1-1-2016

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Recommended Citation

Lee, H. (2016). Analysis of Carbon Dioxide and Cloud Effects on Temperature in Northeast China. Procedia Computer Science, 91, 690–699. https://doi.org/10.1016/j.procs.2016.07.172

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 91 (2016) 690 – 699

Procedia Computer Science

Information Technology and Quantitative Management (ITQM 2016)

Analysis of Carbon Dioxide and Cloud Effects on Temperature in Northeast China

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Abstract

With the observed rise in temperature, many researchers have tried to identify the causes of such climate change to help mitigate its effects. The objective of this study is to determine whether, under the same carbon dioxide (CO_2) concentrations, CO_2 with lower cloud coverage would raise the temperature at a greater rate than CO_2 with higher cloud coverage. The hypothesis was tested through data analysis and modeling. The relationships between the temperature and the CO_2 emissions, the temperature and the cloud coverage, and the CO_2 emissions and the cloud coverage were identified using Pearson's correlation test. The data analysis concluded that the relationship between the temperature and the CO_2 emission is positively proportional with a significant correlation. The relationship between the cloud coverage and the temperature and the relationship between the CO_2 emissions and the cloud coverage were determined to be negatively proportional with significant correlations. For modeling, the temperature increased more rapidly as cloud coverage shrank. The results supported the hypothesis that the cloud coverage mitigates warming effects created by carbon dioxide emissions. Further research is anticipated to reduce the uncertainties in the data along with specification of cloud types.

Peer-review under responsibility of the Organizing Committee of ITQM 2016

Keywords: Carbon Dioxide Emissions; Cloud Coverage; Environmental Science

1. Introduction

1.1. Background Research

On The temperature of the Earth is determined by the balance between the input and output of energy [1]. In other words, if the energy coming in from the Sun and the energy escaping out of the Earth by emitting radiation to space were in balance, the Earth's temperature would remain constant [2]. However, according to the Intergovernmental Panel on Climate Change (IPCC), the average global temperature has risen roughly 0.85ºC in the last 100 years [3]. In addition, the last three decades from 1983 to 2012 were said to be the

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Peer-review under responsibility of the Organizing Committee of ITQM 2016
doi:10.1016/j.procs.2016.07.172

warmest period of the last 1400 years; the term for such trend is called climate change [3]. Thus, the temperature of the Earth has risen, and it is because of the energy imbalance [2].

As the amount of energy coming from the Sun is relatively constant, most scientists agree the main cause of the current global warming is the anthropogenic increase in the greenhouse gases that trap the energy radiation from the Earth toward the space [4]. Among other greenhouse gases, carbon dioxide (CO_2) gets most of the attention as the key element of the Earth's climate system [5]. For example, Delworth et al. claimed that the doubling of carbon dioxide had influenced many regions, especially the tropics, with an increase in temperature [6]. For the future, IPCC, in 2007, estimated that Earth would warm between two and six degrees Celsius over the next century, depending on how fast the carbon dioxide emissions grow [4]. Given the effects of CO_2 have on radiation and climate change, many researchers and policymakers have focused on finding the CO_2 reduction targets to lessen its effects [2].

While the question of what to do about future climate change has been pending, some researchers saw cloud coverage as a potential factor of temperature change. Carslaw, Harrison, and Kirkby suggested that variations in the intensity of galactic cosmic rays in the atmosphere would alter in cloud coverage, leading to change the temperature of the Earth [7]. However, the effects of clouds on temperature are uncertain so many studies have tried to identify whether the cloud coverage has a negative or a positive feedback to the warming effects. For example, Dessler concluded that cloud coverage has a positive effect on the temperature [8]. Likewise, Clement, Burgman, and Norris and Lauer et al. claimed the cloud has a positive effect over the eastern Pacific [9-10]. Spencer and Braswell even claimed not carbon dioxide but cloud cover causes global warming [11]. On the other hand, McLean claimed that the reduced cloud coverage from 1987 to late 1990s accounts for the rise in temperature since 1987 [12]. Similarly, Kauppinen, Heionen, and Malmi, discussing the impact of cloud cover on the temperature, claimed that one percent increase in low cloud cover decreases 0.11 degree Celsius [13].

