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SHRINKING OF THE ARCTIC SEA ICE COVER

An Interactive Qualifying Project

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By

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Abstract

The purpose of this IQP is to examine the importance of studying the shrinking Arctic Sea Ice cover, its effect on the ecosystems, and to perform statistics based computer stimulations in order to predict the decline of Arctic Sea Ice. We also present an overview of dynamic climate models as they relate to sea ice. This paper uses information obtained from the National Sea and Ice Data Center and Intergovernmental Panel on Climate Change's websites among other sources. It was found that the decline in Sea Ice has been underestimated thus far by climate models, and summer sea ice may disappear as soon as 2030.

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1 Introduction

The purpose of this paper is to examine the importance of studying Arctic Sea Ice. This paper will also examine the rate at which Arctic Sea Ice is declining and whether this decline can be predicted by dynamical climate models.

First, we will explain why the Arctic was to be the focus of this paper rather than the Antarctic. The Arctic differs from the Antarctic in that the Arctic Ocean is surrounded by land whereas the Antarctic is land surrounded by a body of water. The Sea Ice in the Arctic is less likely to melt in the summer as opposed to Antarctic Sea Ice. The Earth has not experienced a summertime free of Arctic Sea Ice in over 125,500 years, see (1).

Albedo, a unitless quantity that indicates the percentage of solar energy reflected by a surface, was considered in this paper. The effects of the Milankovitch cycles are also reviewed in this paper. The Milankovitch cycles dictate how much solar energy reaches the Earth and how it is distributed at different latitudes. The tilt of the Earth on its axis, the Earth's eccentricity and the Earth's precession constitute the three Milankovitch cycles, see (2).

The ecosystems in the Arctic are more unique than those from other areas. In the Arctic, there is very little functional redundancy among species. As such, when one species experiences a change, it has a large impact on the rest of the ecosystem. In other areas, a change within one species would not produce as large of a change on the ecosystem because other species that perform the same function would prevent it, see (3).

In this paper, we fit data from1970 to 2009 of sea ice extent with both a linear fit and a quadratic fit. These approximations were used to predict the sea ice extent for 2050. It was found that the quadratic models produced the most accurate fit to the data for both the summer and wintertime sea ice extent. The fit showed that we could experience a summertime free of Arctic sea ice as soon as the year 2030. This was consistent with the findings in the dynamical model in section 2.2.3.

The current dynamical climate models all predict that sea ice will decline; however the predictions are not matching with observations. The source of this error may be due to the overestimation of sea ice thickness. If dynamical climate models are able to use more accurate ice thickness measurements, it may be possible to obtain more accurate sea ice cover predictions. In order to obtain this data, there will need to be continuous and improved monitoring of sea ice thickness and drift.

2 The Role of Arctic Sea Ice

2.1: Arctic vs. Antarctic Sea Ice

First, we will examine the differences between Arctic and Antarctic sea ice. According to the National Sea and Ice Data Center's website (NSIDC), see (1), a major difference between Arctic and Antarctic sea ice is mobility. The Arctic is surrounded almost completely by land, thus making the ice far less mobile. In comparison, the Antarctic is a land mass surrounded by water. As such, the ice is able to float into warmer waters in the summer and thus melts more quickly. Since the area in the Arctic is more confined, floes are prone to bumping into each other. Floes are sheets of unbroken pack ice greater than twenty meters across. When these floes bump into each other and converge, the sea ice becomes thicker. The thicker the ice, the longer it takes to melt. The typical thickness of Antarctic sea ice is one to two meters. The thickness of Arctic sea ice is usually between two to three meters with some areas having thicknesses of four to five meters. Also, since there is no land at the pole in the Arctic, the sea ice is able to move to the pole where it receives less solar energy.

Another important difference is the amount of precipitation in the Arctic as opposed to the Antarctic. The Arctic is surrounded by land and the ocean is mainly covered by ice, thus there is much less precipitation than in the Antarctic. In the Antarctic moisture is more prevalent. Antarctic sea ice is covered by a much thicker layer of snow then the Arctic. Snow can accumulate to a point where it is so heavy it pushes the top of the ice underwater which causes salt water to mix with the snow.

The water in the Arctic is also less dense since rivers from both Russia and Canada empty out into the Arctic Sea. This allows for more ice growth.

These differences are important when it comes to the study of sea ice. The conditions surrounding Arctic Sea Ice allow more of it to keep from melting in the summer. According to NSIDC's website, Earth has not experienced "a summertime free of sea ice in 5,500 years", and it is possible that it has been over 125,500 years since there was a summer free of ice. In subsequent sections, we will give a theoretical explanation of when we may begin to experience summers free of ice and what impact this may have on the ecosystems of the Arctic.

2.2: Percentage of Earth's Surface Area above the Arctic Circle

We will now calculate the percentage of the Earth's surface area that is found above the Arctic circle. Assume the Earth is a sphere with radius r. We can express the surface area of a section of the earth using the following double integral:

$$A = \int_0^{2\pi} \int_0^{\alpha} r^2 \sin(\varphi)\, d\varphi d\theta;$$

$$A = r^2 \int_0^{2\pi} (-\cos(\alpha) + 1)\, d\theta$$

$$A = 2\pi r^2 (1 - \cos(\alpha))$$

Therefore, to calculate what percentage of the Earth's surface is found in this section, we must divide by the total surface area of the Earth.

$$A_{earth} = 4\pi r^2$$

$$\text{Area Ratio} = \frac{2\pi r^2 (1 - \cos(\alpha))}{4\pi r^2}$$

$$\text{Area Ratio} = \frac{(1 - \cos(\alpha))}{2}$$

Now we substitute the value for α[1], therefore the Area Ratio ≈ 4.1%.

2.3: Albedo's Effect on Sea Ice

We will now examine the importance of albedo as it affects sea ice and the Earth's atmosphere. According to the book, *The Complete Guide to Climate Change*, see (2), albedo is a measure of the reflectivity of a surface. Albedo is a non-dimensional, unitless quantity between zero and one that indicates the percentage of solar energy reflected by a surface. An albedo of zero would mean that the surface is a "perfect absorber", and absorbs all incoming solar energy. An albedo of one would imply that the surface reflects all solar energy. Darker surfaces have lower albedos than lighter surfaces. Pure black surfaces absorb all light in the visible spectrum; therefore absorbing all the solar energy. White surfaces reflect all light in the visible spectrum, and do not absorb solar energy. Absorbed solar energy is able to heat the surface, see (4).

Any change in albedo has an effect on the climate. As the albedo increases the earth cools and visa versa. Table 1 below shows the albedo's of some common surfaces. When forests are replaced with cities the albedo goes up. Over the past two centuries, earth's albedo has increased by approximately 0.4%. This is mainly due to change in land use and changes in the cloud cover.

Surface	Albedo
Asphalt	≤.10
Forest	.05-.10
Ocean	.06
Cities	.14-.18
Grass	.20-.25

[1] Alpha is determined by the tilt of the Earth on its axis which varies with time. This is the current correct value for α as determined by the Milankovitch cycles (see section 2.4).

Sand	.20-.30
Developed Terrain	.51-.71
Sea Ice	.50-.60
Thick Cloud	.70-.80
Snow	.90
Spherical Water Droplets with low angle of incidence	.99

Table 1-Albedo's of common surfaces, see (2)

The angle of incidence can affect the albedo of a surface. The lower the angle of incidence, the greater the reflectivity and thus the higher the albedo. This is especially true of transparent surfaces. An example of looking through a window is given in *The Complete Guide to Climate Change.* When you look through a window at an angle, you see a reflection; however, when you look straight through the window there is no reflection. Sunlight at the poles has a very low angle of incidence.

According the NSIDC's website, see (5), sea ice has a much higher albedo than most other surfaces. This means that it absorbs less solar energy, and therefore less heat than most other surfaces. The albedo of the ocean is typically 0.06. The ocean reflects six percent of incoming solar energy and absorbs ninety-four percent of the incoming energy. Sea ice has an albedo between 0.5 and 0.7. This means that sea ice reflects fifty to seventy percent of incoming solar energy. Since it reflects most of the energy, the surface is kept cooler than the sea itself. The higher albedo allows the ice to warm up and melt slower than the open ocean heats up, see (5). Snow has a higher albedo than sea ice at 0.9. When snow covers sea ice, it helps insulate the ice and prolongs melting in the summer. When the snow begins to melt, pools of water form on the surface of the snow and ice. There are called melt ponds. When melt ponds are present the albedo drops from 0.9 to 0.75. As the snow continues to melt and the melt ponds deepen, the albedo will continue to drop. Figure 1 below shows a negative and positive feedback loop for sea ice albedo.

