in the past century. They also found that the annual precipitation has increased by 35% in southern Canada over the same period, which coincides with the increasing trend of precipitation we found in North Central Region of the U.S. With the best

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available data in this study and others, we are fairly confident that western United States is experiencing a significant warming trend. This trend is likely linked to the increasing sea surface temperature (SST) of the Pacific Ocean (Zhang and Levitus 1997, Karnauskas et al 2009).

Keywords: *Global Warming, Climatic Change, Temperature Trend, Precipitation Trend.*

INTRODUCTION

Much effort has been committed to studies on global climatic change and has yielded a significant amount of evidence of global warming. The majority of the studies focus on seasonal and regional variations of the warming, which is appropriate since the warming trend has shown distinctive seasonality and regionality (Wang et al 2009). By examining maximum and minimum daily temperature data from 1900–1998, Zhang et al. (2000) found that the greatest warming occurred during spring and summer periods in southern and western Canada. They also claimed that a warming trend was most evident in winter and spring based on data for 1950–1998. The positive trends of minimum temperatures, especially during winter and spring, were suggested as the major contributor to the increase of mean annual temperature. Since the publication of the Climatic Research Unit dataset known as CRU TS 2.1 (http://www.cru.uea.ac.uk, Mitchell and Jones 2005), climatologists have constructed spatial and seasonal climatic trends for the contiguous United States (Wang et al 2009) for 1950–2000 and most areas of the world (Ionita et al. 2008). Consistently, winter and spring were considered as the seasons showing the most significant warming trend, especially in North America (Wang et al 2009). While examining seasonal trends may reveal some insight on contributing factors to global warming, we should be cautious about drawing conclusions solely from a seasonal trend. It is often tangled with seasonal changes of global air circulation patterns that commonly include extremes that may be part of normal fluctuations. No one has quantitatively linked a seasonal warming trend to the relatively high carbon dioxide concentration during winter and spring. As matter of fact, Zhang at al. (2000) admit that mechanisms other than anthropogenic factors may be responsible based on the timing of the changes. As it is often said, the difference between weather and climate is a measure of time. Intentionally staying away from seasonality in this study, we examine the climatic trend using annual temperature and precipitation data for 1931-2000 in four regions of United States with different inherent climatic conditions.

Regionality of global warming, on the other hand, has been recognized and deemed a very important dynamic by many intensive studies on terrestrial and oceanic climatic trends (Zhang and Levitus 1997, Zheng et al 1997, Gaffen and Ross 1999, Venzke at al. 1999, Zhang et al. 1999, Karanauskas et al. 2009, Wang et al. 2009, Polyakov et al. 2010, Zhang et al. 2010). Regional variations of climatic change with a distinctive spatial pattern may be helpful in explaining the source of energy. The pattern seems clear that temperature and precipitation exhibit a greater positive trend in high-latitudes of the Northern Hemisphere (GISS, 2009) while northwest North Atlantic and high-latitude North Pacific regions are experiencing a cooling trend for the past four decades (Nicholls et al. 1996). Specifically, southwestern Canada and northern and western United States (Wang et al. 2009) were identified as the hot spots of regional warming according to CRU TS 2.1 data for 1950-2000. With an additional 20 years of mean annual temperature and precipitation data, we intend to verify the findings so that we can draw a general conclusion about the trend and explore possible explanations of the regionality.

METHODS

Data and study areas

Data of mean annual temperature and annual total precipitation of 70 years (1931–2000) was downloaded from the website of National Climate Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) of the United States (http://www.ncdc.noaa.gov/oa/mpp/freedata.html). The study areas are delineated into four regions for their distinctive climatic conditions (Table 1) including the Northeast, South Atlantic, North Central, and Pacific West (Figure 1). The Northeast region encompasses the states of Maine, New York, New Hampshire, Rhode Island, Vermont, Connecticut, New Jersey, Pennsylvania, and Massachusetts. The North Central region is defined by the states of North Dakota, South Dakota, Nebraska, Montana, and Wyoming. The South Atlantic region includes the states of Delaware,

Table 1. Summarization of the climatic data in the four regions

	Northeast	North Central	South Atlantic	Pacific West
Average temperature (°C)	8.05	8.55	16.38	11.90
StDev of temperature	0.58	0.79	0.53	0.51
Average precipitation (cm)	105.57	66.59	124.17	68.35
StDev of precipitation	10.85	9.19	11.65	10.95

