Ice-Free Arctic: Arctic Ice Extent Prediction

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This paper presents a linear regression model with the aim of predicting ice extent in the Arctic from 2019 to 2023 and the first ice free period and year in the future using the data from 1978 to 2019. The results suggest that the ice extent will continuously decline every year and September of 2098 will be the first ice-free month and the first year of ice-free Arctic will be in 2259.

INTRODUCTION

Ice Free Arctic

Prediction of ice-free year in the Arctic has changed over year. Some scientists predicted that the Arctic Ocean will be ice free during the summer in the next 40 to 60 years due to the fact that already summer ice cover is about 50% of winter cover. Some scientists predicted we may see the first ice free period before the next decade.

CO_2 and Temperature

According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, the predominant cause of the decline in Arctic sea ice extent is greenhouse gas forcing[1]. These changes are seen as results of the greenhouse effect which is caused by the increased carbon dioxide (CO_2) concentration. The Arctic has the largest CO_2 concentration and winter-summer variations in the world and due to that, the greenhouse effect is one of the most popular topics for the Arctic. Gosink and Kelley showed that sea-ice cover is highly permeable to CO_2 at the temperature above 15 degree.[2]. Due to these effects, climatic changes in the Northern Hemisphere lead to remarkable changes in the environment of the Arctic Ocean[3].

METHOD

Data

The Arctic ice extent data can be found in the National Snow and Ice Data Centre(`https://nsidc.org/data/seaice_index/archives`). The global mean temperature data is in the website of National Aeronautics and Space Administration(NASA) Goddard Institute for Space Studies(`https://data.giss.nasa.gov/gistemp/`). The CO_2 concentration annual mean data is in the website of National Oceanic and Atmospheric Administration(NOAA) Earth System Research Laboratory(`https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html`).

Least Squares Estimation

The format of linear regression model is $\hat{Y}_i = \theta_0 + \theta_1 X_i$. The main task is to get the optimal θ_0 and θ_1. Least squares estimation gives the estimates of θ_0 and θ_1 as:

$$\theta_1 = \frac{\sum X_i Y_i - \frac{(\sum X_i)(\sum Y_i)}{n}}{\sum X_i^2 - \frac{(\sum X_i)^2}{n}} \tag{1}$$

$$\theta_0 = \bar{Y} - \theta_1 \bar{X} \tag{2}$$

The criterion of least squares estimation is that the Least Squares solution must give the smallest possible sum of squared deviations of the observed Y_i from the estimates of their true means provided by the solution.[4]

Gradient Descent

Min-Max Normalisation

$$X_i' = \frac{X_i - \min(X)}{\max(X) - \min(X)} \tag{3}$$

We normalized the data using the equation above to condense all the data into the range (0,1) with equation (3) in order to keep the process of Gradient Descent in the next step feasible and more effective.

Iteration with Gradient Descent

$$\theta_i = \theta_i - \alpha \frac{\partial}{\partial \theta} J(\theta) = \theta_i - \alpha \left(h_\theta(X) - Y \right) x_i \tag{4}$$

$$J(\theta) = \frac{1}{M} \sum_{i=1}^{M} \left(\theta_1 X_i + \theta_0 - Y_i \right)^2 \tag{5}$$

In gradient descent, we update θ_i and loss value J in each iteration with the equation above. "M" is the amount of data. We set the iteration time large enough to make the linear regression model accurate. Loss value J shows how well the model fits the original data. With gradient descent, we can get a linear regression model for the normalized data.

Reversion of parameters

We have to revert the parameters θ_0, θ_1 to the original coordinate to get the linear regression model which fits the original model. The parameters in the original coordinate:

$$\theta_1' = \theta_1 \frac{k_2}{k_1} \tag{6}$$

$$\theta_0' = -\theta_1' \min(X) + \min(Y) + k_2\theta_0 \tag{7}$$

k_1 and k_2 are the ratios of condensation in x coordinate and y coordinate.

Polynomial Model for Seasonality

Seasonality is a characteristic of a time series in which the data experiences regular and predictable changes that recur every calendar year. A polynomial model is built to fit the monthly data in 2018 which is the latest year which has data for all the months.

