Challenges in Teaching Climate Science Literacy in Alabama, Part I: Climate Change and the Southeast U.S. Warming Hole.

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INTRODUCTION

Climate change has become one of the most serious and challenging global issues of our time, threatening public health, biological and ecological systems, food security, and the economy. Scientific research has built a consensus of the scientific community around anthropogenic climate change (ACC) (Rosenberg et al., 2010; Good et al., 2011; IPCC, 2013, 2018). According to the 2014 Intergovernmental Panel on Climate Change (IPCC) report, human influence on climate is "clear" and "warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen" (IPCC 2014:2). Although the environmental and societal consequences of a changing climate demand immediate action from society and individuals alike, the complexity of climate change processes makes it difficult for people to understand the short- and long-term impacts that the world faces.

Despite overwhelming scientific consensus that the earth's climate is changing rapidly, and that human activity is largely responsible, there is a significant percentage of the population that remains skeptical or doubt the seriousness and urgency (Leiserowitz et al., 2011). This doubt is amplified by the misinformation, misunderstanding, and lack of knowledge about the scientific data. Because the next generation is critical in making changes in policy to combat the effects we already see from climate change, teachers and leaders play a critical role in educating young people about climate change and its causes.

One approach in improving climate science literacy is to initiate the lesson with a phenomenon that your audience has experienced and can specifically relate to – local weather patterns. Additionally, to fully understand and acknowledge the complexities of earth's changing climate, it is crucial to appreciate the difference between weather events, what we experience during a relatively shorter period of time, and climate, an averaging of weather conditions over a much longer interval. People often interchange and/or confuse climate with weather, making it difficult to understand the even more complicated subject of "climate change." Single weather events, no matter how extreme, do not represent the overall climate in a region. However, by amassing long-term weather data, it is possible to discern trends that constitute climatic drifts. This study specifically examines historical temperature trends in northwestern Alabama since the 1940s and average

temperatures for the state since the late 19th century. These long-term trends are then used to address climate science education and literacy, particularly focusing on the complexities of Earth's climate systems and the differences in weather and climate events. In this paper, we attempt to use information about local weather, climate, and regional anomalies to improve understanding and climate literacy.

CHALLENGES IN TEACHING CLIMATE CHANGE

Research has shown that the level of environmental consciousness is directly related to environmental knowledge (Zsóka et al., 2013). Yet teaching about the environment is not without its challenges (Lombardi and Sinatra, 2010; Sinatra and Mason, 2008) including the students' limited knowledge, misconceptions, belief and culture, a resistance to change (Dole and Sinatra, 1998), and lack of "systems thinking" (Goldstone and Sakamoto, 2003). Further complicating the issue, research has shown that teachers' personal beliefs and attitudes about science can influence a student's perspective (Duschl, 1990; Waters-Adams, 2006).

The politicization of this issue has additionally intensified the struggle of communicating good scientific information about climate change to the public. A March 2018 Gallup Poll (Brenan and Saad, 2018) indicates that there is a marked divide along partisan political lines, with 69% of Republicans and only 4% of Democrats believing that the seriousness of global warming is generally exaggerated. The same poll indicates that 55% of the American public do not think that global warming will pose a serious threat in their lifetime. While these numbers reflect the inherent difficulty in trying to convince the public that climate change is a serious issue that requires immediate action, they also amplify the necessity in improving climate science literacy in general.

This is especially important, and challenging, in the politically conservative southeastern United States, including Alabama. In a region where many people have already made up their minds based on misinformation, teaching climate science literacy requires a nuanced approach. It is also imperative to avoid and discourage the use of anecdotal "evidence" either in support of, or in contradiction to, long-term climate change. Used either way, there is little to no scientific validity to such an argument without corroborative data.

Climate is complex and consists of various components. As we show below, regional anomalies in climate patterns can be contradictory to the overall trend of global temperature increases. This further complicates the teaching and understanding of global climate change. But even contradictions can lead to a teachable moment.

