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The Effect of CO₂ Emissions on the North Western American Alpine Tundra

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By

Mark Watkins

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Approved:

Professor Theodore C. Crusberg, Advisor

Abstract

The climate of the Rocky Mountains is being altered drastically due to the effects of global climate change. If current rates of temperature change continue the alpine tundra in this region faces extinction. Using data gathered from various sites located in the Niwot Ridge (CO) this project discusses changes in the plant and animal life of the area due to apparent recent changes in the local climate.

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I. Introduction

Humans have impacted their environment more than any other species in history.

Throughout history there have been various events that have caused people to adapt to the environment as well as to adapt the environment to suit their needs. These adaptations are easily the number one reason for technological advancement. Without diseases mankind would not have began looking into the study of gene therapy. Without the limit of natural resources, transportation today would still involve engines running on coal. Adversity is the reason that the human race has come so far. However, the result of overcoming adversity is usually the creation of another problem to be overcome in the future.

Examples of this throughout history are numerous. When people decided that the horse and carriage were no longer suited to provide the services required for transporting goods, people began working on other ways to transport materials. From this, eventually, came the steam engine. This engine was highly efficient in moving large masses of things that horses could not. But, with this invention mankind entered into an age where coal was the number one source of fuel. This polluted the environment to an unimaginable extent. To this day the buildings in London, England still have soot on them from the era when coal was the primary fuel source. People suffered from a variety of illnesses from breathing in the toxic fumes that the coal gave off including black lung.

Another example of this is easily found when production of goods by individuals was no longer considered a viable option for providing for the masses. People had to create a new form of production to meet with consumer demands, factories. Although the use of assembly lines and factories produced more than enough of the commodities being called for, the toxic fumes being given off polluted the environment with acid rain and greenhouse gasses. These factories are still producing these toxic emissions and humans are still feeling the effects of these greenhouse gasses today. This is mostly due to the fact that most factories today are very similar to the factories used long ago with the exception of some emission laws.

This problem with greenhouse gasses is a key issue in today's society. As most people are fairly convinced the greenhouse gasses emitted by our cars, factories, heating implements in our house, and basically everything that we use emit the most prevalent greenhouse gas CO₂. Due to this fact the human population once again is facing extreme adversity. Our climate is changing more rapidly than ever before and although many of the effects to come are not known, there may be a way to calculate what the effects will be by looking at an exceptionally fragile environment. Which environments would be beneficial to look at? Obviously environments in which small changes have dramatic results would be a logical choice, and from this data one can interpolate what a large change over time will do to the environment as a whole in its more stable areas. A

perfect environment to use for this is clearly the alpine tundra, and it is for this reason that the alpine tundra's changes in recent years will be analyzed here.

II. Background

A. The Western Alpine Tundra

The alpine tundra is a harsh environment. This environment consists of strong winds, inadequate soil for most plants, a short growing season, intense sunlight, low temperature extremes, and limited water. The region of alpine tundra that will be discussed here in detail is located in the western United States and it encompasses various states. These states are Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. These states each contain a portion of the Rocky Mountains and it is on these high mountain tops that the alpine tundra exists.

The Rocky Mountains were formed approximately 80 million years ago when the two tectonic plates beneath the mountains began to crash together. This collision of plates raised the earth into a mountain range larger than what the Rocky Mountains are today. Over the years the mountains have persevered from rising due to tectonic plate movement as well as shrinking due to erosion and weathering. Today these mountains have a diverse topography. In some regions there are steep slopes with ravines carved out of them caused by the glaciers that have on more than one occasion ravaged the mountain side. There are also regions with a milder slope containing boulder

fields, which are regions of land where boulders that have fallen from the regions above the field have landed and gathered with many other boulders to create a literal field of loose stones.

This region cannot be defined by its slope alone as elevation has a great deal to do with the environment of the mountain. At approximately 10,000 feet the Rocky Mountains completely change shape from dense coniferous forests to frozen grasslands with little to no plants above a few inches. Above the 10,000 foot marker is the alpine tundra and it is a region that is one of the harshest and also most fickle in the world. The plants in this region, although some can reach multiple inches high to a foot tall, are generally less than an inch tall and hug to the ground for survival.

