**CBE 4485: Energy and Society**

**Assignment 1: *Mathematical Correlations Between Earth temperature and atmospheric CO2 concentration in the last 500 000 years***

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Abstract

Global climate change is one of the greatest threats facing mankind today. In examining ways to combat climate change two contributing elements are considered, greenhouse gases and solar radiation. Green House Gases are a necessary part of the earth’s atmosphere however in high concentrations may lead to increasing temperatures. Concerns related to the relationship between human activity and increasing global temperatures has led to much discussion and analysis within the scientific field. The largest quantity substance found within Green House Gases is CO2. In this report, the concentration of CO2, solar radiation, and other Green House Gases as shown is analyzed. The relationships are correlated utilizing R. The results obtained from the model produced show several significant conclusions. In the model 45 different green house gases were considered and the backwards elimination method was used to determine the significance levels of each gas. From the model it was concluded that the solar radiation levels and CO2 levels did not result in an effect on the global air temperature. This conclusion leads to the possibility of other Green House Gases being contributors to the effects on the global air temperature, and therefore should be further studied.

Introduction

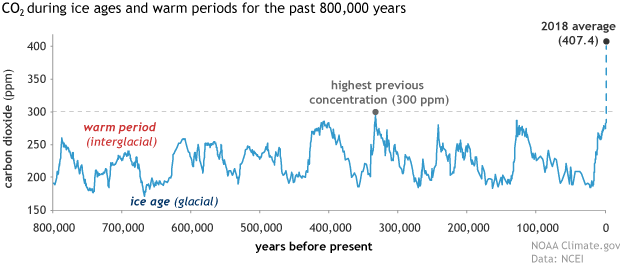
One of the most challenging problems and issues that humans are facing is the need to stabilize and determine contributing global emissions that effect the Earth’s temperature and in turn climate change. Global air temperature has become the primary metric for indications on global climate change (Wang & Dickinson, 2013). Currently, there are two major elements that are potentially contributing to this challenge: greenhouse gases (GHGs) and solar radiation. The presence of GHGs is important as it helps trap heat in the Earth’s atmosphere; as a result, this allows the Earth to be habitable by humans. However, the concern lies around the increasing atmospheric GHGs concentrations that might cause additional warming leading to higher surface temperatures. This ultimately leads to melting of polar ice, rising sea levels, environmental threat to coastal areas, and creating challenges for adaptability for certain species (Explore, 2020). The relationship between temperature and human activity has been greatly debated in recent years and scientists are in attempts to determining correlations to better understand the changes and fluctuations observed in the Earth’s temperature.

Due to the increasing demands; the use of conventional fossil fuels (coal, oil, natural gas etc.) has also increased the raising concerns around environmental and economical levels (Pandey, 2011). The use of fossil fuels has led to high emission levels of greenhouse gases (GHGs) as seen in **Table 1**, global warming, and unexpected environmental fluctuations. Furthermore, the planet’s average surface temperature has risen to approximately 0.9 oC since the late 19th century and according to NASA this change has been driven by the large increase in carbon dioxide (CO2) and other human-made emissions into the atmosphere (Explore, 2020).