REGIONAL CLIMATE CHANGE AND THE WARMING HOLE

Local and regional climate systems consist of several physical weather variables and their interactions, such as temperature, precipitation, wind, and storm patterns, averaged over time. It is appropriate to think of climate as what is "normal" for an area during the course of a year. One of the most common misperceptions is that any extreme weather event, a deviation from the normal, is evidence of a changing climate. Droughts, floods, severe storms, and extreme temperature events represent only a single weather episode that must be averaged over time with all comparable conditions.

By analyzing a data set of archived temperature records from a local meteorological station in northwest Alabama, we can emphasize the distinction between short-term weather events and long-term climatic conditions. Archived temperature records beginning in December 1940 were obtained for the Northwest Alabama Regional Station using NOAA's National Centers for Environmental Information (https://www.ncdc.noaa.gov/cdo-web/datasets/GSOM/stations/GHCND:USW00013896/detail); Supplemental File 1). We use monthly averaged values of daily low, high and average temperatures rather than temperate extremes. These three averages were plotted showing annual and long-term temperature variations.

Ten-year incremental plots as well as a composite plot from December 1940 through April 2019 were produced (Figure 1a-i). Several minor temperature trends are apparent when examining the 10-year increments. For example, there is a warming spike in the mid-1950's, followed by cooling at the end of the decade. What especially stands out, particularly when increments are combined into a composite record (Figure 1i), is apparent stability. Temperatures during the most recent decade (2010's) are not appreciably different from what was experienced in the 1940's, and the overall trend appears to be remarkably flat. For most, this stands in stark contrast to expectations related to the impact of "global warming".

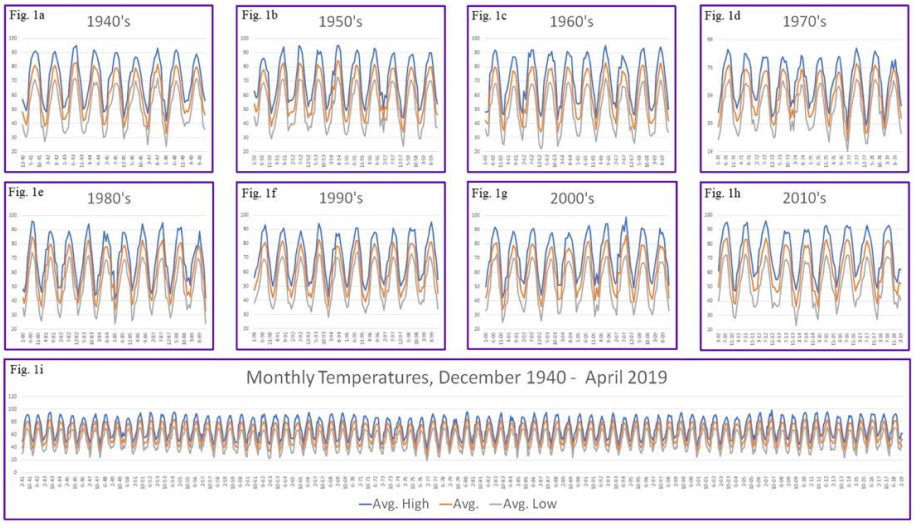

Figure 1. Decadal plots (a-h) and composite plot (i) of monthly average high (blue), average (orange) and average low (gray) temperatures for the Northwest Alabama Regional Weather Station from December 1940 through April 2019. Historical data is from National Centers for Environmental Information and is provided in Supplemental file 1.

Data in Figure 1 illustrate temperature variations observed at only a single weather station in northwest Alabama. We also analyzed statewide-level data obtained from the Southeast Regional Climate Center (www.sercc.com). Figure 2 shows average monthly temperature trends for what is normally the coldest month in Alabama (February) and the hottest month (August). Although both graphs show a marked cooling trend from the 1950's into the early 1980's, it is most pronounced in the February data. Examination of Figure 2 also demonstrates that Alabama has seen little if any significant temperature change since 1895. Although the several most recent February temperature averages are well above the norm, August temperatures are not significantly different than they were at the end of the 19th century.