The animals in this area are unique as well. Many of them have specific adaptations that allow for them to survive in the frigid winters of the alpine tundra. For instance the ptarmigan, the only bird that lives in this region year round, has grown feathers on the bottoms of its feet in order to provide warmth while walking on the permafrost soil. The pika, another animal in the tundra similar to that of a chipmunk or a small rabbit, has a furry shell that can over double the apparent size of the creature. This shell keeps it warm in the winter, but as temperatures rise some of these animals are actually smoldering due to the air temperature not being cold enough to penetrate the furry exterior.

This region is extremely important for many reasons, not the least being its ability to provide water to various regions of the United States and Mexico. It may seem counterintuitive at first, but the alpine tundra can have a snow storm on any day of the year as temperatures almost never rise above 60 degrees F and are usually much colder. This snowfall accumulates throughout the winter months and, in the summer this snow melts and makes its way down the mountain side by means of both montane ponds and various streams until it meets the Colorado River. The Colorado River flows from Colorado into Utah and then into both Arizona and California. It finally ends its journey in Mexico, but along the way it serves many functions. The Colorado River, aided by winter snowpack melting, can deliver anywhere from four thousand to seventeen thousand five hundred cubic feet of water per second (Kammerer p.1). This water provides irrigation and electricity to countless people located in this region.

Aside from the water supply that this region provides it is unique for another reason. This region and its inhabitants are immensely affected by climatic changes. This includes both temperature changes in the air and soil and precipitation changes. A change of a few degrees can cause various plant and animal life to perish and or change drastically. As will be discussed in detail later, a $.1^{\circ}$ -. 3° C change in temperature per decade can result in some plant life increasing the area they are contained in by 25% and others can be forced into extinction.

B. Greenhouse Gases and the Greenhouse Effect

Issues involving greenhouse gasses are some of the most talked about among environmentalists today. These gasses are supposedly responsible for the melting of the polar ice caps, changing weather patterns, increased desert surface areas, and the overall increase in average temperature on the Earth. Knowing what the effects of these gases are one, must ask what gasses are classified as greenhouse gases, and how exactly do these greenhouse gases accomplish these astronomical feats? The answer to the first portion of this question is rather straightforward. The gases classified as greenhouse gases are numerous, but there is a limited amount of these gases that make up a vast majority of the total greenhouse gases in the environment. These gases are carbon dioxide, nitrogen dioxide, methane, and fluorocarbons, with the overwhelming majority of gas affecting the environment being carbon dioxide which accounts for over 80% of all greenhouse gasses (DOE p.1).

However, answering how these substances affect the environment is much more complex. The Earth heats up in various stages. First the Sun gives off massive amounts of solar radiation which heats up the Earth as the radiation passes into the Earth's atmosphere. Some of this radiation heats the surface of the Earth and the remainder of the radiation is reflected back out towards the atmosphere. While this process of transmission and reflection is occurring the greenhouse gases function as an insulator for the Earth and trap the radiation within the atmosphere by absorbing and

remitting the infrared radiation from one CO₂ molecule to another. Without the greenhouse gases present most of this radiation would have escaped the Earth's atmosphere and been returned to space. This process is called the Greenhouse Effect. Among all of the greenhouse gasses there is one that accounts for over 80% of all greenhouse gas in the atmosphere. This gas is CO₂ (Carbon Dioxide). This gas is produced when fossil fuels are burned. Fossil fuels are made up of hydrogen and carbon, but when they are burned the hydrogen and carbon bonds are broken and the carbon then bonds with two oxygen molecules to form carbon dioxide.