**Table 1:** GHGs effecting Earth’s surface temperatures

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | MW (g/mol) | Other Name(s) | Use(s) / Source of Emissions | Class |
| c-C4F8 | 200.03 | Octaflurorocyclobutane | In production of semiconductors, as a replacement for ozone depleting CFCs |  |
| C2F6 | 138.01 | Hexafluoroethane | Semiconductor production |  |
| C3F8 | 188.02 | Octafluoropropane, R-218 | Semiconductor production, component of refrigeration mixtures |  |
| C4F10 | 238.03 | Perfluorobutane | Newer generation microbubble ultrasound contrast agents, Sonazoid formulation by Amersham Health uses this as the core gas |  |
| C5F12 | 288.036 | Perflenapent | It has several biomedical applications including: propellant for pressurized metered dose inhalers; gas core in microbubble ultrasound contrast agents; and occlusion therapy via the conversion of nanometer liquid droplets into micrometer sized gas microbubbles. |  |
| C6F14 | 338.04 | Perfluorohexane | It is used in one formulation of the electronic cooling liquid/insulator Fluorinert for low-temperature applications due to its low boiling point of 56 °C and freezing point of −90 °C |  |
| C7F16 | 388.05 | Perfluoroheptane | It is used in deacidification of paper as a medium carrying powdered magnesium oxide |  |
| C8F18 | 438.06 | Perfluorooctane | Perfluorooctane is chemically inert, but has useful physical properties, leading to its employment in diverse areas: heat transfer agent, dialectric fluid, tamponade in eye surgery |  |
| CO2 | 44.01 | Carbon Dioxide | Mainstream “bad” GHG |  |
| CCl4 | 153.82 | Carbon tetrachloride | Used for dry cleaning, degreasing metals, fumigating, manufacturing refrigerants and aerosol propellants, and is also used in fire extinguishers |  |
| CF4 | 88.0043 | Tetrafluoromethane, R-14 | Is a low temperature refridgerant and is also used in a variety of wafer etch processes |  |
| CFC-11 | 137.37 | Trichlorofluoromethane, R-11, freon-11 | They are used in the manufacture of aerosol sprays, blowing agents for foams and packing materials, as solvents, and as refrigerants. | CFCs |
| CFC-11 equivalents | - | Needs research | Needs research | CFCs |
| CFC-12 | 120.91 | Dichlorodifluoromethane, R-12, freon 12 | Is an ozone-depleting refrigerant and potent greenhouse gas that was widely used in air conditioners for automobiles and trucks for over 30 years, up until the mid-1990s | CFCS |
| CFC-12 equivalents | - | Needs research | Needs research | CFCs |
| CFC-113 | 187.375 | 1,1,2-Trichloro-1,2,2-trifluoroethane, R-113 | One of the many forms of CFCs that were made to eliminate toxic and flammable substances in the areas that they were used. It has been used as a cooling agent in refrigerants and air conditioners, aerosol propellant, and a cleansing agent for electrical and electronic components. | CFCs |
| CFC-114 | 170.92 | 1,2-Dichlorotetrafluoroethane, R-114 | Its primary use has been as a refrigerant. | CFCs |
| CFC-115 | 154.466 | Chloropentafluoroethane, R-115 | Chloropentafluoroethane is a chlorofluorocarbon once used as a refrigerant. Its production and consumption has been banned since 1 January 1996 under the Montreal Protocol because of its ozone-depleting potential. | CFCs |
| CH2Cl2 | 84.93 | Dichloromethane | Dichloromethane is used as a solvent in food technology. It is used in aerosol formulations. It is am ethane foam blowing agent. Used as a solvent in the manufacturing of pharmaceutical products. CH2Cl2 is used as a degreasing agent. Used in the manufacturing of electronics. |  |
| CH3CCl3 | 133.4 | 1,1,1-Trichloroethane, Methyl Chloroform | This colourless, sweet-smelling liquid was once produced industrially in large quantities for use as a solvent.[4] It is regulated by the Montreal Protocol as an ozone-depleting substance and its use is being rapidly phased out. |  |
| CHCl3 | 119.38 | Chloroform | It is a colorless, sweet-smelling, dense liquid that is produced on a large scale as a precursor to PTFE. It is also a precursor to various refrigerants. |  |
| Halon 1211 | 165.36 | Bromochlorodifluoromethane, BCF | BCF was introduced as an effective gaseous fire suppression agent in the mid-1960s for use around highly valuable materials in places such as museums, mainframe rooms, and telecommunication switching centers. |  |
| Halon 1301 | 148.91 | Bromotrifluoromethane, BTM | As above |  |
| Halon 2402 | 259.82 | Dibromotetrafluoroethane | As above |  |
| HCFC-22 | 86.47 | Chlorodifluoromethane, R-22 | It is commonly used as a propellant and refrigerant. These applications are being phased out in developed countries | HCFCs |
| HCFC-142b | 100.495 | 1-Chloro-1,1-difluoroethane | HCFC-142b is used as a blowing agent for foam plastics production, as a refrigerant, and as feedstock to make polyvinylidene fluoride (PVDF).[4] It was mainly used to replace the CFCs that had been initially banned by the Montreal Protocol, but now HCFCs are also banned due to their ozone-depletion ability. | HCFCs |
| HFC-23 | 70.01 | Fluoroform, R-23 | CHF3 is used in the semiconductor industry in plasma etching of silicon oxide and silicon nitride. Known as R-23 or HFC-23, it is also a useful refrigerant, sometimes as a replacement for chlorotrifluoromethane (cfc-13) and is a byproduct of its manufacture. When used as a fire suppressant, the fluoroform carries the DuPont trade name, FE-13. CHF3 is recommended for this application because of its low toxicity, its low reactivity, and its high density. HFC-23 has been used in the past as a replacement for Halon 1301[cfc-13b1] in fire suppression systems as a total flooding gaseous fire suppression agent. | HFCs |
| HFC-32 | 52.023 | Difluoromethane | HFC-32 (difluoromethane) is a chemical used in pure form as a refrigerant in air conditioning and heat pump systems. It is considered the most balanced next generation refrigerant for residential and commercial air conditioners, cooling and heat pump systems. | HFCs |
| HFC-125 | 120.02 | Pentafluoroethane | Is an effective fire extinguishing agent that can be used on many types of fires. It is effective for many surface fires and most solid combustible materials. | HFCs |
| HFC-134a | 102.03 | 1,1,1,2-Tetrafluoroethane | is used in refrigeration and air conditioning systems, as a blowing agent for polyurethane foams, and as a propellant for medical aerosols. Yearly production is estimated at 175,000 tons. | HFCs |
| HFC-134a equivalent | - | Needs research | Needs research | HFCs |
| HFC-143a | 84.04 | 1,1,1-Trifluoroethane | mainly used as a blend component for air conditioning and refrigeration systems. | HFCs |
| HFC-152a | 66.05 | 1,1-Difluoroethane, R-152a | This colorless gas is used as a refrigerant, where it is often listed as R-152a or HFC-152a. It is also used as a propellant for aerosol sprays and in gas duster products | HFCs |
| HFC-227ea | 170.03 | 1,1,1,2,3,3,3-Heptafluoropropane, FM200 | fire extinguishant used as a flooding agent to help protect assets including data and data processing equipment in the event of a fire. FE-227™ (HFC-227) is a fire extinguishing replacement for Halon 1301 in total flooding applications. | HFCs |
| HFC-236fa | 152.04 | 1,1,1,3,3,3-Hexafluoropropane | fire suppressant used as a replacement for Halon 1211 in many portable fire extinguisher applications | HFCs |
| HFC-245fa | 134.05 | Pentafluoropropane | primarily for closed-cell spray foam insulation produced by Honeywell and in Asia by Sinochem | HFCs |
| HFC-365mfc | 148 | 1,1,1,3,3-pentafluorobutane | Foam blowing | HFCs |
| HFC-4310mee | ‎252.05 | 2H,3H-Decafluoropentane | Needs research | HFCs |
| CH4 | 16.04 | Methane | Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills |  |
| CH3Br | 94.94 | Bromomethane | is used in organic synthesis; as a low-boiling solvent; as a refrigerant and as a fumigant. |  |
| CH3Cl | 50.49 | Chloromethane | used as a refrigerant, as a catalyst solvent in Butyl rubber, as a reagent in silicone production, in organic synthesis, in the manufacture of tetramethyllead, as a solvent, and as a starting material in the manufacture of such chemicals as methyl mercaptan, methylene chloride, ... |  |
| NF3 | 71 | Nitrogen trifluoride | used in the plasma etching of silicon wafers. Today nitrogen trifluoride is predominantly employed in the cleaning of the PECVD chambers in the high-volume production of liquid-crystal displays and silicon-based thin-film solar cells. |  |
| N2O | 44.013 | Nitrous Oxide | Nitrous oxide forms during combustion, just like nitrogen dioxide, and is also released into the atmosphere from farm animals, sewage, and fertilizers. |  |
| SF6 | 146.06 | Sulfur hexafluoride | It makes a hugely effective insulating material for medium and high-voltage electrical installations. It is widely used across the industry, from large power stations to wind turbines to electrical sub-stations in towns and cities. |  |
| SO2F2 | 102.06 | Sulfuryl fluoride | insecticide fumigant in wooden structures to control termites and wood-infesting beetles, and used in organic synthesis. Sulfuryl difluoride is a sulfuryl halide. It has a role as a fumigant insecticide. |  |

