College of Art and Computer science

Ice Coverage in the Arctic Climate over Time

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Article Info

Article history:
First review April 11, 2019
Second review April 11, 2019
Submitted April 30, 2019

Keywords:
Ice coverage
Polar bears
Decline

ABSTRACT
The Arctic plays a vital role in regulating global temperatures. Through extensive research, it was found that the region's oldest and thickest ice on this extent has significantly and continually decreased over the years. The thinning of ice due to warmer temperatures over the years is directly affecting the population of polar bears negatively. As the ice constitutes polar bear prey territory, the thinning of ice makes it more difficult for polar bears to prey on seals; ice is more easily moved by ocean currents and wind when it is thin. By the monitored ice coverage in the Arctic from as early as 1980, to 2016, and on a yearly scale, data has been collected from previous research to modify a mathematical model under climate change to accommodate the declining of ice coverage. It was determined that ice is at its thickest in March, and at its thinnest in September. By analyzing one month on the segment of the decline of ice coverage, a first-order differential equation was generated based on the rate of ice coverage change. Utilizing Excel, Matlab and concepts learned in the Differential Equations class, modeling ice coverage based on the available data makes it possible to generate an equation by solving a first-order differential equation to predict a trend of the ice coverage in future years. The results of the work allow the public to be more conscious about the warming of global temperatures. With knowledge of this subject, the public can look into aspects of their daily lives and find better ways to regulate global temperatures in a positive way. This opportunity creates a chance to save the lives of polar bears.

1. Introduction

The predator-prey cycle is an interesting subject matter. Even though humans are not always directly in contact with species or climates in neighboring regions, that does not mean humans are not directly affected by results of those surrounding areas. The Arctic is a powerful region, playing a large role in regulating of global temperatures. The ice coverage in the Arctic climate over time is an important matter for the reason that the rising of sea levels due to melting ice is to a certain extent of an irreversible effect. By, developing a model to track the trend of data on ice coverage in the Arctic, a potential solution to the decline of ice coverage, and subsequently, the decline of the polar bear population that inhabits the Arctic can be found. Extinction is a serious matter and with this project it is in hopes that a way to prevent the loss of not just polar bears, but other animals that are associated with the arctic region be found.

2. Literature Review

The oldest and thickest ice of the Arctic region has dropped by 95 percent in the past 33 years. Currently, this old and thick ice only makes up less than 1 percent of the total ice pack in the Arctic region, as stated in Green 2018 [5]. Without older and thicker ice, the region's ice remains younger, thinner than, and not as expansive as in the past years. The side-by-side images shown in Figure (1) are pictured during the month of September, which is typically the lowest extremity of ice in the Arctic [1].

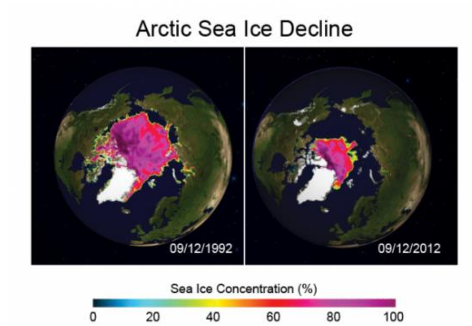

Figure (1): Over a span of 20 years, the ice extent of the Arctic Sea has continued down a path of significant decline [1].

When the ice of the Arctic region thins out, the ice becomes more easily susceptible to being moved by ocean currents and wind. As a result, polar bears are having to travel further and faster to prey on seals. Polar bears already on average burn over 12,000 calories per day, as presented in Pereira 2018 [8]. When the polar bears are forced to travel farther and faster, they are contributing even more to the number of calories that they burn per day. It is a tragic concept for the polar bears. If polar bears choose to stay put in hopes to wait for seals to show up, it is likely they will starve to death. If polar bears decide to travel and burn extra calories, their physical state eventually will be in distress as they will soon become too tired or weak to hunt any more, as shown in Figure (2).

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Figure (2): Due to melting ice, polar bears are pushed further away from their prey [4]. Polar bears have to travel further to hunt which causes them to burn more calories and use up their energy [3].