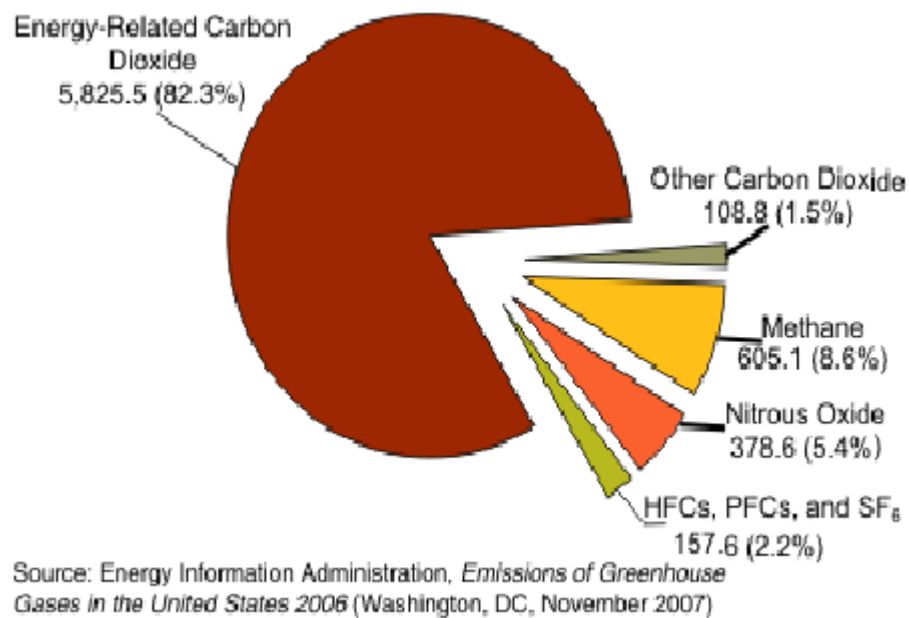


Figure 2: U.S. Anthropogenic Greenhouse Gas Emissions by Gas (million metric tons of Carbon Dioxide Equivalent)

Although the Earth naturally has a periodic cycle of mild heating and cooling, in recent years the Earth has been heating much more rapidly than it should. Scientists believe that the radiation in

the atmosphere is causing this change. The reason for this is the direct correlation between global climate change and the atmospheric carbon dioxide concentration.

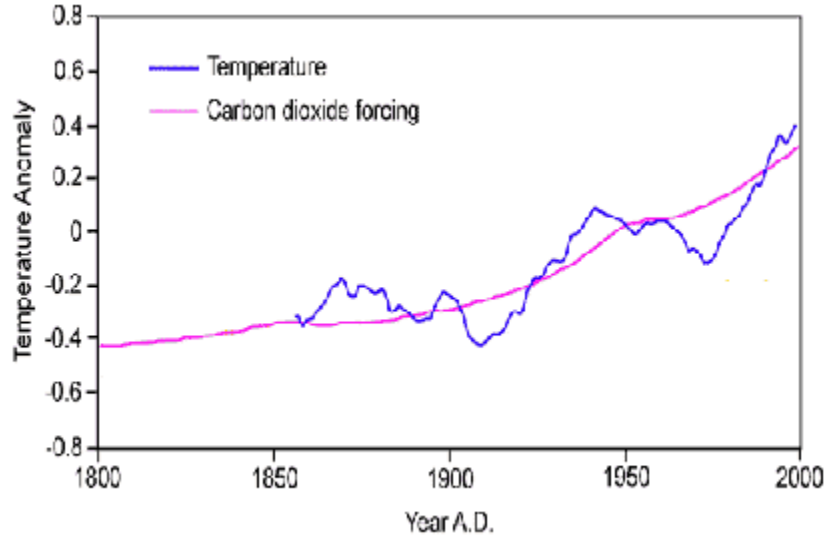


Figure 3: CO2 concentrations over time compared to Temperature Increase (University of California San Diego Climate Change)

