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ANALYSIS OF SURFACE HEATING TRENDS FROM 1994 TO 2004 USING OKLAHOMA MESONET DATA

Scott E. Stevens *, Bradley G. Illston, Jeffrey B. Basara
Oklahoma Climatological Survey, University of Oklahoma, Norman, Oklahoma

1. INTRODUCTION

Atmospheric heating is a critical issue in today's society, and much depends on the establishment of its existence, cause, and extent. Long-term models and simulations are often employed in forming theories that explain the causes and extent of global warming in the past. However, as long-term research quality datasets become more prevalent, local, regional, and global thermal trends can be utilized for in-depth analyses. Using data from the Oklahoma Mesonet, this study investigated the presence and extent of heating trends in Oklahoma from 1994-2004.

2. LITERATURE REVIEW

Numerous studies have been conducted over the past several decades to diagnose global atmospheric heating trends. Studies have focused upon temperature (Jones et al. 1999; Hamblin and Christiansen 2001), concentration of greenhouse gases (Peixoto and Oort 1992; Reid 2000), and solar radiation (Peixoto and Oort 1992; Reid 1997; Reid 2000; Liepert 2002; Solanki and Krivova 2003).

2.1 *Possible Sources*

There are several plausible causes for long-term climate changes. For example, the Earth does not revolve in a perfect circle, but rather an ellipse that changes over time. Fluctuations in the shape of this ellipse can alter both the angle and the proximity from which the Sun's energy is received at the surface. These new balances can cause changes in atmospheric thickness, composition, and temperature (Peixoto and Oort 1992; Keeling and Whorf 2000). On a much smaller time scale, Peixoto **(**1992) suggests that manmade changes in the makeup of the atmosphere have been suggested as causes of a heating trend. For example, industry has introduced particles and aerosols into the atmosphere not present before the 20th century. The human influence is strong, with concentrations of aerosols ranging from only 400 cm^{-3} over the open oceans to as high as 150,000 cm^{-3} over larger cities (Peixoto and Oort 1992). These aerosols can have numerous effects. For example, aerosols can refract, reflect, or absorb incoming solar radiation, impacting the amount that reaches the lower atmosphere and the surface.

* *Corresponding Author Address:* Scott E. Stevens, Oklahoma Climatological Survey, 100 E. Boyd St, Ste. 1210, Norman, OK, 73019; email: sestevens@gmail.com

In addition, the aerosols can serve as condensation nuclei for cloud formation. Clouds themselves can then affect the solar energy just as the aerosols can (Peixoto and Oort 1992). For example, Croke et al. (1999) found that there is a correlation between cloud cover over certain regions and global temperature.

Fluctuations in solar output have also been suggested as causes for global temperature change. A correlation has been found between the observed number of sunspots in a given year and the global temperature (Reid 1997; Reid 2000; Solanki and Krivova 2003). The pattern can even be seen on a timescale as small as the Sun's 11-year solar cycle. From approximately 1650 to 1750, there was a period when practically no sunspots were observed called the Maunder Minimum. During this time period, the Earth experienced what is now known as the Little Ice Age, when temperatures were about 0.3°C below the running average. During the 20th century, the number of sunspots observed steadily increased. Many have suggested that this is the driving force behind the recent warming of the Earth's surface (Reid 1997; Reid 2000; Solanki and Krivova 2003).

2.2 *Extent of Trending*

Scientists have found methods of determining surface and atmospheric mean temperatures for time periods millions of years ago (Gosnold et al. 1997; Huang et al. 2000). As a result, data have been deeply analyzed in the search for a long-term trend. Even a very small change in global temperature can have extreme consequences. For example, evidence shows that during the last recorded Ice Age, global temperatures were only 3 - 5°C colder than they are today (Hamblin and Christiansen 2001). The general consensus among scientists today is that the Earth's mean temperature has risen by approximately 0.8°C within the past 100 years (Lindzen 1990; Hansen et al. 1999; Hamblin and Christiansen 2001; Jones et al. 2001,). Studies have also found that the rise in temperature is not from an increase in daytime maximum temperatures, but rather an increase in nighttime minima. As a result, the diurnal range of temperature has decreased by around 0.7 – 0.8 °C (Jones et al. 1999; Karl et al. 2001). In a study that divided the Earth's surface into 5° by 5° grid squares, Jones et al. (1999) found that the square containing Oklahoma has actually cooled down over the past 150 years. The decrease has been seen mostly in the maximum temperatures, with the diurnal range decreasing by roughly 3°C. In contrast, however, NCDC data suggests a slight warming of this region since