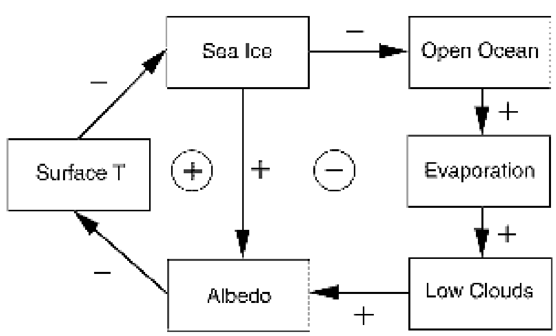

Figure 1-See (6), This figure shows negative and positive feedback loops for sea ice. If sea ice decreases, than open ocean in creases thus increasing evaporation and the amount of low clouds. An increase in low clouds will result in an increase in albedo and therefore a decrease in surface temperatures. If sea ice increases, then albedo also increases resulting in a decrease in surface temperatures. This figure does not provide information on other factors that contribute to earth's albedo.

2.4: Effects of Milankovitch Cycles

The Milankovitch cycles are an important consideration when studying sea ice extent. Milutin Milankovic, a mathematician, hypothesized that variation in the earth's axial tilt and orbit dictate Earth's climatic patterns. This became known as the Milankovitch Cycles. In *Climate Change: a Multidisciplinary Approach*, see (7), the Milankovitch theory is broken down into three cycles. The first is the **eccentricity** or orbit of the Earth. The Earth's orbit varies in ellipticity throughout the cycle. The ellipticity varies between zero and five percent over the course of 100,000 years. Today, the ellipticity is three percent, meaning there is a three percent difference between the aphelion (point farthest from the sun) and the perihelion (closest point). The difference in orbit causes the distance between the sun and the Earth to change. The second factor or cycle is the **tilt of the Earth** on its axis. During a 41,000 year span, the Earth's tilt varies between 21.5 and 24.5 degrees. This axial tilt dictates how much contrast there will be between the seasons. Currently the Earth axis is tilted at 23.5 degrees. The final factor is the Earth's **precession**. Precession is the wobble of the earth as it spins on its axis. It varies between pointing at Polaris (the North Star) and the star Vega. When the Earth is tilted toward Vega, winter and summer solstices in the Northern Hemisphere will correspond with aphelion and perihelion respectively. The figure below demonstrates aphelion and perihelion.

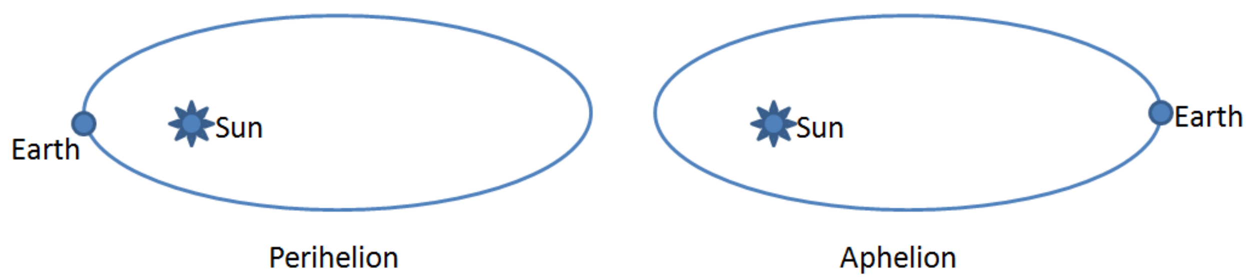

Figure 2-Perihelion and Aphelion

The tilt of the Earth results in greater seasonal contrast. Currently, in the Northern Hemisphere, the perihelion falls very close to the date of the winter solstice. This means that the Earth is farther from the sun in the summer than it is during the winter in the Northern Hemisphere. This means that the Arctic regions experience less solar input than if summer fell during the time when the Earth was closest to the sun. The precession cycle has a period of 23,000 years.

The Glacial Cycles can be broken down into four major stages:

1. Interglacial
2. Preglacial
3. Glacial
4. Post Glacial

We are currently in the interglacial stage referred to as the Holocene Interglacial. The last know interglacial period called the Eemian Interglacial was approximated to have occurred 125,000 years ago. During interglacial periods, the Earth experiences a period of warmer temperatures referred to as optimums. In the northern hemisphere, temperatures during the Eemain were about two to three degrees Celsius warmer than they are today, see (7). The last optimum was characterized by heavier rainfall to the subtropics, and also by the fast spreading of agriculture. The optimum provided the best conditions for vegetation to spread farther poleward than it would normally. The tropical deserts shrank and became more humid. The Holocene Optimum was thought to have occurred about 5,500 years ago due to the combination of the three Milankovitch cycles. The percession cycle is 23,000 years, meaning that the halfway point is 11,500 years. So 11,500 years ago the perihelion (closet point to the sun) fell on the summer solstice in the Northern Hemisphere. This would maximize the solar input in the summer for the Arctic. The effects of this are not immediate. There is a one to two millennium delay before the effects of this have an impact on the mean temperatures.

By studying these cycles, it is possible that we can try to predict the changes in climate that the Earth will undergo in the future discounting human contribution.

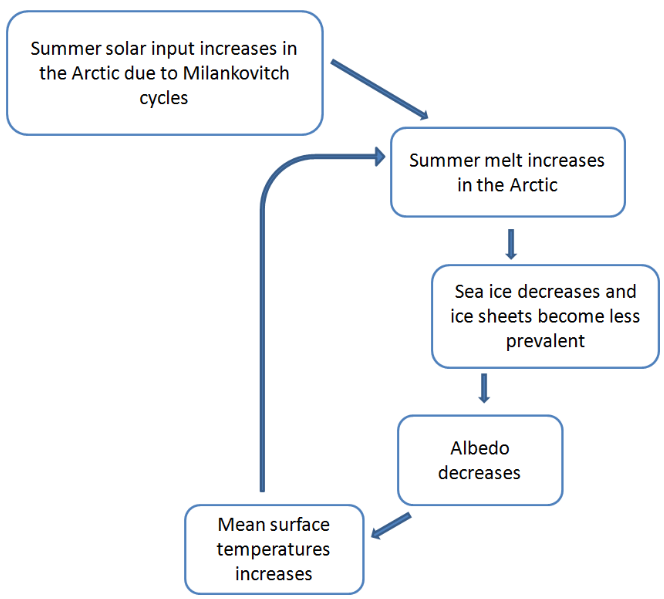

Figure 3-This figure shows the feedback loop for a small increase in solar energy due to the Milankovitch cycles. An increase in solar energy will result in a decrease albedo and therefore an increase in mean surface temperatures.

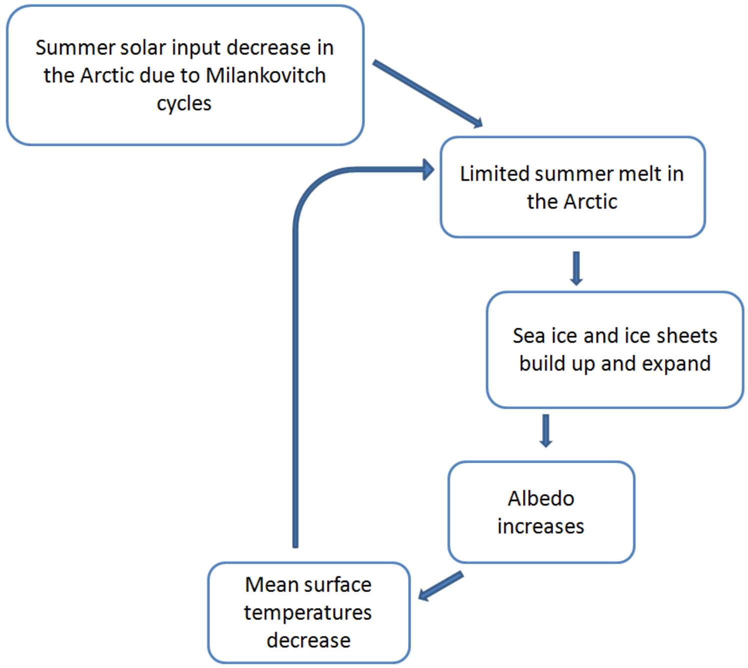

Figure 4-This figure shows the feedback loop for a small decrease in solar energy due to the Milankovitch cycles. An decrease in solar energy will result in an increase albedo and therefore an decrease in mean surface temperatures.

