ANNUAL TEMPERATURE RANGE TIME-SERIES TRENDS AND LONG-RANGE FORECASTING

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Abstract

This research seeks to establish whether there has been significant variation in the annual temperature range (ATR) across the contiguous United States during the study period 1951-2000 and discusses the application of ATR trends as an operational tool for long-range forecasting. Based on the NOAA/National Climatic Data Center's U.S. Standard Regions for Temperature and Precipitation and a five-year running mean to dampen interannual variability, time-series line graphs were produced to depict each region's warmest and coolest months as well as the ATR. Correlation analyses were conducted to determine whether an association exists between the independent variable, time, and these dependent variables. The results suggest that from 1951-1980, most of the regions experienced an increase in ATR, and from 1961-1990, the majority of the regions exhibited a stable ATR. During the 1971-2000 period, seven regions experienced a significant decrease in ATR and two regions remained stable. The contributing factor appears to be fluctuations in the mean temperature of the coolest month. Possible influences affecting the time-series include the frigid winters of the late 1970s and the record warm years during the 1990s. Possible explanations for the cooler winters include atmospheric variability and an increase in the occurrence of continental polar air masses. The warmer winters could be associated with higher amounts of atmospheric water vapor resulting in enhanced cloud cover over certain regions. As a key component of meteorological and climatological indices, the ATR could be a beneficial variable in time-series analysis for long-range forecasting.

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) (2001), Earth's mean surface temperature has increased by approximately 1.1°F during the past century. Karl et al. (2000) report most of the warming has taken place since 1976 with the rate of temperature increase approximating 0.31°F per decade during this time. The recent temperature increase over the past few decades is associated with an overall rise in the daily minimum temperatures, and to a lesser extent, a slight increase in the daily maxima. Easterling et al. (1997) suggest a global increase in daily minimum temperatures of 0.36°F per decade and a rise in daily maximum temperatures of 0.18°F per decade during the latter part of the 20th century. As a result of these disparate amounts of change, the diurnal temperature range (DTR) for much of the world has decreased approximately 0.18°F per decade since the 1970s.

Among other factors, the DTR is influenced by land use with rural areas generally exhibiting larger daily ranges than urban areas as noted by Gallo et al. (1996). However, when comparing worldwide trends in the DTR for rural stations to all stations for the period from 1950 to 1993, rural stations reveal a 0.009°F per decade decrease in both maximum and minimum temperatures according to Easterling et al. (1997). This suggests that the difference between urban and rural stations is not significant for large-scale assessment of the DTR as described by Jones et al. (1990).

Mitchell et al. (1990) assert that climate models indicate the probability of extreme cold days decreases while the probability of extreme warm days increases when daily mean temperatures rise. Yonetani and Gordon (2001) confirmed this finding using various climate model designs. Zwiers and Kharin (1998) imply that a global coupled atmosphere-ocean model based on a doubling of CO_2 yields 20-year return values for the daily minimum surface air temperature of 68°F for the continental interior of the United States. Similarly, Gregory and Mitchell (1995) propose that other global models predict northern mid-continental regions will experience increased variation in daily temperatures. The IPCC's (2001) estimates of confidence in projected changes suggest it is very likely there will be slightly higher daily maximum temperatures and a more pronounced increase in daily minimum temperatures accompanied by a reduced DTR over most land areas during the 21st century.

The apparent decrease in the DTR revealed by archived data and implied through the use of climate models raises the question of variations in the annual temperature range (ATR). That is, has the annual difference between the mean temperatures of the warmest month and of the coolest month varied significantly in recent decades? Although the reduction in DTR is well documented, inquiries determining if there has been a significant change in the ATR across the continental United States are limited. This research seeks to establish whether this is the case by conducting a spatial analysis of variation in the ATR across the contiguous United States.

