PUBLIC PERCEPTION OF WEATHER EVENTS VERSUS ACTUAL CLIMATE DATA

An Interactive Qualifying Project

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Degree of Bachelor of Science

By

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Abstract

After some parts of the world experienced a particularly cold winter in 2009-2010 and climate scientists from the Hadley Center for Climate Prediction and Research were accused of manipulating data, a controversy over the veracity of global warming sparked. The purpose of this IQP is to understand how climate data is sampled and analyzed, and to reassert that despite recent weather events, a global analysis of temperature in space and time strongly indicates a warming trend. We will also point to weaknesses in the arguments offered by the so called global warming skeptics.

I: A Scientific Approach - Dr. James Hansen's 2010 Paper, "Global Surface Temperature Change"

1.1. Goddard Institute for Space Studies (GISS) Analysis

The Goddard Institute for Space Studies (GISS) is one of several groups which analyze global temperature data to compute average temperatures and identify trends in temperatures. GISS analyses were first published in 1981 and the intention of this ongoing analysis was to estimate global temperature change and compare the temperature data, therefore giving us a window into the pace and progress of climate change. Dr. James Hansen is the head of the NASA Goddard Institute for Space Studies in New York, NY, and has a Ph.D. in atmospheric physics. One of the goals of Dr. Hansen and his team was to use this data to compare climate models to real world data, identifying anomalies in temperature. Similar experiments are frequently conducted in order to calibrate constants. The data analysis uses the time period between 1951 and 1980 as the reference period, for several reasons. The US National Weather Service (USNWS) defines a three-decade period as average, or "normal", temperature. When GISS analysis began, that thirty year period used by USNWS happened to be 1951-1980. In order to have consistent data analysis there has to be a fixed time period in which to compare current data with, because as with every experiment there needs to be a set of "control" data. This is because without a fixed set of data, it is more likely that errors in trend computation will arise. These 30 years also have a larger amount of temperature data than years prior to it, making it a good reference period due to the volume and consistency of data. Dr. Hansen and his team also use a relatively large time period to include several El Nino/La Nina cycles. During an El Nino year, temperatures are generally warmer. If the time period included only one El Nino/La Nina cycle it may have appeared to be warmer than normal, skewing the data. By including several cycles and averaging them, the departure from normal is not unintentionally affected.

GISS analysis of global temperature relies on sufficient weather stations for the data provided to be spatially correlated. Temperature data from these stations is used to estimate global climate by a function of station separation to describe this correlation. The relationship between temperature data from weather station to weather station is continuous, meaning that we should be able to predict with some degree of accuracy the data readings from one station based upon the data collected from other nearby stations in the region. The correlation between this data can then be used to track climate anomalies. This correlation of data is strong for temperature anomalies, but the correlation is much weaker for average temperature. In the next section we will demonstrate this correlation in temperature anomalies. Data becomes more accurate when there are more weather stations closer together and therefore temperature differences can be tracked with much greater accuracy. Adding more sources of temperature data therefore allows us to more precisely determine climate trends, much like a curve on a plot becoming more accurate as more points are defined. GISS does not, in fact, estimate temperature anomalies prior to 1880 because the lack of sufficient data and the scarcity of climate recording centers produce a large error, rendering any estimate unusable. GISS analyses also include a homogeneity adjustment to minimize bias due to human activity. Anthropogenic warming and cooling bias can occur due to buildings and energy use (warming bias) or activities such as irrigation and farming of vegetation (cooling bias). Because of this, Dr. Hansen includes the nighttime radiance imagery in Figure 1of his article (1) to establish which weather stations are in urban centers as the effects of urban warming usually outweigh those of cooling. Warming and cooling bias affects the average temperature, but this project report analyzes and investigates the departure from the normal. The departure from normal in temperature data is more indicative of a change in climate trends than the absolute temperature, as we will explain.

1.2. Departure from Normal versus Actual Temperature

The departure from normal for the average temperature for an area is examined specifically to identify a change in climate. We will examine where, when, and how the temperature differed from normal, and therefore we're not necessarily concerned with the actual temperature. Although warming bias does have a drastic effect on regional temperature, it does not have an effect on temperature anomaly. Dr. Hansen addresses this in his report, and proves through statistical analysis that the warming bias has no statistically relevant effect on climate anomaly data. This is made clear in the report because it has been theorized that weather stations placed in urban settings, and therefore subject to the urban warming effect, may skew data used to prove the existence of global warming. Dr. Hansen proves in his report that the warming effect does not influence climate change data. For this project we examine data gathered from multiple weather stations across a specific region in order to replicate Dr. Hansen's analysis, on a much smaller scale, to illustrate his point.

Dr. Hansen and his team include a rigorous analysis of the data in their report and found that the urban warming bias has little to no effect on long term temperature anomalies. In their report, they address how the public's perception of the progress and existence of global climate change can be falsely influenced by the current temperature and weather. For example, the report discusses how the winter of 2009-2010 was colder than normal in some specific regions of the world, leading to public opinion of global warming towards skepticism. However, they state that drastic monthly weather fluctuation is more common than the general public may realize, and tracking trends on climate data is the only way to truly understand and track climate change. To emphasize this conclusion, Dr. Hansen's article outlines how anomalies found in the data correlate to meteorological events which are result of global warming. For example, he points out that extreme negative Arctic Oscillation was a major cause of the colder than normal temperature readings in some parts of the Eastern United States during the winter of 2010 (December 2009 through February 2010). For future reference: climatologists define "winter" for the northern hemisphere as the three month period between December and February.

1.3. Global Climate Systems

1.3.1. Arctic Oscillation

The Arctic Oscillation(AO) is a system of opposing pressure patterns north of 20N. The “negative” and “positive” phases refers to whether the oscillation exhibits a high atmospheric pressure over higer lattitudes or midlattitudes, respectively. When the AO is positive, high pressure at midlattitudes pushes ocean storms and swells north to the Arctic Circle, while if the AO is negative lower pressures at midlattitudes and high pressures up north push them south. The AO cycles between positive and negative and is correlated to average temperature in the United States. For example, when the AO is positive as a result the eastern half of the United States is warmer than normal, while if it is negative, as in the report, cold air extends south into the continental U.S. A positive AO results in colder temperatures in northern Canada and Greenland, while a negative AO results in the opposite.

1.3.2. North Atlantic Oscillation

The North Atlantic Oscillation (NAO) has a major role in the temperature patterns of the northern hemisphere. The NAO is a system of fluctuations in atmospheric pressure between the Icelandic Lows and Bermuda-Azores High leading to a variability in the strength of westerlies across the Atlantic ocean. (8,9,10) Much like the Atlantic Oscillation, the NAO has both positive and negative phases. The primary difference between these two phases is the pressure gradient across the north Atlantic, and as we can see below in Figure 1 this pressure gradient determines the strength of the Jet Stream and westerlies moving into Europe (12). During its positive phase, the pressure tends to be higher in the Bermuda-Azores and lower in the Icelandic Lows. During this phase, westerlies are stronger, leading to mild and wet winters over northern Europe and the eastern United States, but cold, dry winters in Canada and Greenland. In the negative phase, the opposite pressure pattern exists, with higher pressure in the Icelandic Lows and lower pressures in the Bermuda-Azores. This causes weaker westerlies, leading to cold, dry winters in northern Europe and cold snowy winters across the eastern United States.