2.5: Importance of Sea Ice for Ecosystems

2.5.1-The Timing of Seasons Problem

A recent article in Science Magazine written by Dr. Eric Post, see (8), attempts to explain some of the effects of Arctic Sea Ice decline on the ecosystem. The decrease in sea ice has resulted in widespread vegetation shifts and a decline in certain animal populations. The length of the growing season has increased due to early onset of sea ice melting in the spring. Plant flowering now begins twenty days earlier than it did ten years ago. The timing of Caribou calving has not changed to correspond with the shift in vegetation. The demand of reproductive females for vegetation no longer corresponds to the seasonal peak for vegetation. As a result, caribou calf production and survival have both decreased.

The earlier onset of spring rain has also had an effect on ringed seals. In the Canadian Arctic, the rain has resulted in a washout of the birth lairs for these seals. The seal pups are then left exposed on bare ice and are more susceptible to predators and also to hypothermia.

2.5.2-Direct Effects of a Smaller Sea Ice Cover

The species most affected by the decrease in sea ice are those with more limited distributions and specialized feeding habits. These animals depend on ice for foraging, reproduction, and predator avoidance. Examples of this are gulls, walruses, ringed seals, hooded seals, narwhals, and polar bears.

2.5.3-Marine Life

Another important aspect of the ecosystem is the migration patterns of some fish. The change in migration increases the likelihood of the fish colonizing once fishless lakes. This change could alter the entire lake ecostructure and function. There has also recently been an increase in the density of filter feeders in the Arctic.

Also, according to the NSIDC's website, see (9), the more ice that melts the more nutrients are left behind. These nutrients are eaten by plankton, thus increasing the amount of plankton. Plankton are at the bottom of the food chain, and are a food source for larger marine life. The earlier the ice begins to melt the more nutrients will be available for the plankton. According to an article on Discovery news, see (3), it is not yet clear exactly what effect the increase in plankton will have on the rest of the Arctic ecosystem.

2.5.4-Changes in Population Distributions due to Northward Expansion of Species

The expansion of shrubs and trees in the Arctic serves to promote even more shrub growth in the Arctic. The increase in shrubs causes more snow accumulation and an increase in winter soil temperature. This results in more soil microbial activity and enhanced nutrient mineralization rate. Collectively, these two things force an increase in shrub growth. The increase in vegetation has resulted in an increase in reindeer population and has also allowed for the red fox to migrate further northward. The recent migration of the red foxes has now resulted in a decrease in Arctic fox population.

The overall shift in population of different species may serve to alter the land-atmospheric green-house gas balance. Also, the change in density of certain animals has an effect on the overall species to other species interactions.

2.5.5-Conclusion

The ecosystem in the Arctic is important to study since each individual species has a very important role. In the Arctic, there is very little functional redundancy among species; therefore when one species experiences a change, it has a large impact on the rest of the ecosystem. In other areas, you would not see this drastic a change because other species that perform the same function would prevent it. It is unknown whether the ecosystem in the Arctic will now experience permanent instability or if it will be able to rebound due to species resilience.

The figure below is a demonstration on how changes in the environment have a significant impact on ecosystems.

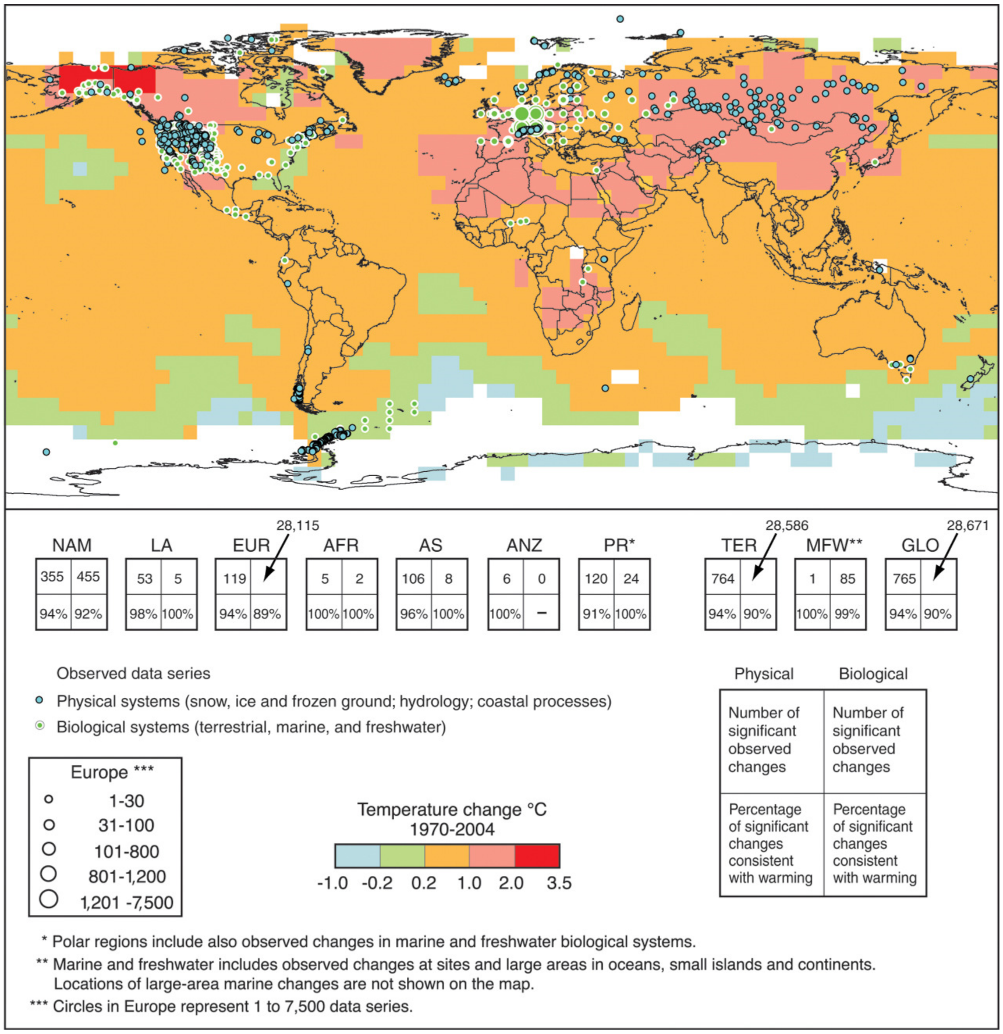

Figure 5-See (10), This figure shows a correlation between the change in amount of physical changes (such as sea ice) and the effect on biological systems. The figure shows four boxes for each region of the Earth researched (NAM=North America, LA=Latin America, EUR=Europe, AFR=Africa, AS=Asia, ANZ=Australia/New Zealand, PR=Polar Regions). The first box shows the number of physical changes observed, with the box below it showing the percentage of these changes consistent with global warming. The box in the top right show the number of biological changes, and the percentage consistent with global warming. As the number of physical changes increase, the number of biological changes also increase. The map at the top of the figure is color coded to show the temperature change experienced from 1970 to 2004.

2.6: Maritime Navigation Routes-the Arctic Shortcut

A recent New York Times article entitled *Arctic Shortcut Beckons Shippers as Ice Thaws,* see (11), discusses the impact of the shrinking of the Arctic Sea Ice cover as it relates to shipping routes. The thawing of sea ice in the Arctic provides a shortcut that may speed trade between Asia and the West. The Northern passage is several thousand miles shorter than other currently used southerly routes. Russian ships have used the Arctic coastline to transport goods in the past, but the impending passage of German ships may serve to show that the Northern passage can be a reliable shipping route. While the Northern passage has less ice than in the past, there are still sheets of pack ice and icebergs that float free in the Arctic Sea. The two German ships have been accompanied thus far by Russian nuclear icebreakers in case the ships encounter either one of these. The window of opportunity to use the Northern passage is only two weeks, but according to the article, this voyage will still be an economically beneficial shortcut. There is also a possibility that in the future the window of opportunity to use the passage will be longer than two weeks.

