Temperature Change in New England: 1895-2012

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Abstract
Over the past century, the globe's temperature has been increasing at a higher rate than in the past. Over the last century increasing temperature is due to higher levels of human-generated greenhouse gases. Global warming has a dominating effect and will cause changes in climates all over the world. Since 1895 air temperature data have been collected from stations across the United States and the data have been aggregated in the U.S. Historical Climatological Network (USHCN) data set with temperatures for the New England states. To determine if there has been a change in temperature in New England between the years 1895 until 2012, we calculated the USHCN data into annual, seasonal annual, decadal, and seasonal decadal anomalies for each state and New England as a whole. We then analyzed the anomalies using temperature change measurements. The decadal and annual temperature change values for each state were mapped so the data could be spatial analyzed. We also compare temperature change in New England to Global and Northern Hemisphere (44°N to 64°N) change. We did this by comparing the USHCN data to the Goddard Institute Space Studies (GISS) Surface Temperature Analysis (GISTEMP) data set.

Keywords
Climate Change, Temperature Rise, New England, Statistical, USHCN Data Set, GISTEMP Data Set

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INTRODUCTION

History of Global Warming and Climate Change

Global warming and climate change have recently become popular topics addressed in the scientific, government and media fields. According to the United States Environmental Protection Agency (EPA) “global warming is recent and ongoing rise in global average temperature near earth’s surface” and it is causing climate patterns to change (EPA, 2013a). The EPA defines climate change as “any significant change in the measure of climate lasting for an extended period of time” and which includes changes in temperature, perception and wind patterns (EPA, 2013a). The earth’s climate naturally goes through various climate cycles. Over the past 650,000 years there has been seven cycles of glacial advances and retreats. The Earth’s modern climate started approximately 7,000 years ago (NASA, 2013). Past changes to the climate were caused by natural changes in solar energy, greenhouse gases, and atmospheric aerosols. But since the Industrial Revolution, however, humans have added carbon dioxide and other greenhouse gases to the atmosphere which has contributed to temperature rise and modern-day climate change (EPA, 2013b).

Throughout the 20th century average global temperatures have been increasing (Alexander, et al, 2006). Just in the past 30 years the average global temperature has risen 1.1°F (Hansen, 2006). There is a strong correlation between temperature rise and increasing carbon dioxide levels. Carbon dioxide levels are currently the highest they have been in at least 800,000 years (Luthi, et al., 2008). According to the Intergovernmental Panel on Climate Change (IPCC) human emissions of greenhouse gases have risen 70% from 1970 to 2004. The IPCC states that the rise of global temperatures is due to human activity and predicts the average global temperature can rise 2 to 11.5°F by 2100 (IPCC, 2013).

Human Drivers of Climate Change

Human activities started to influence the earth’s climate during the start of the Industrial Revolution around 1750. These activities altered the incoming solar radiation and outgoing infrared (thermal) radiation that are part of the earth’s energy balance which causes changes in earth’s climate. The significant increase of all four principal greenhouse gases (carbon dioxide, methane, nitrous oxide, and halocarbons) from the start Industrial Revolution has increased the energy in the Earth’s atmosphere causing it to warm. Carbon dioxide levels have increased due to fossil fuel use in transportation, building heating and cooling and the manufacture of cement and other goods as well as deforestation. Agriculture, natural gas distribution, and landfills have increased the level of methane. Nitrous oxide levels have increased due to fertilizer fuel use and fossil fuel burning. The increase levels of halocarbon gas have also been influenced by human activities. Climate change is also affected by human activities influence on levels of aerosols and cloudiness in the Earth’s atmosphere. However, the main human activity that has driven climate change is the increase in greenhouse gases (IPCC, 2007).

Signs of Climate Change in New England

There have already been signs of climate change in the New England region of the United States (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont) with earlier dates of spring lake ice-out (Hodgkins et al. 2002) and river ice-out (Dudley and Hodgkins 2002), as well as earlier snowmelt-driven...
spring runoff (Hodgkins et al. 2003) and fewer snow-covered days in winter (Burakowski et al. 2008). The annual average temperature of the U.S. Northeast has risen 2°F since 1970 (Bretts, 2011). New England’s temperature is predicted to rise between 6 to 10°F by 2100. To put this into perspective with climate change, if the temperature rises only 6°F Boston’s climate will be similar to Charlotte, North Carolina. If the temperature rises 10 °F then Boston’s climate will be similar with Atlanta, Georgia (Union of Concerned Scientists, 2006).

