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Global Warming and Carbon Dioxide Concentration

Zhuoming Liang [1], Linlin Huang[2], Siyuan Tu[3], Keqin Wang [4]

[1]Whittle ShenZhen school and studio, Shenzhen, 518000 china

[2]Suon Academy, Toronto, M9N3X9, Canada

[3]Nansha College Preparatory Academy, Guangzhou, Guangzhou, 510000, China

[4]Thomas A. Blakelock High School, Oakville, L6L 1Y9, Canada

Abstract. At present, global warming is one of the most important environmental problems that people pay attention to. We generally believe that the main factor causing the problem of global warming is the emission of greenhouse gases. Among them, the most important greenhouse gas is carbon dioxide (CO2). The prediction and correlation analysis of CO2 concentration and land-ocean temperature allows us to accurately get the level of future CO2 concentration and land-ocean temperature. The great significance for knowing environmental protection work and specifying environmental protection policies. However, the prediction of future CO2 concentration/land-ocean temperature in the existing research work lacks scientific analysis. Therefore, this paper study the trend prediction method of CO2 concentration and land-ocean temperature. We first established a prediction model for the change of CO2 concentration with time. And The prediction of land ocean temperature and its relationship with the change of CO2 concentration are studied. Finally, the reliability of the model prediction results is analyzed.

Keywords: global warming; carbon dioxide concentration; land ocean temperature regression model; gray model.

1. Introduction

At present, global warming is one of the most important environmental problems that people pay attention to [1,2]. We generally believe that the main factor causing the problem of global warming is the emission of greenhouse gases. Among them, the most important greenhouse gas is carbon dioxide (CO2) [3,4]. Since the beginning of the Industrial Revolution, the fields of industry and transportation have developed rapidly, and the consumption of energy such as oil and natural gas has resulted in a large amount of carbon dioxide emissions. In addition, due to human production activities, forest resources are greatly reduced, vegetation is destroyed, and the absorption of CO2 is reduced. The above phenomenon has caused the CO2 concentration to increase year by year, from 280 parts per million (ppm) to the current 417.16 ppm by November 2022 [5].

The increasing concentration of CO2 has led to the problem of global warming. Global warming has seriously threatened the balance of the natural ecological environment, leading to the melting of polar glaciers, the rise of sea levels, and the accelerated extinction of biological species. Not only that, global warming also has many adverse effects on human beings. The greenhouse gases will make flowers bloom longer, and then the symptoms of human allergies will become more severe. Consequently, the sensitivity of the eyes and respiratory system will increase, the function of the lungs will decrease, and the symptoms of inflammatory nasal response will become more pronounced [6].

Faced with the problem of global warming, there is broad scientific research on the changing trend of CO2 concentration and land-ocean temperature. That is to predict the future CO2 level based on historical data. However, the existing prediction methods are simple, and the accuracy of the obtained results lacks effective analysis and basis. Therefore, this paper will study the trend prediction method of CO2 concentration and land-ocean temperature. We first established a prediction model for the change of CO2 concentration with time. And The prediction of land ocean temperature and its relationship with the change of CO2 concentration are studied. Finally, the reliability of the model prediction results is analyzed.

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The variables used in our model are listed and explained as in Table 1.

Table 1 Definitions of Variables

$x(t)$	Variable of CO2 concentration
c	average increase rate
$y(t)$	Variable of land-ocean temperature
$r_{x,y}$	Pearson correlation coefficient
σ_x	standard deviation of CO2 concentration
σ_y	standard deviation of land-ocean temperature
ε_1	random error of CO2 concentration
ε_2	random error of land-ocean temperature.

2. CO2 Concentration Prediction Model

The prediction model of CO2 concentration changing over time is to find an accurate function to establish the quantity relationship between the value of CO2 concentration and time. Then, we use the historical data to fit our model and calculate the parameters of our models. Because we lack direct information on the change of CO2 concentration, it is very difficult to establish the function of CO2 concentration change with time. We will use linear and non-linear regional functions to establish multiple prediction models. It also analyzes the fitting effect of models on historical data and the development of future prediction trend, evaluates the accuracy of the model, and selects the most accurate model. In addition, we use our models to predict the future CO2 concentration.

2.1 Average Increase Evaluation Model

Increase rate plays an important role in analyzing and predicting the change trend of CO2 concentration. Due to the complexity of CO2 concentration changes, we analyze the average increase rate through the data every 10 years to explain the CO2 concentration changes. According to some research results, the 10-year average increase of CO2 concentration in 2004 is larger than any previous 10-year period.