3 Projections of Future Trends in Arctic Sea Ice Extent

3.1: Simple Projections Based on Statistical Analysis

The National Sea and Ice Database's (NSIDC) contains data on Arctic Sea Ice Extent for each month for the years 1979 to 2009. For projections of Arctic Sea Ice Extent, the most significant months are March and September. Arctic Sea Ice reaches its peak in March and reaches its lowest point in September. The raw Sea Ice Extent Data can be seen in Table 2 below.

Year	Sea Ice Extent-March (million sq km)	Sea Ice Extent-September (million sq km)
1979	16.44	7.2
1980	16.13	7.85
1981	15.61	7.25
1982	16.15	7.45
1983	16.1	7.52
1984	15.62	7.17
1985	16.06	6.93
1986	16.08	7.54
1987	15.95	7.48
1988	16.13	7.49
1989	15.52	7.04
1990	15.88	6.24
1991	15.5	6.55
1992	15.47	7.55
1993	15.88	6.5
1994	15.58	7.18
1995	15.32	6.13
1996	15.12	7.88
1997	15.58	6.74
1998	15.66	6.56
1999	15.4	6.24
2000	15.27	6.32
2001	15.61	6.75
2002	15.44	5.96
2003	15.49	6.15
2004	15.05	6.05
2005	14.74	5.57
2006	14.43	5.92
2007	14.65	4.3

2008	15.23	4.68
2009	15.16	5.36

Table 2-Data obtained from NSIDC's website for the Arctic Sea Ice extent in September and March

The NSIDC has created a graph to show sea ice extent versus year for the months of March and September. The graph was created by plotting the percent difference from the mean for the years 1979 to 2000 (the mean is 15.7 million sq km in March and 7.0 million square km in September). These graphs can be seen in Figures 6 and 7 below. A linear fit was applied to the data and the rate of decrease for March was found to be -2.7% per decade, while the decrease in September was found to be -11.2% per decade.

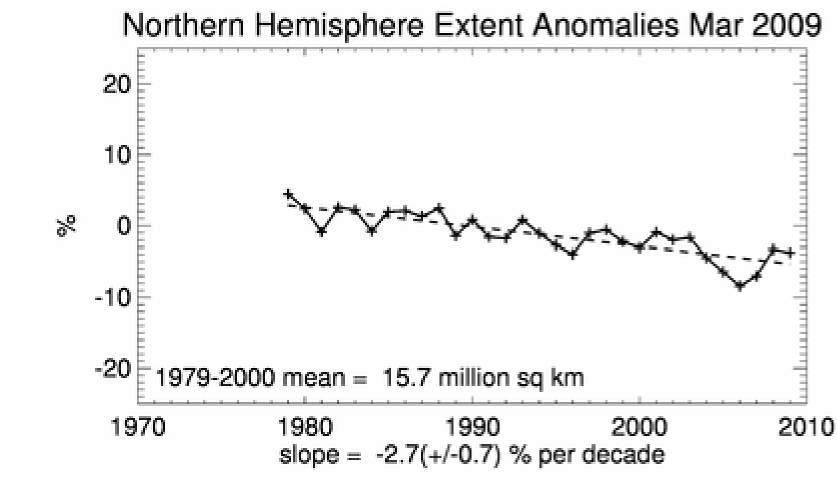

Figure 6-The graph above from NSIDC's website, see (12), shows the extent of Sea Ice in the Arctic as it varies from the mean. March is the month in which the sea ice extent is at its maximum.

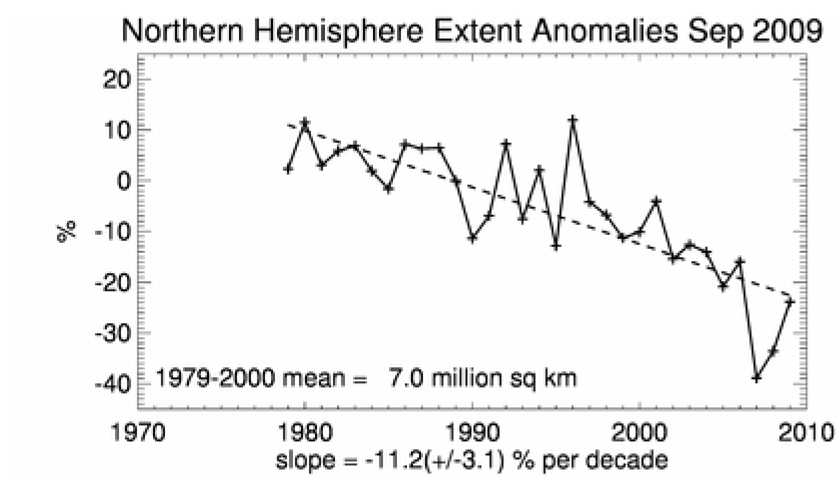

Figure 7-The graph above from NSIDC's website, see (13) shows the extent of Sea Ice in the Arctic as it varies from the mean. September is the month in which the sea ice extent is at its minimum.

To verify the accuracy of these graphs, we have replicated them in MATLAB using the data found in Table 2. The percent difference from the mean was calculated using the following equation:

$$\%\ difference\ from\ mean = \frac{sea\ ice\ extent - mean}{mean}$$

The mean used for March and September were 15.7 million square kilometers and 7 million square kilometers respectively. A linear fit was applied to the data. The graphs along with the equations for the lines of best fit can be seen in Figures 8 and 9 below.

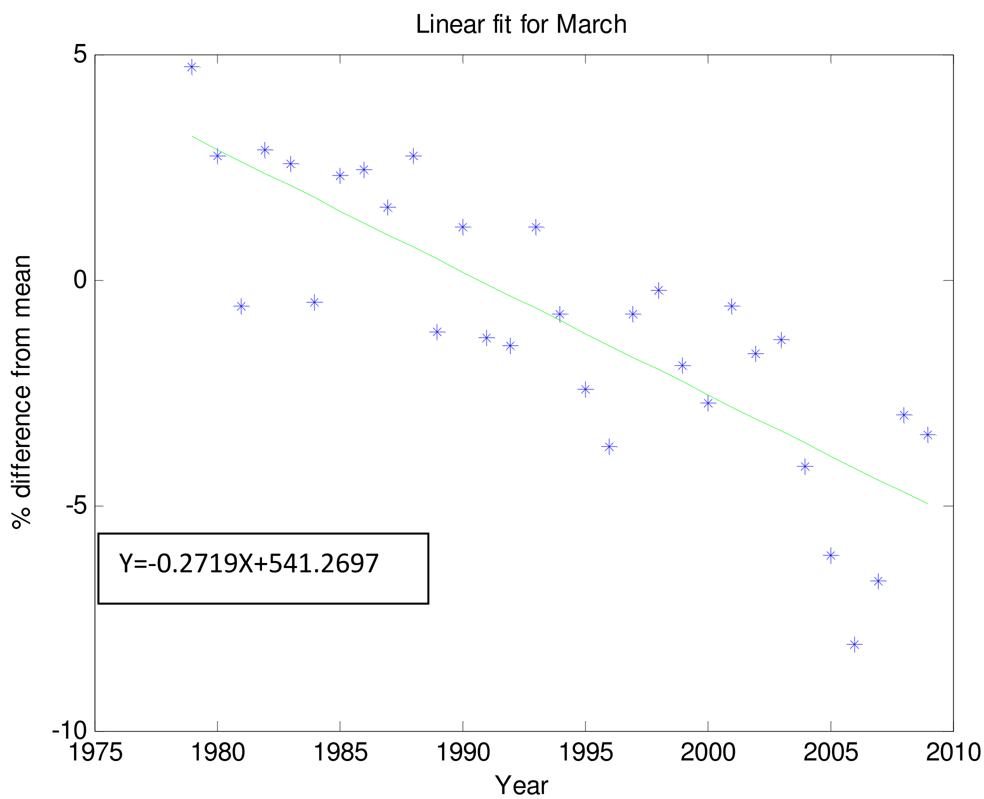

Figure 8-The graph above plots the Arctic Sea Ice Extent for March as it differs from the mean of 15.7 million square kilometers for the years 1979 to 2009. The linear fit shows that the sea ice is decreasing at a rate of 0.27% per year (see appendix for code).