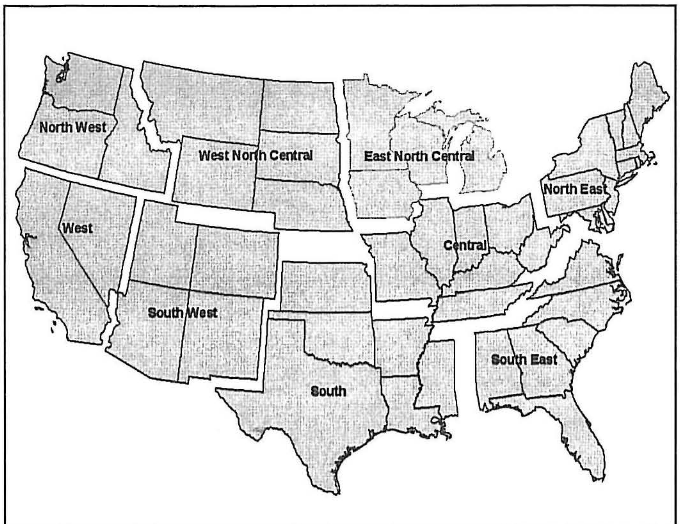

Fig. 1. NCDC U.S. Standard Regions for Temperature and Precipitation

Indices based on the ATR have a long history in meteorology and climatology. As early as 1905, Kerner developed a measure of maritime influence that included the ATR in the formula which he referred to as the thermoisodromic ratio. Gorczynski derived a method for quantifying the continental characteristics of a location based on latitude and the ATR in 1920 (Oliver and Fairbridge 1987). Gorczynski's formula was later amended by Conrad (1946) while retaining the use of the ATR in the equation. Since the 1950s, numerous researchers have applied Conrad's index to their work. Fobes (1954) conducted an assessment of New England, D'Ooge (1955) examined the western United States, Kopec (1965) analyzed the Great Lakes region, and Trewartha (1961) investigated all of North America. Understanding that large ATRs are associated with cold winters and warm to hot summers while moderate seasons yield smaller ATRs, these studies suggest that insight into ATR trends offers a means of better anticipating weather extremes in a particular region during the winter and summer. Thus, use of the ATR would appear to hold promise in long-range forecasting, especially in the application of time-series analysis.

At a recent meeting of the World Meteorological Organization (WMO), among the main topics addressed were the importance of long-range forecasts coupled with concerns about environmental change, as well as the need to propose and develop methodologies in order to study interseasonal characteristics and climate extremes (WMO 2003). As Subbiah and Kishore (2001, p. 1) note regarding attempts by farmers to predict the weather, the "prevalence of traditional forecast practices reflects the demand for long-range forecasts to manage uncertainties associated with climatic variability." In short, when advance information concerning the weather is available, its adverse effects can be minimized. This paper attempts to discover and discuss the possible role of the ATR in anticipating such impacts.

2. Procedure

The study area consists of the contiguous United States and is delineated based on the U.S. Standard Regions for Temperature and Precipitation according to the NOAA/National Climatic Data Center (NCDC), which divides the country into nine zones as shown in Fig. 1. The data associated with each zone are derived from the boundaries of the U.S. Climate Divisions for each state, also available from the NCDC, and consists of the means of daily temperature for a given year and month (Guttman and Quayle 1996). The study period for the research is 1951 to 2000 with subdivisions based on 30-year normal periods of 1951-1980, 1961-1990, and 1971-2000. The difference between the mean temperature of the warmest month and the mean temperature of the coolest month determines the ATR for each year in each of the nine standard regions. The mean ATR for the study period in each particular region is compared to the ATR for each year to ascertain whether the ATR increased, decreased, or remained stable.

Once these values are calculated, time-series line graphs for the study period 1951-2000 will be generated to visually depict each region's annual mean temperature of the warmest month, coolest month, and the ATR. As is typical with a time-series analysis, a running mean is used to reduce the effect of short-term deviations, such as ENSO events, and to provide a clearer view of the true underlying behavior of the time-series on an interdecadal time-scale. In this case, a five-year running mean with each value replaced by the average of itself and the surrounding five-year span of observations is incorporated into the research design.

Correlation analyses are conducted to determine whether an association exists between the independent variable, time, and the dependent variable, the standard regional ATR, for each of the three study period subdivisions. The null hypothesis assumes that no *a priori* relationship exists between time and the ATR while the two-tailed alternate hypothesis supposes there is a relationship between the two variables. The results of the analysis will be entered into a Geographic Information System (GIS) to produce choropleth maps depicting any significant variation in the ATR over time based on the values of the correlation coefficients for each of the nine regions.

3. Analysis

a. Measures of central tendency

The mean ATR and standard deviation, as well as the largest and smallest ATRs for the study period 1951-2000 along with the year in which they occurred for each of the nine U.S. Standard Regions, are listed in Table 1. The South East, West, and North West exhibit the smallest ATRs with means of 33.9°F, 35.1°F, and 37.0°F, respectively. The continental interior of the United States, comprised of the East North Central and West North Central regions, demonstrate large ATRs with means of 56.4°F and 52.4°F, respectively.

As Table 1 reveals, the years between 1977-1979 demonstrate a discernible increase in ATR above the

Table 1. 1951-2000 average, standard deviation (SD), largest, and smallest annual temperature ranges (ATR)

Region	Mean ATR	SD	Largest ATR	Year	Smallest ATR	Year
North West	37.0	4.05	48.7	1979	28.3	1953
West	35.1	3.02	40.3	1960	26.6	1986
South West	41.6	3.12	49.0	1963	33.9	1986
West North Central	52.4	6.09	66.3	1979	37.2	1992
East North Central	56.4	5.62	69.1	1977	42.3	1992
North East	47.4	4.42	58.3	1994	38.5	1990
Central	46.2	4.90	62.4	1977	35.5	1990
South East	33.9	4.17	45.5	1977	19.7	1974
South	39.9	4.03	50.4	1978	30.2	1952

Table 2. 1951-1980 correlation coefficients [r] and probability values [p] for annual temperature range, coolest month temperature, and warmest month temperature versus time (n = 30)

Region	Annual Range	Significance	Coolest Month	Significance	Warmest Month	Significance
North West	r = .1929	p = .2902	r = .0155	p = .9329	r = .2134	p = .2409
South West	r = .4058	p = .0212*	r = -.4427	p = .0112*	r = -.1278	p = .4858
East North Central	r = .7781	p = .0001*	r = -.7836	p = .0001*	r = .0901	p = .6238
West North Central	r = .5648	p = .0008*	r = -.5098	p = .0029*	r = .1025	p = .5767
North East	r = .6828	p = .0001*	r = -.6967	p = .0001*	r = -.4037	p = .0219*
Central	r = .6262	p = .0001*	r = -.7541	p = .0001*	r = -.3318	p = .0636
South East	r = .4272	p = .0147*	r = -.5296	p = .0018*	r = -.4153	p = .0181*
West	r = -.2978	p = .0978	r = .3072	p = .0872	r = -.0101	p = .9562
South	r = .6013	p = .0003*	r = -.7039	p = .0001*	r = -.1933	p = .2891