Annual Average Global Surface Temperature Anomalies 1880-2008

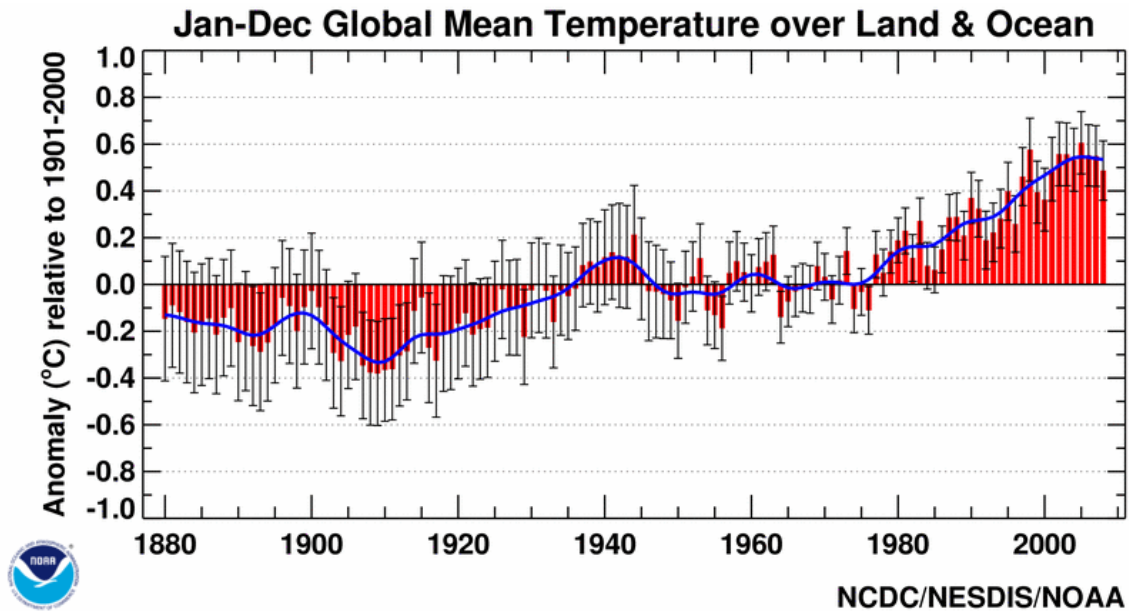


Figure 4: Annual Average Global Temperature Anomalies Taken from U.S. EPA

The reason for this is that when visible light is absorbed by the Earth's surface it does not necessarily need to be emitted with the same frequency or wavelength. Instead Earth's surface emits light with a wavelength in the infrared region of the light spectrum. This new infrared light is absorbed by the greenhouse gases at the surface. When the greenhouse gases reemit the infrared light other particles of greenhouse gas in a close proximity to the original particle absorbs the light. This process repeats many times which causes heat to remain near the Earth's surface and eventually heat the planet much faster than its natural cycle (Ophardt p.1). A pictorial description is given of this process below (U.S. National Assessment of The Consequences of Climatic Change p.8).

Greenhouse gases are an extremely important issue when considering how the human population has impacted different ecosystems or the world as a whole. Climatic changes due to the Greenhouse Effect have impacted not only the global temperature but also various plants and animals. With the effects of these gases just finally coming into fruition there is no way to truly know the full extent of what these gases have/can do to the environment as a whole.



Figure 5: How visible light is re-emitted as UV radiation (NASA)

C. Methods of Analyzing Climate Change

The issue of global climate change due to greenhouse gasses, although some scientists still refer to it as speculation, is almost impossible to deny. The correlation between the amount of carbon dioxide in the atmosphere and the temperature of the Earth follows an almost exactly proportional graph (See Figure 2). As the amount of carbon dioxide in the air increases the temperature does as well.

It is because of this that various governments, including the United States, have taken an interest in the potential effects of global climate change. They have employed the talents of physicists, climatologists, mathematicians, and various other scientists in order to find out what the

full scope of this problem by trying to create models of how the climate will change due to the effects of greenhouse gasses.

