Climate Modeling

Kayla Ebright

Abstract

For the past several years climate change has been a frequent feature in world news. Climate scientists are urging policymakers to act while there is still time to reverse the dangerous effects before they cause catastrophic events while climate change skeptics are calling the field a hoax made to stop progress. With such a hot button issue surrounded by controversy and competing interests, it is important to know all the facts and understand how and why predictions are being made. This paper will discuss research into how climate models are made and which environmental factors they are considering. I will also state the general conclusions of climate scientists related to climate change and describe the potential effects of inaction. Finally, I will discuss how this issue relates to other fields of study and what can be done to help decrease the effects of climate change.

Introduction

Throughout the history of the Earth, the planet has gone through cycles of warming and cooling as seen in Figure 1. These cycles are determined by examining the amount of carbon

Figure 1. The Earth has gone through warming and cooling periods which can be seen by examining carbon dioxide levels. This period is particularly concerning because carbon dioxide levels are the highest they have been in the past 400,000 years [1].

dioxide present in ice cores and sediment samples. These samples provide information on the temperature of the Earth thousands of years ago because carbon dioxide is a greenhouse gas[1] and the presence of greenhouse gases in the atmosphere are indicators of higher temperatures. The current period of warming is especially significant because carbon dioxide levels are the highest

[1] Other common greenhouse gases that are being put into the atmosphere are methane, nitrous oxide, and fluorinated gases but carbon dioxide is typically the most present. Greenhouse gases cause increases in global temperatures because they are dense enough to trap heat energy from the sun and prevent it from escaping the Earth's atmosphere.

they have been in the past 400,000 years and this increase has been caused directly by human activities. Rising global temperatures are believed to be a direct result of this effect.

Weather and Climate [2]

Before moving forward with a discussion about climate change, it is necessary to distinguish the differences between weather and climate. Weather is conditions that occur in the short term. This includes sunshine, rain, cloud cover, winds, etc. Climate is the long term pattern of weather that is measured over years[2]. This includes averages of precipitation, temperature, humidity, and other measures of weather.

It is important to note that there is significant uncertainty in predicting weather. Predicting the weather in hours or days is difficult and often predictions can be inaccurate. This means that trying to predict future variations in climate can be even more complicated but the need for predictions to be accurate is even more vital.

Evidence for Climate Change [3]

Data from satellites and advances in technology have allowed climate scientists to gain a clear view of the evidence and potential effects of climate change. The clearest indicator is increasing global temperatures as seen in Figure 2. The average global temperature has risen by approximately 1.62°F since the beginning of the 19th century and starting in the 2000s almost every year has been the warmest year on record. This increase has caused ice sheets, glaciers, and snow covers to begin melting and retreating. The areas of the Earth that are typically covered in ice or snow year round have been steadily decreasing for the past five decades.

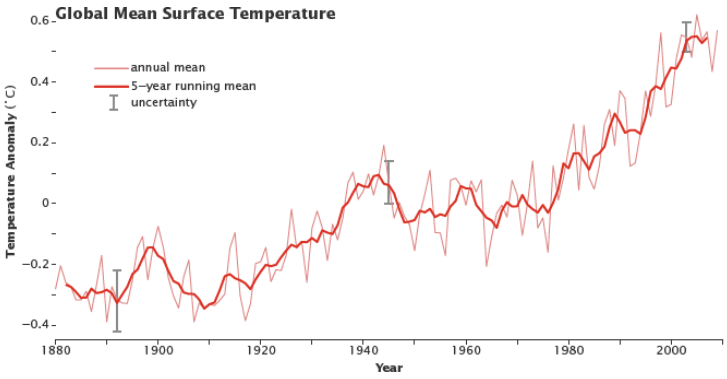

Figure 2. The sharp increase in global temperature provides support for scientists' claims that human activities are driving climate change.

Additionally, ocean temperatures have risen 0.4°F since 1969. This is problematic because rising ocean temperatures damage coral reefs and can cause increasingly devastating hurricanes. These increasing temperatures have also caused ocean levels to rise as ice in the arctic melts. In the past century, ocean levels have risen by approximately 8 inches and the rate of this increase has doubled in the past 20 years. Finally, ocean acidification has been occurring because the ocean is a major sink[3] for carbon dioxide. This has caused the pH level of the ocean to decrease by about 30 percent.

[2] Typically climate models use 30 years of data or more.
[3] A sink is a natural "reservoir" where materials, in this case carbon dioxide, accumulate.

Finally, the increase in severe weather events is another indicator of climate change. The number of extreme droughts, wildfires, hurricanes, and storms have been increasing as global temperatures have been rising.