Here, we first define a 10-year average increase evaluation method. In this regard, we use the regression line to express the change of CO2 concentration in 10 years, so as to define the slope of the regression line, representing the average growth rate of CO2 concentration in ten years. Then, we establish an average increase evaluation index of a period of 10 years as follows,

First, we define a small data set of CO2 concentrations of a 10-years period $\{x(t), x(t+1), x(t+1), \cdots, x(t+9)\}$ 。 Let c denote the average increase rate from the t-th year to the (t+9)-th year. It is a constant. Then we have the evaluation model of 10-year average increase as in equation (1):

$$x(t) = c_0 + c \times t \tag{1}$$

Where c_0 is a constant, which is the parameter of model in equation (1).

We use the CO2 concentration data of ten years to fit the average increase c in equation (1). As we can see that the parameter c is the slope of a linear function. Here, we use the solution of linear regression problem to solve the value of average increase for a given CO2 concentration data set of 10 years. Let $\{x(t_1), x(t_2), \cdots, x(t_{10})\}$ denote the data of 10 years.

In this paper, we study on the average increase of a period. Then we define the average increase as in equation (2):

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$$\min \ J(c, c_0) = \sum_{k=t-10+1}^{t} \left(x(k) - ck - c_0 \right)^2 \tag{2}$$

By solving the optimization problem in formula (2), we get the calculation expression of average increase as follows:

$$c = \frac{\sum_{k=t-9}^{t} k * x(k) - 10 * \bar{k} * \bar{x}}{\sum_{k=t-9}^{t} k^2 - 10 * \bar{k}^2} \tag{3}$$

According to the calculation method of average increase index defined in Formula (3), we first calculate the average increase before 2004. Draw the trend chart of average increase over time, as shown in Fgirue1 (a).

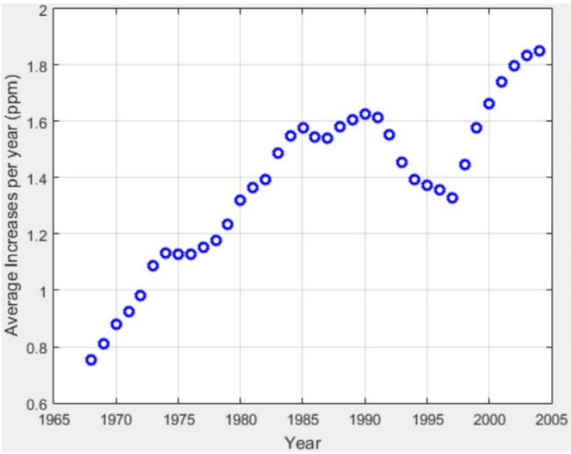

Figure 1(a) Trend of average increase from 1968 to 2004

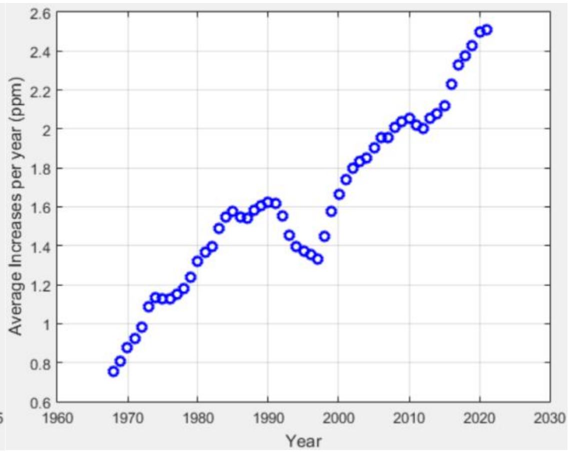

Figure 1(b) Trend of average increase from 1968 to 2021

According to Figure 1(a), we can identify that the 10-year average increase rate in 2004 reaches to 18.53 ppm per year. It reaches the largest 10-year average increase up to that time. Therefore, we agree that the March 2004 increase of CO2 resulted in a larger increase than observed over any previous 10-year period.