Through a predatory-prey cycle [2], a food chain depicting the effect the polar bear population as it plays on many other species living in the Arctic Sea is shown in Figure (3).

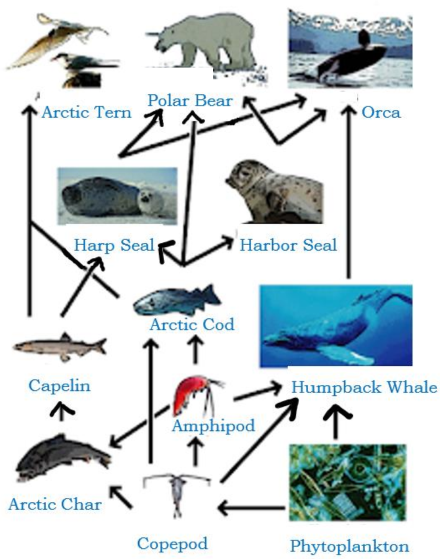

Figure (3): A food chain in the Arctic Sea [6].

Sea ice also possesses another use to help polar bears hunt, besides being the ground that they use to walk on. Sea ice is an essential tool for helping polar bears catch their prey because of its color. In the hunt, ice poses as a camouflaging tool for polar bears, whose fur coat is light in color like ice, as explained by Koblenski 1970 [6]. Just as well, the sea ice is a weakness of seals. In this sense, seals must locate breathing holes every so often, coming up for air after being in the water for an extended time. These breathing holes are targets for polar bears to lie in wait and catch their prey. When there is more water than ice, Polar bears can be forced to submerge themselves in the water to prey on seals. But this is an unsuccessful method to the hurt, as polar bears are slow-moving in water.

One would think that sea ice being light in color is a positive trait when it comes to attracting the sun's rays, but sea ice is, in fact, highly reflective. The ice's color has little impact on the slowing down of melting ice. When there is less ice coverage, there is more water. The water displays a darker color than ice, which attracts the warm sunlight rays. A contribution of the further melting of ice is the rising water temperature [10]. Essentially this is an exponential declining trend. As the Arctic displays darker colors, the sun's rays are attracted even more so and will speed up the melting of the sea ice coverage. With the rising temperatures over the years, substantial melting in inhospitable, or difficult to live in regions is apparent, as explained in Green 2018 [5]. With this problem, larger regions come about and can pose as potential new homes to species in the coming years. The rise in temperatures gives an opportunity for species to spread out and occupy those types of regions. The spreading out of species, such as seals for example, will make it even more difficult for polar bears to reach their prey [7].

When evaluating ice coverage over a year, it is determined that sea ice grows and shrinks throughout that period. Each fall, less sunlight reaches the Arctic compared to the other seasons. When this happens, air temperature begins to drop and additional sea ice forms. By the time March rolls around, the coverage of ice has reached a maximum. As the year continues and spring season is apparent, the sea ice will begin to shrink back due to the warmer air temperatures having an impact on the ice. By September, sea ice coverage is at a minimum [3]. However, as the years continue, the melting period will increase in time, resulting in a shorter refreezing period of ice. This trend is a direct result as to why researchers are seeing a concrete decrease in ice coverage as the years go on.

3. Why is the Population of Polar Bears a Concern?

Polar bears are a very intelligent species. They are capable of signaling that there are problems in the arctic marine ecosystem [9]. Polar bears also take care of the dead animal carcasses that occupy the arctic region surfaces. As they are not typically picky eaters, polar bears will take what they can get, if they are not able to catch seals. But this food source of animal carcasses for them is not beneficial. Seals supply a large amount of blubber that polar bears need to survive in the arctic region. Once polar bears start dying off, they will not be present to regulate, or take care of, the animal carcasses any longer, as presented in [6]. The carcasses will start piling up and begin to rot, where there is a greater chance for the spread of disease due to bacteria. The increase and spread of bacteria will likely affect the other species that also negatively inhabit the Arctic. Lastly, the polar bear population matters for the predator-prey cycle relating to species in contact with polar bears. The decrease in the population of polar bears will cause an increase in the population of seals. As a result of this, as seals prey on fish, the population of fish will consequently decrease. As well, other species that consume seals such as whales and sharks will try to compensate for the overpopulation of seals. It is noticeable that one problem in the cycle can cause a total imbalance for the other species.

