Regional trend of climatic change in the USA

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Abstract

Purpose – The purpose of this paper is to focus on the climatic trends of mean annual temperature and annual precipitation from 1931 to 2000, in four regions of the USA: Northeast, South Atlantic, North Central, and Pacific West.

Design/methodology/approach – Five-year moving averages are calculated for each climatic variable of all regions and used for the trend analysis. 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.

Findings – The data show a 0.62°C increase in temperature in the Pacific West from 1931 to 2000. Over the same time period, precipitation has increased by 10.4 centimeters in the North Central Region, which is 10 percent higher than the long-term average for the region.

Originality/value – The 0.62°C increase suggests that the 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.* who also found that annual precipitation has increased by 35 percent in southern Canada over the same period, which coincides with the increasing trend of precipitation found in the North Central Region. With the best available data and the findings from other studies, the authors are confident that the warming trend in the western USA is likely linked to the increasing sea surface temperature of the Pacific Ocean.

Keywords United States of America, Climatic change, Global warming, Temperature trend, Precipitation trend, Regional climate

Paper type Research paper

1. 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 to 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 (www.cru.uea.ac.uk, Mitchell and Jones, 2005), climatologists have constructed spatial and seasonal climatic trends for the contiguous USA (Wang *et al.*, 2009) for 1950-2000 as well as for most areas of the world. Consistently, winter and spring were considered to be 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 seasonal trends. These are often tangled with seasonal changes of global air circulation patterns which commonly include extremes

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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 *et 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 USA 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 *et al.*, 1999; Zhang *et al.*, 2000, 2010; Karnauskas *et al.*, 2009; Wang *et al.*, 2009; Polyakov *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 (Goddard Institute for Space Studies (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 USA (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.

2. Methods

2.1 Data and study areas

Data of mean annual temperature and annual total precipitation of 70 years (1931-2000) was downloaded from the web site of National Climate Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) of the USA (www.ncdc.noaa.gov/oa/mpp/freedata.html). The study areas are delineated into four regions for their distinctive climatic conditions (Table I) 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, 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

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

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

Data Quality Act, which was implemented by the US 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).

2.2 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: $Y = aX + b$, where Y is the estimated temperature or precipitation and X is the corresponding year (31, 32, 33, … 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: $\Delta Y = (aX_{100} - aX_{31}) + b$.

3. 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 < 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 I). The F-test result showed, however, that the trend was not significant at the level of $p < 0.0001$ (Table II). The analysis on the original annual precipitation data for 1931-2000 showed that only the trend line for the North Central region had an $R^2 > 0.1$; however, its F value equaled to 0.0045 and was insignificant (Table II). 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 I).

Figure 1.
The four delineated regions of the contiguous USA

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

Table II. R^2s and p-values of the trend lines for temperature (temp.) and precipitation (ppt.)

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

4. Discussion

Clearly, the significant increase of R^2 values for the five-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 *et al.* (2009) that annual temperature in

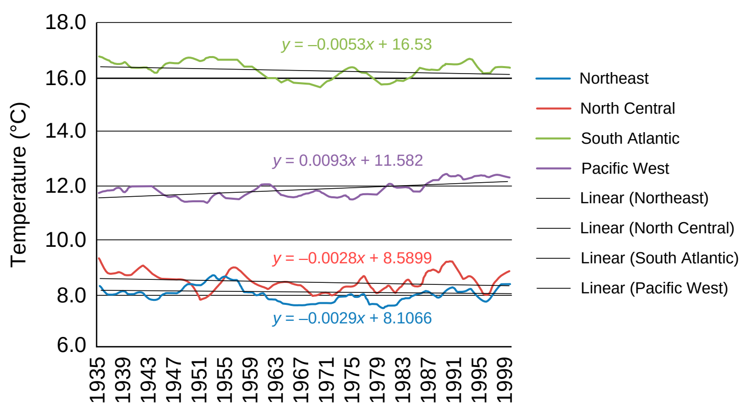

Figure 2. The results of trend line analysis for the four regions using five-year moving averages of mean annual temperature

western USA 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 USA. 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 USA and southwestern Canada are 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). 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 USA.

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 USA, 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 USA 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 USA, most notably in central USA (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 USA have also been confirmed (Gaffen and Ross, 1999).

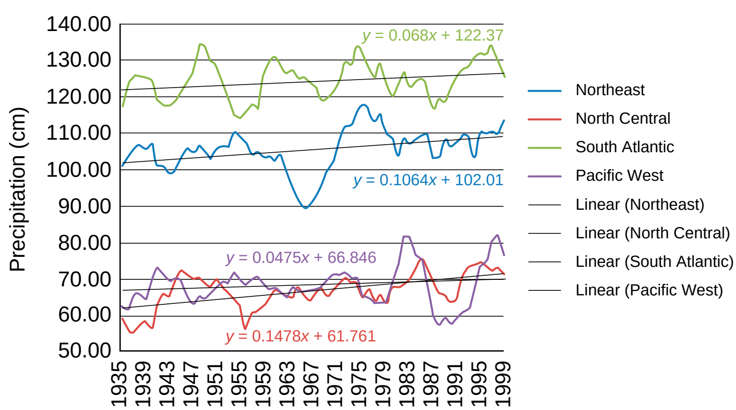

Figure 3.
The results of trend line analysis for the four regions using five-year moving averages of total annual precipitation

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.

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