Based on these studies, solutions related to clouds were proposed to lessen climate change. For instance, Lomborg of Copenhagen Consensus Center came up with a proposal to develop cloud whitening technology to reflect solar radiation [14]. Similarly, Russell claimed cloud brightening research had merit in combating global warming [15]. Since these recent studies have reflected the importance of clouds to the climate, it is time to verify the correlations among the CO_2 emissions, the cloud coverage, and the temperature and identify the impact of clouds.

1.2. Motive

The objective of this study is to examine the interactive effects of the CO2 emissions and the cloud coverage on temperature. By analyzing the relevant data sets from Northeast China and using the climate change model of NetLogo 5.2., this study is to identify the relationship and the interactions between CO2 concentration and cloud coverage and, thus, find a more efficient way to mitigate global warming.

2. Methodology

2.1. Hypothesis

If the Earth has a constant CO_2 concentration, then the CO_2 with lower cloud coverage will raise the temperature at a greater rate than the CO_2 with higher cloud coverage. In other words, the warming effects from the increase in the carbon dioxide level will be mitigated more when accompanied by the increase in cloud coverage than by the reduction in carbon dioxide emissions alone.

2.2. General Overview

This study applied two methods: data analysis and modeling. Real-world data from Northeast China will be analyzed to examine the correlation between the temperature and the CO_2 emissions, the correlation between temperature and cloud coverage, and the correlation between the cloud coverage and the carbon dioxide emissions. For modeling, NetLogo 5.2., a modeling program made by Northwestern University for simulating natural phenomena, was used to test interactive effects of carbon dioxide and cloud amount on temperature. The results from the model and the data analysis were compared to cross-check the relationship between the variables.

2.3. Data Sets

China was chosen as the region for data analysis since it released the largest amount of CO_2 [16]. However, as China is the third biggest country in the world, the region was limited to be Northeast China to reduce the error. Since the CO_2 emissions data were not limited to a specific region of China, the uncertainty was taken into account. The seasonal temperature and cloud coverage data over Northeast China and annual CO_2 emissions data from China were used for data analysis.

The monthly temperatures of Northeast China from 1909 to 2012 was acquired from Osborn and Jones [17-18]. The data contain monthly mean temperatures over Northeast China. The data report the temperatures to the hundredths place in degrees Celsius.

The seasonal coverage of clouds over Northeast China during 1951-1994 were acquired through the work of Kaiser [19]. The cloud data were excerpted from a database of daily weather observations provided by the National Climate Center of the China Meteorological Administration. The data were received from 196 Chinese stations. To minimize errors, Kaiser differentiated daytime and nighttime observation since it is troublesome to accurately measure the cloud coverage when the sky is dark. The cloud coverage was averaged for each station over four seasons.

The annual emissions of CO_2 in China from 1751 to 2008 were acquired from the Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory, which is supported by the U.S. Department of Energy [1]. The data were found on the Carbon Dioxide Information Analysis Center homepage. The authors analyzed the trends for the CO_2 along with the data.

2.4. Process

Data for temperature, CO_2, and cloud coverage were computed into Microsoft Excel for analysis. Since the time interval of the data and the averaged times were different, the data needed to be processed to be comparable. The monthly temperature data were averaged over four three-month meteorological seasons over each year: spring (March, April, and May), summer (June, July, and August), autumn (September, October, and November), and winter (consecutive December, January, and February). The annual data of the CO_2 emissions were used to compare to the seasonal data of the temperature and the cloud coverage. The risk of error was taken because the seasonal temperature and the cloud coverage data could be biased if averaged. The seasonal differences may not be taken into account if seasonal cloud coverage was averaged annually. For instance, the cloud coverage for the spring of 1953 was 43.03 percent, and the cloud coverage for the fall of 1953 was 68.56 percent; on the other hand, the cloud coverage for the spring of 1993 was 30.60 percent and the cloud coverage for the fall of 1993 was 71.53 percent. The cloud coverage for spring was higher in 1953, but the cloud coverage for fall was higher in 1993. Hence, the annual average of cloud coverage is not the best representation for the cloud coverage. The same goes for temperature data. Due to the Arctic Oscillation, winters get colder than other seasons during certain years [20]. The air moves from high pressure to low pressure; accordingly, if the air pressure is higher in the Arctic, then the cold air from the Arctic moves farther south [20]. Therefore, like the cloud coverage data, the annual average of temperature would not be suitable to represent the temperature data since the colder winter temperatures would lower other seasons' temperatures. Therefore, annual data of the CO_2 emissions was used to compare to other seasonal data.