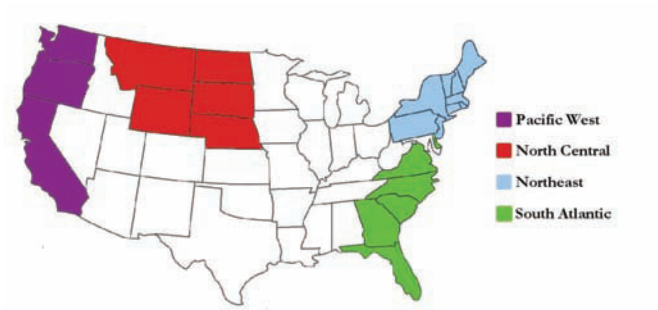

Figure 1. The four delineated regions of the contiguous U.S.

Virginia, North Carolina, South Carolina, Georgia, and Florida. The Pacific West region covers states of Washington, Oregon, and California.

NOAA's National Climatic Data Center not only provides an extensive database for various pieces of climatic information, but it also assures the accuracy and integrity of the data provided. These publicly shared records follow the guidelines of the *Data Quality Act*, which was implemented by the United States government to uphold the value of information utilized by federal agencies. NOAA also performs continuous quality control mechanisms to verify the accuracy of their data. These methods include visual speculation of the data to ensure it lies within the physical realm of possibility for a given condition and location, as well as comparisons of equivalent data with other groups. The instruments used in the field to record data are also tested to ensure they are functioning correctly and formulating precise measurements (NOAA, 2006).

Statistical analysis

Regression analysis was performed to examine the trend line relationship of annual temperature and precipitation in the 70-year time sequence for each region. A simple linear regression model: $Y = \mathbf{a}X + \mathbf{b}$, where Y is the estimated temperature or precipitation and X is the corresponding year (31, 32, 32, …100) with **a** as the slope and **b** as the intercept, was used to fit the relationship. An F-test was conducted for every trend line showing $R^2 > 0.1$. A trend with $P < 0.0001$ was considered statistically significant throughout the study. To reduce the impact of outliers and variation, five-year moving averages of temperature and precipitation were calculated for an alternative trend analysis in comparison with the results from the original data. Temperature and precipitation changes over the 70 years based on a significant trend line model were calculated as ΔY, which equals to $(\mathbf{a}X_{100} - \mathbf{a}X_{31}) + \mathbf{b}$.

RESULTS

Regression analysis of the original mean annual temperature data for 1931–2000 failed to identify any significant trend in the Northeast, North Central, or South Atlantic regions as the R^2 values of these trend lines were less than 0.1. The R^2 value of the trend line for the Pacific West was 0.13 and the standard deviation was 0.51, which was the lowest among the four regions (Table 1). The F-test result showed, however, the trend was not significant at the level of $P < 0.0001$ (Table 2). The analysis on the original annual precipitation data for 1931–2000 showed that only the trend line for the North Central region had an R^2 greater than 0.1, however its F value equaled to 0.0045 and was insignificant (Table 2). Clearly, no other precipitation trend was significant enough to reach the level of $P < 0.0001$ either. However, it is interesting to know that the standard deviation of annual precipitation in the North Central region was also the lowest and the variations of annual precipitation are much higher than that of mean annual temperature for all four regions (Table 1).

The data of five–year moving average temperature told a different story (Figure 2). A positive trend in the Pacific West was identified from the R^2 (0.36) of the trend line and tested significant according to its F value (1.07E-07) (Table 2). Mean annual temperature of the Pacific West has increased by 0.62°C from 1931 to 2000 according to this trend model. No significant trend was observed for any of the other three regions. The data of five-year moving average precipitation showed a significant increasing trend in the North Central region (Figure 3), with an R^2 of 0.35 and a significance F value of 2.87E-07 (Table 2). Annual