RESULTS

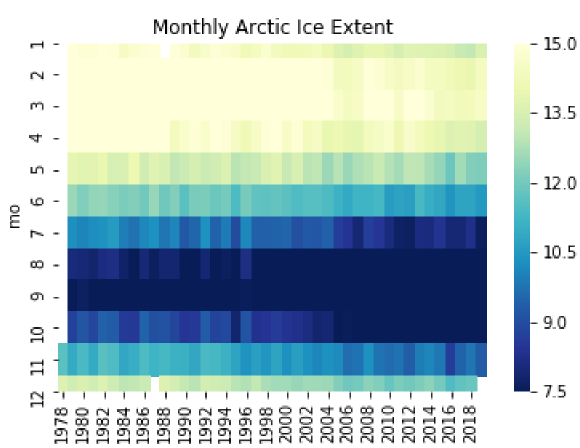

FIG. 1. It shows the Arctic ice extent monthly data heatmap. As the year passes, the area of darker places is expanding in the vertical direction, which shows the ice extent is decreasing by year.

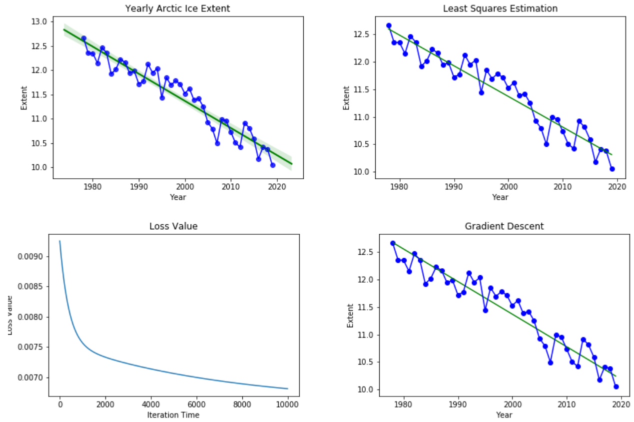

FIG. 2. It shows the data of yearly arctic ice extent and the year-extent linear regression model. The first figure is plotted by Seaborn library. The second figure is plotted with the method of least squares estimation (θ_1=-0.055, θ_0 =122.818). The third figure shows the changes of loss value. The fourth figure shows the model built with gradient descent (θ_1=-0.0595, θ_0 =129.616).

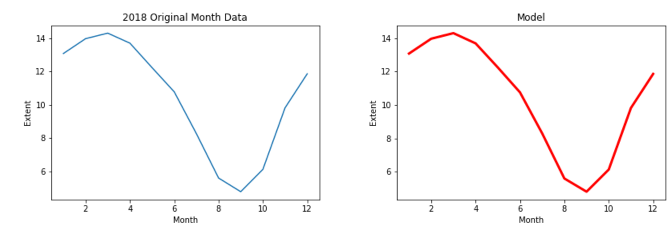

FIG. 3. The first figure shows the original data in 2018 and the second figure is the polynomial model which fits the monthly data in 2018.

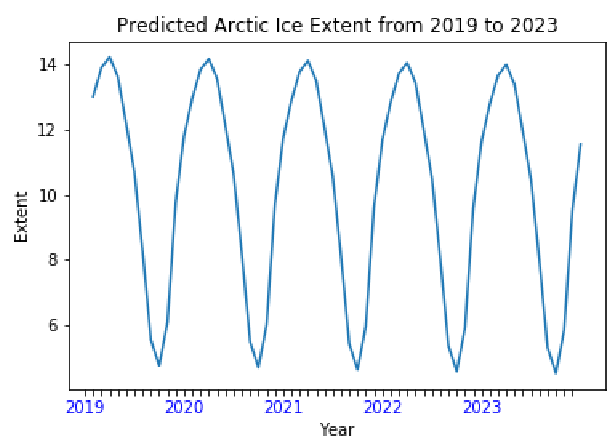

FIG. 4. It shows the predicted arctic ice extent 2019-2023 in the monthly values.