Effects of Climate Change

In the beginning of October 2018 the United Nations Intergovernmental Panel on Climate Change (IPCC) issued a report stating the planet will reach the 2.7°F threshold by 2030 if carbon dioxide emissions continue at the current level [4]. This is significant because if the Earth reaches this level of temperature increase, severe droughts, wildfires, floods, and food shortages are guaranteed to occur. It will also become considerably more difficult to reverse the effects of climate change if this threshold is exceeded.

In order to prevent these devastating effects, action must be taken now to reduce greenhouse gas emissions. This means major changes need to be implemented regarding energy, industry, transportation, buildings, and more. These changes would be very costly and difficult to enact which proves the importance of accurate predictions and models. The sections below will examine how climate models are created and how accurate they have been proven to be.

Simple Temperature Model

To begin the process of climate modeling, we will examine a simple temperature model called an energy balance model [5]. We will assume that the Earth has an average temperature, T. The first part of the equation is the sun's heat energy shown below.

$$(1-a)S$$

where a = albedo[4] of the Earth (currently valued at 0.31)

S = incoming power of the sun (estimated at 342W/m^2)

The next part of the equation is to include the heat energy is radiated back into space.

$$\sigma e T^4$$

where σ = Stefan-Boltzmann Constant (5.67x10^{-8} W/m^{2}K^4)

e = emissivity[5] (e=0.605 for Earth's atmosphere)

T = average temperature

Setting these two equations equal to each other and solving for T yields the following equation.

$$T = \left(\frac{(1-a)S}{\sigma e}\right)^{1/4}$$

[4] The amount of energy from the sun that is reflected off of the surface of the Earth.
[5] The transparency of the atmosphere. The higher the value is, the less atmosphere the planet or moon has.

From this equation we can plug in the constant values and return a current mean temperature of 288K or 59ºF. To illustrate how small changes can greatly influence global temperatures, we will decrease the values of albedo and emissivity. It was mentioned above that ice sheets are melting and glaciers are retreating and ice is a strong influencer of albedo because energy is best reflected off of white surfaces. Therefore, we will decrease the albedo to 0.21. Emissivity decreases as more greenhouse gases enter the atmosphere because the atmosphere becomes more dense and less energy is able to radiate back to space so we will decrease the emissivity to 0.505. When these values are changed and plugged into the equation, the average temperature increases to 313K or 104ºF. This is concerning because albedo and emissivity were only changed by 0.1 and drastic changes occurred. Obviously, this model is extremely simplified which can be a cause of this major change but it is still important to note the dramatic temperature increase.

Adding More Complex Factors

When making more accurate and complex climate models, there are four factors that it is necessary to model: atmosphere, ocean, land, and ice. Each of these factors uses multiple partial differential equations as seen in Figure 3. These equations must take into account coriolis force, the sun's radiation, water vapor, other gases in the atmosphere, gravity, friction, and many more factors. This causes models to become very complicated very quickly.

$$\frac{\partial \vec{u}}{\partial t} + \vec{u} \bullet \nabla \vec{u} + 2\Omega \times \vec{u} = -\frac{1}{\rho}\nabla p + g\hat{k} + \vec{F} + \Im(\vec{u})$$

$$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \vec{u}) = 0$$

$$p = \rho RT;\ \rho = f\,(T,q)$$

$$\frac{\partial T}{\partial t} + \vec{u} \bullet \nabla T = SW \updownarrow + LW \updownarrow + SH + LH + \Im(T)$$

$$SW = f\,(clouds, aerosols \ldots)$$

$$LW = f\,(T, q, CO_2, GHG \ldots)$$

$$\partial q + \vec{u} \bullet \nabla\, q = Evap - Condensation + \Im(q)$$

$\Im$ convective mixing

Figure 3. A sample of the differential equations modeling atmosphere used by the Mathematical Sciences Research Institute [6].

A computer model used by the Australian government and created by a company called CSIRO splits the Earth into boxes of 200km by 200km with more complicated regions of land, such as mountains or coast land, split into 50km by 50km or smaller boxes [7]. These weather data for these boxes over multiple years is examined in order to form a model. These models are then to make predictions about conditions decades into the future and are updated periodically as new data is gathered.

Accuracy of Climate Models

Uncertainty is an important aspect of climate modeling to recognize. These models are highly complex and model dynamic factors so constants are often estimates because exact levels of energy and other measures cannot be known for specific moments in time. Human factors also cause ambiguity because human behavior is hard to predict and incorporate into a model but human behavior is a main cause of increases in greenhouse gases in the atmosphere. Additionally, climate systems are inherently unpredictable and because of this, climate scientists agree that there is no one "best model" that makes significantly better predictions than all the others [8]. Despite this, almost all reliable models are able to accurately predict the increase in global temperatures and most climate scientists agree that this is directly the cause of human emissions of greenhouse gases.

