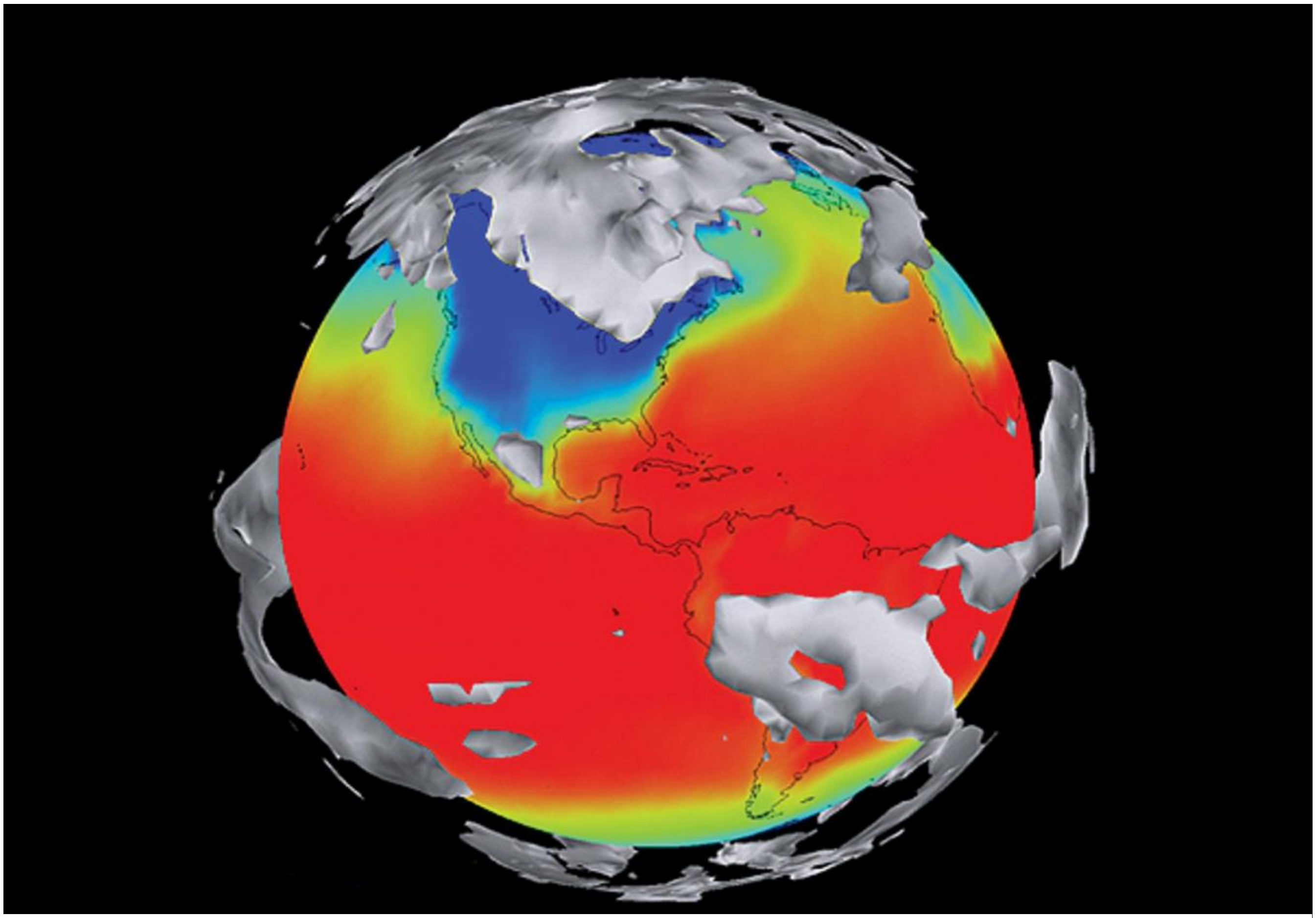
Global Warming: Temperatures rising faster in Boston than in San Francisco



Mena Ekelemu

April 2020

Summary

Global weather trends were analyzed with a special focus on five US cities: Boston, Chicago, Charlotte, San Francisco and Seattle. After extracting the data with SQL queries, the resulting csv files were exported to an excel file for further cleaning. Each excel table of average temperatures was then modified by creating a column of ten-year moving averages to help smooth out the plot lines for easier visualization of the weather trends.