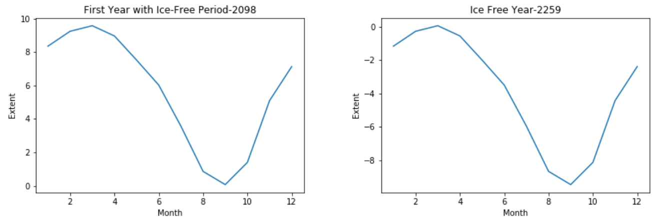

FIG. 5. The first figure shows the extent of the first year 2098 with ice-free month, and the second one shows the extent of the first ice-free year which is 2259.

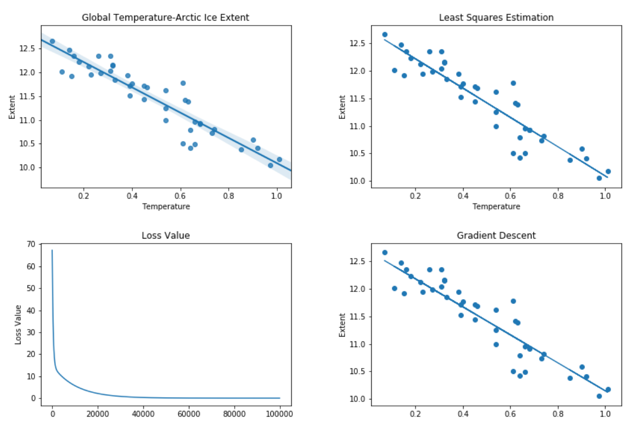

FIG. 6. It shows the temperature-extent linear regression model. The first figure is plotted by Seaborn library. The second figure is plotted with the method of least squares estimation (θ_1=-2.656, θ_0 =12.747) The third figure shows the changes of loss value. The fourth figure shows the model built with gradient descent(θ_1=-2.535, θ_0 =12.685).

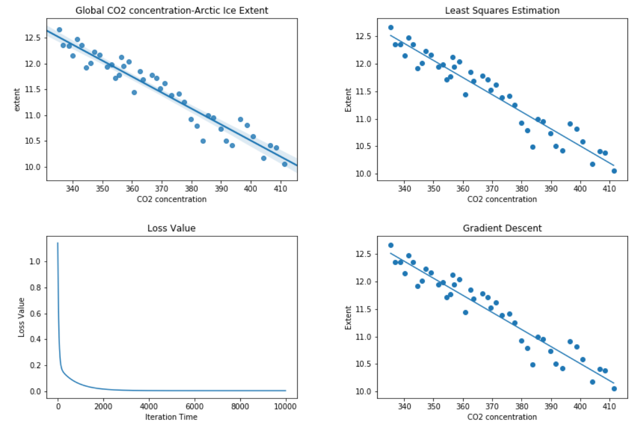

FIG. 7. It shows the CO_2 concentration-extent linear regression model. The first figure is plotted by Seaborn library. The second figure is plotted with the method of least squares estimation (θ_1=-0.031, θ_0 =22.903) The third figure shows the changes of loss value. The fourth figure shows the model built with gradient descent(θ_1=-0.031, θ_0 =22.883).

CONCLUSION

In this paper we introduced a linear regression model that predicts the Arctic ice extent from 2019 to 2023 and the first ice free times in the future using the data from 1978 to 2019. According to our predictions with the models, the ice extent will continue to decrease over time and the first month that the Arctic will be ice free will be the September of 2098. In 2259, our model suggests that we will live in the first year of ice-free Arctic time. Our model suggests that from the end of 2259, the amount of ice extent in the Arctic will stay below zero for the whole year. Continuing decrease in the Arctic ice extent should be considered as an emergent situation. Awareness about this issue should be increased. It is necessary for people to limit the emission of CO_2 and other greenhouse gases. Only with the effort of both governments and each single individual can we prevent the coming of ice-free era.

[1] O. C. CHANGE, World Meteorological Organization (2007).
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[3] K. A. Morison, J. and M. Steele, Arctic **53**, 359371 (2000).
[4] P. S. Rawlings, J. and D. Dickey, *Applied regression analysis* (New York: Springer, 2005) pp. 3–4.