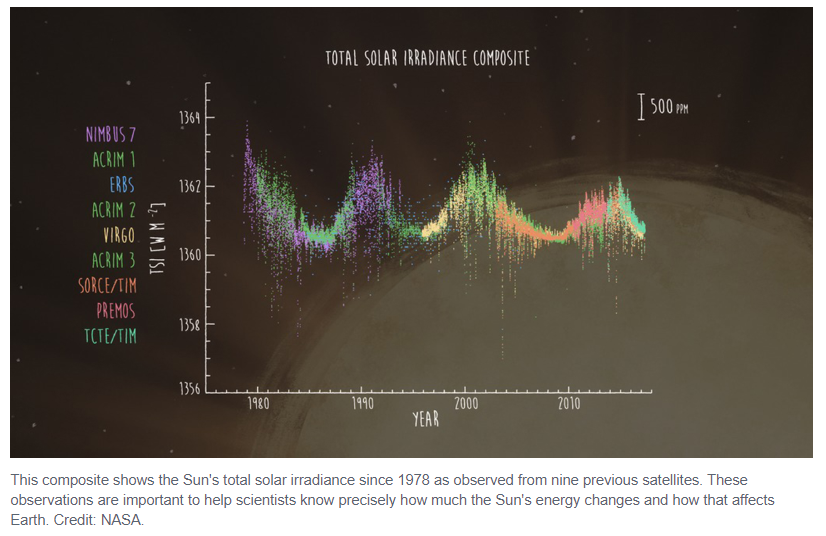
CO2 is a trace gas and it has the ability to absorb parts of the infrared radiation that is emitted upwards by the Earth’s surface and as a result, the lower atmosphere and the planet’s surface are warmer due to the phenomena of greenhouse effect. The main contributor to GHGs emissions in terms of quantity is CO2, which according IPCC accounted for about 76.7% of total anthropogenic greenhouse gas emissions in 2004 (Martínez-Zarzoso & Maruotti, 2011). This trend was expected to grow due the increasing energy consumptions maintained over the years and according to NASA there is a constant relationship between fossil-fuel burning and the relentless rise in CO2 (Etheridge et al., 2010). In 2018, the global average atmospheric CO2 was 407.4 ppm with a range of uncertainty of plus or minus 0.1 ppm and as seen in Figure 1, CO2 levels currently are higher compared to the past 800,000 years (Lindsey, 2019). The peaks and valleys in CO2 level track the ongoing ice ages and warmer interglacials.



**Figure 1:** Atmospheric CO2 in for the past 800,000 years based on EPICA (ice core) data (Lindsey, 2019)

In addition to CO2 being a major factor effecting the Earth’s surface temperature: another factor that must be examined is the activity of the Sun in terms of solar radiation. Solar radiation is the cause if fusion of atoms inside the sun and when the solar radiation enters the Earth’s atmosphere: energy is removed by scattering or absorption by surface molecules, clouds and particulate matter (Ismail et al., 2012). The thermal structure and composition of the atmosphere is determined by the incoming solar irradiance and provides the major source of heating for Earth’s atmosphere therefore, having direct impacts on the Earth’s surface temperature (Haigh et al., 2010). NASA over the past 40 years has measured the total solar irradiance utilizing the Total and Spectral Irradiance Sensor (TSIS-1). The data provided by TSIS-1 shown in **Figure 2** has displayed many fluctuations which might be a leading reason or cause to explain the Earth’s surface temperature fluctuations and changes observed by scientists.

Many researchers believe that the steady rise in sunspots since the late 17th century is major contributor for as much as half of the 0.6 degrees of global warning over the last 110 years (SORCE Fact Sheet, 2003). According to the 2001 report published by the Intergovernmental Panel on Climate Change (IPCC), the resulting imbalance between incoming solar radiation and outgoing thermal radiation will likely increase the Earth’s surface temperatures.



**Figure 2:** Composite shows the Sun's total solar irradiance since 1978 as observed from nine previous satellites. These observations are important to help scientists know precisely how much the Sun's energy changes and how that affects Earth (Feature, 2017)

In this report, the concentration of CO2, solar radiation, and other GHGs as shown in **Table 1** vs temperature in one model will be analyzed based on the data collected. This data was collected from Berkeley Earth for temperature source, NOAA for Solar Irradiance Source, and CO2 Earth for GHG atmospheric level source. The relationships are correlated utilizing R. The results obtained from the model produced are discussed and a recommendation for future studies is provided to help determine the correlations between the Earth’s surface temperature rise and solar radiation and GHGs.

Problem Description

Planet Earth has had a rich history evolving over billions of years with different climates and conditions through various eras. While the Earth’s temperature has experienced relatively cyclical changes which appear to become more drastic, other factors sustaining life on Earth have also been impacted. From NASA’s global temperature data, which has tracked the Earth’s surface temperature for hundreds of thousands of years, it can be determined that the global temperature is on an upward trend. More so, there has been a radical increase since 2001, resulting in some of the hottest surface temperatures ever recorded (Earth Science Communications Team, 2020). Solar irradiation changes have also been experienced over the Earth’s lifetime. Each part of the solar irradiance changes over the 11-year solar cycle, becoming brighter than average at solar maximum and dimmer than average at solar minimum (Garner, 2017). Each wavelength also changes as the Sun rotates and during solar flares, so many changes on Earth are experienced due to this. Another aspect of climate which has also been on the rise is the atmospheric concentration of carbon dioxide (CO2). From data collected by NASA, pre-industrial CO2 levels were found to be lower than 300 ppm, while data from recent years shows CO2 levels reaching as high as 400 ppm (Earth Science Communications Team, 2020). The rise in CO2 levels is speculated to be a result of increased greenhouse gas emissions during the industrialization period. The CO2 levels are on an upward curve, similar to the global temperature, which leads many theorists to believe that the two phenomena are related. In order to determine if a significant relationship exists between Earth temperature and atmospheric CO2 concentration, they must both be graphed. By shifting the temperature data curve to best fit the CO2 concentration graph, an accurate depiction of the relation between the two phenomena can be drawn. This will show whether temperature is the leading factor and if CO2 trails this phenomena. Additionally, the time lag can also be determined between the leading and trailing factor. By studying temperature anomalies with and without the impact of atmospheric CO2 concentration, it can be determined if CO2 levels actually correlate to the rising Earth temperatures. It is important to consider that factors such as solar irradiance and a large variety of greenhouse gases can have a significant contribution to the rising Earth temperature, in addition to the effect of CO2.

Drawing a mathematical correlation between Earth temperature and atmospheric CO2 concentration is the first step in helping us better understand the current state of the Earth, as well as future trends. As a result, we can attempt to mitigate undesirable outcomes which can harm life on Earth.

Experimental Data

See appendix B for models and appendix C for statistical analysis.

Mathematical Tools Used

In order to analyze the data related to the concentration of CO2, solar radiation, and other GHGs R code was used. R is a coding environment and language used for statistical computing allowing for ease of calculations and data manipulation (R Project, N.D.). This environment is a GNU project, meaning it runs off the GNU operating system which is an operating system focused on providing more flexibility for developers (GNU, 2020). The code used can be found in Appendix A and has been commented to allow for ease of understanding.

Results and Discussion

While visually looking at the figure it appears that the predicted model fits the actual temperature, it must be considered that the model incorporates 45 different factors into account. This means that virtually no constructive information outside of the overall fit of the model can be extracted from the visual figure. In order to look in depth at the weight of each factor, we must analyze the dataset used to create the predicted model. The estimate in the first data column describes the actual values that the coefficient contributes to the model. The standard error describes the variance of each factor within the 1900-2014 timeframe. The t-value is a parameter that looks at the size of the differences relative to the variation. It quantifies the difference between the factors and the actual temperature. The lower the t-value, the more statistically significant the factor is to the model. The Pr(>|t|) column also describes how close the model is to the actual temperature. The closer the number is to 1, the greater the chance is of the factor being significant. Inversely, the smaller the significance level, the smaller the chance of the factor being significant. Any significance level (SL) under 0.05 is deemed insignificant, meaning that the factor most probably has no consequence on the model. Figure 1 represents a simulated annual temperature based on the influence of all the GHG’s considered. Based on the SL values, it appears that all but 4 factors are significant enough based on the commonly accepted 0.05 cut-off; these factors are the CO2 levels, Halon 2402 levels, HCFC142b, and N2O levels, with N2O being especially low, meaning that N2O has the highest chance of not causing an effect on the temperature. Other standout factors are CFC11, CFC113, CFC114, CHCl3, and HCFC22 levels, which each have significance levels above 0.90, indicating that there is over a 90% chance of these factors playing a part in the temperature model.