* Statistically significant

Table 3. 1961-1990 correlation coefficients [r] and probability values [p] for annual temperature range, coolest month temperature, and warmest month temperature versus time (n = 30)

Region	Annual Range	Significance	Coolest Month	Significance	Warmest Month	Significance
North West	r = -.0211	p = .9087	r = .1801	p = .3240	r = .0245	p = .8941
South West	r = -.5062	p = .0031*	r = .4049	p = .0215*	r = -.3358	p = .0602
East North Central	r = -.3684	p = .0380*	r = .5359	p = .0016*	r = .6704	p = .0001*
West North Central	r = -.5390	p = .0015*	r = .5660	p = .0007*	r = .2557	p = .2142
North East	r = .1048	p = .5681	r = .0692	p = .7067	r = .7127	p = .0001*
Central	r = .0941	p = .6088	r = .1056	p = .5651	r = .8232	p = .0001*
South East	r = .2600	p = .1507	r = -.0723	p = .6941	r = .7950	p = .0001*
West	r = -.1652	p = .3662	r = .4539	p = .0091*	r = .3945	p = .0255*
South	r = -.1073	p = .5589	r = .1129	p = .5384	r = -.0642	p = .7270

* Statistically significant

Table 4. 1971-2000 correlation coefficients [r] and probability values [p] for annual temperature range, coolest month temperature, and warmest month temperature versus time (n = 30)

Region	Annual Range	Significance	Coolest Month	Significance	Warmest Month	Significance
North West	r = -.3034	p = .0914	r = .2800	p = .1206	r = .2797	p = .1210
South West	r = -.7328	p = .0001*	r = .7385	p = .0001*	r = .4096	p = .0199*
East North Central	r = -.6609	p = .0001*	r = .5754	p = .0006*	r = -.2888	p = .1089
West North Central	r = -.6244	p = .0001*	r = .5571	p = .0009*	r = -.2317	p = .2020
North East	r = -.5176	p = .0024*	r = .5459	p = .0012*	r = .2254	p = .2148
Central	r = -.4612	p = .0079*	r = .5137	p = .0026*	r = .2368	p = .1919
South East	r = -.0781	p = .6709	r = .2835	p = .1159	r = .7917	p = .0001*
West	r = -.5873	p = .0004*	r = .6436	p = .0001*	r = .0266	p = .8851
South	r = -.4218	p = .0162*	r = .6296	p = .0001*	r = .3363	p = .0598

* Statistically significant

mean for most of the U.S. Standard Regions, which is especially evident during 1977 when the annual range rose 12.7°F above the mean in the East North Central region and 16.2°F above the mean in the Central region, and again in 1979 when the West North Central region experienced a 13.9°F increase above the mean for the study period. Conversely, the years between 1990-1992 exhibit a marked decrease in the ATR for these same regions with the range in the Central region dropping 10.7°F below the mean in 1990, while in the East North Central and West North Central regions, the ATR decreased 14.1°F and 15.2°F below the mean, respectively, in 1992.

b. Time-series line graphs and correlation analyses

Annual values based on a five-year running mean covering the study period 1951-2000 for each of the nine U.S. Standard Regions were used to generate time-series line graphs portraying each region's annual mean temperature of the warmest month, coolest month, and the ATR (Fig. 2. a-i). The line graphs reveal that the mean temperature of the warmest month shows little variation in most of the regions while the mean temperature of the coolest month demonstrates a greater degree of disparity, especially in the continental interior areas, which also is reflected in the ATR.

While the time-series graphs offer visual insight into the distribution of ATR over time, formal testing is required to determine whether significant change has been taking place. Designating the study period subdivisions 1951-1980, 1961-1990, and 1971-2000 as time, or the variable x, Pearson's product-moment correlation analyses were conducted for the nine standard regions based on a five-year running mean. The analyses are designed to determine whether an association exists between time and the ATR. Further analysis of the coolest and warmest months was conducted to help ascertain which parameter might be a contributing factor. The results of the correlation analyses are listed in Tables 2-4.

As Table 2 representing the period 1951-1980 indicates, a positive correlation exists between time and the ATR with most of the standard regions demonstrating a statistically significant increase in the ATR with the exception of the North West and the West. Significant positive correlation coefficients (r) and probability values (p) range from a low of r = .4058 (p = .0212) in the South West to a high of r = .7781 (p = .0001) in the East North Central region. This increase in the ATR appears to be the result of a decrease in the mean temperature of the coolest month. Each of the seven regions exhibiting a positive correlation between time and the ATR also displays a negative correlation between time and the mean temperature of the coolest month. Figure 3 is a choropleth map for the period 1951-1980 that indicates an increase in the ATR across much of the continental United States.