Each data set was graphed against time to analyze the trend. The graphs showed that temperature had been rising over time. Thus, the data support the warming in China. The CO_2 emission had also been rising as China became developed. The cloud coverage had been constantly decreasing over time. Although it seemed like a minor change, the decrease had been decreasing for 43 years.

The Pearson's correlation test was used to determine the correlation between the temperature and the carbon dioxide emission, the temperature and the cloud coverage, and the carbon dioxide emission and the cloud coverage. Additionally, the regression line slopes and the constants were calculated to visualize and determine the trend. Only graph for the spring season was created and referenced because other seasons showed the same pattern.

Firstly, the correlation between the temperature and the CO_2 emission was calculated through data from China. The graph (Fig. 1) was created to visualize the relationship between carbon dioxide and temperature. Since the carbon dioxide emission is an anthropogenic factor and was not dependent upon temperature, the carbon dioxide emission was determined to be the independent variable and the temperature was determined to be the dependent variable. As the graph (Fig. 1) shows, the carbon dioxide and the temperature have a positively proportional relationship. The correlation was determined by comparing the correlation coefficients (r) to critical values of Pearson's correlation test and interpreting coefficient of determination (r^2). The degree of freedom (n-2) was 41. With the level of significance of 0.05, the critical value was determined to be 0.3008. The critical values were compared to the absolute values of the correlation coefficients to signify the correlation.

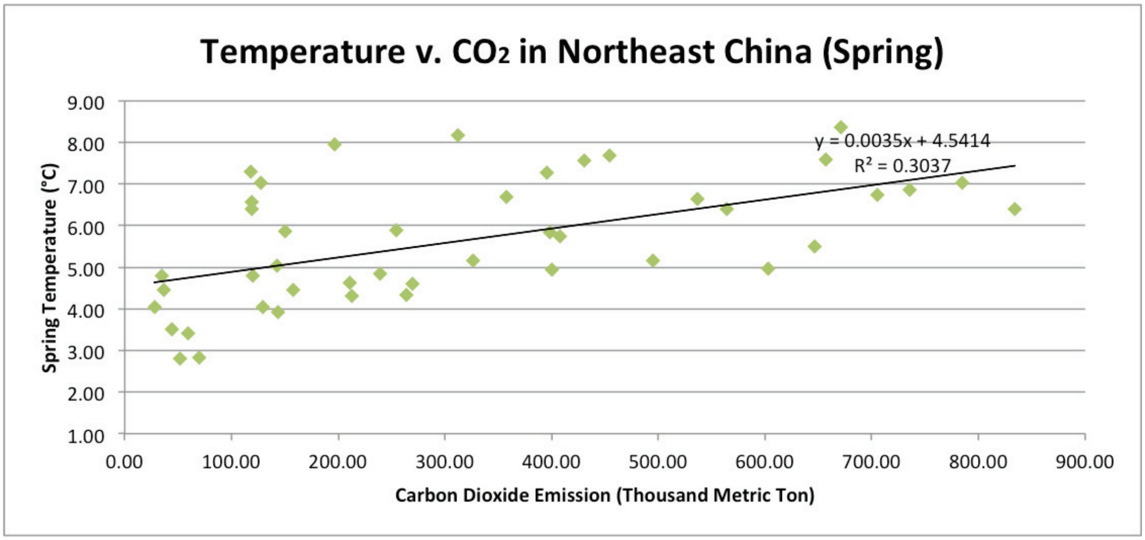

Fig. 1. Graph showing the correlation between the carbon dioxide emission and temperature during 1951-1994

Second, the correlation between the temperature and the cloud coverage was calculated through data from China. Likewise, the graph (Fig. 2) visualizes the relationship between the cloud coverage and the temperature. Given Carslaw, Harrison, and Kirkby suggesting that variations in the cloud coverage lead to the temperature change of the Earth, the cloud coverage was determined to be the independent factor, and the temperature was determined to be the dependent factor [7]. As seen in the figure (Fig. 2), the cloud coverage and the temperature are negatively proportional. In a similar fashion, the correlation was determined by comparing the correlation coefficients to critical values of Pearson's correlation test and interpreting coefficients of determination. The degree of freedom was 41 for spring, summer, and autumn and 40 for winter. With the level of significance of

0.05, the critical value was determined to be 0.3008 for spring, summer, and autumn and 0.3044 for winter. The critical values were compared to the absolute values of the correlation coefficients to signify the correlation.