This is all the more evident when analyzing Figure 2, where backwards elimination is used to remove the insignificant factors. Backwards elimination involves the removal of factors to determine the effect the removal has on the model. From this we see a drop in the t-value, and by extension, a rise in its SL. The resulting data shows that all the factors play a negligible part in temperature determination. Based on the figure however, the model seems to fit well.

Figure 3 removes the influence of CO2. From this we see that the other insignificant factors vary compared to Figure 1. This time, CH4, N2O, and Halon 2402 have SLs lower than 0.05. Another thing to note is that HCFC142b is very close to the threshold for insignificance, and effectively is insignificant. Contrary to Figure 1, the highest SL this time is from CHCl3, with an SL of 0.97. In Figure 1 several GHG levels were big contributors statistically, however that is not the case this time. Looking at Figure 3, the fit seems similar to that of Figure 1.

Treating Figure 3 with backwards elimination, we get similar results to Figure 2 in the sense that all the factors become insignificant. Unlike Figure 2, C8F18 and N2O yield the largest SL levels in this dataset. When looking at Figure 4, it looks virtually similar to that of Figure 3.

The R squared value is defined as the proportion of the variance in the dependent variable that is predictable from the independent. In other words, this value describes how well a set of data is represented by a curve such as a line of best fit. In this scenario, the predicted temperature anomalies are compared to the Measured Temperature Anomalies for each of the four figures.

Regarding the various figures, the R squared values are 0.6205, 0.6272, 0.6193, 0.6268. Since all of these values hover around 0.6, it can be seen that insignificant parameters such as CO2 do not really affect the over correlation from the model to the measured anomalies. All figures seem to visually look the same regarding both data sets. However, they are not exact correlations, as an r squared value of 0.6 means that even though there is a correlation, it is a relatively weak one. A factor that may have affected this is likely the early years of the model. It can be seen in each of the four figures that the blue and orange lines do no exactly match and vary much more than the later years. This is likely due to an inaccurate predicted temperature in those early years. Notice how from years 1900 to about 1940 the orange line (predicted line) steadily increases whereas the blue line (measured temperatures) fluctuates. A possible explanation for the fluctuations in the measured temperatures is likely either due to the lack many of these GHG’s within the atmosphere, or the lack of any measurements of said GHG’s for this time period. The model is essentially a y=mx+b relationship but with 45 different “mx” terms. When a particular GHG has a concentration of 0ppm, as seen in the 1900’s-1940’s, the corresponding “mx” term within the model drops to 0, which greatly reduces the accuracy of the model for that time.

Reiterating what was mentioned earlier, at earlier dates the model may not necessarily be accurate due to the limits of technology at that time. In addition, at earlier stages of the industrial revolution, GHGs may not have had very high atmospheric levels. The predicted temperature anomaly model may have had the GHG levels increasing steadily over the early years. However in reality, the GHG levels may have been extremely low during these early years but then took an exponential rise during the industrial revolution rather than increasing at a steady rate. Therefore, the abrupt change in atmospheric GHGs, and population fluctuation may not have been accounted for in the predicted model, resulting in a weak correlation that can be seen in the early years.

When analysing the solar irradiance in Figures 1 and 3, we see that its SL levels of 0.68 and 0.76 do not stand out in any way. Due to the SL being so high, there is clearly no impact of solar irradiance on the model’s predictive ability. This also explains why solar irradiance was moved for the backwards elimination model. Relating to "The Great Global Warming Swindle”, during the documentary they attributed global warming levels to increasing levels of sunspots. This does not match the model, which, shows that the temperature increase is not a consequence of solar irradiation levels.

When analyzing the effect CO2 has on the temperature, based on Figure 1 we see that CO2 has no effect on the atmosphere based on its very low significance level of 0.02. This means that there is a 2% chance of CO2 having any kind of correlation to temperature, and then to determine which is the cause and which is the effect based off of such a small SL would be scientifically inaccurate and would result in fabrication of a trend that really has no correlation. Another way this can be determined is by looking at the difference between Figure 1 and Figure 3. The only difference between these two figures is that Figure 3 does not have any CO2 factored into its model. This means that CO2 levels as a whole have no effect on the overall temperature model. While the SLs of Figure 3 are different than Figure 1, that has no effect on the overall model.

There is one thing that was not considered for the models that were derived, which is that the model was fit based on the assumption that changed to the GHG levels or solar irradiation would be immediately felt that same year. This is a huge assumption as typically the gases are not normally equally distributed throughout the whole global at the same time. Winds spread the gases to other parts of the planet, and that takes time. Even if we assume that the gases were uniformly distributed around the globe, it still requires time to heat up the atmosphere if it is sunny. If certain regions are cloudy, then that would also affect how much and how fast the temperature changes, and it would be hard to say for sure that all these changes can occur within a year of the increased GHG levels.

Conclusion

The purpose of this report was to model the correlation between Temperature and CO2 as well as Temperature and solar radiation. The increased awareness of climate change has many people worried with regards to increased greenhouse gases being released into the atmosphere. To determine if these worries were warranted, multiple linear regression models were used on R to show the correlations, taking into account monthly solar irradiance and monthly temperature anomalies. There were 45 different green house gases taken into account and the significance levels of each variable was determined using a backwards elimination method. The main conclusions that could be taken away were that temperature increase was not caused by solar irradiation levels and CO2 levels did not have an effect on the overall temperature model. These conclusions were made from the models specifically in Figures 1 and 3. The high significance levels of solar irradiance means there is lower predictability resulting in no correlation between solar irradiance and temperature increases. This dispels the idea of many researchers who believed the increase in sunspots resulted in temperature increases (SORCE Fact Sheet, 2003). Similar conclusions were made with CO2 levels in that they do not have a significant effect on the temperature model. The significance level determined from CO2 was too low for it a correlation to be made. It must be noted that the effects of both solar irradiation and green house gases were assumed to be felt that current year but there may be a lag between temperature and these factors. Further studies should be done to model these correlations with assumptions that the effects of CO2 and solar irradiation are felt in separate years which could produce different results. Looking at the effects of different greenhouse gases on the Earth’s surface temperature could also give different results as well.