In the future, rising temperatures are predicted to cause more floods and droughts in New England. Precipitation in New England has increased in the form of extreme downpours and snowfalls. Since 1984 extreme downpour and snowfall events have increases by 85%. These events are likely to continue to increase in the future and cause damaging floods. However they will be spread out and there will potentially be longer periods where water will be scarce which can result in droughts and fires (U.S. House Committee on Natural Resources, 2012).

Climate Change Effects on New England’s Four Seasons

New England’s rising temperatures have had different effects on each of the four seasons. Rising temperatures have resulted in fewer snow-cover days in the winter (U.S. House Committee on Natural Resources, 2012). The reason behind New England losing snow-cover days is the result of less precipitation falling as snow and the snow is melting faster. Most likely in the future there will be more winter rain (Union of Concerned Scientists, 2006). It is predicted that by 2100 Maine will be the only state in New England that will have cold enough temperatures to retain ski resorts (U.S. House Committee on Natural Resources, 2012). An increase in temperature is not only going to shift spring’s seasonal time period but also affect its seasonal environment. In New England spring is estimated to take place one to three weeks earlier by the end of the century. Furthermore spring is estimated to end earlier and the summer season could start more than three weeks earlier by the end of the century. The start of biological spring is measured by the dates of when leaves and blooms are present on diverse species. The appearance of leaves and blooms are connected to temperature. As spring temperatures start earlier, so will the arrival of blooms, leaves and insects. This will affect the insect-eating birds. The bird’s migration is connected to the length of day and not temperature. If the insect population has already peaked when the birds arrive, then the birds will not have enough food sources (Union of Concerned Scientists, 2006). In New England, the increasing temperatures will cause spring snowmelts to happen earlier, this will affect trout and salmon because their life cycle depends on the water from the spring snowmelt (U.S. House Committee on Natural Resources, 2012).

As temperatures increase, the summer season will become lengthier in New England. Summer is projected to start three weeks earlier and last three more weeks into the fall season. Summer’s temperatures are expected to increase and there will be more days with temperatures above 90° F (Union of Concerned Scientists, 2006). In New England, the number of summer droughts are expected to rise due to earlier snowmelt and more runoff from heavier summer rainfall combined with increased evaporation (Betts, 2011). Temperature rise will also cause the fall season to start three weeks later (Union of Concerned Scientists, 2006). Increasing temperatures will cause New England trees to become drought-stressed, which will
change their autumn colors. This would have a negative effect on the fall tourists industry (U.S. House Committee on Natural Resources, 2012).

Sea-level Rise and New England

The rising global temperatures are causing the oceans to became warmer and expand. Because of the ice sheets and glaciers melting more rapidly there is a larger amount of fresh water flowing into the sea as well. These factors are producing global sea levels to rise and increasing the risk of inundation of low-lying coastal land and increasing the risk of wave and flood damage from coastal storms (Nicholls & Cazenave, 2010). The coastline between North Carolina and Massachusetts is experiencing sea-level rise two to four times faster than the global rate. This faster rate is being driven by changes in ocean circulation patterns which cause the flow of water along the coast to slow down and pile up along the coastline (U.S. House Committee on Natural Resources, 2012). Over the past 100 years Boston has experience a sea level rise of 11 inches due to climate change and land subsidence. By 2100 it could rise another 2 to 6 feet. Boston is projected to experience coastal flooding comparable to today’s 100 year storm every two to four years by mid-century and approximately every year by the end of the century (New England Aquarium, 2013).

The effects of global warming have started to be noticed at the regional levels of the world. Although the average temperatures for the entire globe are increasing, the warming is not uniform, as some regions are warming quickly and others much more slowly (Hansen, 2006). In this paper we analyze the U.S. Historical Climatological Network data set (1895-2012) to determine if there has been a measurable temperature change in New England. From 1895 to 2012 we analyze the data at the regional and state levels for the annual and seasonal periods of the data in order to understand how temperature is changing in New England at the temporal and spatial scales.