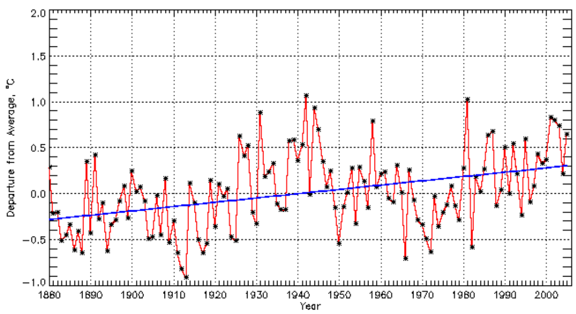

Figure 1. NCDC Temperatures In Southern Plains from 1880-2004

1880. This trend is illustrated in Figure 1, which shows a warming trend of approximately 0.10°C per decade.

When measured by satellite, the lower troposphere has actually exhibited a slight cooling trend over recent years (Singer 1998). This observation has led some to believe that global warming is not actually happening. Singer (1998) suggests that a global warming trend would be beneficial to life on Earth and claims that crops fare better in warm periods than in cold, and a warming trend would result in a longer growing season; this stance is not widely accepted.

2.3. *Thermodynamics*

The main driving force behind our climate and temperature is the radiation received from the Sun. The laws of thermodynamics relate this incoming energy to temperature, pressure, and various other quantities. Sometimes, temperature alone can be misleading, as an increase in energy may cause changes in other variables. To account for this, the concept of heat content, H was utilized in this study. H is defined as $H = C_p T + Lq$, where C_p is defined as the specific heat of air[1] at constant pressure (measured in $JKg^{-1}K^{-1}$), T is temperature (K), L is latent heat of vaporization[2] (JKg^{-1}), and q is specific humidity (Pielke et al. 2004).

Thermodynamics and the conservation of energy laws state that all incoming energy must be accounted. It must be absorbed, reradiated, reflected, or expended in some manner. The law further states that for Earth to maintain an equilibrium level of energy, the incoming radiation must perfectly balance the outgoing. If the incoming radiation exceeds the outgoing, the Earth will experience a net increase of internal energy, and the opposite holds true for the opposite scenario. All other things constant, such a change in the balance of energy would create a shift in temperature. Quantitatively, studies have shown that if the Earth's absorbed energy were to exceed the outgoing energy by just 1% for one year, it would result in a global warming of roughly 7°C (Peixoto and Oort 1992).

[1] Specific heat of air is defined as the amount of heat energy required to raise the temperature of one kilogram of air by 1°C.

[2] Latent heat of Vaporization is defined as the amount of energy required to change one kilogram of water from liquid to gas.

2.4. *Greenhouse Gases*

Evidence has recently begun to show that greenhouse gases may not be responsible for our global heating (Reid 2000). While it is true that increases in global carbon dioxide (CO_2) and methane (NH_4) levels correspond to increases in temperature, the timing of these events seems to show that the temperature begins rising long before the levels of these gases begin to increase. During periods of colder weather, the forests and oceans absorb CO_2 and NH_4 by a process not fully understood by scientists. In the past, when the Earth's temperature has begun to rise, it has been several decades before the forests and oceans have begun to release these gases back into the atmosphere (Reid 2000). Near the end of the last recorded Ice Age, the levels of CO_2 increased just as they have since the beginning of the Industrial Revolution. However, the end of the Ice Age saw a global increase of temperature of nearly 10°C, while in recent years, we have only seen an increase of about 0.5°C. This would suggest that the increase in temperature is occurring due to some other source, as opposed to CO_2 levels (Reid 2000). Carbon dioxide levels have increased from roughly 280 parts per million (ppm) to roughly 350 ppm since the dawn of Industry. However, a look into prehistory shows CO_2 levels over 20 times the levels of the early 20th century. That time period, roughly 450 million years ago, saw no drastic increases in temperature, despite the significantly increased high levels of CO_2 present (Singer 1998).

3. INSTRUMENTATION

In the mid-1980's, a collaborative effort was founded between the University of Oklahoma and Oklahoma State University to establish a statewide network of climate monitoring stations that could be used to disseminate meteorological information to the public. The result was the Oklahoma Mesonet, commissioned on 1 January 1994 as a vast network of 116 stations covering all 77 of Oklahoma's counties. Each station collects data of standard meteorological variables such as air temperature, humidity, radiation, rainfall, pressure, wind components, and various soil characteristics. This information is transmitted every five minutes via the Oklahoma Law Enforcement Telecommunications System (OLETS) network back to a central processing station in Norman (Brock et al. 1995). From 1994 to 2003, temperature data were collected by the Vaisala HMP35C sensor. In 2004, these sensors were replaced by Thermometrics Fast Air Temperature sensors. Since its inception, the Mesonet has used the RM Young Wind Sensor for 2-meter wind speed measurements, the Visual HMP45C for humidity measurements, the Vaisala Barometer for station pressure measurements, and the Li-Cor Pyranometer for solar radiation measurements.