4. Ice Coverage Model

The aim of this study is developing an empirical model of the ice coverage on Arctic Ocean to predicate the future of polar bear population due to climate change. A sinusoidal model of ice in the Arctic Ocean represents the numerical data of melting and refreezing ice coverage in millions of square kilometers that spanned over all 12 months of the year. However, according to recent research, it was realized that the sinusoidal model would be insufficient to represent the decline of ice coverage.

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Therefore, the ice coverage model of the Arctic Ocean is required to be modified to satisfy the annual decline of ice coverage that is shown in Figure (4). Evidently, the downward trend of ice in the Arctic results in a distinct decline to the polar bear population.

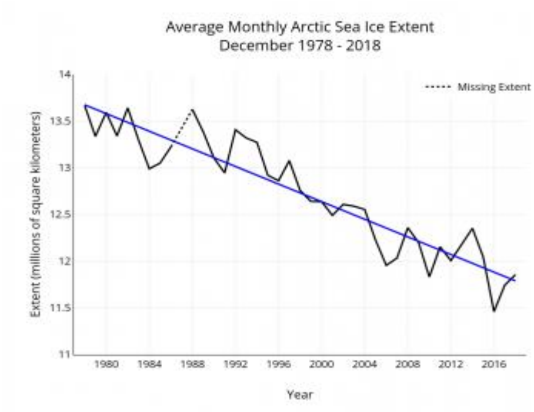

Figure (4): Decline of Arctic Sea ice between1978 to 2018 [7].

A comparison of ice coverage between 1978 and 2018 on two different months, March and September, is presented in Figure (5) which shows a significant decline of sea ice extent in million square miles.

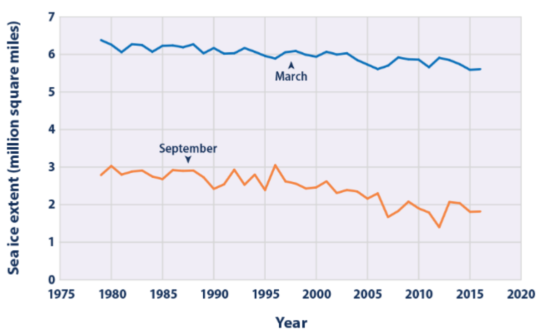

Figure (5): Arctic ice extent in millions of square miles in March and September.

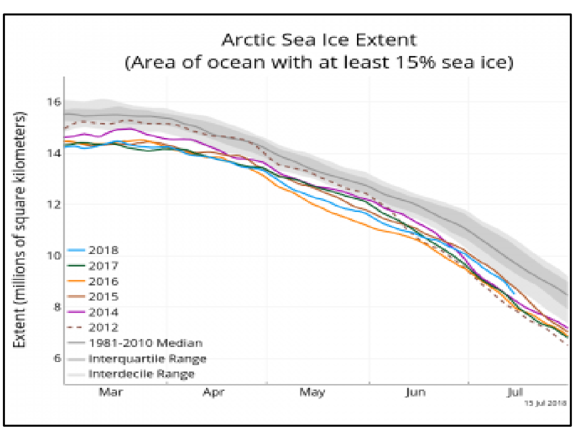

Figure (6): Ice extent of the Arctic Sea between 1981 and 2018 [2].

Emphasizing on a section of the melting season between March and June that is shown in Figure (6), it is clear that the extent of ice coverage is declined over the years between 1978 and 2018 [5].

To model the annual decline of ice coverage, it is required to construct an empirical model based on the data presented in Figure (6), and modify this model to predict future declination of ice coverage.

By analyzing Figure (6) over three months. May, June, and July, the data of ice coverage in millions of kilometers on years between 1981 and 2018 are summarized in Table (1). In order to derive a mathematical model using first order differential equation, it is required to obtain the annual rate of ice coverage based on Table (1).