2.2 CO2 Concentration Prediction based on Regression Model

Regression analysis is the calculation method and theory for studying the specific dependency of one variable (the interpreted variable) on another variable (the explanatory variable), and is an important tool for modeling and analyzing data. Here, we use curve/line to fit these data points. In this way, the distance difference from the curve or line to the data point is the smallest. Here, we will use regression models to study the prediction of CO2 concentration. We studied the prediction method of CO2 concentration based on regression model. First, we draw:

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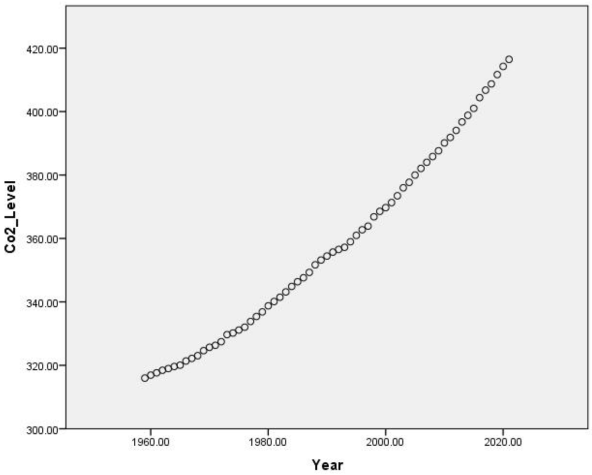

Figure 1 CO2 concentration

From the change trend of CO2 concentration with time in Figure 1, we can see that the CO2 concentration is gradually increasing with time, and the growth trend has accelerated in recent years.

1.1.1. Linear Regression

First, we use the linear regression function to establish the functional relationship between CO2 and time variables. Given data set $\{(x(t_1), x(t_2), \cdots, x(t_n))\}$ 。 n indicates the number of samples. The regression model is as follows:

$$x_t = at + b \tag{4}$$

We use SPSS software to fit the linear model in equation (4) with data of CO2 concentration from 1959 to 2021. The fitting result is as displayed in Table 1.

Table 1 ANOVA of linear regression

	Sum of Square	df	Mean Square	F	Sig.	R Square
Regression	54382.606	1	54382.606	3876.426	0.000	
Error	855.773	61	14.029			
Total	55238.378	62				

According to the results in Table 1, we get the linear regression function as in equation (5)

$$y = 1.61x\text{-}2854.60 \tag{5}$$

1.1.2. Other Nonlinear Regression Models

Above, we used linear regression to establish a regression prediction model. However, in order to more accurately study the change trend of CO2 concentration, we selected four non-linear regression functions to establish the prediction function of CO2 change, as shown in Formula 6.

$$\begin{cases} x(t) = at^2 + bt + c + \varepsilon \\ x(t) = at^3 + bt^2 + ct + d + \varepsilon \\ x(t) = be^{at} + \varepsilon \\ x(t) = ab^t + \varepsilon \end{cases} \tag{6}$$

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In Formula (6), we have selected different functions from 4 such as Quadratic, Cubic, Exponential and Power. Next, we will introduce how to solve these four nonlinear regression functions.

For nonlinear regression models, we usually convert them to linear regression models, and then use the Least Square method to solve them. The function conversion method is shown in the following table:

Table 2 Transform method of nonlinear method

$y=\beta_0+\beta_1x+\beta_2x^2$	$y=\beta_0+\beta_1x+\beta_2x_1,(x_1=x^2)$
$y=\beta_0\beta_1^x$	$lny=ln(\beta_0)+ln(\beta_1)x$
$y=e^{\beta_0+\beta_1^x}$	$lny=beta_0+\beta_1^x$
$y=\beta_0+\beta_1(ln(x))$	$y=\beta_0+\beta_1x_1,(x_1=ln(x))$
$y=\beta_0+\beta_1x+\beta_2x^2+\beta_3x^3$	$y=y=\beta_0+\beta_1x+\beta_2x_1+\beta_3x_2(x_1=x^2,x_2=x^3)$
$y=e^{\beta_0+\beta_1/x}$	$lny=\beta_0+\beta_1x_1,(x_1=1/x)$
$y=\beta_0e^{\beta_1x}$	$lny=ln(\beta_0)+\beta_1x$
$y=\beta_0+\beta_1/x$	$y=\beta_0+\beta_1x_1,(x_1=1/x)$
$y=\beta_0e^{\beta_1}$	$lny=ln(\beta_0)+\beta_1x_1,(x_1=lnx)$
$y=\frac{1}{\frac{1}{\mu}+\beta_0\beta_1^x}$	$ln(\frac{1}{y}-\frac{1}{\mu})=ln(\beta_0+ln(\beta_1)x)$

1.1.3. Gray Prediction Model of CO2 Concentration

Grey prediction is a method to predict the system with uncertain factors. Grey prediction is to identify the degree of difference between the development trends of system factors, that is, to conduct correlation analysis, and to generate and process the original data to find the rules of system changes, generate data sequences with strong regularity, and then establish the corresponding differential equation model to predict the future development trend of things. The grey prediction model is constructed by using a series of quantitative values that reflect the characteristics of the prediction object observed at equal time intervals to predict the characteristic quantity at a certain time in the future or the time when it reaches a certain characteristic quantity [5].

