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A Simple Model for Quantitative Prediction of Future Climate Change

Heming Huang, Xinmeng Li, Xiaoyu Tian, and Andrew Zhang

Abstract—**In this work, we propose a simple but effective model to predict the future changes in global temperature based on the greenhouse gases emission rate. Our model provides an empirical formula which connects the global average temperature with the atmospherical concentration of carbon dioxide. Parameters of the model are estimated by evaluating the existing climatic data. Good agreements are observed by comparing the predicted results with the Representative Concentration Pathways (RCPs) data. Moreover, a novel carbon dioxide elimination model that considers the impact of energy and climate governance is reported, and it could serve as a general approach when considering the influences from different climatic factors.**

Index Terms—**Representative concentration pathways (RCPs) data.**

I. INTRODUCTION

Being one of the most hotly debated topic of the 21st century, global warming and climate change has become not just a challenging issue for scientists, but also a dangerous topic in politics; Environmentalists argue that global warming has become too immense of a problem be ignored and call for regulations on businesses as well as lifestyle changes. Skeptics on the other hand claimed that the issue is exaggerated by researches with political intentions instead of tangible proofs.

Global warming can be generally defined as the long-term rise in the overall temperature of earth's atmosphere caused by the increasing level of greenhouse gases caused by human activities. Greenhouse gases include carbon dioxide (from burning of fossil fuel), methane (agricultural activities, waste management, energy usage, and biomass burning), Nitrous oxide (use of fertilizers ad burning of fossil fuel), and fluorinated gases (including hydro fluorocarbons, per fluorocarbons, and sulfur hexafluoride that comes from industrial processing, refrigeration, and consumer products), each playing different roles on raising the temperature of our planet [1], [2].

With the goal of educating ourselves as well as providing our own approach on this incredibly grand-scale problem, we began with researching on the Internet on the RCPs' and other models' approach to related problems [3]-[6]. It did not take us long to realize the scope of this problem make it one with so many uncertainties that it is impossible to have a single and accurate model. Too many aspects of nature and human causes can turn the fate of our planet in the matter of years. Factors like the population of human, the rate of deforestation and other possible land uses, economic growth of every country across the sea, the development of renewable energies, the intensity of government regulations are merely the human factors that can cause dramatic alterations to our predictions of the future.

With massive amount of factors that can change our result and erase our effort within the matter of seconds, we decided to separate this issue into several steps; the first step is to predict the future carbon dioxide emission without taking any human factors into account by using already existing data on global yearly carbon emissions. Another equation is then made to take into account of the human factors but distinctly from the first step so that great uncertainties within this equation will not destroy our predictions of the future carbon emission if it is to raise with the consistent rate it possess at this moment in history. The last part is to predict the average temperature of the atmosphere according to the carbon emission predictions we made about the future.

II. MATHEMATICAL MODEL

A. Assumptions and Justifications

Submit It is crucial to point out that we are only considering the effect Carbon Dioxide has on the temperature of the atmosphere. Other greenhouse gases listed in the Background information section are not being considered in our model.

Justification: Since carbon dioxide has the most direct influence on the climate as well as for simplistic reasons, we are only considering the effect it has on the average temperature of the earth.

Solid particles in the atmosphere such as black carbon aerosol could also impact the temperature are also not being considered.

Justification: Since these are solids that exist in the air, they do not count as greenhouse gases that we are asked to consider. Plus, the effect of carbon aerosol on the global temperature is still open for debate.

All other natural factors that can cause fluctuations to the global temperature including atmospheric circulation, ocean currents, biogeography, etc.

Justification: Changes to these natural factors cannot be predicted, and in turn impossible to be considered in our prediction of the average temperature of the atmosphere.

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B. Notation of Variables and Parameters

$C(t)$: Global concentration of carbon dioxide at time of t.
C_0: Global concentration of carbon dioxide at initial time.
t: Year index.
S: Climate sensitivity factor.
$T(t)$: Global average temperature at time of t.
T_0: Global average temperature at initial time.
P: The progress of eliminating carbon dioxide concentration in atmosphere in per- centage.
k: The rate of change of P.
A: The change of P with respect to time.
O: The objective elimination level of carbon dioxide concentration in percentage.

C. Carbon Dioxide Concentration Model

To predict the atmospherical average temperature, we started by constructing a growth model of the concentration of carbon dioxide. According to the data reported in [1], the atmospheric carbon dioxide concentration grew 1.6 percent annually from the year 1970 to 2004. The function is as follows

$$C(t) = C_0 1.016^t, 1970 \le t \le 2004 \qquad (1)$$

$C(t)$ denotes the concentration of carbon dioxide at time t, and C_0 is the initial concentration. Since it did not provide the data after year 2004, we also gathered the data from the United States Environmental Protection Agency [4]. We observed that the concentration curve follows a linear relation respecting to time. Therefore, we performed the linear regression to predict the future tendency.