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Appendix

Appendix A: R Code

R Code, CO2 in Dataset

#Multiple Linear Regression

# Data Preprocessing Template

# Importing the dataset

dataset = read.csv('MLR\_Dataset\_NYNHFC132aeq.csv')

# Splitting the dataset into the Training set and Test set

# install.packages('caTools')

library(caTools)

set.seed(2)

split = sample.split(dataset$Temperature\_Anomaly, SplitRatio = 0.8)

training\_set = subset(dataset, split == TRUE)

test\_set = subset(dataset, split == FALSE)

# Feature Scaling

# training\_set = scale(training\_set)

# test\_set = scale(test\_set)

#Fitting Multiple Linear Regression to the Training Set

regressor = lm(formula = Temperature\_Anomaly ~ .,

data = training\_set)

#Predicting the Test set results

y\_pred = as.data.frame(predict(regressor, newdata = test\_set))

# To export as a csv, type the following into console: write.csv(y\_pred,"Predicted Values.csv", row.names = TRUE) and write.csv(test\_set,"Real Values.csv", row.names = TRUE)

write.csv(test\_set,"Real Values.csv", row.names = TRUE)

write.csv(y\_pred,"Predicted Values No Backwards Elimination.csv", row.names = TRUE)

#Building the optimal model using Backward Elimination

regressor = lm(formula = Temperature\_Anomaly ~ .,

data = dataset)

summary(regressor)

#Done.

#Automatic Backward Elimination (dynamic)

backwardElimination <- function(x, sl) {

numVars = length(x)

for (i in c(1:numVars)){

regressor = lm(formula = Temperature\_Anomaly ~ ., data = x)

maxVar = max(coef(summary(regressor))[c(2:numVars), "Pr(>|t|)"])

if (maxVar > sl){

j = which(coef(summary(regressor))[c(2:numVars), "Pr(>|t|)"] == maxVar)

x = x[, -j]

}

numVars = numVars - 1

}

y\_pred = as.data.frame(predict(regressor, newdata = test\_set))

write.csv(y\_pred,"Predicted Values Backwards Elimination SL\_0.05.csv", row.names = TRUE)

return(summary(regressor))

}

SL = 0.05

dataset = dataset[, c(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46)]

backwardElimination(training\_set, SL)

R Code, No CO2 in Dataset

#Multiple Linear Regression

# Data Preprocessing Template

# Importing the dataset

dataset = read.csv('MLR\_Dataset\_NYNHFC132aeq.csv')

# Splitting the dataset into the Training set and Test set

# install.packages('caTools')

library(caTools)

set.seed(2)

split = sample.split(dataset$Temperature\_Anomaly, SplitRatio = 0.8)

training\_set = subset(dataset, split == TRUE)

test\_set = subset(dataset, split == FALSE)

# Feature Scaling

# training\_set = scale(training\_set)

# test\_set = scale(test\_set)

#Fitting Multiple Linear Regression to the Training Set

regressor = lm(formula = Temperature\_Anomaly ~ .,

data = training\_set)

#Predicting the Test set results

y\_pred = as.data.frame(predict(regressor, newdata = test\_set))

# To export as a csv, type the following into console: write.csv(y\_pred,"Predicted Values.csv", row.names = TRUE) and write.csv(test\_set,"Real Values.csv", row.names = TRUE)

write.csv(test\_set,"Real Values.csv", row.names = TRUE)

write.csv(y\_pred,"Predicted Values No Backwards Elimination.csv", row.names = TRUE)

#Building the optimal model using Backward Elimination

regressor = lm(formula = Temperature\_Anomaly ~ .,

data = dataset)

summary(regressor)

#Done.

#Automatic Backward Elimination (dynamic)

backwardElimination <- function(x, sl) {

numVars = length(x)

for (i in c(1:numVars)){

regressor = lm(formula = Temperature\_Anomaly ~ ., data = x)

maxVar = max(coef(summary(regressor))[c(2:numVars), "Pr(>|t|)"])

if (maxVar > sl){

j = which(coef(summary(regressor))[c(2:numVars), "Pr(>|t|)"] == maxVar)

x = x[, -j]

}

numVars = numVars - 1

}

y\_pred = as.data.frame(predict(regressor, newdata = test\_set))

write.csv(y\_pred,"Predicted Values Backwards Elimination SL\_0.05.csv", row.names = TRUE)

return(summary(regressor))

}

SL = 0.05

dataset = dataset[, c(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45)]

backwardElimination(training\_set, SL)