Table 3 represents the period from 1961-1990 and reveals no significant trends in the ATR for most of the U.S. with the exception of the South West and the two North Central regions, which display a decrease in the ATR during the time period. Significant negative correlation coefficients range from an r = -.3684 (p = .0380) in the East North Central region, to an r = -.5390 (p = .0015) in the West North Central region. The decrease in the ATR for these three regions seems to be associated with a significant increase in the mean temperature of the coolest month, although the East North Central region also exhibits a significant increase in the mean temperature of the warmest month as do four of the other standard regions. The choropleth map in Fig. 4 depicts the decrease in the ATR in the central U.S. and the stability of the ATR across the rest of the country for the period from 1961-1990.

As Table 4 demonstrates, during the period from 1971-2000 seven of the nine U.S. Standard Regions experienced a significant decrease in the ATR over time, while the North West and South East continued to exhibit a stable ATR. Significant negative correlation coefficients range from a low of r = -.4218 (p = .0162) in the South, to a high of r = -.7328 (p = .0001) in the South West. This decrease in the ATR appears to be associated with an increase in the mean temperature of the coolest month for each of the seven regions displaying a decrease in the ATR. The positive correlations between time and the mean temperature of the coolest month yield statistical-

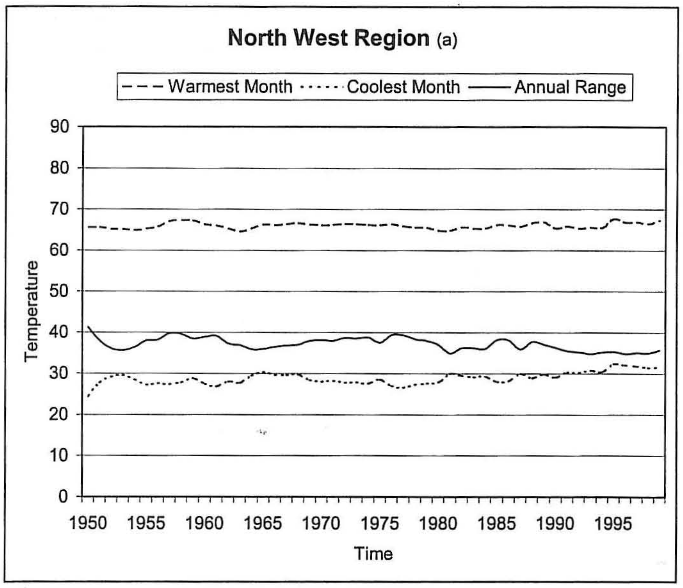