DATA

In this paper we analyze the U.S. Historical Climatological Network (USHCN) data set. This data set was downloaded from NOAA’s National Climatic Data Center (NCDC) website. The USHCN data are based on air temperature data collected in the U.S. since 1895. The data set uses air temperature data from a number of stations in each state of the continental United States. Air temperature data are compiled in monthly means by state. Along with the USHCN data we downloaded and analyzed NOAA’s National Climate Data Center (NCDC) data set. However, according to Keim et al. (2003), the NCDC data is considered to be less accurate than the USHCN data. The main reason for this is because the number and locations of the NCDC stations have changed over time with no explanations. The USHCN stations on the other hand were selected based on length and quality of data. Furthermore the USHCN stations have been adjusted over time to take into account the validity of extreme outliers, time of observation bias, changes in instrumentations, random relocations of stations, and urban warming biases (Keim, 2003). Therefore, in this paper we only used the USHCN data.

To compare temperature changes in New England with global changes we downloaded the Goddard Institute for Space Studies (GISS) Surface Temperature Analysis (GISTEMP) data set from the NASA Goddard Institute. This data set has annual mean anomaly data for the world as well as global zones, such as the Northern Hemisphere, $0^\circ - 24^\circ$, $24^\circ - 44^\circ$, $44^\circ - 64^\circ$, $64^\circ - 90^\circ$.
and 64° – 90°. Although this data set goes back to 1880, we only used data from 1895 to 2012 which is the same time period for our USHCN data set. The base period for the GISTEMP data set is 1951 – 1980, and so when comparing anomalies with the global data, we recalculated the USHCN data set to 1951 – 1980 as the mean from which to create the annual anomalies.

METHODS

The USHCN data for the six New England states were downloaded from the U.S. Department of Commerce’s Climate Data Center’s website and were imported into Microsoft Excel. In Microsoft Excel the monthly means for each station in each state were combined into state-level annual means. The annual mean for each state for each year from the years 1895 to 2012 was calculated from the monthly mean data. Then in each state all the annual means from 1895 to 2012 were averaged to create a long-term, full-period mean. The annual means were then used to calculate the annual anomalies where the annual anomaly equals the annual mean minus the full-period mean. Then in Excel the annual anomalies were graphed with trend lines. The graphed trend lines show if the change in temperature throughout the period was positive (increasing) or negative (decreasing).

The data were then analyzed seasonally (averaging the three months per season): spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December (from the prior year) along with the months of January and February). The same procedure used with the annual averages (creating full-period means and anomalies) was also used for each of the seasons. To be able to compare the four seasons with the anomalies’ values, the year 1895 was not used for the winter season because there was no December 1894 data.

Additionally the data were calculated into decadal annual and decadal seasonal values. The years were grouped from 1900-1909, 1910-1919… with the last decade being 2000-2009. The decadal annual and decadal seasonal values were graphed with trend lines in Excel. Because the first period (1895-1899) and the last period (2010-2012) are not full decades, the decadal analysis used a 110-year period starting with the 1900 decade (1900-09) to the last 2000 (2000-09) decade.

Each state’s values for the data sets (annual, seasonal annual, decadal and seasonal decadal) were calculated together to create values for all of New England. Similar to the state level, New England was analyzed at the annual and decal levels. The individual state annual and decadal temperature change values were imported into ArcMap and were used to create maps to do a spatial analysis on the data.

To determine the change in temperature during the time period, we differenced the first and last years of the data set (2012 temperature minus 1895 temperature). Because annual temperatures can fluctuate considerably, to determine temperature change throughout the whole period we also averaged the first five years (1895, 96, 97, 98, 99) and the last five years (2008, 09, 10, 11, 12) and differenced them. In addition, we differenced the first full decade (1900-1909) and the last full decade (2000-2009).