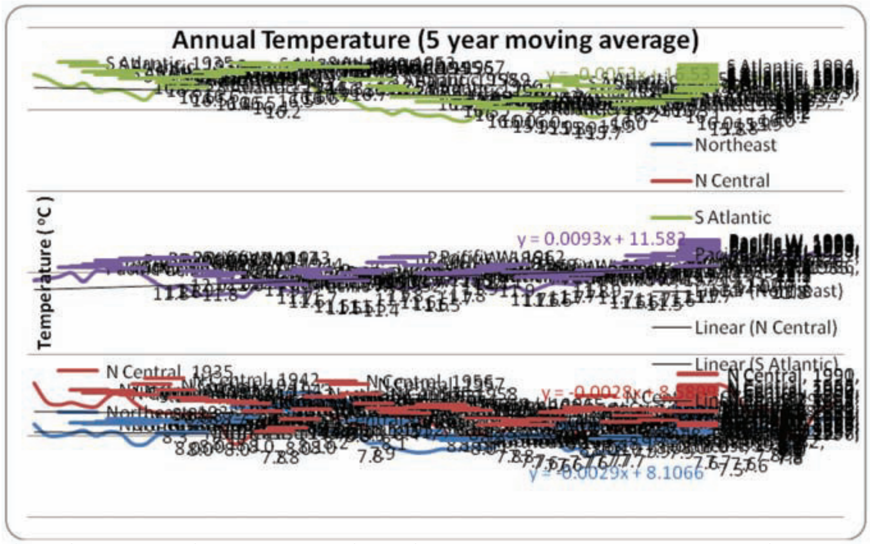

Figure 2. The results of trend line analysis for the four regions using 5-year moving averages of mean annual temperature.

Table 2. R2s and P-values of the trend lines for temperature (temp) and precipitation (ppt)

	Northeast	North Central	South Atlantic	Pacific West
R^2 s				
Mean annual temp (°C)	0.093	0.0049	0.0442	**0.1304**
5-yr moving average of temp	0.0362	0.0239	0.0995	**0.3588**
Annual ppt (cm)	0.0411	**0.1126**	0.0135	0.0087
5-yr moving average of ppt	**0.1199**	**0.3394**	0.0642	0.0275
Significance F values				
Mean annual temp (°C)	N/A	N/A	N/A	0.0021
5-yr moving average of temp	N/A	N/A	N/A	**1.07E-07**
Annual ppt (cm)	N/A	0.0045	N/A	N/A
5-yr moving average of ppt	0.0044	**2.87E-07**	N/A	N/A

precipitation of the region has increased by 10.4 centimeters from 1931 to 2000, which is 10% higher than the long-term average of the region. No significant precipitation trend was evident in any other region studied.

DISCUSSION

Clearly, the significant increase of R^2 values for the 5-year moving averages of temperature and precipitation in comparison to corresponding original data is a result of the variation reduction. It confirms that variation matters in trend analysis. Even though it was necessary to smooth the curves to show a clearer direction, the increasing trend of mean annual temperature in the Pacific West region does validate the discovery by Zhang et al. (2000) and Wang

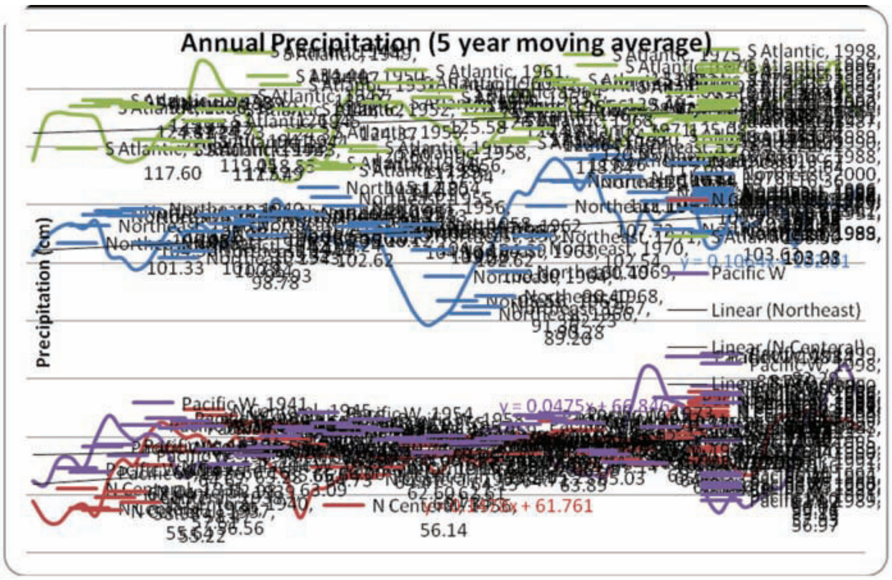

Figure 3. The results of trend line analysis for the four regions using 5-year moving averages of total annual precipitation