Winters during this period are normally worse overall, potentially portraying a colder than average weather trend to the average observer. The NAO index for the winter of 2009-2010 was abnormally low at a -4.1, leading to the abnormally cold winter for the United States during this period. (11) This was, however, true specifically for the United States and Europe, not for the entire globe. Given the impact of the Atlantic Oscillation system and the North Atlantic Oscillation system we can see that the climate patterns of the northern hemisphere, especially across the Atlantic Ocean. To determine the state of the North Atlantic Oscillation trend all temperature and climate data from across both the eastern United States and Europe has to be examined. Therefore, in order to make informed assumptions concerning patterns of climate change, one must examine global weather systems over a long enough period of time to understand trends in climate. Due to this oscillation cycle it is common for trends in winter weather related to NAO to vary frequently. According to Ottersen, et al, 75% of deviation in NAO activity occurs within a ten year time period. (12) One isolated year cannot account for a whole climate trend.

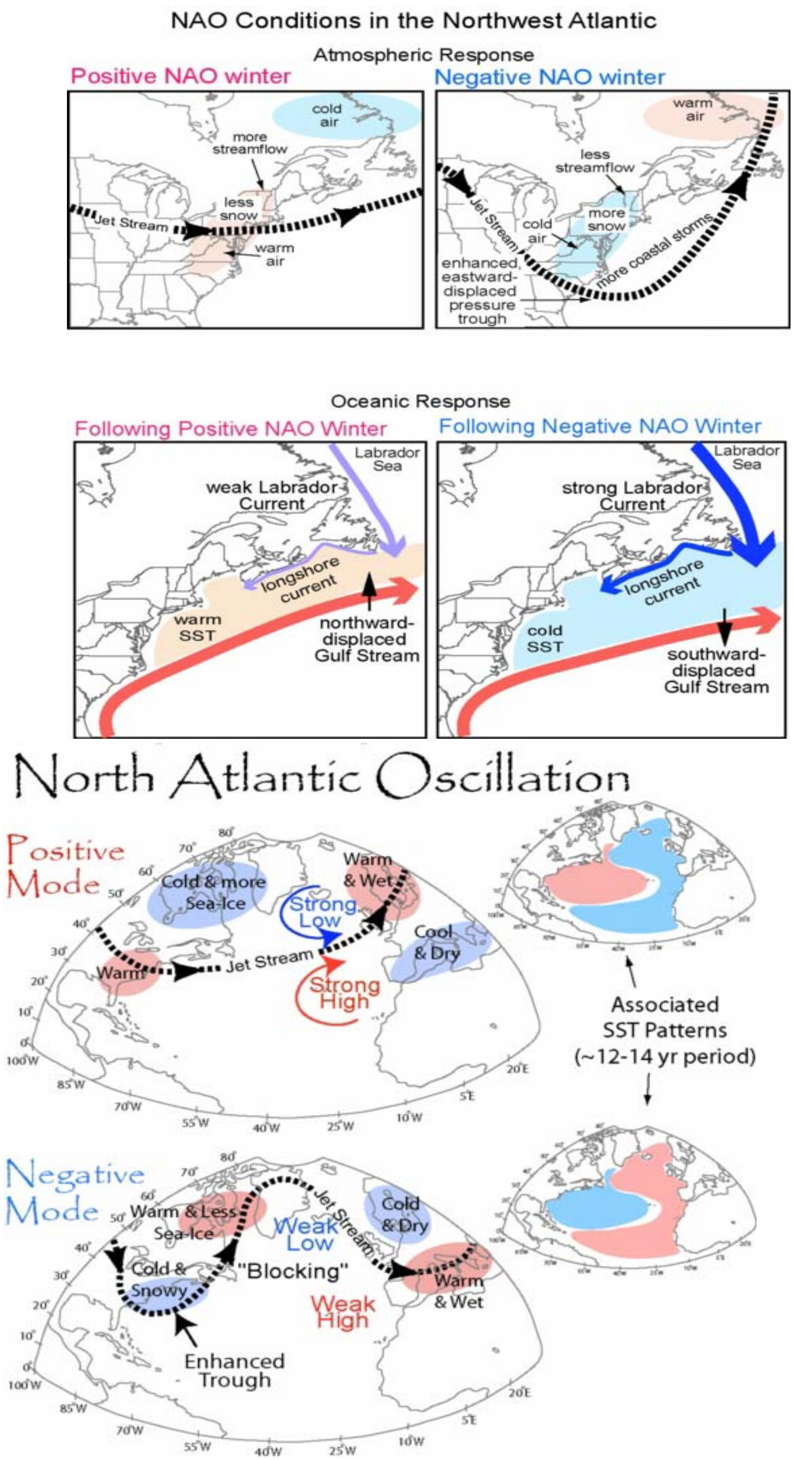


Figure 1: effects of the positive and negative phase of the North Atlantic Oscillation on Atlantic currents and wind patterns, specifically the Jet Stream and the Gulf Stream.