Table (1): Ice coverage I(t) in millions of kilometers

Year	I(t)		
	May	June	July
1981	12.65	11.1	8.5
2012	12.48	9.5	6.8
2014	12.2	10	7.2
2015	11.76	10.2	7.3
2016	11.2	9.3	7
2017	12	10.1	6.9
2018	11.65	10.3	NA

The rate of change of the ice coverage is presented in Figure (7) and computed in Table (2) using equation (1).

$$\frac{\Delta I}{\Delta t} = \frac{I_2 - I_1}{t_2 - t_1} \quad (1)$$

Where:

$\frac{\Delta I}{\Delta t}$ is the rate of change of ice coverage on Arctic Ocean.

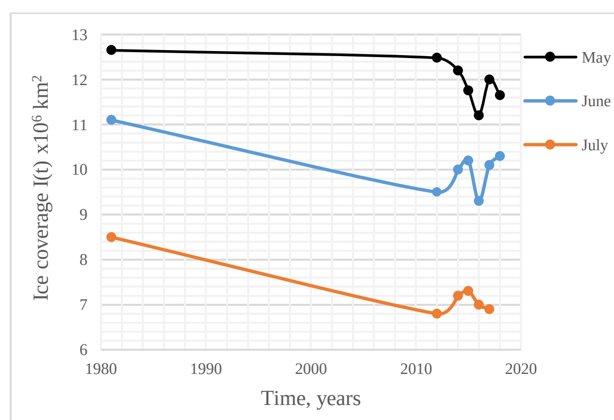

Figure (7): Ice coverage I(t) in millions of square kilometers

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Table (2): Annual rate of ice coverage $\Delta I(t)/\Delta t$ in millions of square kilometers per year

Year	$\Delta I(t)/\Delta t$, $x10^6$ km^2/year		
	May	June	July
1981			
2012	-0.052	-0.051	-0.055
2014	-0.14	0.25	0.2
2015	-0.44	0.2	0.1
2016	-0.56	-0.9	-0.3
2017	0.8	0.8	-0.1
2018	-0.35	0.2	NA

By approximating the annual rate of change $\frac{\Delta I}{\Delta t}$ as the derivative of ice coverage with respect to time, $\frac{dI}{dt}$, a first order differential equation can be achieved based on Figure (8).

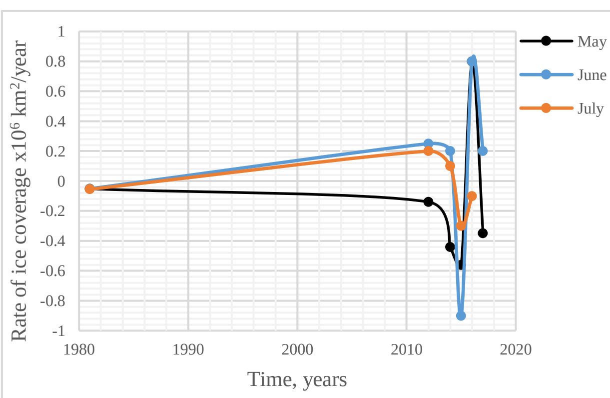

Figure (8): Annual rate of ice coverage in millions of kilometers

A best fit curve with its equation that represents the data of rate of ice coverage change on one month, May is shown in Figure (9).

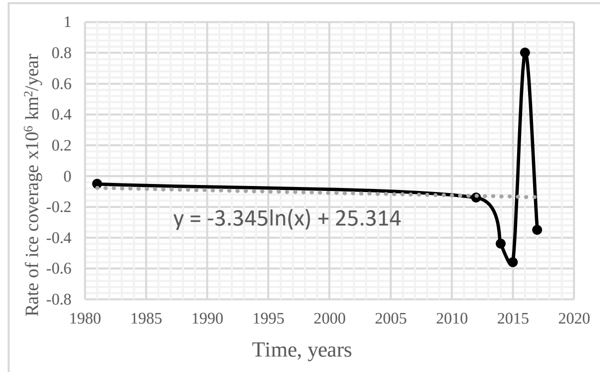

Figure (9): Annual rate of ice coverage change in May

$$\frac{dI}{dt} = -3.345ln(t) + 25.314 \quad (2)$$

$\frac{dI}{dt}$ is the rate of change of ice coverage,

t is the independent variable which represents time in years,

I is the dependent variable which represents ice coverage in million square kilometers.