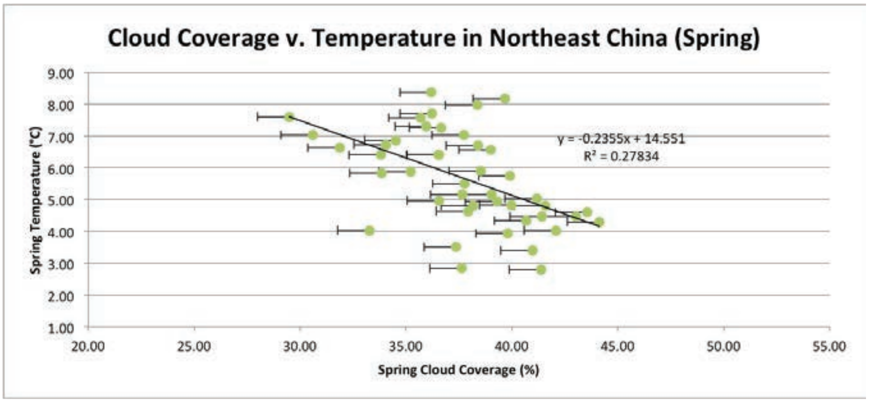

Fig. 2. Graph showing the correlation between the cloud coverage and temperature during 1951-1994

To determine the interactive effects of carbon dioxide and cloud coverage, the correlation between those two factors were also calculated through data from China. Furthermore, even if cloud coverage had a correlation with the temperature, the correlation could have been triggered by carbon dioxide emissions. In other words, the carbon dioxide emission could be the factor for both the cloud coverage and the temperature. Therefore, the correlation between carbon dioxide emission and the cloud coverage were calculated through data from China. Likewise, the figure (Fig. 3) was created to represent the relationship between cloud coverage and carbon dioxide. Since the carbon dioxide emission is an anthropogenic factor and is not hindered by nature, the carbon dioxide emission was determined to be the independent variable, and the cloud coverage was determined to be the dependent variable. As seen in the graphs (Fig. 3), the cloud coverage and the carbon dioxide emission are negatively proportional. Correspondingly, the correlation was determined by comparing the correlation coefficients to the critical values of Pearson's correlation test and interpreting coefficients of determination. The degree of freedom was 41 for spring, summer, and autumn and 40 for winter. With the level of significance of 0.05, the critical value was determined to be 0.3008 for spring, summer, and autumn and 0.3044 for winter. The critical values were compared to the absolute values of the correlation coefficients.

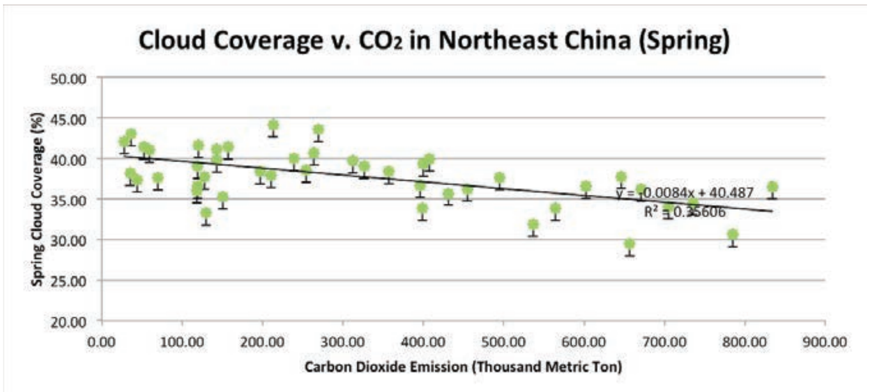

Fig. 3. Graph with the correlation between the cloud coverage and carbon dioxide emissions during 1951-1994

2.5. Modeling

NetLogo is simple but well equipped with the features necessary for modeling climate change [21]. NetLogo visualized the interactions among variables related to climate change. The available factors of NetLogo are the sun-brightness, albedo, cloud coverage, and CO_2 concentration. The carbon dioxide concentration, sun-brightness, and albedo were control factors and left constant. The cloud coverage was set as the dependent factor in the model while the temperature was observed as the explained variable. The cloud coverage was set to be the independent factor because the hypothesis attempts to observe how the cloud coverage mitigates the warming effects of carbon dioxide. The temperature change was observed over time, and the unit of time was set as ticks. The temperature was observed after given 1103~1124 ticks.