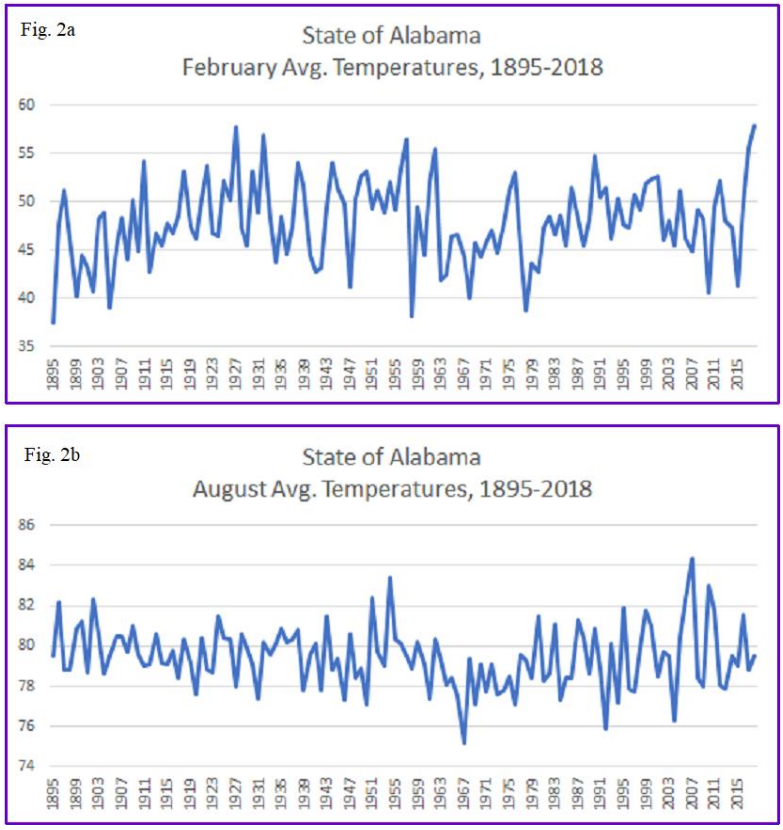

Figure 2. Plots of average temperatures in February (a) and August (b) for the state of Alabama. Data is from the Southeast Regional Climate Center (www.sercc.com) and is provided in Supplemental file 2.

So, how can this data be used to help explain and make a case for global climate change despite it showing little warming in the southeast? This anomaly can serve two purposes:

1. **These data introduce the complexity of climate change and illustrate the existence of a SE "warming hole".**

Because of the complexity of "climate change," regional differences in warming trends can be extremely helpful in understanding the mechanisms controlling warming. The differential heating characteristics of land versus water suggests continents will experience more warming than the oceans, polar latitudes warm faster than low latitudes largely due to albedo changes as snow cover melts (Holland and Bitz, 2003), and mountains warm more than low area (Liu and Chen, 2000). There are only a few regions on Earth that deviate from these patterns: the southeast United States and the north Atlantic. We see this illustrated in the data shown above.

While the vast majority of the globe has experienced a substantial warming of about .85°C (Hartmann et al., 2013), studies have shown that southeastern U.S. has actually experienced cooling in the twentieth century, most noticeably a .5°C cooling since 1880. This climate anomaly can be seen in Figure 3 (IPCC, 2013), which shows the observed change in surface temperatures between 1901 and 2012. These regions have recently been termed "warming holes", since they represent a cooler hole (or lack of warming) in what is otherwise a warming planet. This U.S. "warming hole" (Figures 4 and 5) has been recognized for over a decade (Robinson et al., 2002; Pan et al., 2004; Kunkel et al., 2006).