http://www.newx-forecasts.com/nao.html

II. Perceived Recent Weather Patterns as Reported in the Media

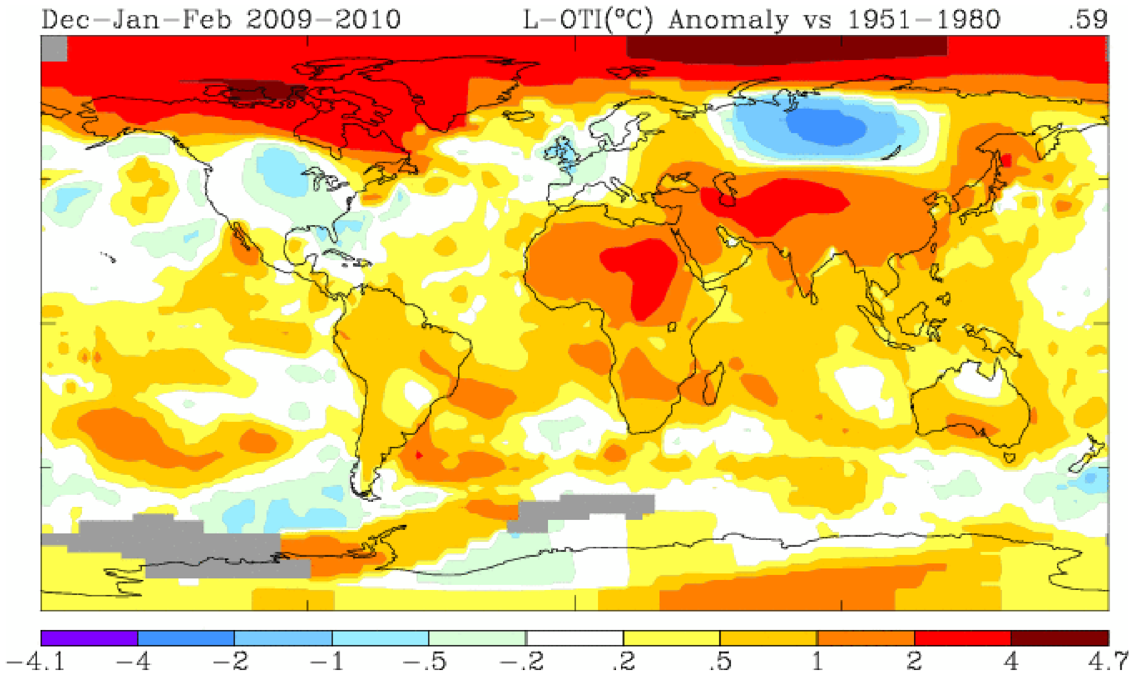
2.1. Misunderstanding of Climate Trends

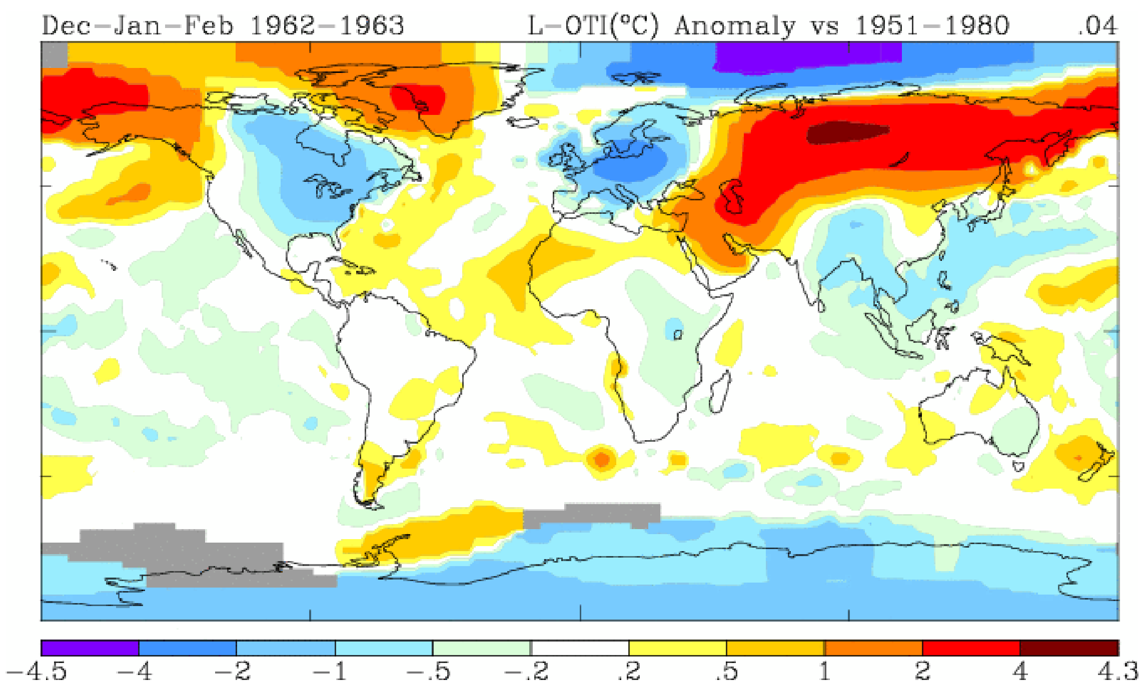
Temperatures, as we have seen, are mostly reliant upon weather systems such as the NAO, and by themselves don't provide enough information regarding the state of climate change. This is where many opponents of global warming are flawed in reasoning. Since the concept of man-made global warming was initially presented, there have been critics questioning its existence. However, many of the arguments are based upon limited data, ignoring global trends in scientific data. An example of this can be seen surrounding the winter of 2009, which was the coldest recorded winter for the eastern and mid-western United States in roughly a decade. During this winter, Chris Field, a member of the Intergovernmental Panel on Climate Change, or IPCC, spoke out about the rise of greenhouse gases and the potential for unprecedented warming trends, worse than previously predicted. Skeptic website GlobalClimateScam.com columnist Dan McGrath comments in his article (3) that Fields' statement is contradicted by the record low temperatures occurring during that winter. What McGrath ignores is the fact that these cold temperatures represent only one part of a much larger climate system, and therefore on their own are not a reliable indicator of climate trends. As we established previously, when examining climate for the United States, one must examine temperature data over a long enough period of time to determine whether or not the data indicates an anomaly or is part of a predictable trend.

2.2. Lack of Peer Review, Anecdotal Evidence Provided

When researching opposition to climate change, we often find little which is based on hard scientific evidence. In her article (6) author Kristen Byrnes proposes that Dr. Hansen consistently exaggerates the severity of the evidence pertaining to global warming actually is. Byrnes' argument states that patterns of ice cap recession and rising temperatures have been occurring consistently since the "little ice age". What Byrnes does not examine is the departure from normal of these patterns which have been occurring. Byrnes simply acknowledges that the patterns explored by Dr. Hansen have been occurring for a while. This is another example of the opposition to global warming examining an isolated aspect or set of data to make an assumption on the veracity of global climate change. In his article (7) author Julio Godoy claims the winter of 2010 being the coldest in 50 years in central and northern Europe. Godoy, referencing meteorologists and climatologists, states that such a cold winter contradicts global warming rather than proving an exception. In the article, Godoy includes that temperatures in Greenland are 15˚C above average, showing the reader that such a cold winter is only an indication of climate in one region, not on a global scale. This is an example of how global climate trends must be examined to determine whether or not there is a trend in climate change rather than an isolated anomaly. Godoy is, in fact, incorrect in his claim, as we can see in Figure 2 that GISS temperature readings show that during the winters of 1962-1963 and 1975-1976, the average global anomaly is much more negative than that of 2009-2010, proving Godoy false in his statement.