4. CANDIDATE DAYS

A series of filtering processes was performed on all available data in order to extract the research-quality observations needed for the study. The temperature sensors used at Mesonet sites include an instrument error that varies inversely with wind speed (i.e. reduced wind speeds yield increased temperature error). To minimize error in the analysis, only days with an average 2-m wind speed of six miles per hour or greater were used. In addition, the Mesonet records the number of bad or questionable temperature readings during a 24-hour period. All days were discarded which contained any bad temperature data. Finally, as some calculations in this study depended on moisture and pressure data as well, all data were removed which contained erroneous data in these variables. As a result of the data filtering, a collection of usable days (i.e. “candidate days”) with minimal error was created. The number of candidate days varied greatly spatially and temporally. Most of the data discarded were a result of insufficient wind speeds, mostly during the summer, as wind speeds are typically lower in Oklahoma during the summer months. Spatially, the western half of Oklahoma saw a much greater percentage of acceptable data than the eastern half, especially during the summer months, with sites such as Idabel, Stigler, and Miami containing no sufficient days at all during some summers. This resulted from much slower wind speeds among the most eastern stations, possibly because of increased vegetation and topography in the eastern part of the state. Overall, the percentage of usable days ranged from 18% at Idabel to 80% at Goodwell.

5. METHODS

Ten sites were selected throughout Oklahoma for the analyses. Sites were selected based on data availability over the entire study period and geographic diversity. Figure 2 shows their relative locations throughout the state.

Data on temperature, pressure, humidity, and wind were collected from each of these sites each day from 1 January 1994 through 31 December 2004. After filtering, the data from the candidate days were used to calculate heat content and effective temperature. Data

Figure 2. Locations of Selected Mesonet Sites.

Sample Months	**MARCH**	**APRIL**	**MAY**
Sample Numbers	-2.2	14.4	35.0
	8.3	35.0	23.9
	3.9	16.7	16.7
	16.1	24.4	
	28.3	25.6	
	23.3		
	32.8		
Monthly Average	15.8	23.2	25.2
Method A	**20.2**		
Method B	**21.4**		

Table 1. Example of Different Averaging Methods

for maximum, minimum, average, and effective temperatures were averaged by month for each site for the duration of the study period. Months were then averaged into seasons, discarding those months that contained fewer than six candidate days. Rather than computing a seasonal mean by averaging each day within the season (Method A in Table 1), this value was obtained by averaging the means (Method B) of the three months that comprise a season (e.g. March, April, and May were averaged to obtain a spring mean). This was done because the data filtering process produced varying amounts of data in each month. By normalizing the data this way and giving equal weight to each month, the situation is avoided in which different parts of the season are given more weight, thus skewing results into values that could potentially be unrepresentative of the season.

An 11-year average was calculated for each parameter as well as Z-Scores for each year. This standardization allows one season to be compared to another by comparing Z-scores rather than raw temperature values.

6. RESULTS

Through comparison of Z-scores for each season for a particular climate region, some trending of temperatures was evident. For Oklahoma, statewide average temperatures increased slightly over the period of the study. This trend is particularly evident in the spring season, when average temperatures steadily increased from approximately 14.7°C in 1994 to 16.9°C in 2004. This statewide trending was most heavily influenced by those stations located in the eastern part of the state, where springtime temperatures increased from 13.3°C to 18.4°C over the study period (Fig. 3).

Linear regression of the data reveals an average increase in temperature of 0.27°C per year during spring in eastern Oklahoma. As previous studies have suggested, the increase is most influenced by minimum temperatures rather than daytime high

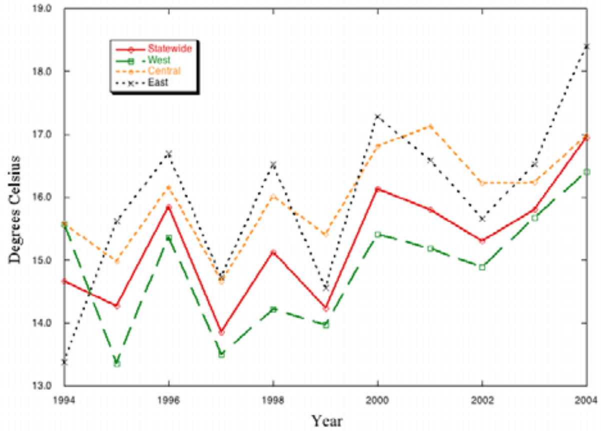

Figure 3. Springtime Average Temperatures by Region.