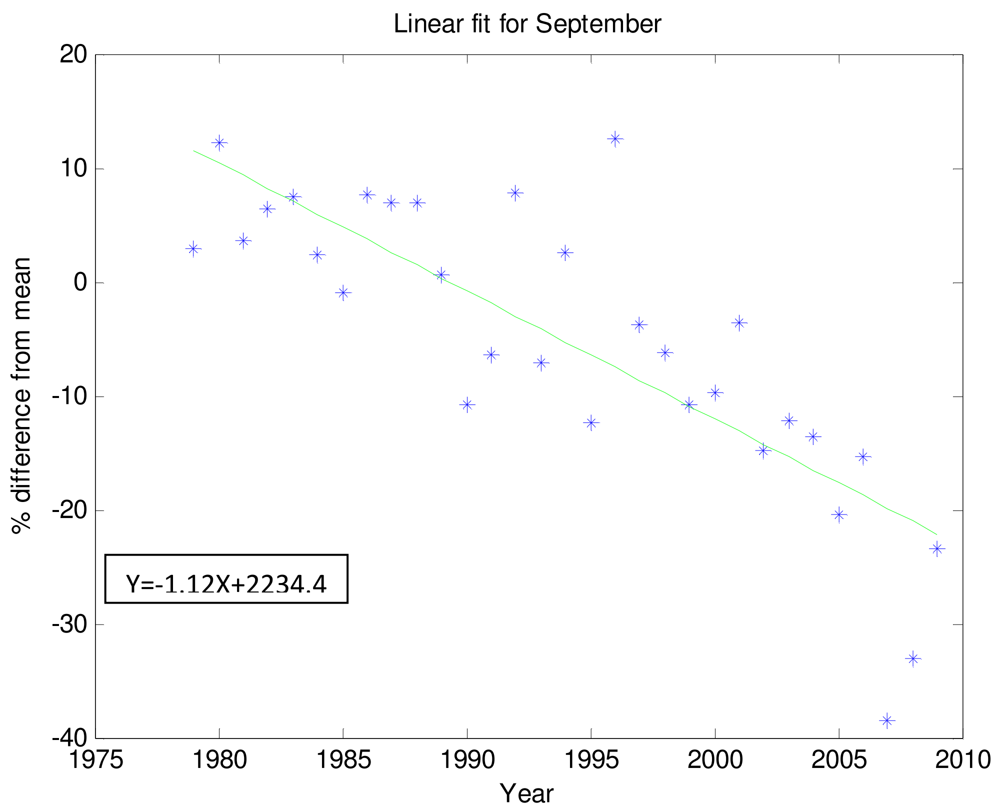

Figure 9-The graph above plots the Arctic Sea Ice Extent for September as it differs from the mean of 7 million square kilometers for the years 1979 to 2009. The linear fit shows that the sea ice is decreasing at a rate of 1.1% per year. This is a much larger decrease per decade than for March (see appendix for code).

Plotting the data, the graphs from NSIDC's website were replicated. The procedure in which the graphs were obtained was verified. The graphs of NSIDC's website predict the sea ice decline to be 2.7% and 11.2% per decade for March and September respectively, however, we are in disagreement with the math. The NSIDC obtained this value by multiplying the decline per year by the total number of years (ten). When dealing with percentages, you must account for the fact that the total amount of sea ice from the previous year is changing. In order to find the change per decade, you must do $(1-0.0027)^{10}$ and $(1-0.012)^{10}$ for March and September respectively. You would then obtain a decrease of 2.7% per decade for March and 10.7% per decade for September.

To predict the future trends in Arctic Sea Ice a Matlab code was created to apply a linear and quadratic fit to the data from Table 2 (see appendix for code). The Sea Ice Extent was plotted versus year and predictions were up to the year 2050. The graphs can be seen in Figures 10 and 11 below.

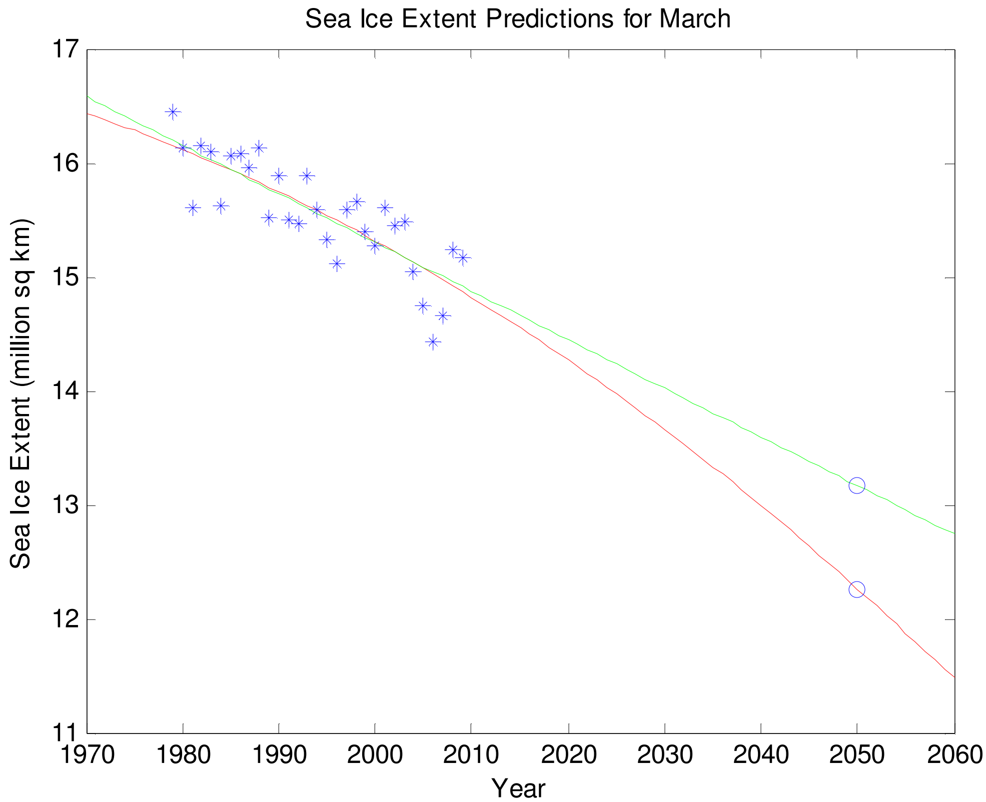

Figure 10-In the above graph, the blue dots are the Arctic sea ice extent data points for March versus year (from NSIDC). The green line is the linear fit to the data while the red line is the quadratic fit for the data. The quadratic and linear trend lines are fit to the data with approximately the same degree of error (see appendix). The linear fit predicts the Arctic Sea Ice Extent in March for the year 2050 to be about 13.3 million square kilometers, while the quadratic trend predicts it to be 12.2 million square kilometers.

The quadratic and linear trend lines are fit to the data with approximately the same degree of error. The linear fit predicts the Arctic Sea Ice Extent in March for the year 2050 to be about 13.3 million square kilometers, while the quadratic trend predicts it to be 12.2 million square kilometers.