To further his position that average temperature is not a reliable indicator of climate trends, Dr. Hansen visually portrays the effects and the impact of the urban warming bias in his report. Figure 1 in Dr. Hansen's article (1) is added to display where urban centers are located in relation to the location of weather stations. In this case, the "darkness" of an area at night is used as a measure of a) energy use and b) locations of man-made structures. Both of these result in a warming bias. Therefore, the author adds the diagrams of which weather stations are in "pitch dark" regions to show the opposite side of the coin: while the first image indicates the location of urban centers, the second shows where there are rural centers. The report states that energy consumption, which is related to nightlight radiance, is not a valid judge of population density outside of the United States since per capita energy consumption in the U.S. greatly exceeds the rest of the world. In his 2010 article Dr. Hansen states that the warming bias does not have an effect on temperature anomaly, whereas it does have an effect of average temperature. Because they are not affected by the warming bias, the calculations in Dr. Hansen's report use temperature anomaly. Therefore it does not have any significant effect on any climate calculations. The urban warming effect which the report talks about has a significant effect on the temperature of urban areas. Figure 1 (1) defines this clearly, which is why the temperature data is adjusted for use. This figure is also used to outline where stations that are "urban" or "rural" stations are. The report establishes that the adjustment of urban station records uses the rural station data to define long term trends, yet uses the urban station data to define high frequency variations. Data from rural stations is less affected by the urban warming bias which may increase or decrease as time progresses. Urban centers usually have a higher density of weather stations making them ideal for defining high frequency variations. Figure 2 in reference (1) is added to the report to show the temperature change from 1900-2009 with urban adjustments and without urban adjustment. From this Dr. Hansen and his team show that the effect of urban warming is small.


Dec−Jan−Feb 2009−2010
L−OTI(°C) Anomaly vs 1951−1980
.59
−4.1 −4 −2 −1 −.5 −.2 .2 .5 1 2 4 4.7


Dec−Jan−Feb 1962−1963
L−OTI(°C) Anomaly vs 1951−1980
.04
−4.5 −4 −2 −1 −.5 −.2 .2 .5 1 2 4 4.3

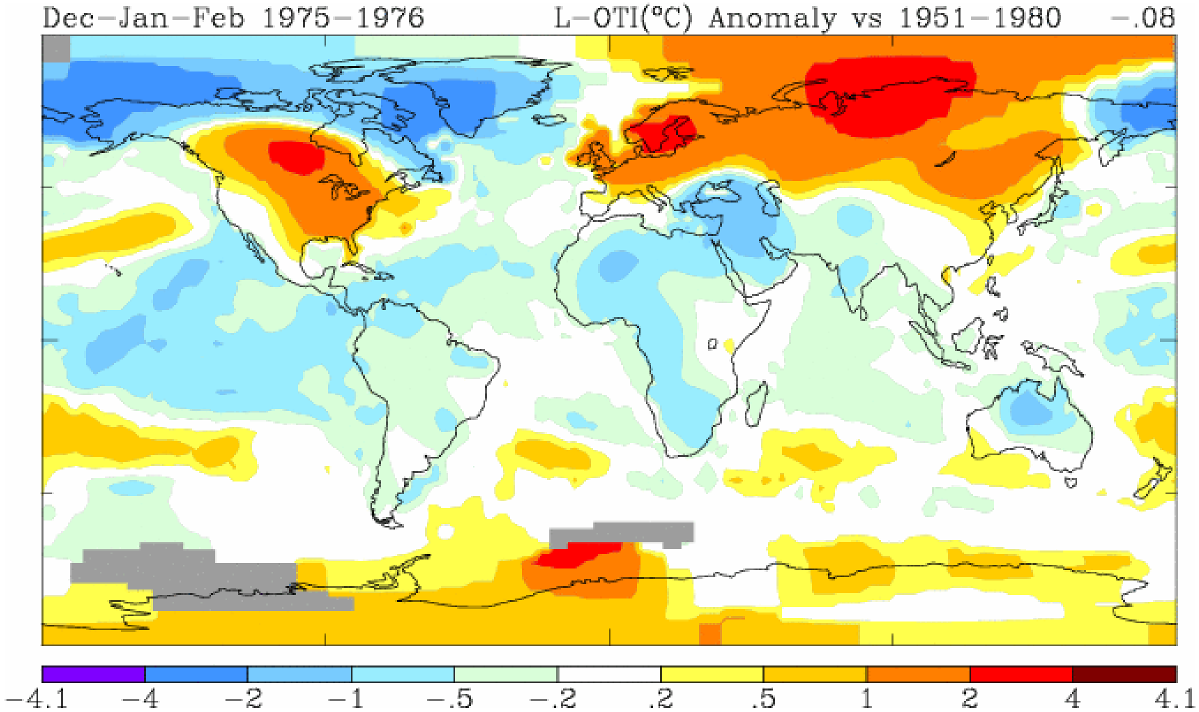


Figure 2: Temperature anomaly maps for December through February for the winters of 2009-2010, 1962-1963, and 1975-1976. The winter of 2009-2010 was stated in the media as the coldest winter in fifty years. The above maps discount this claim illustrating how that particular winter was warmer than normal. The base period used was 1951-1980 using GISS analysis for land data and Hadl/Reyn_v2 as a source for ocean data. Smoothing radius was set to 1200 km.

http://data.giss.nasa.gov/gistemp/maps/

III: Verification of the Method – Example of Interpolation of Climate Data between Weather Stations

3.1. Purpose of Experiment

In order to validate Dr. Hansen's claim, we repeated the same experiment and analysis, only this time on a smaller scale across a single region. In this experiment, we examined both the temperature and the departure from normal, or the anomaly, to verify that measuring the anomaly in temperature rather than the absolute temperature gives us a better understanding of climate change and global warming. This is in opposition to the voices in the media proposing that the recent cold winters are an indication that the global warming theory is false. Through this analysis we attempt to prove that the error in data for the anomaly is less than that of the absolute temperature. We first demonstrate this for the region surrounding Manhattan Island, and then for the region surrounding Worcester, Massachusetts.

Weather Station	*Average Monthly Temp. for July 2010*	*Departure from Normal*
NYC Cent. Pk	81.3	4.8
Islip, NY	78.0	3.4
Albany, NY	74.9	3.8
Allentown, PA	76.5	3.2
Range of Data (Min-Max)	74.9 – 81.3	3.2 – 5.9
Δ (Min-Max)	6.4	2.7

Table 1: Average temperature for the month of July 2010. (Source: National Weather Service Forecast Office (http://www.erh.noaa.gov))