Fig. 2a. North West region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

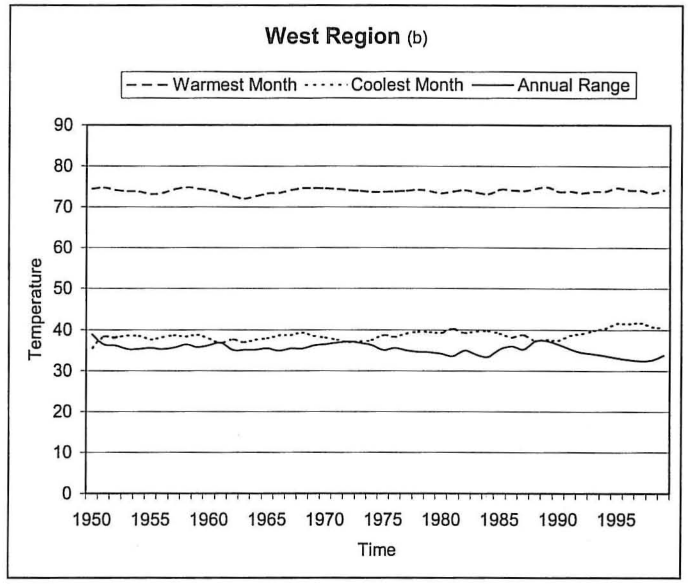

Fig. 2b. West region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

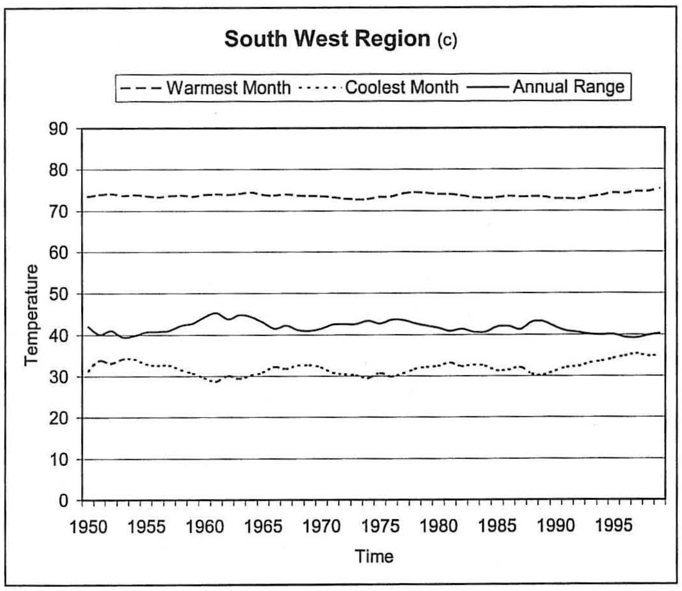

Fig. 2c. South West region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

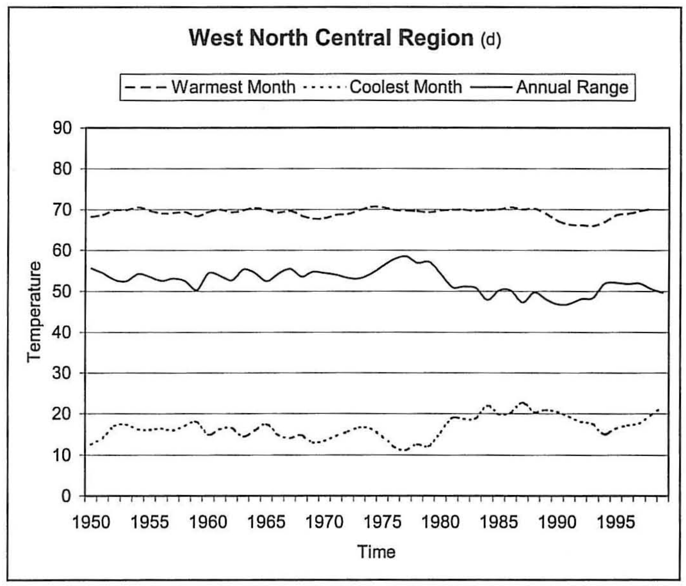

Fig. 2d. West North Central region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

ly significant p-values ranging from p = .0026 in the Central region, to p = .0001 in the South, West, and South West. Figure 5 is a choropleth map portraying the decrease in the ATR over most of the country, with the ATR in the North West and South East remaining stable during the period from 1971-2000.

4. Discussion

Analysis of the period from 1951-1980 reveals an increase in the ATR over most of the contiguous United States, which is likely a result of the cooler winters at the end of the time-series, while from 1961-1990 six of the nine U.S. Standard Regions experienced a stable ATR as the cooler winters moved to the middle of the time-series. During the final period from 1971-2000, there was a significant decrease in the ATR in seven of the nine regions as the time-series began with cooler winters in the 1970s and ended with warmer winters in the 1990s. The following discussion examines several possible factors influencing these trends.

a. Cooler winters

According to the National Oceanic and Atmospheric Administration (1978, 1979), January 1977 was one of

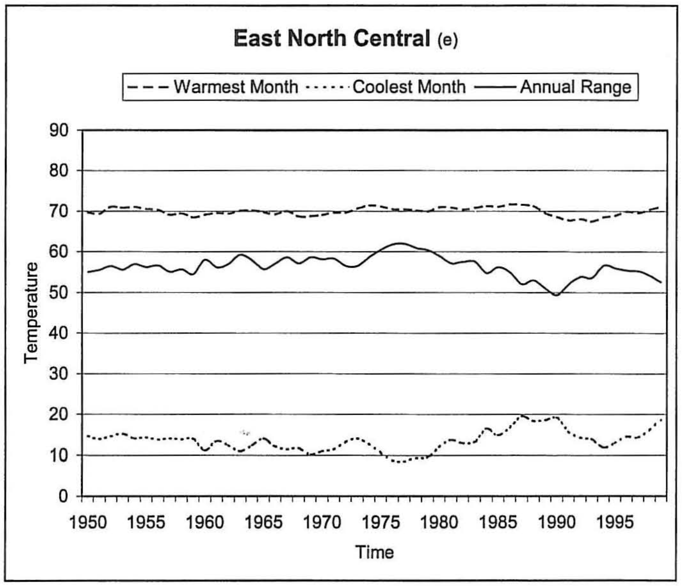

Fig. 2e. East North Central region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