The table of average temperatures for each of the five cities was combined into one excel sheet and temperatures were plotted alongside the global average temperatures on a chart to visualize how the city trends compared to the global trend. Some observations were made from the chart.

A temperature differential table was used to further analyze the global trend, and the trends of the five cities included in the study, followed by key observations on temperature differentials between average temperatures in 2013 and the lowest average temperatures ever recorded for each city, as well as a computation of the rate of annual increase over the periods between the highest and lowest temperatures.

This project was rounded up with a brief statistical regression analysis of the relationship between the year, global 10-yr-MA, and the 10-yr-MA of the city of San Francisco between the years 1858 and 2013. A regression table and correlation plot were used for more visualization purposes.

Data Extraction and Cleaning

The database contains three tables:

- city_list: A list of cities and countries in the database
- city_data: Contains the average temperatures (deg C) for each city by year
- global_data: Contains the average global temperatures (deg C) by year

SQL queries were executed to extract the data used for the analysis, then the results of the queries were exported to an excel worksheet for further analysis. Except for San Francisco and Seattle with no data till the 1800s, data for the other cities were filled with temperatures from prior cells to match the global years data; only one or two cells were missing data per city.

<u>SQL query to extract global_data information</u>

The temperature will be converted from degrees Celsius to Fahrenheit for familiarity purposes. The code below yields all the non-null rows of average yearly temperatures in Fahrenheit, and gives data from 1750 through 2015

- ```
  SELECT year, (avg_temp *(9/5) + 32) AS avg_temp_fahr

  FROM global_data

  WHERE avg_temp IS NOT NULL

  ORDER BY 2
  ```

SQL query to extract city_data information

The code below was used to extract the data table for each of the cities studied. The example code shown below was written to extract the annual average temperatures for the city of Chicago.

- ```
  SELECT year, city, (avg_temp *(9/5) + 32) AS avg_temp_fahr

  FROM city_data

  WHERE city = 'Chicago' AND avg_temp IS NOT NULL

  ORDER BY 1
  ```

SQL query to determine max and min average temperatures

By using the ORDER BY statement, we can determine the minimum and the maximum average temperatures and the accompanying years for each maximum and minimum. The code below provides the maximum average temperature recorded for the city of Charlotte. The ‘DESC’ was dropped from the code to obtain the minimum temperature. The LIMIT statement ensures that only the max or min temperatures are displayed in each case.

- ```
  SELECT year, city, (avg_temp *(9/5) + 32) AS avg_temp_fahr

  FROM city_data

  WHERE city = 'Charlotte' AND avg_temp IS NOT NULL

  ORDER BY avg_temp_fahr DESC

  LIMIT 1
  ```
  ```