Although the process should check the agreement between the data analysis and the model, the modeling was done under the present global condition to predict the outcome after current situation. The model was based on the carbon dioxide concentration rather than the carbon dioxide emission. Since the data analysis is based on the emissions of carbon dioxide, a direct comparison may be hard to make, but the model gives a general overview of the role of the carbon dioxide. The average carbon dioxide concentration was 392.7 ± 2.6 parts-per-million (ppm) in 2011 of China [22]. Since the model escalates by 25 ppm, the model was set to the concentration of 400 ppm.

The cloud coverage was incremented by 25 percent starting from 0 percent. However, the model had a vague system of adding clouds. NetLogo 5.2. had 'add cloud' button and the visualization of the system, but it did not give the exact number of cloud coverage. The area of clouds and the area of atmosphere needed to be determined to calculate the cloud coverage.

First, the cloud coverage was estimated through eyes into 0 percent, 25 percent, 50 percent, 75 percent, and 100 percent. The settings with 0 percent and 100 percent did not need to be calculated. The software MATLAB 8.5 was used to calculate the area of the clouds. The cloud coverage is represented by the color white. Image Analyst provided a program that calculates the area of a certain color in a gray scale picture [23]. The program was modified to calculate the area of the clouds. Therefore, screenshots of the model were taken and the picture went through visual analysis through code. The code converted the picture into gray scale and analyzed the picture. The area of each cloud was acquired through the data. Afterwards, the areas were put into Microsoft Excel for addition. The area of the clouds for estimated 25 percent cloud coverage was 97,175 pixels, and the area of the clouds for estimated 50 percent cloud coverage was 186,188 pixels. The area of the clouds for estimated 75 percent cloud coverage was 308,837 pixels. Since the screenshot was a 1121 × 371 sized picture, the area of the atmosphere was calculated to be 418,117 pixels. The area of the clouds divided by the area of the atmosphere multiplied by 100 gives the cloud coverage. After calculation, the cloud coverage was determined each to be 23.24 percent, 44.53 percent, and 73.86 percent. Therefore, the modeling was done under the settings with cloud coverage as 0.00 percent, 23.24 percent, 44.53 percent, 73.86 percent, and 100.00 percent.

3. Results

3.1. Results

The Pearson's correlation test was used to verify the correlation between the carbon dioxide emission and the temperature. The correlation coefficients were 0.5511 for spring, 0.4446 for summer, 0.4300 for fall, and 0.4666 for winter. Positive correlation coefficients indicate that the carbon dioxide and the temperature have a positive relationship. The coefficients of determination were 0.3037 for spring, 0.1976 for summer, 0.1849 for autumn, and 0.2177 for winter. The coefficient of determination calculates the percentage of value that can be predicted and is acceptably high. The absolute values of correlation coefficients were greater than the critical values over all seasons, 0.3008. Therefore, the hypothesis that the temperature was related carbon dioxide emission was supported by the data with the confidence interval of 0.05.

The Pearson's correlation test was also used to determine the correlation between the carbon dioxide emission and the temperature. The correlation coefficients were -0.5276 for spring, -0.6180 for summer, -0.4517 for autumn, and -0.3106 for winter. Negative correlation coefficients indicate that cloud coverage and temperature have a negative relationship. The coefficients of determination were 0.2783 for spring, 0.3819 for summer, 0.2040 for autumn, and 0.0964 for winter. The absolute values of correlation coefficients were higher than the critical values over all seasons, 0.3008 for spring, summer, and autumn and 0.3044 for winter. Therefore, the hypothesis that the temperature was related cloud was supported by the data with the confidence interval of 0.05.

The Pearson's correlation test was also used to check the correlation between the carbon dioxide emission and the cloud coverage. The correlation coefficients were -0.5967 for spring, -0.4718 for summer, -0.3749 for fall, and -0.4015 for winter. Negative correlation coefficients demonstrate that carbon dioxide emissions and cloud coverage have a negative relationship. The coefficients of determination were 0.3561 for spring, 0.2226 for summer, 0.1406 for autumn, and 0.1612 for winter, which is an acceptable number for r^2. The absolute values of correlation coefficients were higher than the critical values over all seasons, 0.3008 for spring, summer, and autumn and 0.3044 for winter. Therefore, the possibility that carbon dioxide could be the factor of the cloud coverage is supported by the data with the confidence interval of 0.05.