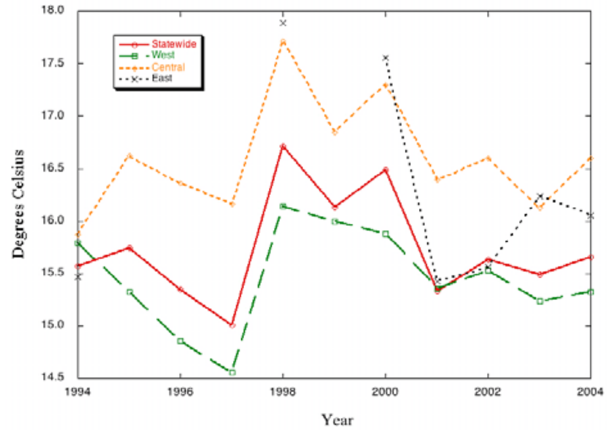

Figure 5. Annual Average Temperatures by Region.

temperatures (Jones et al. 1999). In this study, minimum temperatures increased by roughly 0.37°C per year, while maximum temperatures increased by only 0.21°C per year. Other seasons did not exhibit such clear trending. For example, the statewide data during the summer are much more erratic, but trend slightly downward, decreasing at a rate of roughly 0.10°C per year (Fig. 4).

Overall, any temperatures rising in one season seems to be balanced by temperatures falling in another. When the annual average temperature is analyzed, no trend is evident over the period of the study in any region, despite some years in which temperature is unusually high or low (Fig. 5).

Any trending in temperature is amplified when humidity is taken into account. Effective temperature was calculated by dividing the heat content of air by the specific heat at constant pressure. Analysis of effective temperature over the study period reveals similar trending, but on a larger scale. Figure 6 shows springtime effective temperatures by region. The trend is similar to that of the springtime average temperatures, but the rise is much greater over the study period. For example, effective temperatures in the east have risen approximately 10°C since 1994. Much like the average temperatures, the greatest increase is observed in the east, and the smallest in the west.

7. CONCLUSION

Over the 11-year study period, there are indications of climatological change occurring in Oklahoma. Temperatures in all parts of the state rose significantly during the springtime, yet were balanced by falling temperatures in the other seasons, particularly summer. Spatially, eastern Oklahoma exhibited the largest changes, showing springtime heating in excess of 3°C during the study period. While the other areas of the state also experienced heating, it was to a lesser degree. Showing similar trending, the effective temperatures across Oklahoma also increased during the study period, rising as much as 10°C in eastern Oklahoma. Thus, the results of this study revealed that over the study period that spring months in Oklahoma were getting warmer, while the summer months were cooling to compensate.

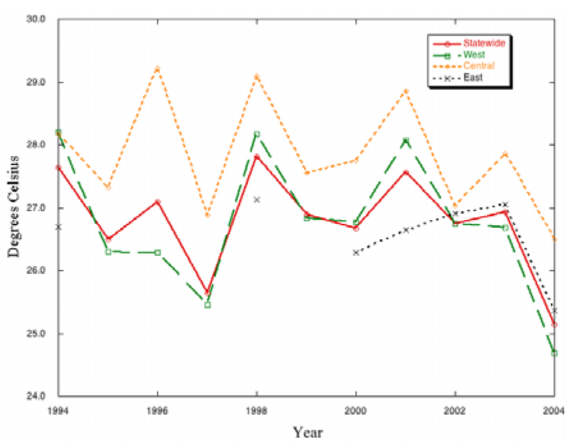

Figure 4. Summertime Average Temperatures by Region.

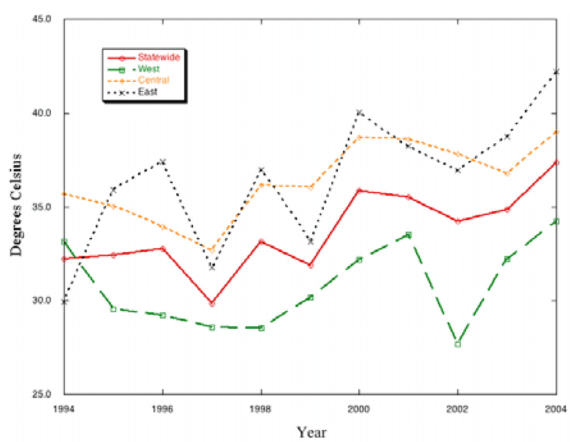

Figure 6. Springtime Effective Temperatures by Region

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