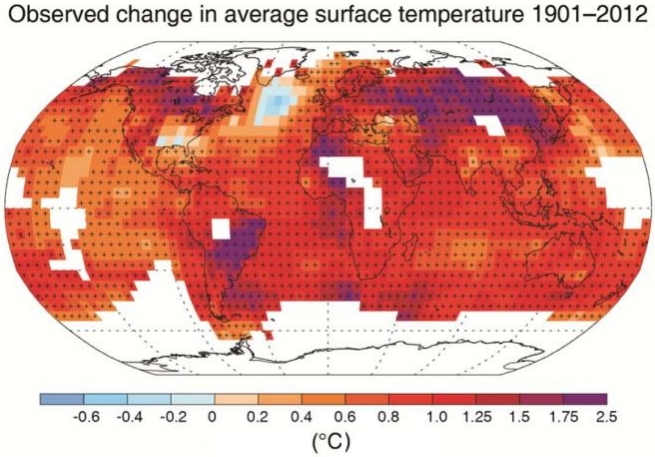

Figure 3. Observed change in global surface temperature between 1901 and 2012, showing overall cooling (i.e., "warming holes") in the northern Atlantic and southeastern United States. Figure from IPCC (2013).

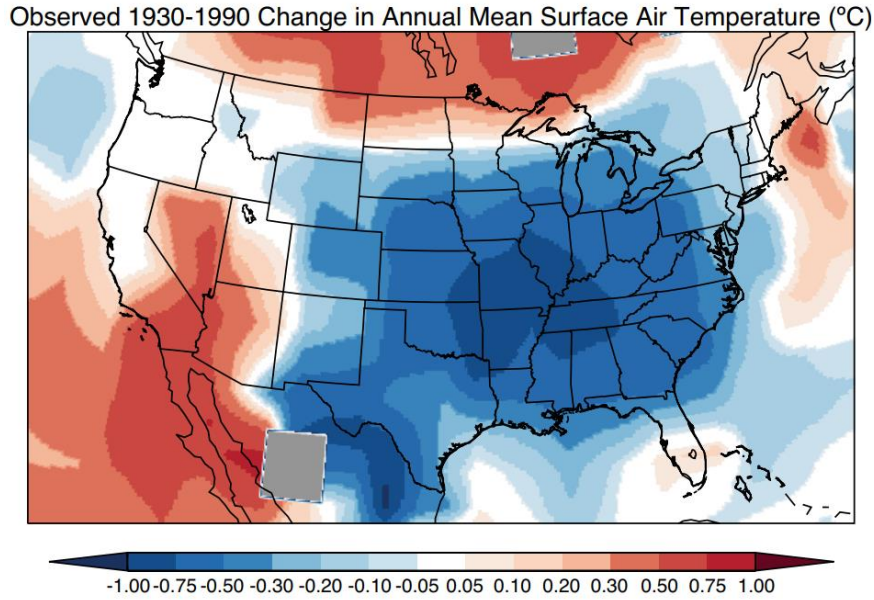

Figure 4. Temperature anomalies between 1930-1990, showing overall cooling in the central and southeastern United States. Figure from Leibensperger et al., 2012.

Figure 5. The location of the winter warming hole in the southeastern U.S. due to the northern polar jet stream. Figure from Dartmouth College, 2018.

2. Explanations for the "warming hole" connect the local absence of warming to global climate change.

The cause of this anomalous, region-specific cooling has been attributed to increased aerosol pollution (Leibensperger et. al, 2012), cloud cover (Rogers, 2013; Yu et al., 2014), and changes in land usage (Misra et al., 2012; Ellenburg et al., 2016). While these may be contributing factors, a number of modeling studies suggest large-scale decadal atmospheric and oceanic patterns that drive the weather and climate in the southeastern U.S., including the North Atlantic Oscillation and the Pacific Decadal Oscillation, are the most significant forcing mechanisms of the warming hole (Meehl et al., 2012). These systems are complex and consist of various components. Partridge et al. (2018) identified a change in the pattern of the polar jet stream during the 1950's as the primary cause for the southeastern U.S. warming hole, bringing colder air from the Arctic southward into the region. They noted that the southeast United States still falls below average global temperature anomalies, suggesting that the warming hole still exists. Models suggest, however, that the anomaly may disappear as early as 2020, followed by a temperature increase of nearly 1°C over the ensuing 5 years (Meehl et al., 2012).