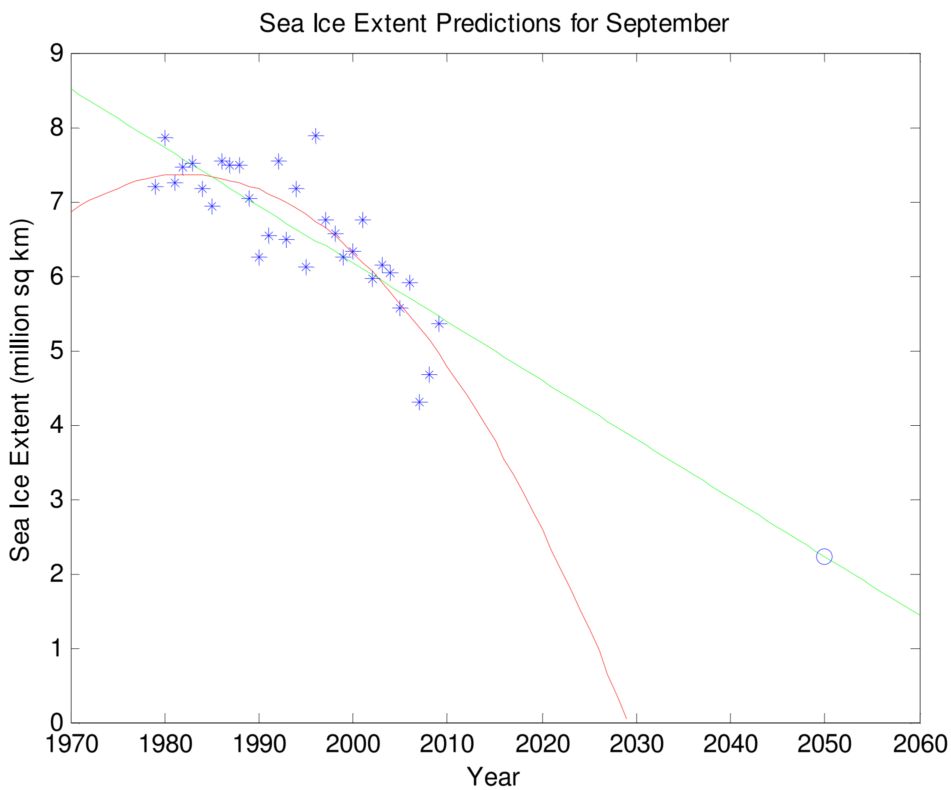

Figure 11-In the above graph, the blue dots are the Arctic sea ice extent data points for September versus year (from NSIDC). The green line is the linear fit to the data while the red line is the quadratic fit for the data. The quadratic fit overall has smaller errors than the linear fit, therefore the quadratic fit is a better prediction for future years (see appendix). In the graph, the sea ice extent will continue to decrease until 2029, when the sea ice extent is predicted to hit zero according to the graph. The linear fit is also decreasing but doesn't hit zero until a later date. The prediction for the linear fit for the year 2050 is approximately 2.2 million square kilometers, which is significantly less than the sea ice extent in 2009.

For September, the quadratic fit overall has smaller errors than the linear fit, therefore the quadratic fit may be assessed to be a better prediction for future years. According to our predictions, the sea ice extent will continue to decrease until 2029, and then the Sea Ice Extent in September will be zero. The linear fit also predicts a decrease, but doesn't hit zero until a later date. The prediction for the linear fit for the year 2050 is approximately 2.2 million square kilometers, which is significantly less than the sea ice extent in 2009.

3.2-Projections Based on Dynamical Climate Models

3.2.1-Climate simulations for 1880–2003 with GISS model E

This article, see (14), discusses how climate models are run with past data to see if they can accurately reproduce a set of climate parameters for the period 1880-2003. This climate model uses several major forcings. The first major forcing used is green house gases. These gases have been proven to cause the earth's atmosphere to retain heat. Another major climate forcing used in this model is aerosols. Aerosols in the earth's atmosphere are capable of blocking sunlight from entering. Land use is also a forcing used in this climate model. The article explains that deforestation is especially significant as it can dramatically change the albedo of the area. Soot on snow and ice reduces albedo and thus is used as a forcing in the model. Lastly, solar irradiance, the only heat source, is a forcing.

With climate models, some parameters are more easily replicated than others. For instance, the average surface temperature of Earth is replicated fairly accurately with the model; however the surface temperature of specific regions of the Earth is not as easy to reproduce. The ocean sea ice cover was not as easily replicated. The model has the sea ice cover declining at a much slower rate than the actual decrease. This is probably due to problems with estimating the thickness of the sea ice. Sea ice thickness is sometimes overestimated and the ice is much thinner, meaning that it will melt faster than predicted. Another important thing to consider is the accuracy of the sea ice data before 1979. Accurate measurements were not obtainable until satellite data emerged, thus the data obtained before 1979 is not as accurate. In figure 12 below, obtained from page 674 of the report, the light blue line is the observed data while the other lines are from different runs of the climate model.

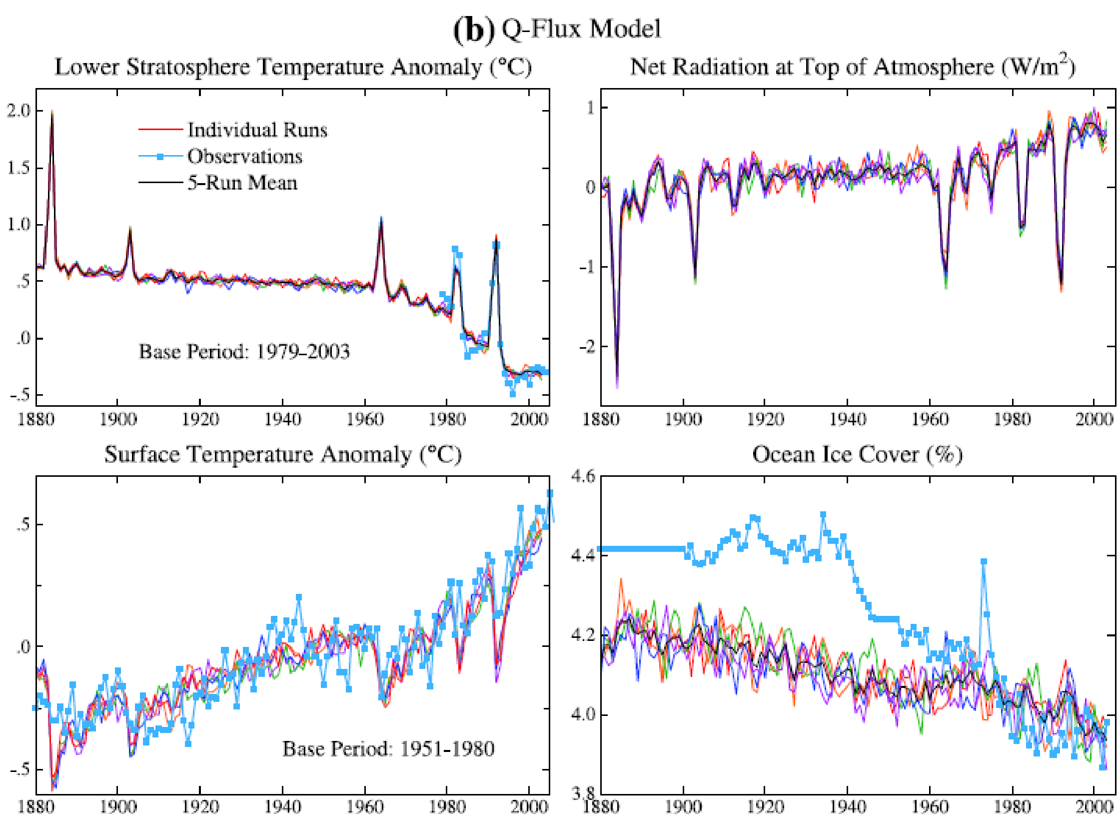

Figure 12-see (14), The figure shows several different runs of climate model along with the actual data. The light blue line is the actual data while the other lines are from different runs of the climate model. Average surface temperature of Earth is replicated fairly accurately with the model, however the surface temperature of specific

regions of the Earth is not as easy to replicate. The ocean sea ice cover was not as easily replicable. The model has the sea ice cover declining at a much slower rate than the actual decrease.

3.2.2-Arctic Sea Ice Decline: Faster than forecast

In a 2007 paper by Julienne Stroeve et al, climate models were used to estimate the impact that green house gases (GHG) will have on the environment, see (15). Almost all climate models are in agreement that Arctic Sea Ice Extent will continue to decline during the 21st Century as a result of GHG. However, none of these climate models have shown decreases that are comparable with the observations currently being made. In figure 13 below, the red line shows the observations while the other lines are different runs of the climate model. The sea ice extent in the observations is decreasing at a much faster rate than any of the climate stimulation runs.