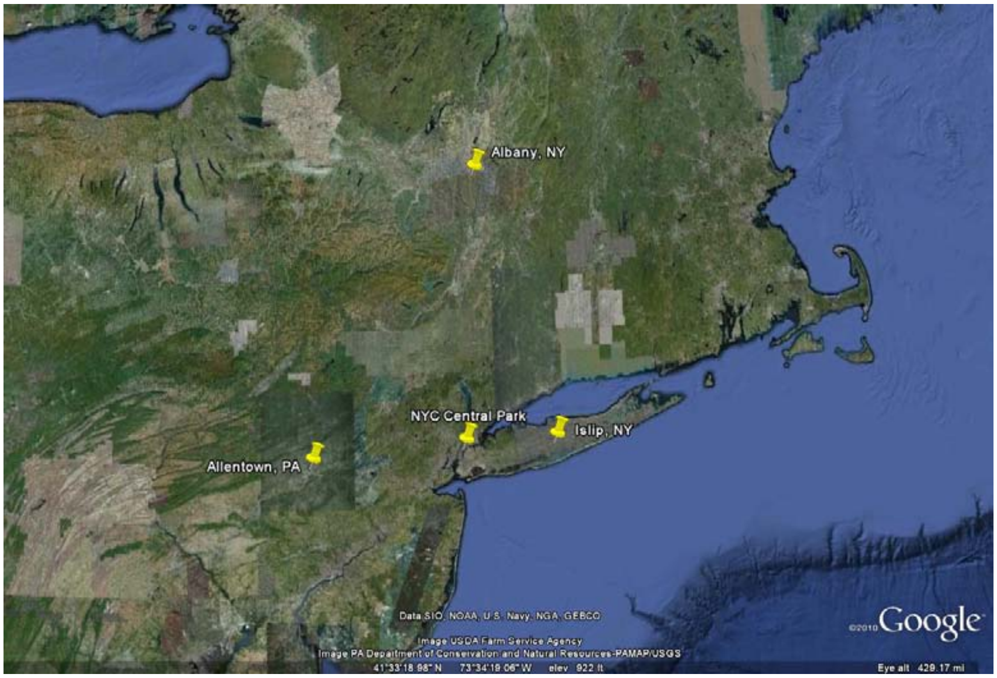


Figure 2: locations of the five weather stations.

Latitude and Longitude of weather stations in Table 1:

NYC Central Park - 40˚46’N, 73˚58’W; Islip, NY - 40˚39’N,73˚47’W; Albany, NY - 42˚45’N, 73˚48’W; Allentown, PA - 40˚39’N, 75˚26’W

We use the departure from normal to quantify how much of an anomaly the average temperature for the month the climate in that particular area is. With this data we attempt to illustrate Dr. Hansen’s analysis of climate on a much smaller scale. Dr. Hansen’s analysis encompasses temperature data from across the globe to track temperature anomalies, however ours encompasses a comparatively small region. We assume at the outset of our experiment, however, that this does not change the continuous relation between data sets. With this, we emphasize Dr. Hansen’s claim that climate change data has been misinterpreted by the media and therefore also by the public.

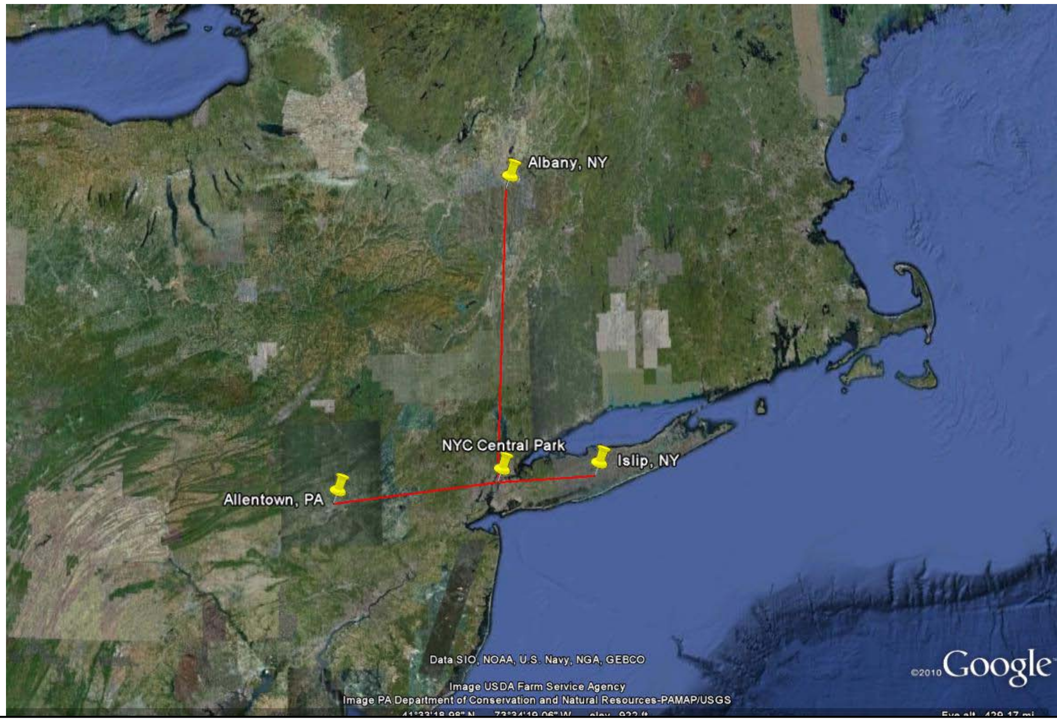


Figure 3: lines drawn between the weather stations analyzed in Table 1. Data found from calculating distance was used to calculate Cartesian coordinates of weather stations. Note that NYC Central Park is used as the origin. Source: Google Earth©

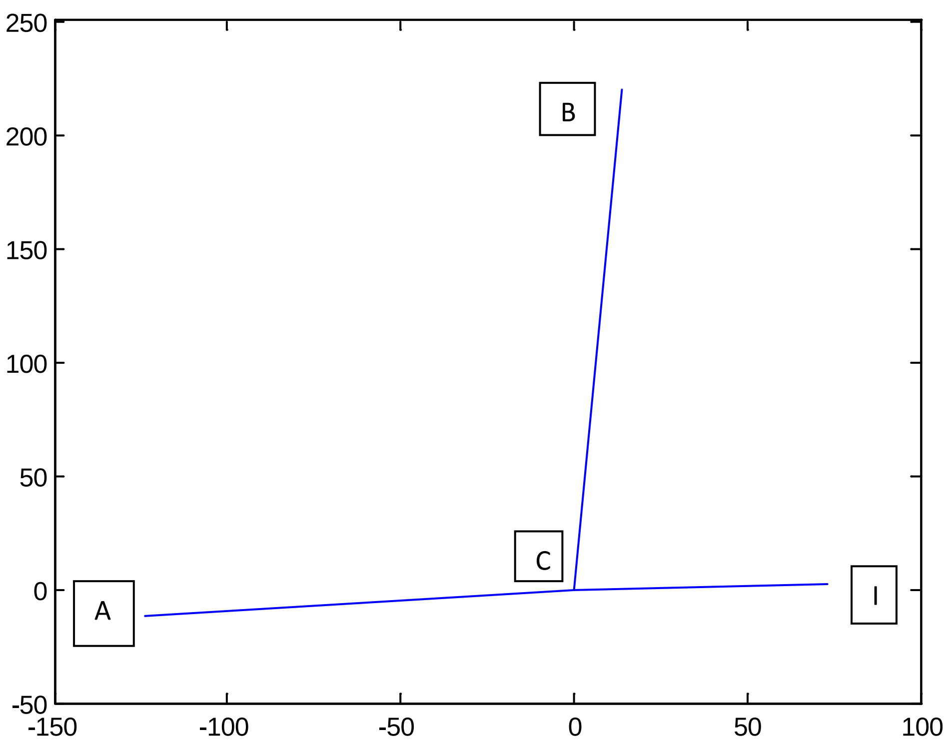


Figure 4: Graph of the four weather stations. The Central Park station is at the origin, the only unlabeled point. *XY*- coordinates of weather stations