Fig. 2 shows the Matlab outputs of the linear model of which provides the following information:

- Estimation of the slope: 1.7664
- Standard Error of the slope: 65.754
- Estimation of the y-intercept: -3161.6
- Standard Error of the y-intercept: 53.688
- Degree of freedom: 38
- Marginal error of the slope: 0.0544
- Marginal error of the y-intercept: 108.6857
- Confidence Interval of the slope: (1.7120, 1.8208)
- Confidence Interval of the y-intercept: (-3270.3, -3052.9)

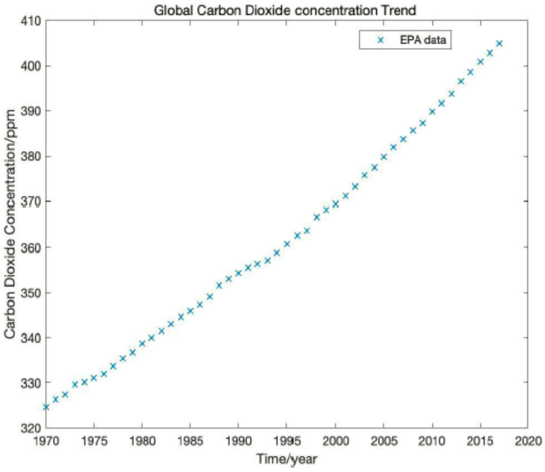
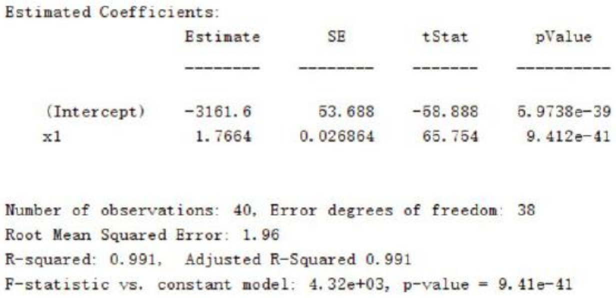


Fig. 1. Global carbon dioxide concentration from year 1970 to 2018.



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Estimated Coefficients:
                   Estimate       SE        tStat       pValue
                   ________    ________    _______    __________

    (Intercept)    -3161.6       53.688    -58.888    5.9738e-39
    x1              1.7664     0.026864     65.754     9.412e-41


Number of observations: 40, Error degrees of freedom: 38
Root Mean Squared Error: 1.96
R-squared: 0.991,  Adjusted R-Squared 0.991
F-statistic vs. constant model: 4.32e+03, p-value = 9.41e-41
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Fig. 2. Confidence interval, result from Matlab fitlm() function.

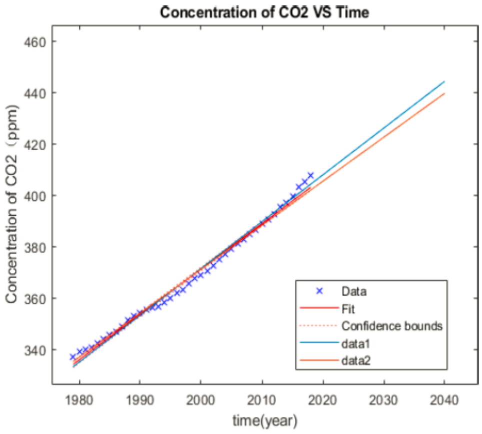

Fig. 3. Expected global annual carbon dioxide concentration.

From equation (1), we obtained a piecewise function of$C(t)$:

$$\frac{dC}{dt} = \begin{cases} In1.016C_0 1.016^t, & 1970 \le t \le 2004 \\ 1.7664 & 2005 \le t \end{cases} \qquad (2)$$

Based on the statement in [3], if the atmospheric carbon dioxide concentration doubles, the global temperature will be expected to see 1.8-4 degree Celsius increase. Hence, we assume the following formula:

$$T(t) = T_0 + S\,long_2(C(t)/C_0), \qquad (3)$$

where $T(t)$ denotes the global temperature at time of t; T_0 denotes the temperature at the initial time; S stands for the climate sensitivity factor.

D. Concentration Elimination Model

Our model is yet to include the scenarios such as changes of human activity and changes of governance regulations that might reduce the concentration of carbon dioxide. In Australia for example, reduction in atmospheric concentration of carbon dioxide has already taken place.