Based on the GM(1,1) model, the parameters of the prediction model can be updated continuously according to the real-time production information in the process of analysis and prediction, so that the data change trend can be analyzed more efficiently and accurately.

Let $x_i^{(0)}=\{x_1,x_2,\cdots,x_n\}$ denote the concentration sequence of carbon dioxide in the atmosphere can be accumulated.

$$x^1{}_i=\{x^1{}_1,x^1{}_2,\cdots x^1{}_n\} \tag{7}$$

The corresponding dynamic matrix and the formula of the least squares method are as in the following equation.

$$\begin{cases} A(i)=\begin{bmatrix} -1/2(x_{i+1}^1+x_{i+2}^1) & 1 \\ -1/2(x_{i+2}^1+x_{i+3}^1) & 1 \\ \vdots & \vdots \\ -1/2(x_{i+n-1}^1+x_{i+n}^1) & 1 \end{bmatrix} \\ B(i)=\begin{bmatrix} x_{i+2} \\ x_{i+3} \\ \vdots \\ x_{i+n} \end{bmatrix} \end{cases} \tag{8}$$

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$$\mu(i)=[A^T(i)A(i)]^{-1}A^T(i)B(i)=\begin{bmatrix}a_i\\u_i\end{bmatrix} \tag{9}$$

The calculated cumulative value is

$$x_{i+n-1}^1=(x_{i+1}-\frac{p}{q})e^{-a_i n}+\frac{p}{q} \tag{10}$$

Where p and q are the whitening coefficients. After the corresponding parameters are obtained from the above equation. Then we have.

$$x_{i+n+1}=x_{i+n+1}^1-x_{i+n}^1 \tag{11}$$

Prediction Model of CO2 Concentration Based on Grey Theory. updates the calculation model in real time according to the real-time parameters during the calculation process, which can follow the trend of CO2 concentration more quickly to ensure the accuracy of prediction.

Based on the prediction method of grey model, historical data is substituted for prediction. For this, we draw the prediction results of the Gray model as shown in the figure below.

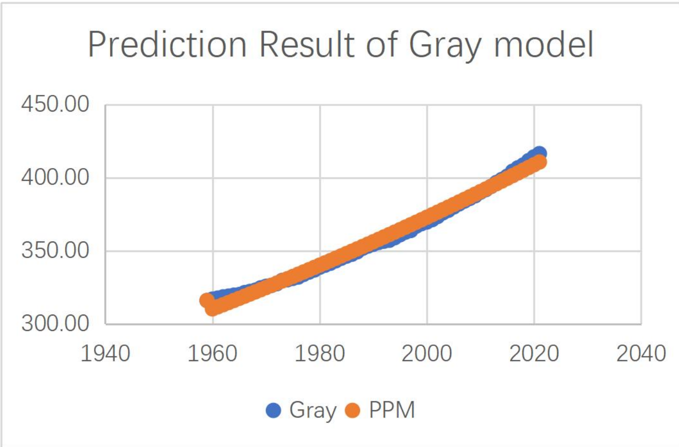

Figure 2 Prediction result of Gray model

It can be seen from the figure that the model has a very good prediction effect. The prediction results based on the grey prediction model are very close to the real data.