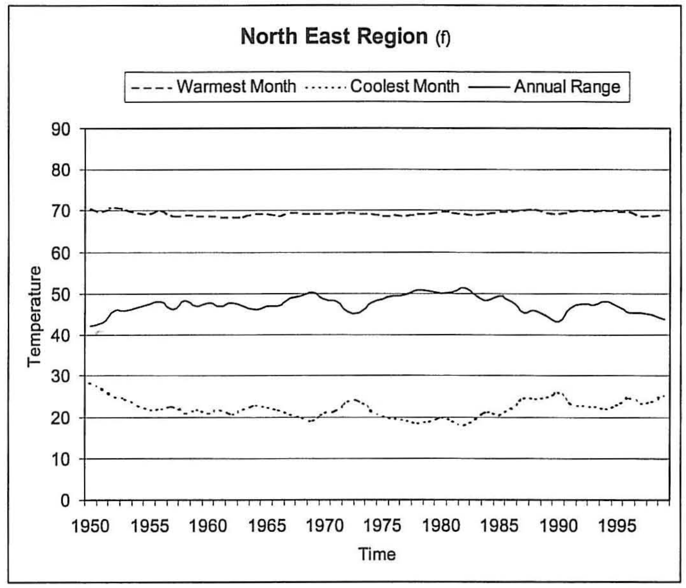

Fig. 2f. North East region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

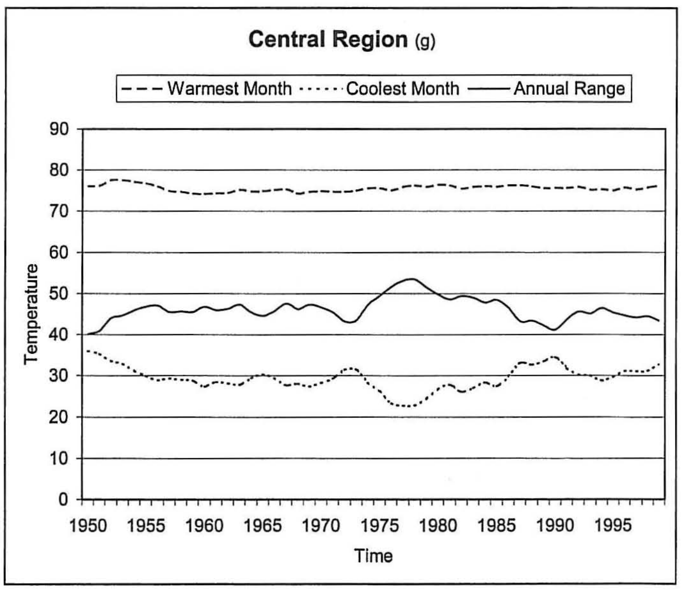

Fig. 2g. Central region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

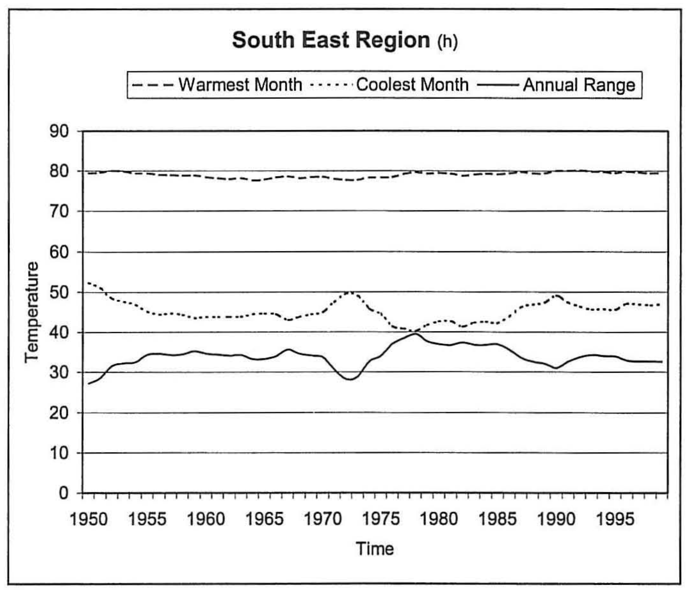

Fig. 2h. South East region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

the coldest months on record. A number of stations in the continental interior of the U.S. did not experience a maximum above freezing during the entire month. Most of the precipitation in these regions fell as snow and several stations reported the heaviest snowfall of any January. Severe freeze damage and snow flurries were reported as far south as southern Florida. By February, temperatures had returned to normal and remained there throughout most of the year.

However, the next winter brought similar conditions with most stations east of the Continental Divide recording temperatures that were 2°F to 5°F colder than normal by the end of December 1977. From 5 to 11 December, an outbreak of cold air moved southward from Canada encompassing the entire region east of the Rockies. The outbreak of cold temperatures deepened in January 1978. Cold fronts from Canada came in continuous waves causing temperatures to remain below normal. The mean temperature in the Midwest was 10°F to 13°F below normal for January, with a record blizzard gripping the Ohio River Valley.

February 1978 exhibited a continuation of the cold trend. At some stations it was the coldest February on record, and for most locations from east of the Continental Divide to the Atlantic Coast, temperatures were below normal. By the second week in February,

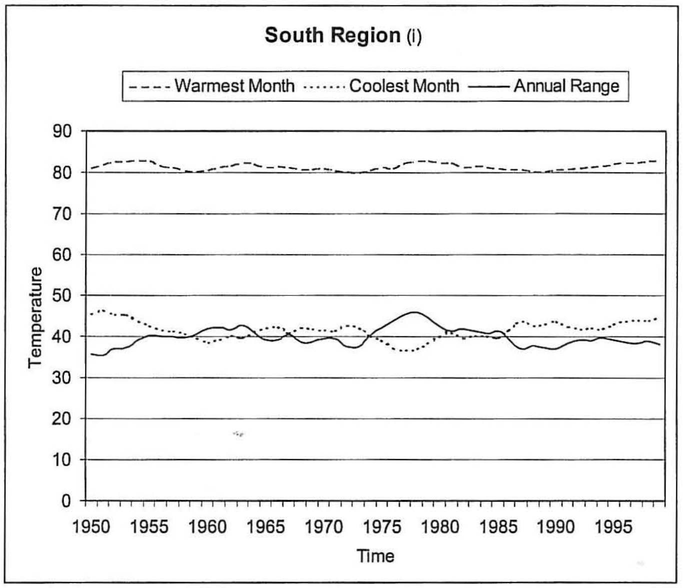

Fig. 2i. South region time-series line graph depicting mean temperature (°F) of the warmest month, coolest month, and annual temperature range for the study period 1951-2000.