Appendix B: Models

Models With CO2 Measurements as Variable

Models Without CO2 Measurements as Variable

***Appendix C: Statistical*** ***Analysis***

Model with CO2 Variable Statistical Analysis

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Call: |  |  |  |  |  |  |  |  |  |
| lm(formula = Temperature\_Anomaly ~ ., data = training\_set) | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Residuals: |  |  |  |  |  |  |  |  |  |
| Min | 1Q | Median | 3Q | Max |  |  |  |  |  |
| -1.0908 | -0.1894 | -0.0001 | 0.1968 | 1.1623 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Coefficients: | Estimate | Std. Error | t value | Pr(>|t|) |  |  |  |  |  |
| (Intercept) | -1.87E+01 | 4.02E+01 | -0.464 | 0.642497 |  |  |  |  |  |
| Total\_Solar\_Irradiance | 1.17E-02 | 2.85E-02 | 0.41 | 0.682078 |  |  |  |  |  |
| Mean\_Global\_PPM\_CC4F8 | 2.16E+04 | 6.50E+04 | 0.332 | 0.739662 |  |  |  |  |  |
| Mean\_Global\_PPM\_C2F6 | 1.69E+04 | 5.08E+04 | 0.332 | 0.739633 |  |  |  |  |  |
| Mean\_Global\_PPM\_C3F8 | 1.89E+04 | 5.69E+04 | 0.332 | 0.73992 |  |  |  |  |  |
| Mean\_Global\_PPM\_C4F10 | 2.43E+04 | 7.31E+04 | 0.332 | 0.740226 |  |  |  |  |  |
| Mean\_Global\_PPM\_C5F12 | 2.76E+04 | 8.33E+04 | 0.331 | 0.740332 |  |  |  |  |  |
| Mean\_Global\_PPM\_C6F14 | 2.97E+04 | 8.94E+04 | 0.332 | 0.739619 |  |  |  |  |  |
| Mean\_Global\_PPM\_C7F16 | 3.37E+04 | 1.02E+05 | 0.332 | 0.74013 |  |  |  |  |  |
| Mean\_Global\_PPM\_C8F18 | 3.73E+04 | 1.12E+05 | 0.334 | 0.73822 |  |  |  |  |  |
| Mean\_Global\_PPM\_CO2 | 3.41E-02 | 1.47E-02 | 2.316 | 0.020688 | \* |  |  |  |  |
| Mean\_Global\_PPM\_CCl4 | -3.07E-02 | 1.84E-01 | -0.167 | 0.867088 |  |  |  |  |  |
| Mean\_Global\_PPM\_CF4 | 6.08E+03 | 1.83E+04 | 0.332 | 0.739576 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC11 | 1.35E-02 | 2.91E-01 | 0.046 | 0.962922 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC11\_eq | -1.76E+04 | 5.28E+04 | -0.332 | 0.739603 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC12 | -2.16E+04 | 6.50E+04 | -0.332 | 0.739603 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC12\_eq | 2.16E+04 | 6.50E+04 | 0.332 | 0.739604 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC113 | 2.89E-02 | 3.04E-01 | 0.095 | 0.924282 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC114 | -4.31E-02 | 3.92E-01 | -0.11 | 0.912475 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC115 | 2.21E-01 | 9.93E-01 | 0.222 | 0.824257 |  |  |  |  |  |
| Mean\_Global\_PPM\_CH2Cl2 | 5.05E-02 | 4.19E-02 | 1.205 | 0.22849 |  |  |  |  |  |
| Mean\_Global\_PPM\_CH3CCl3 | -1.47E-02 | 6.76E-02 | -0.217 | 0.828462 |  |  |  |  |  |
| Mean\_Global\_PPM\_CHCl3 | 6.83E-03 | 9.73E-02 | 0.07 | 0.944042 |  |  |  |  |  |
| Mean\_Global\_PPM\_Halon1211 | 1.86E+00 | 1.81E+00 | 1.029 | 0.30361 |  |  |  |  |  |
| Mean\_Global\_PPM\_Halon1301 | 1.44E+00 | 1.44E+00 | 1.006 | 0.31451 |  |  |  |  |  |
| Mean\_Global\_PPM\_Halon2402 | -2.18E+01 | 8.50E+00 | -2.567 | 0.010354 | \* |  |  |  |  |
| Mean\_Global\_PPM\_HCFC22 | 2.93E-02 | 2.50E-01 | 0.117 | 0.906914 |  |  |  |  |  |
| Mean\_Global\_PPM\_HCFC142b | -6.14E-01 | 3.06E-01 | -2.007 | 0.044931 | \* |  |  |  |  |
| Mean\_Global\_PPM\_HFC23 | 1.22E+04 | 3.66E+04 | 0.332 | 0.739608 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC32 | 7.43E+03 | 2.23E+04 | 0.332 | 0.739637 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC125 | 1.55E+04 | 4.67E+04 | 0.332 | 0.739601 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC134a | 1.08E+04 | 3.25E+04 | 0.332 | 0.739602 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC143a | 1.08E+04 | 3.25E+04 | 0.332 | 0.739583 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC152a | 6.75E+03 | 2.03E+04 | 0.332 | 0.739606 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC227ea | 1.76E+04 | 5.28E+04 | 0.333 | 0.739512 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC236fa | 1.61E+04 | 4.87E+04 | 0.331 | 0.740562 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC245fa | 1.62E+04 | 4.87E+04 | 0.332 | 0.739609 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC365mfc | 1.49E+04 | 4.47E+04 | 0.333 | 0.739545 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC4310mee | 2.84E+04 | 8.53E+04 | 0.332 | 0.73958 |  |  |  |  |  |
| Mean\_Global\_PPM\_CH4 | 2.72E-03 | 1.42E-03 | 1.908 | 0.056648 | . |  |  |  |  |
| Mean\_Global\_PPM\_CH3Br | 2.95E-02 | 1.61E-01 | 0.183 | 0.854605 |  |  |  |  |  |
| Mean\_Global\_PPM\_CH3Cl | -1.05E-02 | 1.06E-02 | -0.992 | 0.321382 |  |  |  |  |  |
| Mean\_Global\_PPM\_NF3 | 1.35E+04 | 4.06E+04 | 0.332 | 0.739703 |  |  |  |  |  |