```
SELECT year, city, (avg_temp *(9/5) + 32) AS avg_temp_fahr
FROM city_data
WHERE city = 'Charlotte' AND avg_temp IS NOT NULL
ORDER BY avg_temp_fahr
LIMIT 1
```

Data Visualization, Observations and other analysis

Chart comparing five US city temperatures to global average

The chart below shows plotted trend lines for the global 10-yr-MA temperatures and lines for the cities of Boston, Chicago, Charlotte, San Francisco, and Seattle.

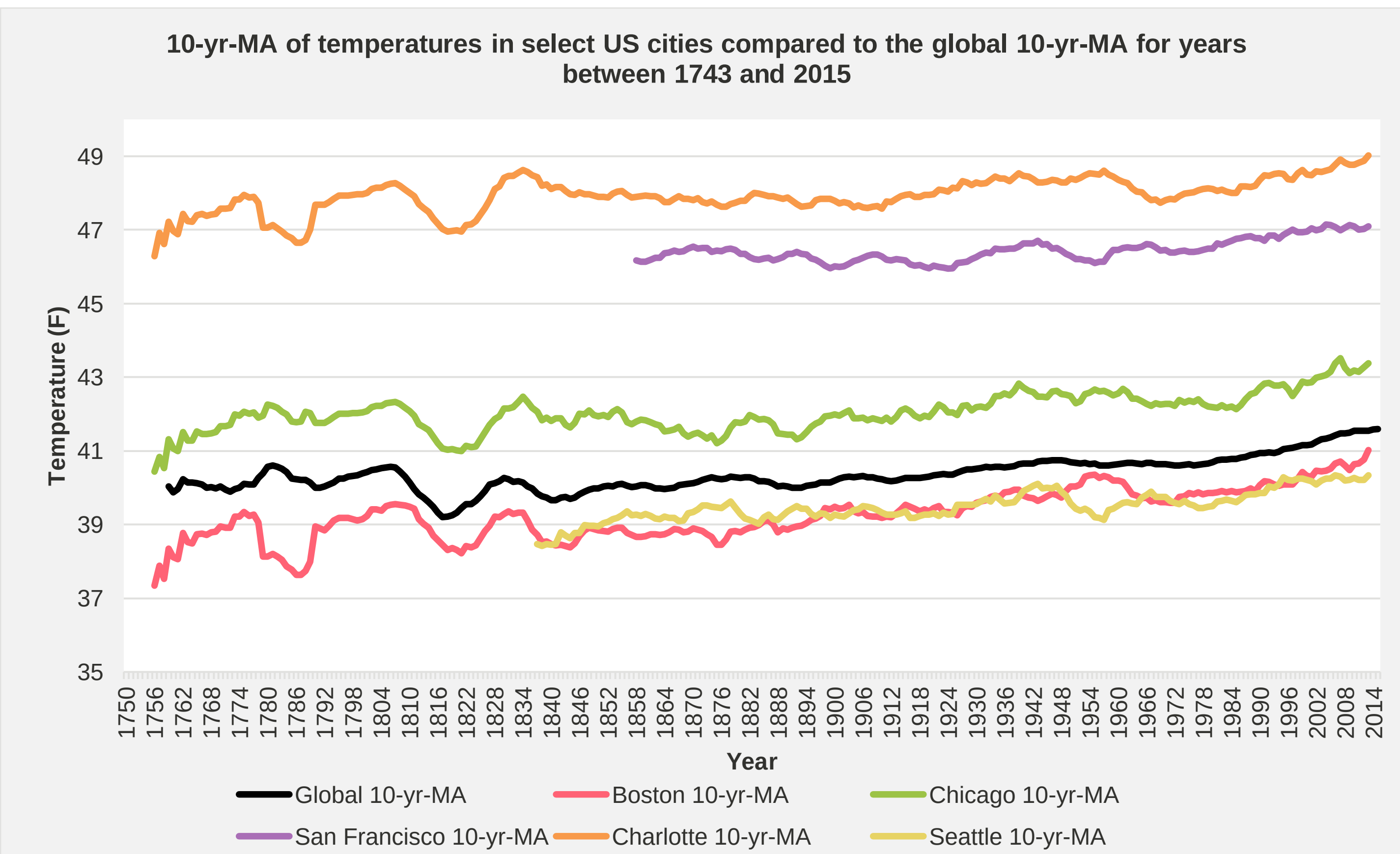


Fig-1, Chart of 10-yr-MA temperatures V year for the globe and select cities

Observations from fig (1)

Cities with lower temperature averages

From the chart of the five cities studied, we can conclude that the city of Boston has been consistently colder on average than the global average temperature between the years of 1750 and 2013. And while no data was available for the city of Seattle before 1829, the chart shows that Seattle was also below the global average throughout the period of study.

Dozen year global cooling

From around 1807/08 till around 1820/21, the global average temperature showed a decline of about 1.00 deg F to about 1.30 deg F. This dozen year cooling was also exhibited on the chart by the three US cities with available data across this time period, which points to the possibility that the dozen year cooling phenomenon may have been a global event.

Change in temperature between 1858 and 2013

- Global temperature change: 1.52 deg F
- Boston temperature change: 2.35 deg F
- Chicago temperature change: 1.57 deg F
- Seattle temperature change: 1.06 deg F
- Charlotte temperature change: 1.12 deg F
- San Francisco temperature change: 0.92 deg F

The rates of change in the 155 year period between 1858 and 2013 for the five cities studied shows that the city of Boston is experienced global warming at a faster rate than the other US cities between 1858 and 2013, while also outpacing the global average rate of change by almost a full degree in the period of study. San Francisco on the other hand is warming at a lower rate than the other cities and the global average.

Overall upward trend between 1845 and 2015

- In the decade between the early 1830s and early 1840s, there was a decline in global average temperatures of about 0.5 deg Fahrenheit. This temperature loss also seems to have been tracked by the US cities shown on the chart. Beyond this period, the global average temperature trend has fluctuated mostly upwards until 2015.
- The cities of Boston and Seattle generally exhibited the same upward fluctuating average temperatures. Chicago's average temperature continued to decline and showed an overall downward trend until around 1893 but have since trended upwards in average annual temperature.