2.3 Test Results of Models

For the given regression model, we calculate the model through SPSS software, and count the goodness of fit, F-test significance test and DW test of each model. The results are shown in the following table:

Table 3 The test results of all models

Model	summary			estimate				DW
	R square	F	Sig.	Constant	b1	b2	b3	
Linear	0.982	3417.509	0.000	-2854.593	1.614			0.015
Quadreatic	0.981	3217.464	0.000	-24025.294	3209.995			1.872
Cubic	0.984	3636.366	0.000	-1249.596	0.000	0.000		1.67
Exponential	0.985	3876.426	0.000	-714.597	0.000	0.000	1.360E-07	0.36
Power	0.990	6320.020	0.000	0.047	0.004			0.19
Gray								2.1

According to the three practical results in Table, all regression models have good goodness of fit, that is, R-square is very close to 1, which means that the model has good prediction accuracy for given historical data. In order to select the most accurate regression model, we use DW test to test

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the distribution of random errors in the prediction results. To help us make choices. First of all, according to the three results in Table, it can be seen that the D-W test results of quadratic and cubic are relatively good, and the numerical value is close to 1. It indicates that the random error has good randomness and does not have first-order correlation. To make it more intuitive, we draw the corresponding residual distribution diagram, as shown below:

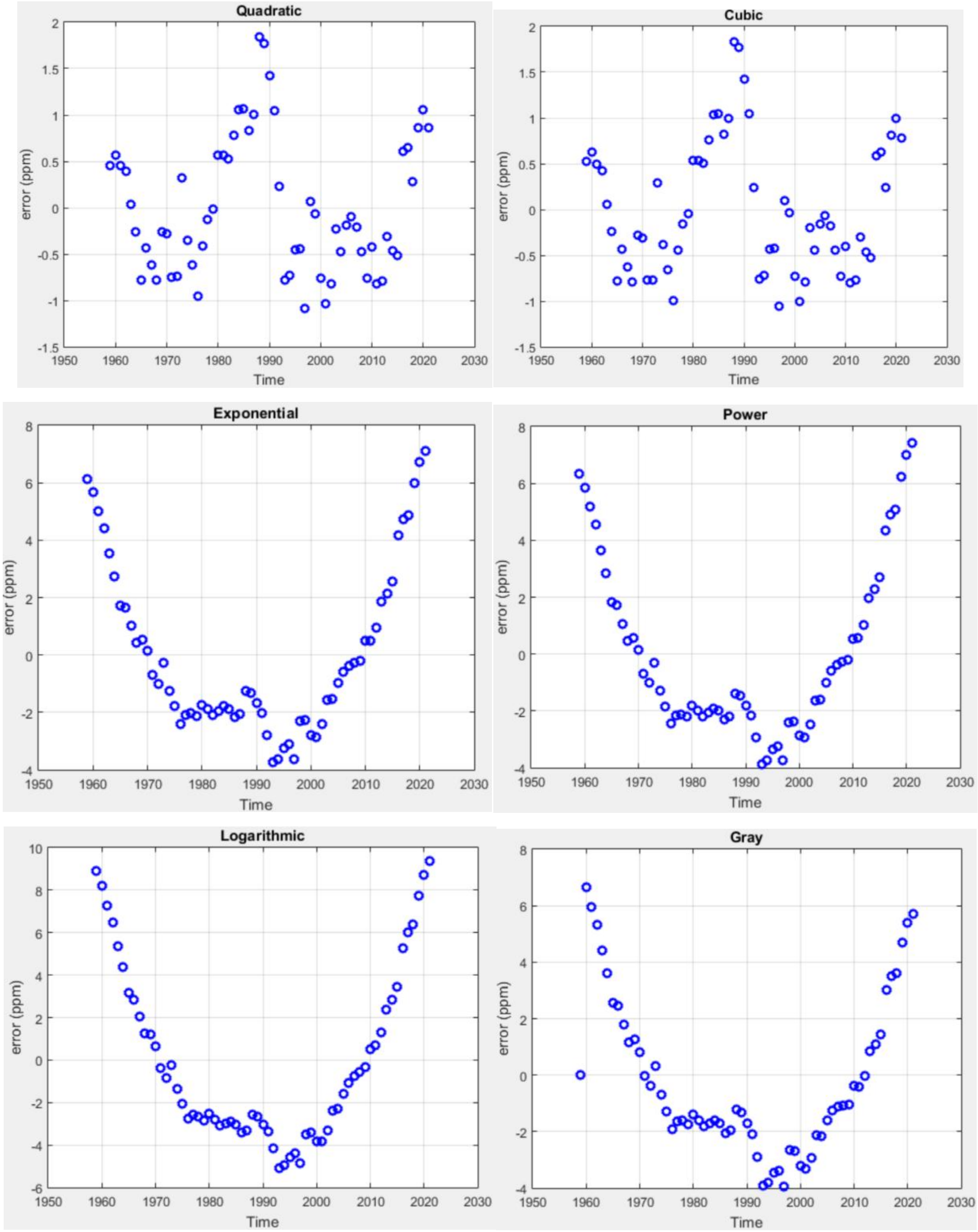

Figure 3 Residual errors plot of all models

According to the results in Figure 3 above, we can clearly point out that the horizontal and cubic have better prediction accuracy.