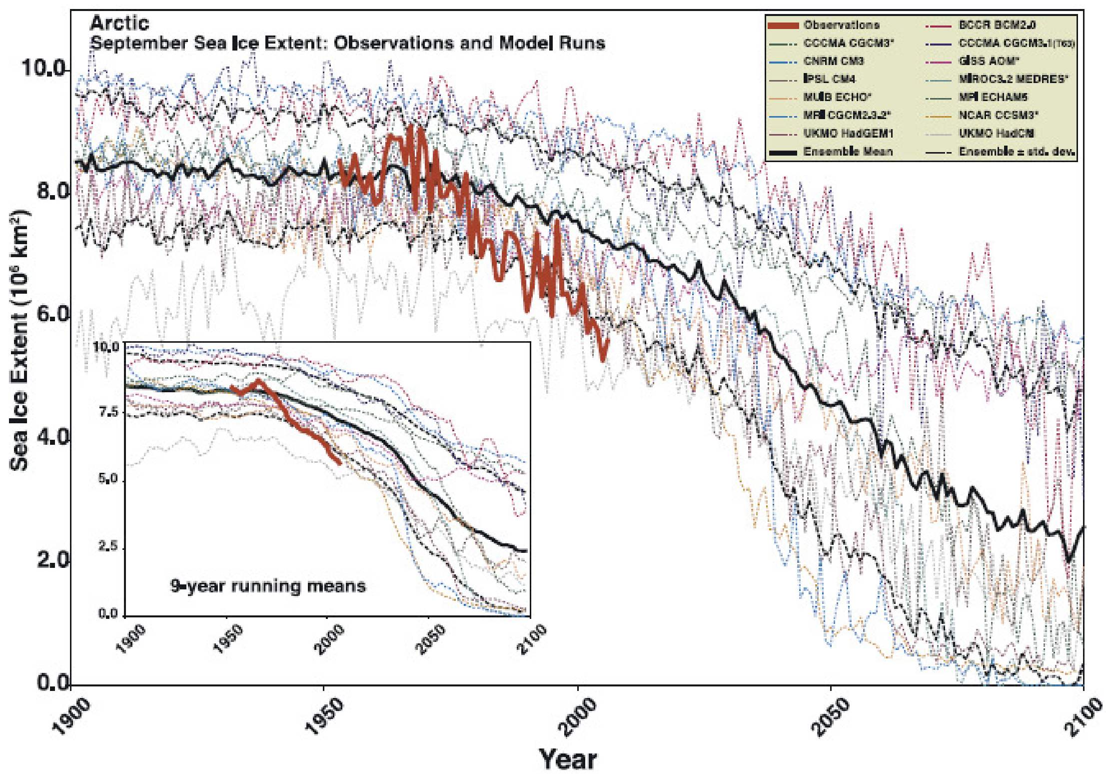

Figure 13- see (15), The figure shows several runs of the climate model. The red line shows the observations while the other lines are different runs of the climate model. The sea ice extent in the observations is decreasing at a much faster rate than any of the climate stimulation runs.

In 2007, the sea ice extent was 30 years ahead of the mean estimated value of the IPCC climate models. The models indicate that we may experience a sea ice free Arctic as soon as 2050 or it could occur in 2100 or beyond. If the models continue to underestimate the GHG effect however, this date may come sooner rather than later.

3.2.3-Arctic Sea Ice Extent Plummets in 2007

An article published by the American Geophysical Union and Earth's Observing System, attributes the underestimate of sea ice decline to natural variability, see (16). As greenhouse gases rise, the sea ice thins. It is believed that the thickness of the ice is overestimated in the model, resulting in a slower decline than that which is being observed. This along with natural variability could cause an initial abrupt loss of Arctic Sea Ice. The summer sea ice will continue to decrease due to the albedo feedback system. The authors believe that the sudden decrease in sea ice in 2007 will set up rapid loss of the remaining summer sea ice cover. Natural variability may be able to stabilize sea ice loss in the short term; however in the long term sea ice will continue to decrease at a faster rate than previously predicted. A summer free of Arctic sea ice could occur as soon as 2030 according to their model. These findings are consistent with our predictions based on quadratic fitting (see section 3.1, Figure 9).

4 Conclusion

In this paper, we first examined the reasons for studying Arctic Sea Ice. We showed how previous records of declining sea ice could be contributed to the Milankovitch cycles. We also studied the rate at which the sea ice extent is declining to see if it can be accurately predicted by climate models.

The Arctic was the focus of this paper rather than the Antarctic. The Arctic differs from the Antarctic in that the Arctic Ocean is surrounded by land whereas the Antarctic is a land mass surrounded by a body of water. The Sea Ice in the Arctic is less likely to melt in the summer as opposed to Antarctic Sea Ice. The Earth has not experienced a summertime free of Arctic Sea Ice in over 125,500 years: this highlights the importance of the changes currently taking place in Earth's climate system.

Albedo, a unitless quanitity that indicates the percentage of solar energy reflected by a surface, was also considered in this paper. We looked to understand the relation between albedo and small changes in the Earth's orbit.

The Milankovitch cycles have dictated the climate patterns of the Earth for the past three million years. The tilt of the Earth on its axis, the Earth's eccentricity and the Earth's precession all impact the amount of solar irradiation the Earth receives. The Milankovitch cycles are important to consider because they may be able to explain the reason for the decline in sea ice extent as they were able to explain the last dramatic decline 125,500 years ago.

The ecosystem in the Arctic is important to study since each individual species has a unique role. In other words, there is very little functional redundancy among species. Therefore when one species experiences a change, it has a large impact on the rest of the ecosystem. In other areas, you wouldn't see this drastic a change because other species that perform the same function would prevent it.

As the Arctic Sea Ice extent continues to decline, it becomes increasingly possible for ships to use an Arctic shortcut. This northern passage cuts down the travel time by almost two weeks over the currently used routes. If sea ice continues to decline, the time frame in which this passage is open will continue to increase.

In this paper, we fit data from1970 to 2009 of sea ice extent was fit with both a linear fit and a quadratic fit. These approximations were used to predict the sea ice extent for 2050. It was found that the quadratic models produced the most accurate fit to the data for both the summer and wintertime sea ice extent. The fit showed that we could experience a summertime free of Arctic sea ice as soon as the year 2030. This is consistent with the findings of other authors in the dynamical model in section 2.2.3.

The current dynamical climate models all predict that sea ice will decline; however the predictions are not matching observations. The likely source of this discrepancy may be the overestimation of sea ice thickness. If dynamical climate models are able to use more accurate ice thickness measurements, it may be possible to obtain more accurate sea ice cover predictions. In order to obtain this data, there will need to be continuous and improved monitoring of sea ice thickness and drift.

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Appendix

Linear fit Code:

```
function linearfit
%code for September
A = 1979:1:2009;B = transpose(A);
C = [2.857142857
12.14285714
3.571428571
6.428571429
7.428571429
2.428571429
-1
7.714285714
6.857142857
7
0.571428571
-10.85714286
-6.428571429
7.857142857
-7.142857143
2.571428571
-12.42857143
12.57142857
-3.714285714
-6.285714286
-10.85714286
-9.714285714
-3.571428571
-14.85714286
-12.14285714
-13.57142857
-20.42857143
-15.42857143
-38.57142857
-33.14285714
-23.42857143
];

P = polyfit(B,C,1)
Q = 1979:1:2009;
L = P(1)*Q + P(2);

plot(Q,C,'*');
hold on
plot(Q,L,'g'),xlabel('Year'), ylabel('% difference from mean'), title('Linear
fit for September');
hold off
pause

%Code for March:
A = 1979:1:2009;
B = transpose(A);
C = [4.713375796
2.738853503
```