C (Central Park) – (0,0), used as origin

I (Islip, NY) – (73.1,2.22)

B (Albany, NY) – (13.6,220.0)

A (Allentown, PA) – (-124,-11.9)

Scale: 1 kilometer

3.2. Method for Determining Coefficients

When calculating the Cartesian coordinate of the four weather stations, we make several assumptions. First, we assume that the Earth is locally flat to remove confusion concerning the natural curvature of the Earth. Second, we assume that the x-axis is given by points of the same latitude of Central Park (point C). Third, we assume that the y-axis is given by points of the same longitude of Central Park (point C). To calculate the coordinate, the bearing of each weather station in relation to Central Park was used in concert with the distance between the two stations to find the longitudal (x-axis) distance and latitudal (y-axis) distance. This information allowed us to triangulate the coordinates. The coordinate data was found using the following trigonometric functions.

$\sin\theta = y/d$ $\cos\theta = x/d$

$y = d\sin\theta$ $x = d\cos\theta$

In the equations, the variable d represents the distance between point C (Central Park) and each respective point on the coordinate plane. This is considered the hypotenuse of the triangle when calculating. The variables x and y represent the length along the x and y axis respectively. The distance d between points are as follows.

Point C – Point B: 137 miles Point C – Point A: 77.4 miles

Point C – Point I: 45.4 miles

The variable θ represents the angle of the hypotenuse of the length d with respect to the nearest axis.

θ_B: 3.53˚ θ_A: 5.50˚

θ_I: 1.74˚

Error in given geographic locations for the weather stations had to be accounted for. Therefore, distance data is presented in three significant figures. This means that distance data is therefore not exact, however the purpose of the data was to demonstrate the correlation between temperature data relative to the distance between recording. This correlation which we are trying to illustrate naturally comes with some error which cannot be avoided. Therefore, concerning ourselves with exact data serves little to further our purpose.

In order to replicate and analyze Dr. Hansen's thesis, we must investigate the correlation between temperature data and distance between weather stations where the data is collected. For this we had to solve the following system of equations:

$$\alpha_A x_A+\alpha_B x_B+\alpha_I x_I=0$$

$$\alpha_A y_A+\alpha_B y_B+\alpha_I y_I=0$$

$$\alpha_A+\alpha_B+\alpha_I=1$$

The coefficients which are found by solving the system of equations in MATLAB are as follows.

α_A= 0.3668

α_B= 0.0136

α_I= 0.6196

3.3. Application of Coefficients to Examine Relations Between Weather Stations

With these coefficients, and given the continuous nature which we would expect temperature data to follow, we expect to use these coefficients and a given temperature data for the three outlying weather stations to predict the temperature and anomaly for Central Park, using the equation:

$$\alpha_A T_A+\alpha_B T_B+\alpha_I T_I\approx T_C$$

We used this equation to analyze the average temperature for July 2010 and July 2009, and to analyze the average temperature anomaly for July 2010 and July 2009. The results read as follows:

<u>Avg. Monthly Temp. July 2010</u>

$\alpha_A(76.5)+\alpha_B(74.9)+\alpha_I(78.0)=77.4$ (actual=81.3; error=3.9°)

<u>Avg. Anomaly July 2010</u>

$\alpha_A(3.2)+\alpha_B(3.8)+\alpha_I(3.4)=3.3$ (actual=4.8; error=1.5)

Avg. Monthly Temp. July 2009

$\alpha_A(70.1)+\alpha_B(68.3)+\alpha_I(70.8)=70.5$ (actual=72.7; error=2.2°)

Avg. Anomaly July 2009

$\alpha_A(-3.2)+\alpha_B(-2.8)+\alpha_I(-3.8)= -3.6$ (actual=-3.8; error= 0.2)

Avg. Year-long Temp. 2009

$\alpha_A(50.9025)+\alpha_B(47.9247)+\alpha_I(51.9096)\approx 51.5$ (actual=54.1; error=2.6˚)

Avg. Year-long Anomaly 2009

$\alpha_A(0.2225)+\alpha_B(0.4888)+\alpha_I(-0.5951)\approx -0.3$ (actual= -0.6; error= 0.3)

Avg. Year-long Temp. 2010

$\alpha_A(52.87189)+\alpha_B(50.2942)+\alpha_I(54.1137)\approx 53.6$ (actual=56.8; error= 3.2˚)

Avg. Year-long Anomaly 2010

$\alpha_A(2.1918)+\alpha_B(2.6375)+\alpha_I(1.6430)\approx 1.9$ (actual=2.1; error= 0.2)

This information shows us that Dr. Hansen's model of tracking temperature data along a continuous curve is possible. With this illustration we verify Dr. Hansen's point on a regional scale, thereby giving veracity to his claim that temperature data is not as necessarily flawed as public opinion can often portray it as. Overall the equation we establish proves sufficient. To validate our claim, we replicated this model again using five weather stations surrounding Worcester, Massachusetts. The same calculations for determining coordinates are used and the process is exactly the same, except in this case we find four coefficients instead of three. The points are labeled point W for Worcester, point B for Boston, MA, point R for Providence, RI, point C for Concord, NH, and point A for Albany, NY. To avoid confusion with the previous coefficients, the coefficients found in MATLAB are labeled β.

Point W – (0,0), used as origin of system

Point B – (43.4,7.2)

Point R – (22.4,-37.4)

Point C – (18.2,64.5)

Point A – (-72.6,11.5)

These coordinate values are used in the following system of equations.

$\beta_B x_B+\beta_R x_R+\beta_C x_C+\beta_A x_A=0$

$\beta_B y_B+\beta_R y_R+\beta_C y_C+\beta_P y_P=0$

$\beta_B+\beta_R+\beta_C+\beta_P=1$

The coefficients found using MATLAB are as follows. MATLAB functions entered can be found in the appendix.