RESULTS and DISCUSSION

Annual and Decadal Temperature Anomalies for New England

Both the annual and decadal anomalies for all of New England show a warming trend. Figure 1 shows the change
in annual temperature anomalies over the 118-year period (1895-2012) for all of New England. The annual data show a positive linear trend line. Based on the annual temperature data (Appendix 1), New England increased in temperature by 3.66°F between 1895 and 2012 (annual mean of 2012 minus annual mean of 1895). Because annual temperature can fluctuate considerably, we smoothed the data by averaging the first and last five years and then differenced them. Concerning the temperature change from the first five years (1895-1899) to the last five years (2008-2012), New England experienced an increase of 2.04°F.

The annual seasonal data indicates that for New England as a whole temperature has increased annually in all four seasons (Appendix 1, Appendix 2). Summer has the lowest temperature change (1.34°F) of the four seasons while winter (5.84°F) and spring (5.31°F) have the highest temperature increase. As seen in Appendix 2, the winter and spring seasons have the greatest variation between years.

Figure 1 shows the change in decadal temperature anomalies over the 110-year period (1900-2010) for all of New England. The decadal time period is shorter than the annual period as 1900 was the first full decade and 2000 was the last full decade of recorded data. The data show a positive trend line similar to the annual data. Based on the decadal temperature data (Appendix 1), New England increased in temperature by 1.86°F between the decades of 1900 (1900-1909) and 2000 (2000-2009).

On the decadal level, again the temperature data indicates that there has been a temperature increase in all four seasons (Appendix 3). Like the annual seasonal data, the winter season had the greatest rise in temperature (2.75°F), but also the greatest variability. Spring had the lowest temperature rise (1.30°F), though it was similar to the summer (1.66°F) and fall (1.64°F).

Spatial Analysis of Individual States

Figure 3 shows the individual states annual and decadal temperature change values. Both the annual and decadal temperature change values show that New Hampshire and Maine had the lowest temperature increase. Vermont, Massachusetts, Rhode Island, and Connecticut had different spatial patterns for the annual and decadal temperature change values.
Appendix 1 shows the annual and seasonal temperature changes for the six states and all of New England at the annual, five-year and decadal levels. On Appendix 1 there are a total of 105 change measurements. For the USHCN data set there were 4 out of 105 (3.8%) with cooling conditions (all less than 0.4°F). On the warming side there were 101 out of 105 measurements showing an increase in temperature (96%), and 48 of these measurements showed an increase of greater than 2.5°F (46%). Based on the USHCN data, Connecticut, Massachusetts and Vermont have been heating up the most, and Maine and New Hampshire the least, especially Maine, which had half of the decreasing values and not a single value increasing greater than 1.7°F. For most of the states the winter and spring seasons show the greatest increases in temperature while the summer season shows the least rise.

Comparing Global and New England Temperature Anomalies

Figure 4 shows the comparison of global temperature anomalies with those of New England for the period of 1895-2012. Both have a similar pattern, though the annual anomalies of New England fluctuate to a greater extent, and indicate a greater increase in temperature over the time period. Figure 5 shows the global anomalies for 44°N to 64°N and those of New England (41°N to 47°N). Except for the first ten years, both of these data sets have similar patterns of change. These graphs show that the temperature changes occurring in the New England region are similar to that of global temperature changes, especially in areas of similar latitudes.
CONCLUSION

By analyzing the temperature data for New England, we have shown that this region, like most of the world, is experiencing increasing temperatures. Global warming and climate change is one of the most important changes happening on the Earth, and as scientists it is important to document this change and try to better understand its patterns of change. Change in temperatures, sea level rise and extreme weather events will start producing changes in New England that will affect ecosystems, wildlife, and land forms. These changes which are all connected to temperature rise will eventually start affecting humans in many ways. That is when global warming and climate change will become a large concern for the general public.

REFERENCES


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APPENDICES

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1. Analysis based on U.S. Historical Climatological Network data
2. CT = Connecticut, ME = Maine, MA = Massachusetts, NH = New Hampshire, RI = Rhode Island, VT = Vermont, and NE = New England
4. Spr = Spring mean (March, April, May), Sum = Summer mean (June, July, August), Fall = Fall mean (September, October, November), Win = Winter mean (January, February: current year and December: prior year).

Appendix 1. Annual Seasonal Temperature Change by State and all of New England

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Appendix 2. Annual Seasonal Temperature Anomalies for all of New England

Appendix 3. Decadal Seasonal Temperature Anomalies for all of New England