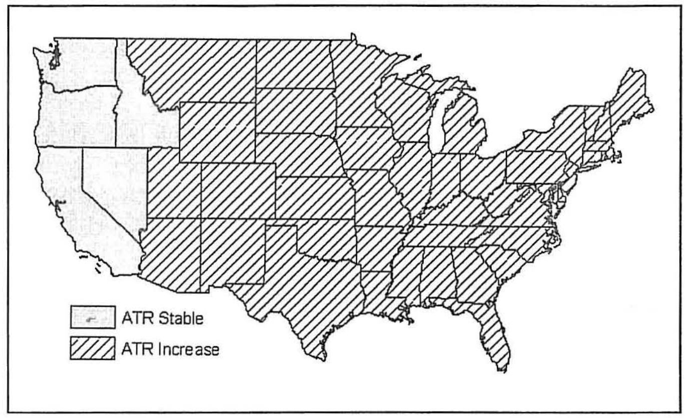

Fig. 3. Choropleth map of regional variations in annual temperature range for the study period 1951-1980.

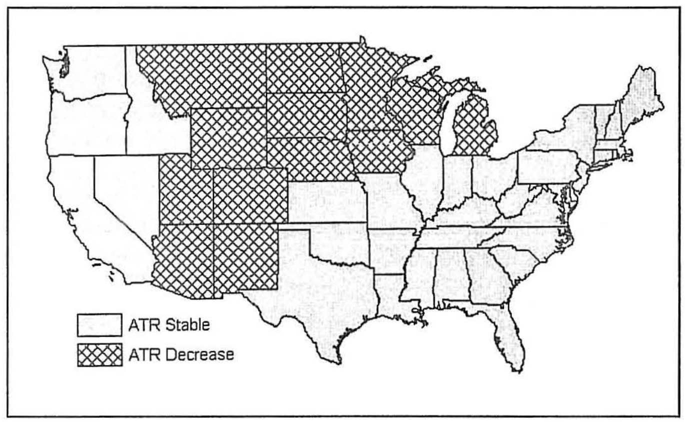

Fig. 4. Choropleth map of regional variations in annual temperature range for the study period 1961-1990.

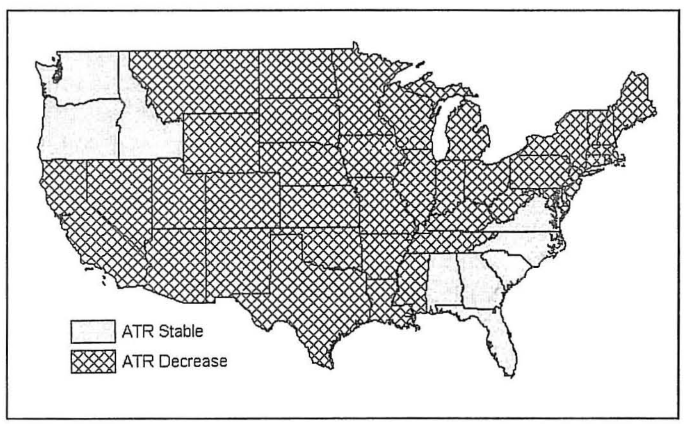

Fig. 5. Choropleth map of regional variations in annual temperature range for the study period 1971-2000.

parts of the Midwest were as much as 15°F to 18°F colder than normal. By mid-February, stations in the Central Plains were 22°F below normal, and during the last week of that month, the 0°F isotherm was pushing southward to the plains of Oklahoma. The cold winter continued through the first half of March with more record low temperatures set at many stations east of the Rockies before the arrival of spring. This unusual outbreak of cold weather is reflected by some of the largest ATRs of the study period, which were 62°F in 1977 and 61°F during 1978 in the East North Central region with mean temperatures of the coolest month averaging 9°F.

The decrease in the mean temperature of the coolest month during the latter half of the 1970s could be attributed to an increase in the dominance of continental polar (cP) air masses across the interior of the United States as a result of variation in atmospheric circulation. According to the IPCC (1996), atmospheric circulation is the main control behind regional changes in wind, temperature, precipitation, soil moisture, and other climatic variables. As a result, much research has been conducted to assess variability in circulation patterns. Born and Florin (IPCC 1996) examined maritime winds over the Atlantic Ocean and reported increasing variability from 1949 to 1989 which they attribute to changes in atmospheric circulation. However, Karl et al. (1995) assert that these modulations in wind regimes do not imply variation in atmospheric circulation over North America. Rather, due to the influence of the Westerlies, one must look to the Pacific Ocean in order to examine the possibility of alterations in circulation patterns across the United States.

For example, during January high pressure typically develops over the eastern Pacific Ocean and western North America. Often, this ridge is associated with a blocking high that originates north of Alaska. According to Harman (1991), the accompanying trough over the continental mid-section of the United States is related to extreme cold events across the Great Plains and the Midwest such as those that occurred during the record cold January of 1977.