$\beta_B= 0$

$\beta_R= 0.5163$

$\beta_C= 0.2594$

$\beta_A= 0.2243$

Avg. Monthly Temp. July 2010

$\beta_B(77.2)+\beta_R(77.5)+\beta_C(73.8)+\beta_A(74.9)=75.0$ (actual=74.0˚, error=1.0˚)

Avg. Anomaly July 2010

$\beta_B(3.3)+\beta_R(4.2)+\beta_C(3.8)+\beta_A(3.8)=4.0$ (actual=3.9, error=0.1)

Avg. Year-long Temp. 2009

$\beta_B(50.8937)+\beta_R(50.8162)+\beta_C(45.3351)+\beta_A(47.9247)\approx 48.7°$ (actual=47.3˚, error=-1.4˚)

Avg. Year-long Anomaly 2009

$\beta_B(-0.8181)+\beta_R(-0.3877)+\beta_C(-0.7134)+\beta_A(0.2679)\approx -0.3251$ (actual=-0.01, error=0.32)

Avg. Year-long Temp. 2010

$\beta_B(53.8762)+\beta_R(53.8510)+\beta_C(48.8304)+\beta_A(50.2942)\approx 51.8°$ (actual=49.9˚, error=2.1˚)

Avg. Year-long Anomaly 2010

$\beta_B(2.1644)+\beta_R(2.6471)+\beta_C(2.7819)+\beta_A(2.6375)\approx 2.8$ (actual=2.5 ;error= 0.3)

When analyzing the coefficients for the region in MATLAB, the program set one of the coefficients, in this case Boston, to zero because there are three equations describing four unknowns. We reconstructed the MATLAB analysis using the least-squares solution for the Worcester region data, giving us four distinct coefficients for β. This second method of calculating coefficients utilizes all available data. By including all this data we obtain a better view of the relation between data collected from the included weather stations. The coefficients found are as follows.

β_B= 0.2413

β_R= 0.3498

β_C= 0.1253

β_A= 0.2836

Avg. Monthly Temp. July 2010

$\beta_B(77.2)+\beta_R(77.5)+\beta_C(73.8)+\beta_A(74.9)=76.2$ (actual=74.0˚, error=2.2°)

Avg. Anomaly July 2010

$\beta_B(3.3)+\beta_R(4.2)+\beta_C(3.8)+\beta_A(3.8)=3.8$ (actual=3.9, error=0.1)

Avg. Year-long Temp. 2009

$\beta_B(50.8937)+\beta_R(50.8162)+\beta_C(45.3351)+\beta_A(47.9247)\approx 49.3$ (actual=47.3°, error=-2.0˚)

Avg. Year-long Anomaly 2009

$\beta_B(-0.8181)+\beta_R(-0.3877)+\beta_C(-0.7134)+\beta_A(0.2679)\approx -0.3$ (actual=-0.01, error=0.29)

Avg. Year-long Temp. 2010

$\beta_B(53.8762)+\beta_R(53.8510)+\beta_C(48.8304)+\beta_A(50.2942)\approx 52.2°$ (actual=49.9˚, error=2.3˚)

Avg. Year-long Anomaly 2010

$\beta_B(2.1644)+\beta_R(2.6471)+\beta_C(2.7819)+\beta_A(2.6375)\approx 2.5$ (actual=2.5 ;error≈0)

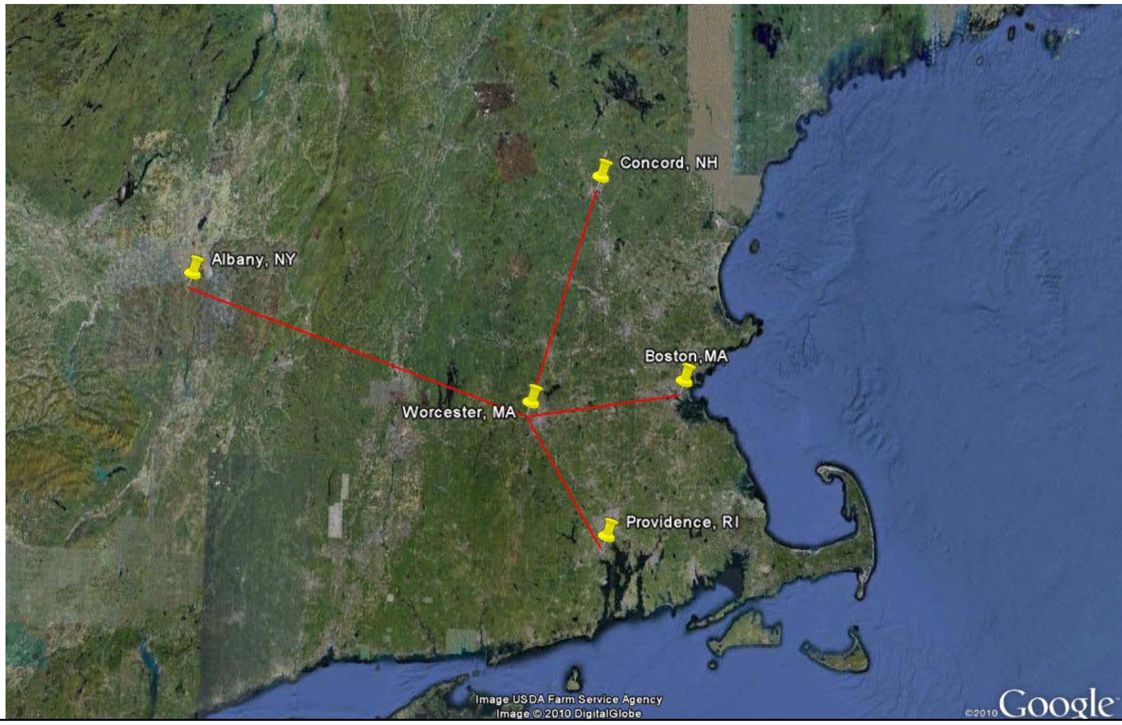


Figure 5: locations of the five weather stations in the Massachusetts area being analyzed.

Latitude and Longitude of weather stations:

Worcester: 42˚ 16’ N, 71˚52’ W; Boston: 42˚ 22’ N, 71˚ 2’ W; Providence: 41˚ 43’ N, 71˚ 26’ W; Concord: 43˚ 12’ N, 71˚ 30’ W; Albany: 42˚45’N, 73˚48’W

These calculations predicting temperature relations for the region validate the model of climate data established by our previous model. In this case the results show an even closer linear relation between data than our previous model.