et al. (2009) that annual temperature in western United States and southwestern Canada has significantly increased in the past century. Although not statistically significant, the temperature changes in the other three regions showed a general cooling trend. This insignificant pattern may favor the suggestion by Zhang et al (2000) and Wang et al (2009) that cooling is taking place in the northeast and central areas of the United States. At the very least, these trends do not contradict their assertion and may serve as means for further investigation in these regions. With the best available data in this study and others, we are fairly confident that western United States and southwestern Canada are experiencing a significant warming trend. This trend is likely linked to the increasing SST of the Pacific Ocean (Zhang and Levitus 1996, Karnauskas et al 2009). In their efforts to search for causes of these trends, Wang et al (2009) attribute the regionality of the climatic trend to SST variations in both the Pacific Ocean and the Atlantic Ocean based on their modeling results. They warned that the SST variations in combination with global warming could result in a much stronger warming trend over the United States.

Examining the changes in SST of the tropical Pacific Ocean using three of the latest versions of observed historical monthly datasets for 1880-2005, Karnauskas et al. (2009) discovered that the SST gradient has significantly strengthened by 0.36°C per century in fall and winter months. Since oceans function as great heat storages, it is no surprise that a relatively small amount of decadal SST variation (about 0.3°C) could have a powerful impact on temperature changes over land (Karnauskas et al. 2009). Prevailing Westerlies are the main influential wind system of United States, especially during fall and winter seasons when the SST gradient is strengthening over the Pacific Ocean. Undoubtedly, the warming trend of the Pacific West region of the United States is directly related to its vicinity to the Pacific Ocean, as well as on-shore wind direction leading from it.

Annual precipitation increased significantly across southern Canada (Zhang et al. 2000) and the U.S., most notably in central United States (Wang et al. 2009). Our finding of the significant ($P<0.0001$) precipitation increase in the North Central region strongly supports this general conclusion. Meanwhile, the precipitation increases in the other three regions, though not significant at a level of $P<0.0001$, are not inconsistent with the general consensus by Wang et al. (2009), as they all possess a positive slope (Figure 3). Significantly higher humidity and dew point temperatures in the past four decades over most of the U.S. have also been confirmed (Gaffen and Ross 1999). Therefore, we believe that the positive trend of precipitation is a side product of the warming trend, which likely resulted in a significant increase in evapotranspiration. Compared to that of other regions, annual precipitation of the North Central region is most limited by humidity due to its continental interior location. Therefore, it would likely benefit the most from a higher humidity.

An additional source for the increased precipitation in the North Central region was linked to the agricultural use of the land (Barnston and Schickedanz (1984) because irrigation adds about 200 billion cubic meters of ground water annually to land surface and has doubled the amount of available water for evapotranspiration in the region (Moore and Rojstaczer (2001). However, it was found that the impacts are minimal and suggest, at best, it is a secondary effect on precipitation according to precipitation data for 1950-1997 (Moore and Rojstaczer 2001). Further research with long term irrigation and precipitation data may be warranted to quantify the impact of irrigation on precipitation.

While dramas of violent weather events on land are highly recognized due to their effects on human life (i.e. death tolls, injuries, and property damage costs), it is often easily ignored that the world ocean endures most of the forces from global warming. Functioning as a global temperature regulator, the world ocean continues to silently absorb heat introduced from both natural and anthropogenic sources. By the time a clear indisputable trend in SST is observed, it may be too late to reverse or prevent inevitable damage to the Earth. Therefore, it is important to not only consider climatic anomalies on land, but to also keep our eyes on the oceans to detect subtle changes that could have drastic effects on the planet.

BIOGRAPHY

Dr. Weihong Fan is an associate professor of Environmental Science at Richard Stockton College of New Jersey. She earned Ph.D. in ecology from Colorado State University at Fort Collins, Colorado. With more than 20 years of experience in the applications of geographic information system, she has been working in the fields of broad scale nitrogen and carbon cycling, climatic change, ecological modeling, and tree special diversity. She successfully led a China Field Study Tour in the summer of 2010, which resulted in the collaborated study on the apple farms in the Northern China with colleagues of Beijing Normal University.

Colleen Carroll is currently studying at the Richard Stockton College of New Jersey. She plans to earn a B.S. in Environmental Science and is considering furthering her educational career at graduate school. Her future career interests involve working for environmental sustainability through statistical analysis and the application of geographic information systems.

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