- Charlotte showed about a full degree decline in average annual temperature between 1836 and 1910 but has since also began to track the global upward average annual temperature trend.
- San Francisco trended sideways from 1859 to around 1925, then began an upward average annual temperature trend similar to the other US cities and the global average annual temperature.

Temperature differential table

	Average Temp. in 2013(F)	Lowest Average Temp (F)	Year of lowest Avg. temp	Temp Difference between 2013 temp. and lowest recorded temp. (F)	Period between lowest avg. temp yr. and 2013 (yrs.)	Annual rate of change over period (F/yrs.)
Globe	41.56	37.78	1752	3.78	261	0.0145
Boston	42.38	35.52	1832	6.86	181	0.0379
Chicago	43.38	33.8	1745	9.58	268	0.0357
Charlotte	49.02	40.94	1779	8.08	234	0.0345
San Francisco	48.23	45.22	1880	3.01	133	0.0226
Seattle	41.95	35.52	1832	6.43	181	0.0355

Table (1) – Temperature change over time between 2013 and year of lowest temperature for the globe and each city

Observations from Table (1)

Average temperature in 2013 compared to all time lowest temperatures

- While by 2013 the global average temperature has gone up about 3.78 deg F since the lowest recorded temperature back in 1752, of the five US cities studied, only San Francisco showed a lower temperature increase between its period of lowest temperature and 2013, albeit this increase also happened in the shortest period, 133 years, compared to the other cities.
- The time span was 268 years for Chicago; not much higher than the global average span of 261 years. But the change in Chicago was almost three times more at 9.25 deg F than the global average temperature change.
- The city of Charlotte was closer to Chicago in both time span and average temperature change at 234 years and 8.08 deg F compared to the other cities; Seattle and Boston had very similar numbers, but Boston showed a slightly higher temperature increase than Seattle

Annual rate of change between year of lowest temperature and 2013

Although the rate of change of temperature per year between the period of lowest recorded average temperature and 2013 was different for the global average and for each of the US cities studied, and the periods of change vary from 133 years to 268 years, this rate may be used to do a rough estimate of future average temperatures both globally and for each city. However, these predictions may not be reliable since this annual rate of change was not statistically tested as a good predictor of future average temperatures. This presents an opportunity for a future more robust study of the global weather trends data.