Various methods are used to help solve the first order differential equation that is given in Equation (2). The general solution of this first differential equation is given in Equation (3).

$$I = -3.345(tln(t) - t) + 25.314t + c \quad (3)$$

Where:

c represents the integration constant

Equation (3) is simplified and presented in Equation (4)

$$I = -3.345tln(t) + 28.659t + c \quad (4)$$

5. Initial boundary conditions

The solution of first order differential equation that is presented in Equation (3), is called a family of solutions because it may represent general data of ice coverage. Therefore, it is required to find a particular solution that represent an empirical model of ice coverage. The data set at year 1981 and 12.65 in May is considered the initial boundary condition using Table (1). Therefore, the derived model is not valid for the years before1981.
The integration constant can be obtained by substituting the initial boundary condition as given in Equation (5).

$$c = 12643530.23 = 12.643530 \times 10^6 \quad (5)$$

Where:

$I = 12.65 \times 10^6\ km^2$

$t = 1981$

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The empirical model is the particular solution of the rate of ice coverage change that is given in Equation (6) after substituting the constant of integration.

$$I = -3.345t\ln(t) + 28.659t + 12643530.23 \qquad (6)$$

6. Results and Discussions

Through the presented analysis of the decline in ice coverage, an equation to predict the trend of ice decline in the coming years has been established. The model in Equation (6) is extended in Figure (9) to the next 10 years to predicate the future of ice coverage based on last twenty years. It is clear from this model that the ice coverage will be less than 7 million square kilometers which cause to reduce the bear's population and other species in Arctic Ocean as well.

With knowledge of the data presented, consideration for the man-made problems such as the fluctuating levels of CO_2 can be better controlled. By burning fossil fuels or deforesting land, heat gets trapped in the atmosphere and causes a rise in temperature. The conscious step people take after being presented with this data, and data alike, can help out the arctic environment and its inhabitants.

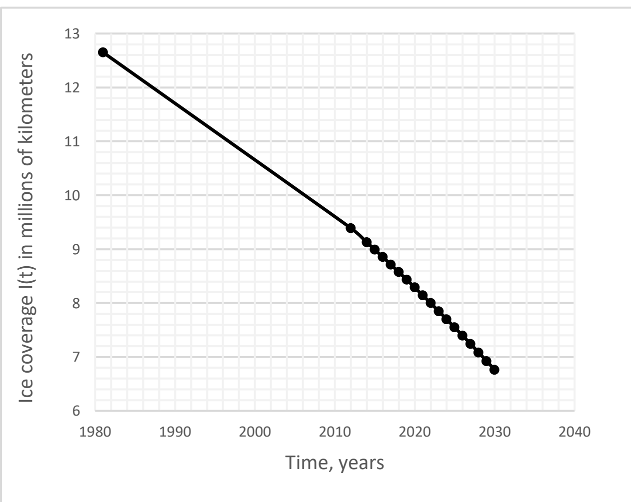

Figure (10): Future of ice coverage predicting model

7. Conclusions :

Based on thorough research, it was determined that the melting season of the Arctic Sea began in March and maintained a continual decrease throughout June. By analyzing a segment of the decline of ice coverage, the rate of ice coverage over time in the arctic climate was computed. With the computed rates, a differential equation was derived as a function of ice coverage over time and the initial boundary condition is considered at 1981 and this model is not valid before this year. Based on methods practiced, as well as the use of Excel and Matlab, a differential equation was obtained to determine the rate at which ice declines over the period of years during the Arctic melting season. It is recommended that more data be collected on the current topic and compared to the results concluded. With this knowledge, the opportunity to find techniques to reverse or slow the decline of ice is available. Humans are given the chance to save the lives of polar bears.

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