| Mean\_Global\_PPM\_N2O | -1.01E-01 | 2.76E-02 | -3.647 | 0.000276 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_SF6 | 3.85E+04 | 1.16E+05 | 0.332 | 0.73959 |  |  |  |  |  |
| Mean\_Global\_PPM\_SO2F2 | 1.35E+04 | 4.06E+04 | 0.332 | 0.739591 |  |  |  |  |  |
| --- |  |  |  |  |  |  |  |  |  |
| Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1 | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Residual standard error: 0.3139 on 1334 degrees of freedom | | | | |  |  |  |  |  |
| Multiple R-squared: 0.6329, Adjusted R-squared: 0.6205 | | | | |  |  |  |  |  |
| F-statistic: 51.11 on 45 and 1334 DF, p-value: < 2.2e-16 | | | | |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Call: |  |  |  |  |  |  |  |  |  |
| lm(formula = Temperature\_Anomaly ~ ., data = x) | | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Residuals: |  |  |  |  |  |  |  |  |  |
| Min | 1Q | Median | 3Q | Max |  |  |  |  |  |
| -1.56571 | -0.19379 | 0.00315 | 0.20402 | 1.12122 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Coefficients: | Estimate | Std. Error | t value | Pr(>|t|) |  |  |  |  |  |
| (Intercept) | -1.68E+00 | 7.64E+00 | -0.22 | 0.825699 |  |  |  |  |  |
| Mean\_Global\_PPM\_CC4F8 | 5.70E+01 | 1.01E+01 | 5.65 | 2.06E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_C2F6 | 5.31E+01 | 8.91E+00 | 5.961 | 3.39E-09 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_C6F14 | 1.86E+02 | 5.44E+01 | 3.428 | 6.31E-04 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_C8F18 | 1.97E+02 | 7.53E+01 | 2.611 | 0.009152 | \*\* |  |  |  |  |
| Mean\_Global\_PPM\_CO2 | 4.03E-02 | 1.24E-02 | 3.257 | 1.16E-03 | \*\* |  |  |  |  |
| Mean\_Global\_PPM\_CCl4 | -1.48E-01 | 5.75E-02 | -2.57 | 0.010294 | \* |  |  |  |  |
| Mean\_Global\_PPM\_CF4 | 1.86E+01 | 3.01E+00 | 6.189 | 8.58E-10 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC11 | -1.99E-01 | 9.28E-02 | -2.142 | 3.24E-02 | \* |  |  |  |  |
| Mean\_Global\_PPM\_CFC11\_eq | -5.28E+01 | 8.61E+00 | -6.137 | 1.18E-09 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC12 | -6.52E+01 | 1.06E+01 | -6.167 | 9.86E-10 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC12\_eq | 6.52E+01 | 1.06E+01 | 6.166 | 9.92E-10 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC113 | -2.20E-01 | 1.05E-01 | -2.095 | 0.036386 | \* |  |  |  |  |
| Mean\_Global\_PPM\_CFC114 | -3.41E-01 | 1.50E-01 | -2.274 | 0.023135 | \* |  |  |  |  |
| Mean\_Global\_PPM\_CH3CCl3 | -5.55E-02 | 2.20E-02 | -2.517 | 1.20E-02 | \* |  |  |  |  |
| Mean\_Global\_PPM\_HCFC22 | -1.91E-01 | 8.40E-02 | -2.279 | 2.29E-02 | \* |  |  |  |  |
| Mean\_Global\_PPM\_HCFC142b | -1.21E+00 | 2.16E-01 | -5.628 | 2.33E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC23 | 3.60E+01 | 5.82E+00 | 6.186 | 8.76E-10 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC32 | 2.19E+01 | 3.59E+00 | 6.092 | 1.55E-09 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC125 | 4.68E+01 | 7.63E+00 | 6.138 | 1.17E-09 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC134a | 3.25E+01 | 5.31E+00 | 6.126 | 1.27E-09 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC143a | 3.32E+01 | 5.39E+00 | 6.16 | 1.02E-09 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC152a | 2.04E+01 | 3.39E+00 | 6.014 | 2.48E-09 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC227ea | 5.86E+01 | 1.02E+01 | 5.746 | 1.19E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC245fa | 4.97E+01 | 8.11E+00 | 6.126 | 1.26E-09 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC365mfc | 4.94E+01 | 9.29E+00 | 5.319 | 1.27E-07 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC4310mee | 1.22E+02 | 2.36E+01 | 5.167 | 2.84E-07 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CH3Cl | -1.75E-02 | 4.38E-03 | -3.986 | 7.19E-05 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_NF3 | 2.68E+01 | 7.51E+00 | 3.565 | 0.00038 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_N2O | -6.46E-02 | 2.44E-02 | -2.646 | 0.008275 | \*\* |  |  |  |  |
| Mean\_Global\_PPM\_SF6 | 1.22E+02 | 1.95E+01 | 6.239 | 6.31E-10 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_SO2F2 | 4.25E+01 | 7.47E+00 | 5.684 | 1.69E-08 | \*\*\* |  |  |  |  |
| --- |  |  |  |  |  |  |  |  |  |
| Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1 | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Residual standard error: 0.311 on 1072 degrees of freedom | | | | |  |  |  |  |  |
| Multiple R-squared: 0.6376, Adjusted R-squared: 0.6272 | | | | |  |  |  |  |  |
| F-statistic: 60.85 on 31 and 1072 DF, p-value: < 2.2e-16 | | | | |  |  |  |  |  |