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3. Temperature Prediction

3.1 Temperature-Time

Here, we use time as the independent variable to predict the future changes of land ocean temperature, and establish a regression model as follows:

$$y(t) = a_1 t + a_0$$

$$y(t) = a_0 t^2 + a_1 t + a_2 \quad (12)$$

$$y(t) = a_0 t^3 + a_1 t^2 + a_2 t + a_3$$

Table 4 regression model result

Summary and Coefficients Estimation									
model	Summary					Estimation			
	R square	F	df1	df2	Sig.	constant	b1	b2	b3
Linear	0.898	537.971	1	61	0.000	-33.117	0.017		
Logarithmic	0.897	531.301	1	61	0.000	-253.694	33.445		
Quadratic	0.899	544.607	1	61	0.000	-16.395	0.000	4.228E-06	
Cubic	0.900	551.201	1	61	0.000	-10.821	0.000	0.000	1.417E-09
S	-	-	-	-	-	-	-	-	-
Exponential	-	-	-	-	-	-	-	-	-

Use historical data to fit the above three equations, and get the results of Table 4. The fitting effect is shown in the following figure. It can be seen from the actual results in the figure that the temperature changes linearly with time. Although the quadratic and cubic functions are also valid at the same time, the coefficients of the high-order terms of the model are very fine, which are basically linear laws.

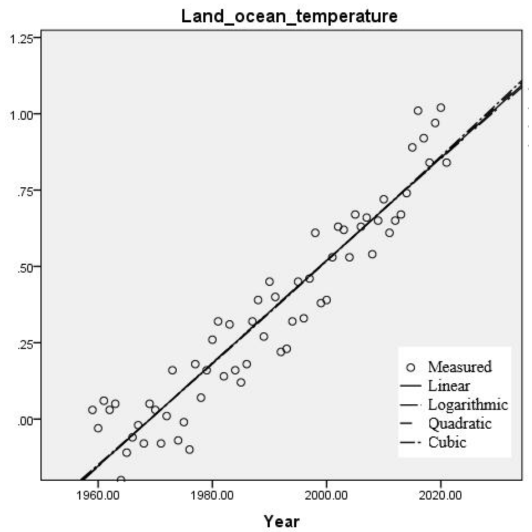

Figure 4 Goodness of fit

3.2 Temperature-CO2

Similarly, establish the function of temperature with respect to the change of CO2 concentration, as shown below:

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$$\begin{cases} y = ax + b + \varepsilon \\ y = ax^2 + bx + c + \varepsilon \\ y = ax^3 + bx^2 + cx + d + \varepsilon \end{cases} \tag{13}$$

The results obtained by using SPSS are shown in the following table. It can be seen from the results in Table 5 that the model has very good linear correlation. In addition, we calculate Pearson correlation coefficient as shown in Table 6. It can be seen that the change of temperature is highly correlated with the change of CO2 concentration.

Table 5 regression model result

Summary and Coefficients Estimation									
model	Summary					Estimation			
	R square	F	df1	df2	Sig.	constant	b1	b2	b3
Linear	0.924	743.036	1	61	0.000	-3.393	0.010		
Logarithmic	0.922	724.092	1	61	0.000	-21.835	3.776		
Quadratic	0.924	365.700	2	60	0.000	-3.008	0.008	2.950E-06	
Cubic	0.924	365.700	2	60	0.000	-3.008	0.008	2.950E-06	0.000
S	-	-	-	-	-	-	-	-	-
Exponential	-	-	-	-	-	-	-	-	-

Table 6 regression model result

		CO2	Temperature
CO2	correlation coefficient	1	.936**
	Sig.		0.000
Temperature	correlation coefficient	.936**	1
	Sig.	0.000	

4. Conclusion

We first established a prediction model for the change of CO2 concentration with time, we can clearly point out that the horizontal and cubic have better prediction accuracy. And The prediction of land ocean temperature and its relationship with the change of CO2 concentration are studied. We find that the model has very good linear correlation. In addition, the change of temperature is highly correlated with the change of CO2 concentration.

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