Regression Analysis – City of San Francisco (1858 – 2013)

I did a regression analysis to test if the year and adjoining global average temperature could be used to predict the average temperature of the city of San Francisco. There was no data available for the city before 1858, so the period under analysis was from 1858 to 2013.

Results table

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.83137017
R Square	0.69117636
Adjusted R Square	0.68713945
Standard Error	0.16880642
Observations	156

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	9.75770502	4.87885251	171.2142	9.18027E-40
Residual	153	4.35982782	0.02849561		
Total	155	14.1175328			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	14.5355912	2.32710208	6.24621987	3.9652E-09	9.938190917	19.1329916
year	-0.0027965	0.00079004	-3.5397366	0.00053085	-0.00435733	-0.0012357
Global 10-yr-MA	0.92052513	0.09047572	10.1742777	6.8161E-19	0.741782171	1.0992681

Table (2) – Summary output of Regression Analysis

Regression Output explained

- From the *Regression Statistics* table, we see that the correlation coefficient or *Multiple R* is 0.8314, which shows a strong positive correlation or relationship between the actual and the predicted values of the average temperatures of the city of San Francisco.
- The *R Square* value of 0.6912 tells us that about 69% of the variance in the predicted average temperatures of the city of San Francisco can be attributed to the year and the global 10-yr-MA temperatures. The *Adjusted R* means essentially the same thing but adjusted for the multiple independent variables, year and global 10-yr-MA.
- The ANOVA table shows a *Significance F* value much lower than 0.05 and close to zero, which validates the results obtained in the Regression Statistics table and means the result obtained is statistically significant.
- The *coefficients* shown in the bottom table for Intercept, year, and global 10-yr-MA are the values on which the equation for predicting San Francisco's average temperatures are based. The *P-values* for all three coefficients are also significantly lower than 0.05 which means these values are significant contributors to the prediction model.

Prediction model and sample predictions

Based on the coefficients from the regression table, the prediction model equation is as follows:

$$y = 0.92052513 * global\ 10yrMA - 0.0027965 * year + 14.5355912$$

Sample prediction table

year	Global 10-yr-MA (F)	San Francisco 10-yr-MA (F)	Predicted San Francisco 10-yr-MA (F)
1858	40.04	46.18	**46.20**
1859	40.07	46.14	**46.22**
1860	40.07	46.14	**46.22**
1861	40.04	46.19	**46.19**
1862	39.98	46.25	**46.13**