Table 1 shows the accuracy of several popular models made in the past 40 years. The general trend is that the accuracy of models has improved over time. This is because of increased measurement accuracy, technological advances, and a better understanding of the signs and effects of increasing global temperatures. As more data is gathered, models are also able to improve their prediction accuracy. Overall, climate scientists are satsified with this level of prediction because of the many intricate factors involved in making these models.

Model	Difference in 1970-2016 mean warming rate vs. Obs
Broecker 1975	+30%
Hansen et al 1981	-20%
Hansen et al 1988	+30%
IPCC 1st Report, 1990	+17%
IPCC 2nd Report, 1995	-28%*
IPCC 3rd Report, 2001	-14%
IPCC 4th Report, 2007	+8%
IPCC 5th Report, 2013	+16% (+9%)#

Table 1. Climate models have been able to predict rising global temperatures fairly accurately and accuracy has increased over time as more data is gathered and models are improved and updated [9].

In 1967 Syukuro Manabe and Richard T. Wetherald created a climate model that is considered to be the first accurate climate model [10]. Though this model was created over 50 years ago, it was able to predict the progression of global warming. Their prediction was that if the amount of carbon dioxide in the atmosphere was doubled, that the average global temperature would increase by 2°C. So far we have seen carbon dioxide levels increased by 50 percent and global temperatures have increased by approximately 1°C proving Manabe and Wetherald's model to be accurate at predicting the rise of global temperatures due to carbon dioxide.

Predictions from Models

Since we have determined that the models can be trusted to predict future climate conditions, it is important to note what the models are predicting. Almost every model shows an increase in global temperature, as seen in Figure 4, that could have devastating effects on global conditions. The increased temperatures would cause the disastrous severe weather events and food shortages predicted by the IPCC if human behaviors are not changed and greenhouse gas emissions are not limited or stopped.

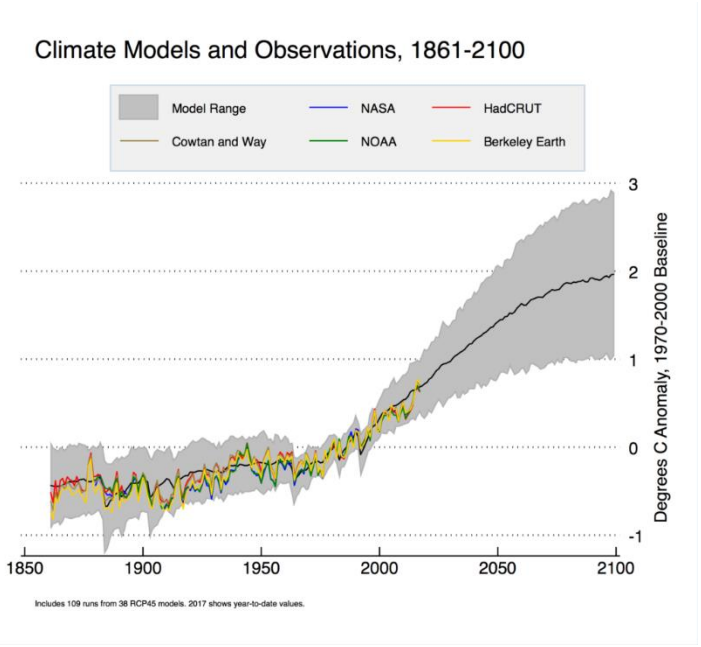

Figure 4. Most models show a dangerous increase in global temperature [9].

This research is particularly significant because action is required now. A solution to greenhouse gas emissions needs to be found in the next few years in order to prevent irreversible damage from being done to the Earth [4]. However, the current governmental administration in the United States has declared climate change as the result of human activities to be "nonsense" even though 95 percent of

climate scientists argue that climate change is a real problem [11]. Experts in the fields of science, mathematics, computer science, and public policy are working together to make accurate predictions and attempt to find a solution for this problem before irreversible damage is caused.

Conclusion

Global warming caused by human emissions of greenhouse gases has been shown to be a substantial problem that needs to be remedied before irreversible damage is done to the planet. Climate scientists are able to predict rises in global temperature accurately using models constructed by examining past data and modeling the functions of the atmosphere, ocean, land, and ice. These models are highly complex and incorporate a significant number of terms relating to environmental and human factors. In order to prevent devastating droughts, wildfires, floods, and famines, it is necessary to make changes to industries that emit large amounts of greenhouse gases such as transportation and manufacturing. The simple model showed that even small changes that can be caused by increased temperatures and greenhouse gases can have major effects on the average temperature of the Earth.

Though climate change is mostly being driven by large companies and corporations, at is important to recognize what can be done at the individual level. Using public transportation, walking, or carpooling can help to reduce the emissions of greenhouse gases. Using reusable products, such as water bottles, and using energy wisely can also help to reduce emissions. However, the most important way to help solve the problem of global warming is to vote for officials and bills that can help to save the planet from the effects of climate change.

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