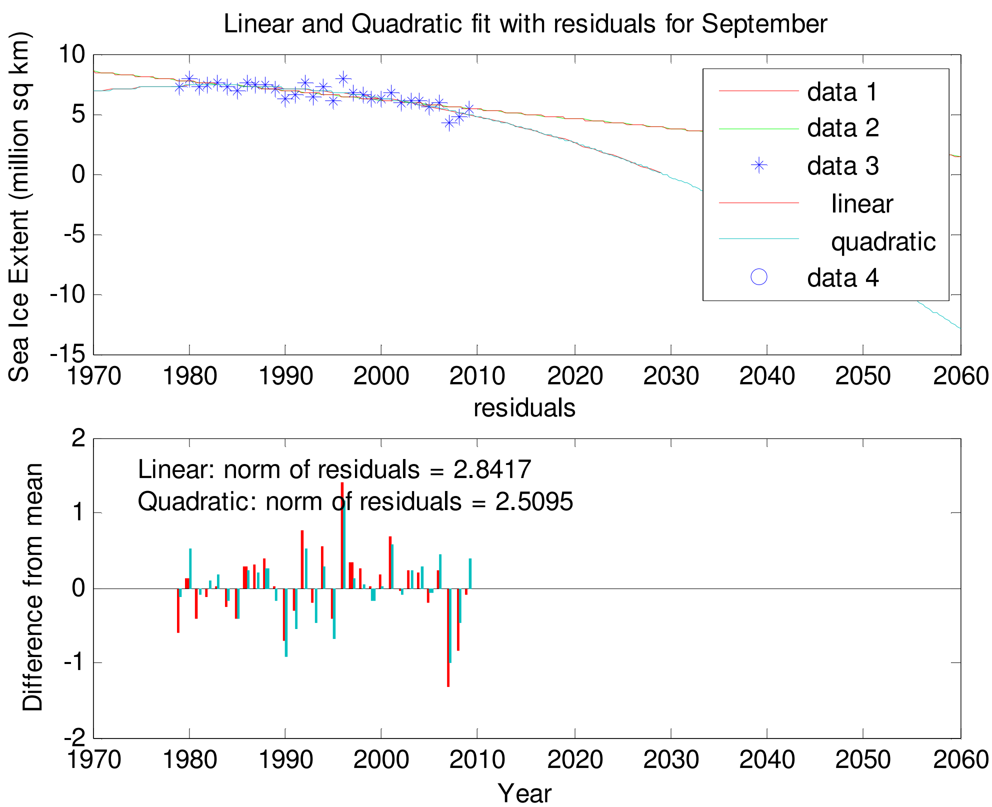
```
-0.573248408
2.866242038
2.547770701
-0.50955414
2.292993631
2.420382166
1.592356688
2.738853503
-1.146496815
1.146496815
-1.27388535
-1.464968153
1.146496815
-0.76433121
-2.420382166
-3.694267516
-0.76433121
-0.25477707
-1.910828025
-2.738853503
-0.573248408
-1.656050955
-1.337579618
-4.140127389
-6.114649682
-8.089171975
-6.687898089
-2.993630573
-3.439490446
 ];

P = polyfit(B,C,1)
Q = 1979:1:2009;
L = P(1)*Q + P(2);

plot(Q,C,'*');
hold on
plot(Q,L,'g'),xlabel('Year'), ylabel('% difference from mean'), title('Linear fit for March');
hold off
```

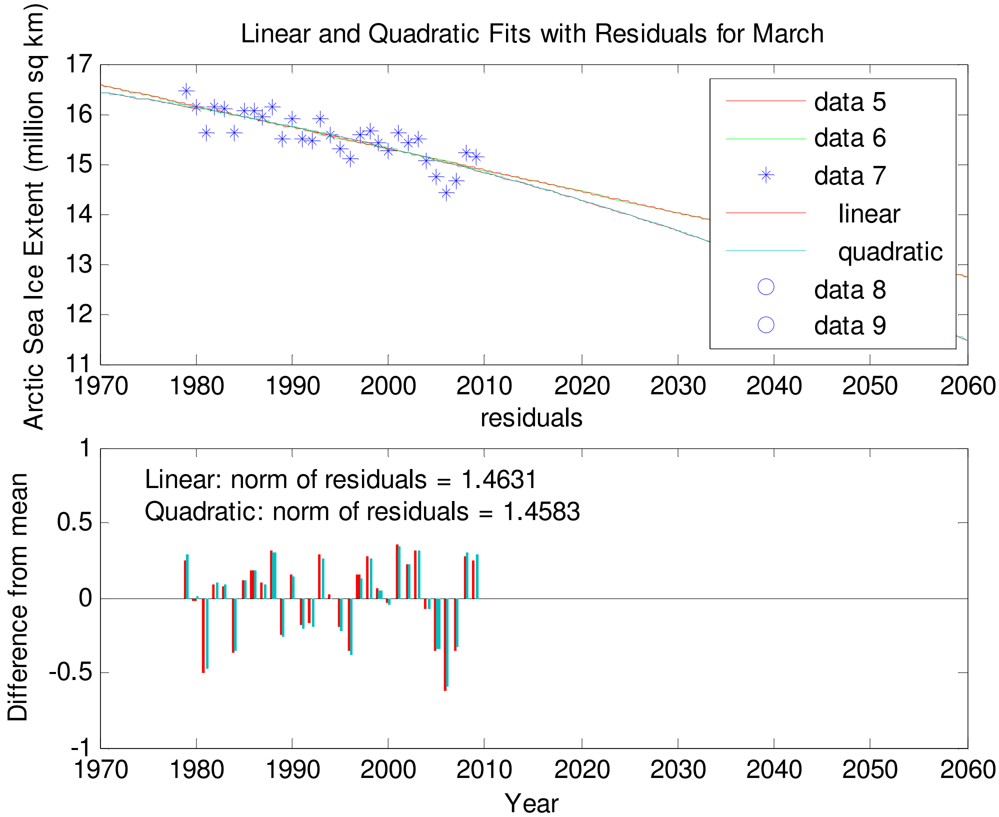
Prediction Code:

```
%code for September
function iqprediction
A = 1979:1:2009;
B = transpose(A);
C = [7.2
7.85
7.25
7.45
7.52
7.17
6.93
7.54
7.48
```

```
7.49
7.04
6.24
6.55
7.55
6.5
7.18
6.13
7.88
6.74
6.56
6.24
6.32
6.75
5.96
6.15
6.05
5.57
5.92
4.3
4.68
5.36
];



P = polyfit(B,C,1);
R = polyfit(B,C,2);
Q = 1970:1:2029;
S = 1970:1:2060;
L = P(1)*S + P(2);
N = R(1)*Q.^2 + R(2)*Q + R(3);


plot(Q,N,'r')
hold on
plot(S,L,'g')
hold on
plot(B,C, '*')
hold on
T = P(1)* 2050 + P(2)
plot(2050,T,'o')
hold off
pause

%Code for March:
A = 1979:1:2009;
B = transpose(A);
C = [16.44
 16.13
 15.61
 16.15
 16.1
 15.62
 16.06
 16.08
```

```
15.95
 16.13
 15.52
 15.88
 15.5
 15.47
 15.88
 15.58
 15.32
 15.12
 15.58
 15.66
 15.4
 15.27
 15.61
 15.44
 15.49
 15.05
 14.74
 14.43
 14.65
 15.23
15.16
];

P = polyfit(B,C,1);
R = polyfit(B,C,2);
Q = 1970:1:2060;
L = P(1)*Q + P(2);
N = R(1)*Q.^2 + R(2)*Q + R(3);
hold off
plot(Q,N,'r')
hold on
plot(Q,L,'g')
hold on
plot(B,C, '*')
hold on
T = P(1)*2050 + P(2);
plot(2050, T ,'o')
hold on
D = R(1)*2050^2 + R(2)*2050 + R(3);
plot(2050, D ,'o')
hold off
```


Linear and Quadratic fit with residuals for September
Sea Ice Extent (million sq km)
10
5
0
-5
-10
-15
1970 1980 1990 2000 2010 2020 2030 2040 2050 2060
residuals
data 1
data 2
data 3
linear
quadratic
data 4
Difference from mean
2
1
0
-1
-2
Linear: norm of residuals = 2.8417
Quadratic: norm of residuals = 2.5095
1970 1980 1990 2000 2010 2020 2030 2040 2050 2060
Year


Linear and Quadratic Fits with Residuals for March
Arctic Sea Ice Extent (million sq km)
17
16
15
14
13
12
11
1970 1980 1990 2000 2010 2020 2030 2040 2050 2060
residuals
data 5
data 6
data 7
linear
quadratic
data 8
data 9
Difference from mean
1
0.5
0
-0.5
-1
Linear: norm of residuals = 1.4631
Quadratic: norm of residuals = 1.4583
1970 1980 1990 2000 2010 2020 2030 2040 2050 2060
Year