In the model, for 0 percent cloud coverage, the temperature increased rapidly. The temperature increased from 12.0°C to 20.3°C over 1103 ticks. For 23.24 percent cloud coverage, the temperature increased sluggishly compared to the temperature increase with 0 percent cloud coverage. The temperature increased from 12.0°C to 15.3°C over 1115 ticks. For 44.53 percent cloud coverage, the temperature increased less rapidly compared to the temperature increase with 23.24 percent cloud coverage. The temperature increased from 12.0°C to 12.9°C over 1113 ticks. For 73.86 percent cloud coverage, the temperature barely increased from 12.0°C to 12.1°C over 1124 ticks. For 100 percent cloud coverage, the temperature stayed constant from 12.0°C to 12.0°C over 1108 ticks. The trend was observed that temperature decreased as the cloud coverage rose.

3.2. Error

Multiple factors contribute to the temperature of the Earth. Most researchers admit that CO_2 and Earth's temperature are closely correlated; thus, they increase and decrease together. However, specifying moderator factors is difficult because numerous factors contribute to climate change and correlate with CO_2. Since only CO_2 emissions and cloud amount are considered in this study, effects of other factors are disregarded. Those neglected the effects from other factors is a source of error.

Additionally, the errors underlie in the acquired data sets. The errors for the cloud coverage data were received from the original data set. The confidence interval for the cloud coverage data of spring is -1.2 percent, and the confidence interval for the cloud coverage data of summer is -0.9 percent [19]. The confidence interval for the cloud coverage data of fall is -1.0 percent; the confidence interval for the cloud coverage data of winter is -0.9 percent [19]. The error bar was created to represent those uncertainties.

Along with the cloud coverage data, the carbon dioxide emissions data set and the temperature data set also contain error. A significant uncertainty lies in measuring the emission of CO_2 since CO_2 is a gas. In addition, CO_2 emission could have been underestimated due to the lack of devices and vast country size. In regards to the temperature, the uncertainty has a similar risk. The equipment might not have been accurate enough to measure the temperature. However, the data were acquired from 1951 to 1994, which is recent. Since confidence interval was not mentioned from the providers. The error was assumed to be up to the last significant digit. Therefore, for carbon dioxide, the confidence interval is ± 0.5 ton, and the confidence interval for temperature is ± 0.005°C. On the figures, the error was too small to be represented with the error bar. Although the error was assumed, the error is not exact; this is counted as one of the limitations.

4. Conclusions and Discussion

The objective of the research was accomplished through the Pearson's correlation test and modeling. The Pearson's correlation test demonstrated the validity of the hypothesis for correlations between three factors, temperature, carbon dioxide emissions, and cloud coverage. The critical values for Pearson's correlation were smaller than the absolute values of all correlation coefficient with 95% certainty; thus, the null hypotheses were rejected.

The initial hypothesis was that the warming effects from the increase in CO_2 would be mitigated more with the increase in cloud coverage than by the reduction in CO_2 emissions alone. The project hypothesis was confirmed with the confidence interval of 0.05 through Pearson's correlation test. However, the research raises uncertainties whether clouds are dependent upon carbon dioxide emission or the temperature is dependent upon both carbon dioxide emission and cloud coverage. Although the question remains unanswered, the trend is being shown with the cloud coverage over time; the decrease had been going on for over 43 years and is certainly notable. Therefore, although model approved that the cloud coverage has an influence over the temperature, the idea that cloud may be dependent upon carbon dioxide emission arises. In conclusion, the reduction of carbon dioxide emission could lead to the multiplication of cloud coverage, and since both factors are accountable for temperature change, the temperature will decrease in greater amount. The research suggests reduction in carbon dioxide could lead to killing two birds with one stone, affecting both cloud coverage and temperature.

The limit of the research lies in the uncertainties in the data and lack of details in the data set. The errors of the carbon dioxide data and the temperature data were not provided. Also, the specifications for the cloud data are deficient. The cloud coverage data does not specify the kind of clouds. Lauer et al. (2010) stated that warming effects differ by cloud types [10]. Thus, although the research concluded that the cloud coverage had a negative effect on temperature, further research is recommended to specify cloud types.

The research could be extended further also by testing whether carbon dioxide emission affects cloud coverage. Although the research put forth Pearson's correlation test to test whether carbon dioxide emission, and temperature, cloud coverage and temperature, carbon dioxide emission and cloud coverage had correlations, it did not determine whether one caused the other. Therefore, if extended research were done to determine the factors, mitigation of climate change could be achieved more efficiently.

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