According to [6], the carbon dioxide concentration in Australia reached its historical maximum in 2009 and then decreased afterwards. Such tendency can also be seen in other developed countries in Europe. This is due to the fact that it has become more common with developed countries which promote sustain- able development plans with more strict regulations to reduce the emission of carbon dioxide.

In this case, a simple growth model won't be an appropriate model to pre- dict the future. Therefore, weimproved our model by considering the impacts from other human factors, such as the using of alternative energy resources and implement- ing regulations in emission.

Logistic differential equation could be a suitable model to determine the relationship between the percentage of progress with respect to time. The logistics growth curve was first published by Pierre Verhulst in 1845 to describe the growth in a population and has since been applied to many fields. Here, logistic growth curve is used to mimic the effect of carbon dioxide elimination. The more time and effort spent in decreasing carbon dioxide emission; the higher percentage of progress is achieved. The logistic growth curve has an upper bound which matches the situation in concentration elimination of carbon dioxide.

Since the atmospheric carbon dioxide serves as the major resource for plants growth through their process of photosynthesis, it is unreasonable to assume that carbon dioxide will be eliminated completely in the atmosphere.

Therefore, it can't be greater than 1.

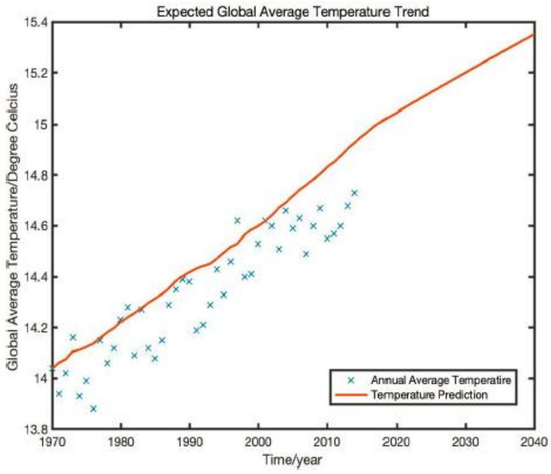

Fig. 4. Predicted global average temperature curve superimposed with existing data

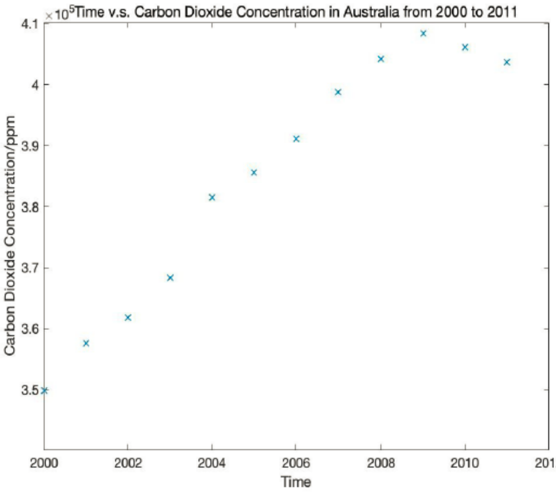

Fig. 5. Carbon dioxide concentration variation in Australia from year 2000 to 2011.

Assuming P (t) the percentage progress of eliminating the greenhouse gases emission with its value within the interval $[0, 1]$, we have:

$$\frac{dp}{dy} = kP(1-\frac{P}{O}) \tag{4}$$

The where k is a positive constant, and it depends on the magnitude of P . O denotes the objective concentration level of carbon dioxide. $(1-O)C(t)$ represents the ideal globalcarbon dioxide concentration. dP denoted the rate of change of P. By separating the variables:

$$\int \frac{dp}{P-(1-\frac{P}{O})} = \int kdt \tag{5}$$

$$In\left|\frac{O-P}{P}\right| = -kt-c \tag{6}$$

in which c denotes the constant that depends on the data. The expression of P (t) is:

$$p = \frac{o}{Ae^{-kt}+1} \tag{7}$$

whereas $A = e^{-c}$. Noted that when $t = 0$, P (t) has to be equal to 0. Finally, our elimination model reads as follows:

$$C^{'}(t) = (1-P(t))C(t) \tag{8}$$

$$T^{'}(t) = T_0 + S\,long_2(C^{'}(t)/C_0) \tag{9}$$

Since the global carbon dioxide concentration is still in the increasing trend, we exemplify the application of our model using the data from Australia. For simplicity, we study the progress of completely eliminating carbon dioxide, namely $O = 1$.