Progressive warming of the Arctic has resulted in greater instability of the northern polar jet stream, which can bring frigidly cold winter weather to the southeastern United States. A strong polar vortex stabilizes the jet stream, keeping colder air to the north. However, warming of the Arctic has a destabilizing effect on the polar vortex, resulting in a wavier jet stream and increased likelihood of expansive extreme cold in its path (Kim et al., 2014; Zhang et al., 2016; Kretschmer et al., 2018; Dartmouth College, 2018). These single weather events coupled with average seasonal temperatures that have varied only slightly and even cooled over the course of the last century, are often the basis for skepticism directed towards the very notion of anthropogenic climate change.

CONCLUSION

Climate system drivers are complex. However, by addressing this complexity and encouraging exploration into the causation of anomalous evidence on a regional scale, it is easier to explain the broader patterns and implications of global climate change. Although Alabama and the southeast United States has seen little warming in the last 120 years, much of the rest of the globe has, particularly at high northern latitudes. This results from greater sensitivity to increases in CO_2 emissions in that region (Leduc et al., 2016; Figure 6).

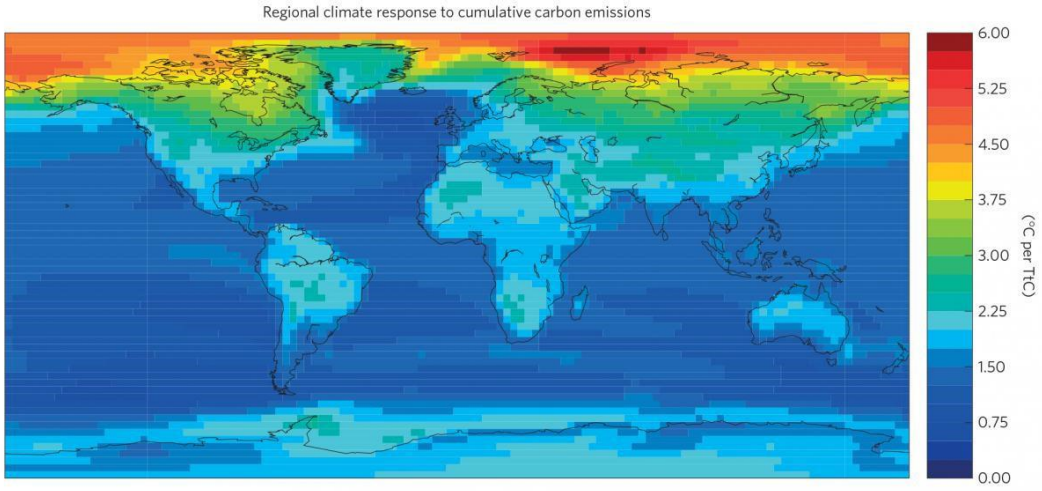

Figure 6. Regional temperature responses to increased CO_2 emissions, showing the elevated impact on high northern latitudes. Figure from Leduc et al., 2016.

Looking at the Earth as a whole, it is the increase in average global temperatures that will bring lasting changes to Earth's systems. Despite the current warming hole in Alabama, we will not be immune from the global impacts of climate change. The most immediate and significant impacts will include an increase in severe weather events (e.g., tropical storms and droughts) as well as the effects of sea level rise on our coastal communities. Recent studies suggest that melting of the Greenland and Antarctic ice sheets could produce an increase in sea level of nearly 2 meters by the end of the century (Bamber et al., 2019). While Alabama has not been greatly impacted by anthropogenic climate change thus far, all indications are that that will soon no longer be the case.

The warming hole that encompasses the southeast United States is just one of multiple factors that has led to a general complacency towards global climate change and increases the challenge of improving climate literacy in our classrooms and communities. Overcoming these challenges is crucial in order that we may build a consensus that leads towards societal action. These actions are vital in reducing the severity of the impacts of the changing climate (mitigation practices), such as energy conservation, increased transition from fossil fuels to renewable energy sources, and CO_2 capture. At this point, though, we must also prepare to deal with the changes that may already be inevitable, including changing land use, migration, and increases in health programs. Educators must be acutely aware and knowledgeable of the existing complexities of Earth's climate system, and not hesitate to incorporate these in their pedagogy.

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