1863	39.99	46.25	**46.14**
1864	39.97	46.37	**46.11**
1865	39.98	46.38	**46.12**
1866	40.00	46.44	**46.14**
1867	40.07	46.41	**46.20**

Table (3) - The model shown in section 4.3 was used to generate the average temperatures for the city of San Francisco based on the values of global-10-yr-MA and the year. Notice that the predicted and actual values are approximately equal, which lends credence to the correlation coefficient obtained from the regression analysis.

Correlation Chart of actual and predicted San Francisco temperatures

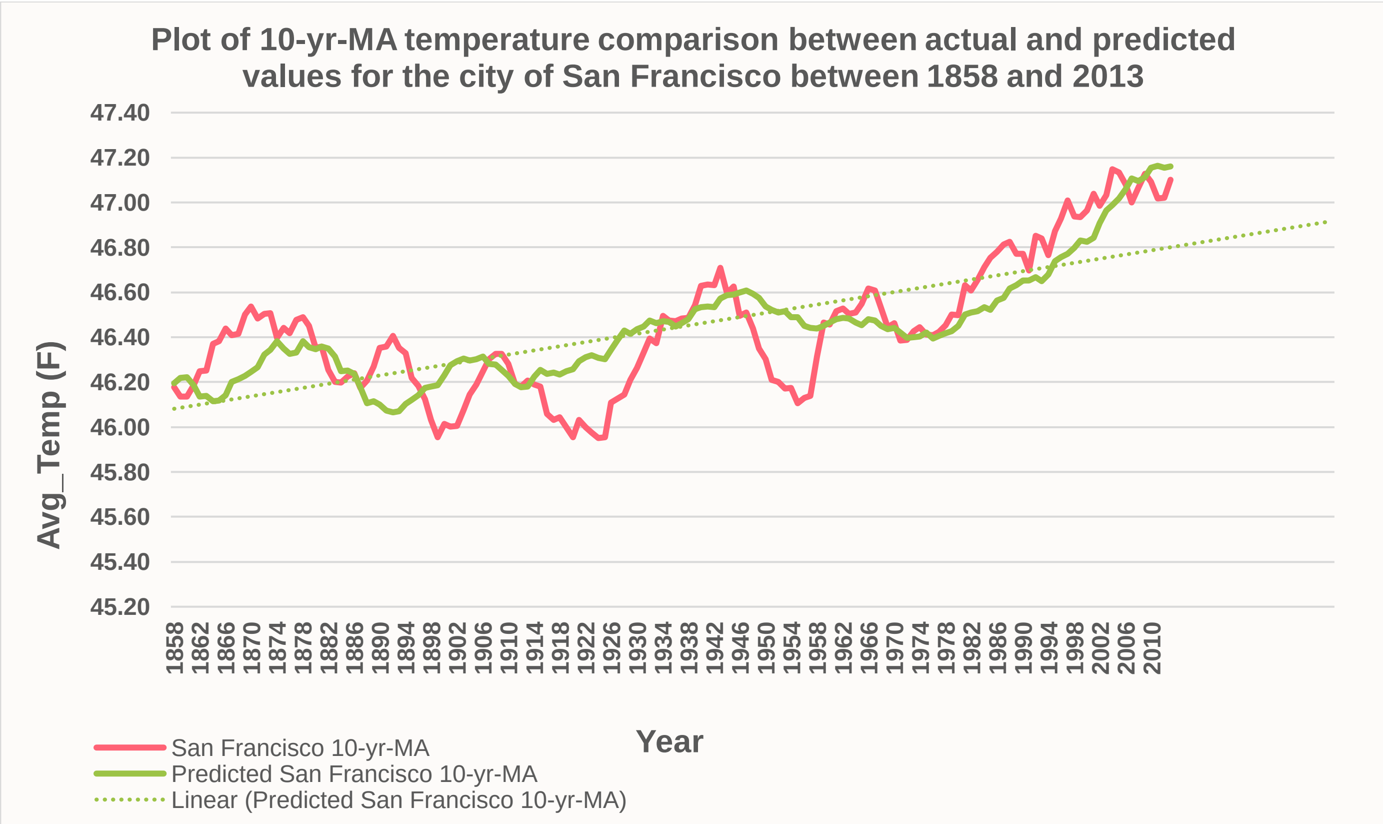


Fig (2) – Chart showing a plot of predicted values overlaid on actual values of average temperatures for the city of San Francisco. Lines underscore the high correlation coefficient computed from the regression analysis.

Limitations, conclusion and outlook

- This was a brief analysis of global weather trends in relation to a handful of US cities. All the cities studied have been getting warmer for the most part of the last century, with Boston showing a much higher rate of temperature change than the other cities and the global average.
- A more robust analysis could be done by including more cities with more variation in annual average temperatures from more diverse climates across the world to paint a clearer picture of the global warming phenomenon.
- Based on the results of this analysis, it is obvious that while global warming affects the whole world on aggregate, the rate and probably the effects of global warming would be different from region to region. A more focused and detailed study of the most affected regions could be done, and results could be used to shape public policy in these regions to start enacting more stringent measures than required in other less affected parts so as to slowdown the rate of global warming.
- Although the San Francisco Bay Area and parts of the state of California experience ever increasing incidents of fires and other extreme weather related calamities like droughts and

flooding, which may all point to the negative effects of global warming and should be taking seriously, attention should also be paid to cities with colder climates which may also be at an eventual higher risk of the effects of global warming. Based on the changes in temperature experienced by the cities studied between 1858 and 2013 as discussed earlier, Boston is heating up faster than san Francisco and Charlotte, cities with higher average temperatures.

- A deeper dive into statistical analysis is possible as a means of building a better prediction model to help estimate future temperatures and better understand the future risks of global warming.