Oliver (1981) reached the same conclusion concerning the winter of 1976-77 noting that the extended ridge over the eastern Pacific caused the jet stream to flow much further north than normal. Consequently, Alaska experienced unusually warm temperatures while the deepening trough east of the Rockies allowed cP air masses to extend further southward causing freeze damage to citrus crops in Florida (Rogers and Rohli 1991). Perhaps due to an increase in the frequency of occurrence of this amplified ridge over the eastern Pacific and western North America in association with the trough to the east, Davis and Dolan (1993) found that beginning in the mid-1970s, the number of mid-latitude cyclones increased over eastern North America. Further, Changnon and Changnon (1992) suggest that this upward trend in cyclonic activity correlates positively with winter storm disasters.

Trenberth and Hurrell (1994) conclude that changes in atmospheric circulation over the North Pacific are associated with a southward shift in storm tracks which are connected with the greater frequency of regional cold outbreaks across the United States. The IPCC (1996) states that such shifts could be interpreted as changes in atmospheric circulation variability, at least on a regional scale. Given that regional atmospheric circulation patterns are changing, it is possible that this variability has allowed cP air masses to cause the mean temperature of the coolest month to decrease in certain regions of the contiguous United States.

b. Warmer winters

New et al. (2000) report that surface measurements from 1975 to 1995 reveal nominally significant (5 percent level) increases in the mixing ratio of water vapor across much of the Northern Hemisphere. Similarly, Ross and Elliott (1996) examined precipitable water records from the surface to the 500-millibar level using data from 1973 to 1995 and found nominally significant (5 percent level) increases in precipitable water over most of North America with the exception of north-eastern Canada. The IPCC (2001) suggests that since the 1970s, each decade has yielded an increase in the total atmospheric water vapor of several percent. It is possible that increased water vapor gave rise to an increase in cloud cover, which likely would affect regional temperatures.

One factor that has been attributed to the decrease in the DTR is an increase in cloud cover over much of the planet. Dai et al. (1997) examined long-term data and found an increase in cloud cover and a decrease in the DTR during the 20th century for the United States, Europe, Australia, the former Soviet Union, and Eastern China. Hansen et al. (1998) assert that the increase in cloud cover is largely due to additional aerosols, which add condensation nuclei resulting in enhanced cloud development, thus affecting the DTR.

According to Karl and Steurer (1990), cloud cover over much of the United States increased during the 20th century. The IPCC (2001) states that many middle latitude and high latitude continental regions have experienced increased cloud cover of approximately 2 percent during the last century and that this increase is negatively associated with a variations in the DTR. That is, as cloud cover has increased, DTRs have decreased. This is largely due to the capacity for clouds to affect the daily radiation balance at the surface, causing nights to be warmer, and the daily minimum temperature to rise, while days are cooler, yielding a decrease in the daily maximum temperature. This increase in cloud cover might help explain warmer winters in some regions of the United States during the 1990s and the resulting decrease in the ATR.

5. Conclusion

Coupled with the finding that the DTR has been decreasing, it was hypothesized that the ATR (the difference between the mean temperature of the warmest month and the mean temperature of the coolest month) has shown significant variation during the study period from 1951-2000. To determine whether this is the case, time-series trend analyses were conducted based on the nine U.S. Standard Regions of Temperature and Precipitation. The results suggest that from 1951-1980, the North West and the West witnessed no change in ATR, while the remainder of the contiguous U.S. experienced a significant increase in ATR. From 1961-1990, the South West, East North Central, and West North Central regions exhibited a significant decrease in ATR, while the range for the remainder of the U.S. remained stable. Finally, the majority of regions during the 1971-2000 period, with the exception of the North West and the South East, displayed a significant decrease in the ATR. It appears that the record low winters in the late 1970s might have influenced the ATR for each of the study period subdivisions with the line graphs correctly identifying these events as they progressed through each of the time-series.

The physical attributes associated with the DTR also tend to apply to the characteristics of the ATR. Regions with wide temperature ranges (diurnal and annual) generally are located in the interior of a continent and are far removed from major sources of moisture, reducing the availability of water vapor and subsequent cloud development. Conversely, regions with smaller temperature ranges typically are situated along coasts or near large water bodies and experience substantial water vapor and cloud cover. Current research indicates that the DTR is decreasing, and the results of this study suggest that since the 1970s the ATR across most of the United States has shown a similar decrease. The discussion proposes that an increase in cloud cover could be associated with this decrease in both the DTR and the ATR.

The use of the ATR in time-series analyses for long-range forecasts appears to have promise after accurately identifying the cooler winters of the late 1970s and the warmer winters of the 1990s. Future research endeavors should examine smaller regional scales across longer time periods to forecast future trends in ATR and the associated seasonal effects. For example, the correlation coefficient of the ATR across the study period 1951-2000 for the West North Central region, the continental core of the contiguous United States, yields an $r = -.5215$ ($p = .0001$), implying that despite the cooler winters of the late 1970s, the region is experiencing a decreasing trend in the ATR which could result in milder seasons over the next few years.

The ability to correctly anticipate interdecadal trends in ATR would have numerous benefits for long-range forecasters. Those regions with a decreasing ATR could expect less severity during the winter and summer, while the converse is likely for regions with an increasing ATR. The applications are apparent as meteorologists constantly seek the means to offer long-range forecasts to energy producers and consumers, agriculturalists, and others to prepare in advance for possible seasonal extremes. Because such events tend to occur during the warmest and coolest months of the year, upon which the ATR is based, additional knowledge regarding trends in the ATR seems highly productive for operational purposes.

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