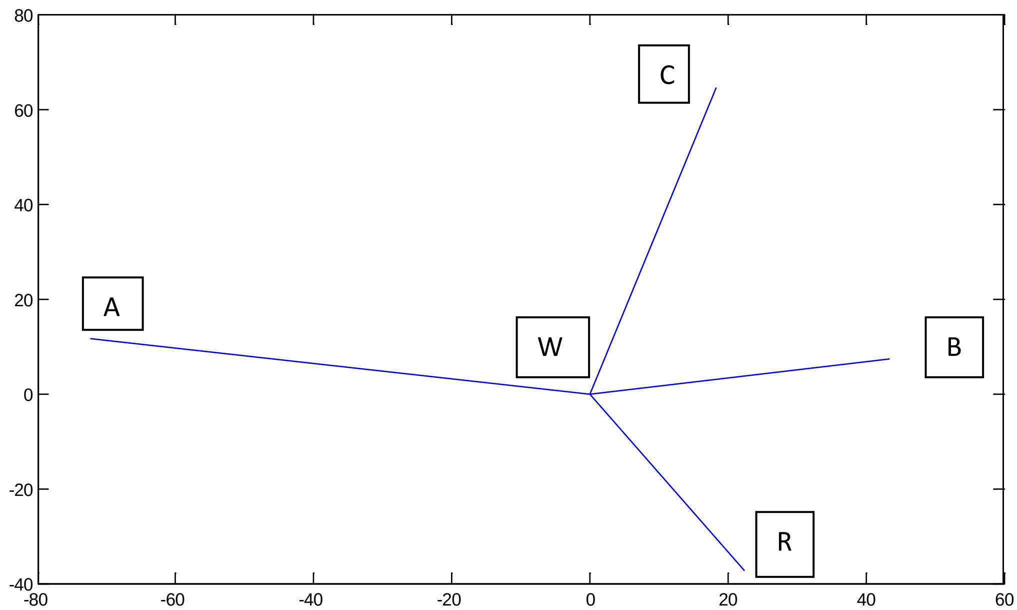


Figure 6: Graph of the four weather stations. The Worcester station is at the origin, the only unlabeled point. *XY*- coordinates of weather stations

W (Worcester, MA) - (0,0), used as origin

B (Boston, MA) – (43.4,7.2)

R (Providence, RI) – (22.4,-37.4)

C (Concord, NH) - (18.2,64.5)

A (Albany, NY) - (-72.6,11.5)

Scale: 1 kilometer

3.4. Conclusion of Findings

These calculations we conducted in this project were intended to replicate Dr. Hansen's calculations which he uses to compare anomaly data being questioned widely in the media. (1) We conducted these calculations on a smaller scale across a smaller region and found that we were able to replicate his experiment quite accurately and arrived at similar conclusions. From these conclusions we were able to illustrate Dr. Hansen's ideas and purpose in his article. To verify the findings from our research we sought to prove that the spatial correlation between data is strong. The regions we chose to examine the spatial correlation in climate data were chosen because they contain weather stations which are closer to one another, resulting in less chance for error and giving us better data. During the experiment, we were able to illustrate that the departure from normal is easier to reconstruct than the average temperature. For example, the average year-long temperature for 2010 for the Central Park region had an error of 3.2° whereas the average year-long temperature anomaly for the same year was significantly less at only 0.3°. When we examined the same time period, 2010, for the Worcester, MA region the error for the average year-long temperature was 2.3° while the average year-long temperature anomaly was miniscule, with almost zero error. In our calculation the Worcester, MA region contained one more set of weather station data, which may have increased the accuracy of the corresponding calculation. The calculations made from data collected shows that the predicted anomaly for each set of data is more accurate than the predicted average temperature of the set of data.

IV: Conclusion

In this project we examined the public perception as seen in the media concerning global climate change and compared it to scientific data. We examined the 2010 journal article written by Dr. James Hansen and his team from the GISS addressing the opposition to the theory of global warming based on the cold winter of 2009-2010. We also researched some opposing views of global warming found in the media to see how the opposing argument was portrayed, examined the evidence of the opposition, and addressed the arguments presented.

Part of this project was to scrutinize statements made by those negating the reality of global warming based upon anecdotal evidence of cold weather and accusations of alleged manipulation of data by the Hadley Institute. We explain how to examine climate trends over time: this has to be done by analyzing departure from normal given by a reference time period. We based our method off of Dr. Hansen's journal article. In it he states that average temperature is not reliable for use in determining climate trends for several reasons. First, average temperature data can be affected by warming or cooling biases stemming from energy use and population density. Second, temperature data can be influenced by regular climate cycles such as the North Atlantic Oscillation and the El Nino and La Nina cycles. Third, the correlation between data from weather stations is stronger for temperature anomaly and weaker for average temperature.

To illustrate his argument, Dr. Hansen uses climate data from weather stations across the globe to interpolate data between stations. He does this to illustrate the strong correlation between temperature anomaly data and the weak correlation between average temperature data. In this project we attempted to validate Dr. Hansen's claims by replicating his calculations on a small scale using data from isolated regions. In our calculations we found that we were able to interpolate data much more accurately for temperature anomaly than we were for average temperature. We performed the same calculations for two different regions, one surrounding the weather station at Central Park in New York City and the weather station in Worcester, MA, and obtained very similar results for both.

During the project, we performed two calculations on the region surrounding Worcester, MA. For the first calculation data from three weather stations was used in interpolating the data for the central station. For the second calculation, data from four stations was used to interpolate data. The second set of calculations was shown to have less error than those using one fewer weather station. During our work we found that stations that were more than 200 kilometers apart provided for inaccurate interpolation of data. For our calculations this was not an issue. However, for real world situations similar interpolation of data might be hampered by sparsely located weather stations. Our work suggests that more weather stations should be established in regions where they are sparse, such as in rural areas and in the Arctic and Antarctic.

References:

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Appendix:

MATLAB for finding coefficients α_A, α_B, and α_I.

```
% "A" is established as the x and y coordinates of the weather stations that are paired with the
%coefficients alpha for the first system of equations on page 13.
A=[-124 13.6 73.1;-11.9 220.0 2.22;1 1 1]
A =
 -124.0000   13.6000   73.1000
  -11.9000  220.0000    2.2200
    1.0000    1.0000    1.0000
% "b" is established as the right side of the system of equations on page 13.
 b=[0 0 1]'
b =
     0
     0
     1
% "C" is the solution for the coefficients found in MATLAB.

 C= A\b
C =
    0.3668
    0.0136
    0.6196
```

MATLAB for finding coefficients β_B, β_R, β_C, and β_A.

```
% "A" is established as the x and y coordinates of the weather stations that are paired with the
%coefficients beta for the first system of equations on page 15.
A=[43.4 22.4 18.2 -72.6;7.2 -37.4 64.5 11.5;1 1 1 1]

A =

   43.4000   22.4000   18.2000  -72.6000

    7.2000  -37.4000   64.5000   11.5000

    1.0000    1.0000    1.0000    1.0000

% "b" is established as the right side of the system of equations on page 15.

 b=[0 0 1]'

b =

     0
```

0

1

% "C" is the solution for the coefficients found in MATLAB.

```
C=A\b

C =

      0

   0.5163

   0.2594

   0.2243
```

*% to find the least-squares solution we repeat the process we used before for the system of %equations on page 15, except we find the coefficients using the code x=pinv(A)*b*

```
 A=[43.4   22.4   18.2   -72.6; ...

   7.2  -37.4   64.5    11.5; ...

   1     1       1      1    ];

b=[0 0 1]';

x=pinv(A)*b

x =

   0.2413

   0.3498

   0.1253

   0.2836
```