Model without CO2 Variable Statistical Analysis

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Call: |  |  |  |  |  |  |  |  |  |
| lm(formula = Temperature\_Anomaly ~ ., data = training\_set) | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Residuals: |  |  |  |  |  |  |  |  |  |
| Min | 1Q | Median | 3Q | Max |  |  |  |  |  |
| -1.08603 | -0.18926 | 0.00282 | 0.19698 | 1.19426 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Coefficients: | Estimate | Std. Error | t value | Pr(>|t|) |  |  |  |  |  |
| (Intercept) | -1.21E+01 | 4.02E+01 | -0.3 | 0.76428 |  |  |  |  |  |
| Total\_Solar\_Irradiance | 8.59E-03 | 2.85E-02 | 0.302 | 0.76308 |  |  |  |  |  |
| Mean\_Global\_PPM\_CC4F8 | 1.91E+04 | 6.51E+04 | 0.293 | 0.7692 |  |  |  |  |  |
| Mean\_Global\_PPM\_C2F6 | 1.49E+04 | 5.09E+04 | 0.294 | 0.76916 |  |  |  |  |  |
| Mean\_Global\_PPM\_C3F8 | 1.67E+04 | 5.70E+04 | 0.293 | 0.76943 |  |  |  |  |  |
| Mean\_Global\_PPM\_C4F10 | 2.14E+04 | 7.32E+04 | 0.293 | 0.7699 |  |  |  |  |  |
| Mean\_Global\_PPM\_C5F12 | 2.44E+04 | 8.34E+04 | 0.293 | 0.76952 |  |  |  |  |  |
| Mean\_Global\_PPM\_C6F14 | 2.63E+04 | 8.95E+04 | 0.294 | 0.76918 |  |  |  |  |  |
| Mean\_Global\_PPM\_C7F16 | 2.98E+04 | 1.02E+05 | 0.293 | 0.76983 |  |  |  |  |  |
| Mean\_Global\_PPM\_C8F18 | 3.31E+04 | 1.12E+05 | 0.295 | 0.76767 |  |  |  |  |  |
| Mean\_Global\_PPM\_CCl4 | -8.71E-02 | 1.82E-01 | -0.478 | 0.63278 |  |  |  |  |  |
| Mean\_Global\_PPM\_CF4 | 5.38E+03 | 1.83E+04 | 0.294 | 0.76911 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC11 | -8.79E-02 | 2.88E-01 | -0.305 | 0.76015 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC11\_eq | -1.55E+04 | 5.29E+04 | -0.294 | 0.76914 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC12 | -1.91E+04 | 6.51E+04 | -0.294 | 0.76914 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC12\_eq | 1.91E+04 | 6.51E+04 | 0.294 | 0.76914 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC113 | -7.35E-02 | 3.02E-01 | -0.244 | 0.80735 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC114 | -2.91E-01 | 3.78E-01 | -0.769 | 0.44174 |  |  |  |  |  |
| Mean\_Global\_PPM\_CFC115 | 2.19E-01 | 9.95E-01 | 0.22 | 0.82565 |  |  |  |  |  |
| Mean\_Global\_PPM\_CH2Cl2 | 5.29E-02 | 4.20E-02 | 1.261 | 0.20752 |  |  |  |  |  |
| Mean\_Global\_PPM\_CH3CCl3 | -3.62E-02 | 6.71E-02 | -0.54 | 0.58946 |  |  |  |  |  |
| Mean\_Global\_PPM\_CHCl3 | -3.25E-03 | 9.74E-02 | -0.033 | 0.97339 |  |  |  |  |  |
| Mean\_Global\_PPM\_Halon1211 | 1.76E+00 | 1.81E+00 | 0.976 | 0.32913 |  |  |  |  |  |
| Mean\_Global\_PPM\_Halon1301 | 1.54E+00 | 1.44E+00 | 1.07 | 0.28496 |  |  |  |  |  |
| Mean\_Global\_PPM\_Halon2402 | -2.16E+01 | 8.51E+00 | -2.534 | 0.01138 | \* |  |  |  |  |
| Mean\_Global\_PPM\_HCFC22 | -5.84E-02 | 2.48E-01 | -0.236 | 0.81365 |  |  |  |  |  |
| Mean\_Global\_PPM\_HCFC142b | -5.86E-01 | 3.06E-01 | -1.915 | 0.05576 | . |  |  |  |  |
| Mean\_Global\_PPM\_HFC23 | 1.08E+04 | 3.66E+04 | 0.294 | 0.76914 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC32 | 6.57E+03 | 2.24E+04 | 0.294 | 0.76918 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC125 | 1.37E+04 | 4.68E+04 | 0.294 | 0.76913 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC134a | 9.55E+03 | 3.25E+04 | 0.294 | 0.76914 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC143a | 9.55E+03 | 3.25E+04 | 0.294 | 0.76912 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC152a | 5.97E+03 | 2.03E+04 | 0.294 | 0.76914 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC227ea | 1.55E+04 | 5.29E+04 | 0.294 | 0.76905 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC236fa | 1.43E+04 | 4.88E+04 | 0.292 | 0.77022 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC245fa | 1.43E+04 | 4.88E+04 | 0.294 | 0.76914 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC365mfc | 1.31E+04 | 4.48E+04 | 0.294 | 0.76907 |  |  |  |  |  |
| Mean\_Global\_PPM\_HFC4310mee | 2.51E+04 | 8.54E+04 | 0.294 | 0.76907 |  |  |  |  |  |
| Mean\_Global\_PPM\_CH4 | 4.20E-03 | 1.27E-03 | 3.295 | 0.00101 | \*\* |  |  |  |  |
| Mean\_Global\_PPM\_CH3Br | -1.10E-01 | 1.50E-01 | -0.735 | 0.4626 |  |  |  |  |  |
| Mean\_Global\_PPM\_CH3Cl | -9.66E-03 | 1.06E-02 | -0.911 | 0.36252 |  |  |  |  |  |
| Mean\_Global\_PPM\_NF3 | 1.19E+04 | 4.07E+04 | 0.293 | 0.7692 |  |  |  |  |  |
| Mean\_Global\_PPM\_N2O | -7.14E-02 | 2.46E-02 | -2.905 | 0.00373 | \*\* |  |  |  |  |
| Mean\_Global\_PPM\_SF6 | 3.40E+04 | 1.16E+05 | 0.294 | 0.76913 |  |  |  |  |  |
| Mean\_Global\_PPM\_SO2F2 | 1.19E+04 | 4.07E+04 | 0.294 | 0.76911 |  |  |  |  |  |
| --- |  |  |  |  |  |  |  |  |  |
| Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1 | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Residual standard error: 0.3139 on 1334 degrees of freedom | | | | |  |  |  |  |  |
| Multiple R-squared: 0.6314, Adjusted R-squared: 0.6193 | | | | |  |  |  |  |  |
| F-statistic: 51.98 on 44 and 1335 DF, p-value: < 2.2e-16 | | | | |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Call: |  |  |  |  |  |  |  |  |  |
| lm(formula = Temperature\_Anomaly ~ ., data = x) | | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Residuals: |  |  |  |  |  |  |  |  |  |
| Min | 1Q | Median | 3Q | Max |  |  |  |  |  |
| -1.07987 | -0.18698 | 0.00279 | 0.18797 | 1.08791 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Coefficients: | Estimate | Std. Error | t value | Pr(>|t|) |  |  |  |  |  |
| (Intercept) | 5.94E+00 | 8.81E+00 | 0.675 | 0.499938 |  |  |  |  |  |
| Mean\_Global\_PPM\_CC4F8 | 5.25E+01 | 1.02E+01 | 5.151 | 3.08E-07 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_C2F6 | 4.80E+01 | 9.10E+00 | 5.281 | 1.56E-07 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_C6F14 | 1.86E+02 | 5.44E+01 | 3.414 | 6.63E-04 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_C8F18 | 1.75E+02 | 7.52E+01 | 2.324 | 0.020292 | \* |  |  |  |  |
| Mean\_Global\_PPM\_CCl4 | -2.15E-01 | 5.48E-02 | -3.922 | 9.34E-05 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CF4 | 1.69E+01 | 3.06E+00 | 5.516 | 4.34E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC11 | -3.08E-01 | 8.73E-02 | -3.521 | 4.47E-04 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC11\_eq | -4.80E+01 | 8.77E+00 | -5.477 | 5.40E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC12 | -5.94E+01 | 1.08E+01 | -5.519 | 4.28E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC12\_eq | 5.95E+01 | 1.08E+01 | 5.518 | 4.31E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC113 | -3.31E-01 | 9.95E-02 | -3.323 | 9.20E-04 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CFC114 | -5.68E-01 | 1.24E-01 | -4.571 | 5.42E-06 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CH3CCl3 | -7.79E-02 | 2.12E-02 | -3.665 | 0.00026 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HCFC22 | -2.81E-01 | 7.89E-02 | -3.557 | 3.91E-04 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HCFC142b | -1.15E+00 | 2.16E-01 | -5.31 | 1.34E-07 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC23 | 3.27E+01 | 5.93E+00 | 5.517 | 4.33E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC32 | 1.98E+01 | 3.66E+00 | 5.395 | 8.41E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC125 | 4.29E+01 | 7.77E+00 | 5.529 | 4.05E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC134a | 2.96E+01 | 5.41E+00 | 5.468 | 5.65E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC143a | 2.99E+01 | 5.51E+00 | 5.428 | 7.06E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC152a | 1.86E+01 | 3.45E+00 | 5.385 | 8.90E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC227ea | 5.18E+01 | 1.04E+01 | 5.005 | 6.53E-07 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC245fa | 4.58E+01 | 8.21E+00 | 5.571 | 3.20E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC365mfc | 4.45E+01 | 9.50E+00 | 4.681 | 3.23E-06 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_HFC4310mee | 1.22E+02 | 2.36E+01 | 5.177 | 2.69E-07 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_CH4 | 3.43E-03 | 1.11E-03 | 3.084 | 2.09E-03 | \*\* |  |  |  |  |
| Mean\_Global\_PPM\_CH3Cl | -1.67E-02 | 4.38E-03 | -3.804 | 1.50E-04 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_NF3 | 2.55E+01 | 7.54E+00 | 3.383 | 0.000744 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_N2O | -6.23E-02 | 2.48E-02 | -2.508 | 0.012283 | \* |  |  |  |  |
| Mean\_Global\_PPM\_SF6 | 1.09E+02 | 1.99E+01 | 5.47 | 5.61E-08 | \*\*\* |  |  |  |  |
| Mean\_Global\_PPM\_SO2F2 | 3.99E+01 | 7.57E+00 | 5.27 | 1.65E-07 | \*\*\* |  |  |  |  |
| --- |  |  |  |  |  |  |  |  |  |
| Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1 | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Residual standard error: 0.3112 on 1072 degrees of freedom | | | | |  |  |  |  |  |
| Multiple R-squared: 0.6373, Adjusted R-squared: 0.6268 | | | | |  |  |  |  |  |
| F-statistic: 60.76 on 31 and 1072 DF, p-value: < 2.2e-16 | | | | |  |  |  |  |  |