From 2009 to 2011, the annual carbon dioxide concentration levels were 408448.47, 406200.99, and 403705.52. By calculating the percentage decreased after taking the annual carbon dioxide growth into account, we obtain that carbon dioxide concentration in Australia decreased by .55 percent from 2009 to 2010, and .0116 percent of total carbon dioxide concentration was reduced from 2009 to 2011. By plugging in this set of data into our model, and set the initial time as 2009, we get a linear system as follows:

$$\frac{\dfrac{1}{Ae^{-K}+1} = 0.0055;}{\dfrac{1}{Ae^{-2K}+1} = 0.0116} \tag{10}$$

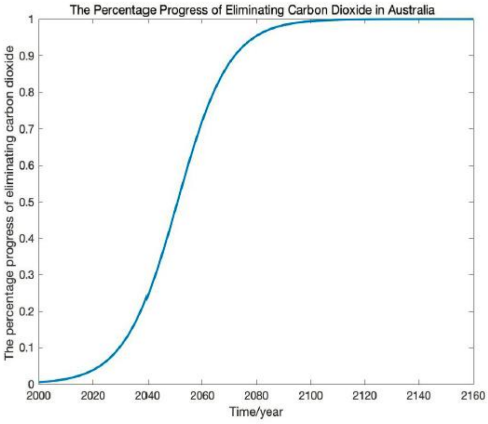

Fig. 6. The percentage progress of eliminating the concentration of carbon dioxide in Australia.

With the following solutions:

$$\frac{A = 383.7156;}{K = 0.7524} \tag{11}$$

Therefore, our model for Australia is:

$$P_A(t) = \frac{1}{383.7156e^{-0.7524t} + 1} \tag{12}$$

III. SENSITIVITY ANALYSIS

After performing the sensitivity analysis of our model, we found that the prediction of the carbon dioxide concentration model depends on the time interval that is chosen from the existing data. Since the model requires to perform the linear regression to predict the emission rate, we observed that a change in the data (data before 2000) wouldn't cause any major alteration in the slope of our regression line. However, there's a variation in the latest data, the regression line will change dramatically. When the error closed to the upper end is bigger than the real value, it will result the regression line to be bigger, thus leads to an over estimation, and vise versa. We remark that our temperature results obtained from the model is not sensitive with respect to the concentration of carbon dioxide. The climate sensitivity factor S may regularize the change, since S depends on data.

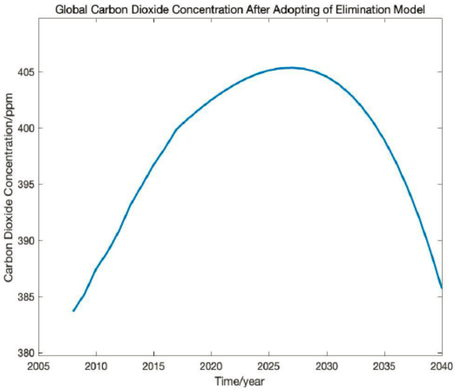

Fig. 7. The predicted curve of global carbon dioxide concentration. and source of information for science writers is [9].

Regarding to the elimination model, since the model is base on logistic growth equation, a small change closed to the two ends will cause significant change in estimating of A and k, and thus alter our prediction. While when the data is in the middle part of the logistic curve, the parameters that generated from the data are less sensitive.

The major advantage of our model is the following: The concept of the model is very simple and it provides an empirical formula to predict the temperature. Therefore, no massive calculation is required.

The elimination model may serve as a general framework to account for impacts which cause carbon dioxide reduction.

We also would like to point out the weakness of the model. According to the data in B1 scenario of Special Report on Emission Scenarios by in intergovernmental Panel on Climate Change (IPCC)[1], there is an increasing usage in clean and resources efficient technologies, which means that it is possible that there will be a descending trend in the future. In our model we only consider the scenario that the concentration of car- bon dioxide will increase. We would only use the elimination model when there is a decreasing trend appeared in the existing data.

This means that we could not use this model to predict the start of the descending trend.

IV. CONCLUSION

We proposed a simple model for quantitative prediction of future climate change. The model consists of three phases. The first part is the carbon dioxide concentration model which calculates the concentration of carbon dioxide over time. Concentration of carbon dioxide data was collected from 1970 to 2018 and the linear regression method was adopted to estimate the emission rate. The second part is the empirical formula for global averaged temperature of which depends on the concentration of carbon dioxide. The third part is the elimination model which considers the government measurements in reducing carbon dioxide. Promising results are observed by comparing the predicted results with the Representative Concentration Pathways (RCPs) data. Moreover, the carbon dioxide elimination model could serve as a general approach to study the impacts of other climatic factors.

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Huang previously finished research regarding the impact on industrial robots in the Chinese labor market, and published and presented this paper in the ICEBT conference in Madrid, Spain. The photo is taken on August 2019, during the conference in Madrid.

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