Modeling climate changes is not an exact science. It requires various assumptions integrated into complex mathematical models. Because of this there are various different methods that have been employed in the creation of these models and they vary drastically from one model to another. However, even though they differ greatly there is no completely accepted model. Only time will tell which models are accurate and which are not. The discrepancies in the models can be shown from two examples. The first is the General Circulation Model E done by the Goddard Institute for Space Science in 2007. This model suggests a raise in global mean temperature of 2.5°C and a raise in the western United States of 4.7°C (Schmidt p.1 attachment). The other General Circulation Model was completed by the Geophysical Fluid Dynamics Laboratory. This model predicted a 3.0°C increase in global mean temperature and a 4.2°C raise in the western United States.

Because of these discrepancies another technique will be used for the purposes of this project. This method is based on empirical data gathered from sites around the region in question. The data that will be analyzed is from the Niwot Ridge data center. This data center has taken temperature readings for the past thirty years and will provide an accurate assessment of actual climate changes in the region in question.

III. Methodology

In order to determine that global climate change is in fact affecting the region one must gather data on the temperature of the region over a prolonged period of time. This sample must include various sites to ensure that the data is accurate and uniform in the region. The data gathered for the purposes of this project was taken by the Niwot Ridge research site. This site is located at 9500 feet above sea level in the Front Range of the Colorado Rocky Mountains. It consists of multiple test sites, and the data is recorded beginning in 1988. However, the first full year studies were not completed until 1989 so the data analyzed in this project will use data from 1989 to the most recent entries in 2006. This specific site was chosen solely because there are no LTER sites located directly in the Colorado River Basin. This is the closest such site and its conditions are very similar to the conditions present in the basin.

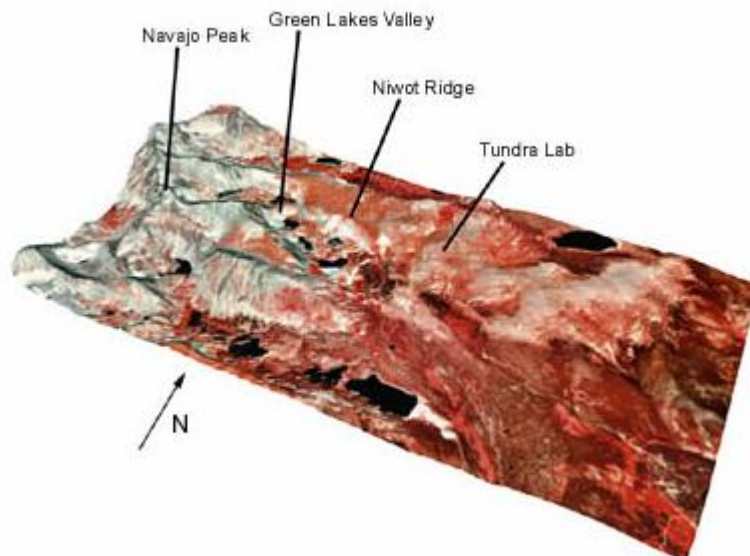


Figure 6: Niwot Saddle Rocky Mountains Colorado

Because there are only a few sites for research in this region the best way to assess the data is to input all valid data available and calculate an average temperature change for the region. This task is not an easy one as much of the data is incomplete. The reasons for this are unknown, but there are various sets of data that are missing up to three months of data and therefore cannot be used to calculate the average yearly temperature and are thus rendered useless for the purposes of this project.

Once all of the data that is acceptable to use, data with less than 2.5 weeks missing, is entered yearly averages of the temperature were calculated. Two and a half weeks may not seem like a large amount of time per year, but it can skew the temperature change drastically.

Calculating the yearly averages was done by adding all of the data points present from each year, defined as January first to December 31, and then dividing this number by the total number of data points for the year. These averages were then graphed to see if there is a trend in a warming or cooling in the Niwot ridge area in Colorado. From these data we were able to infer how the alpine tundra as a whole will change due to the climatic changes.

IV. Results

Niwot Ridge A-1 Yearly Average Temperature

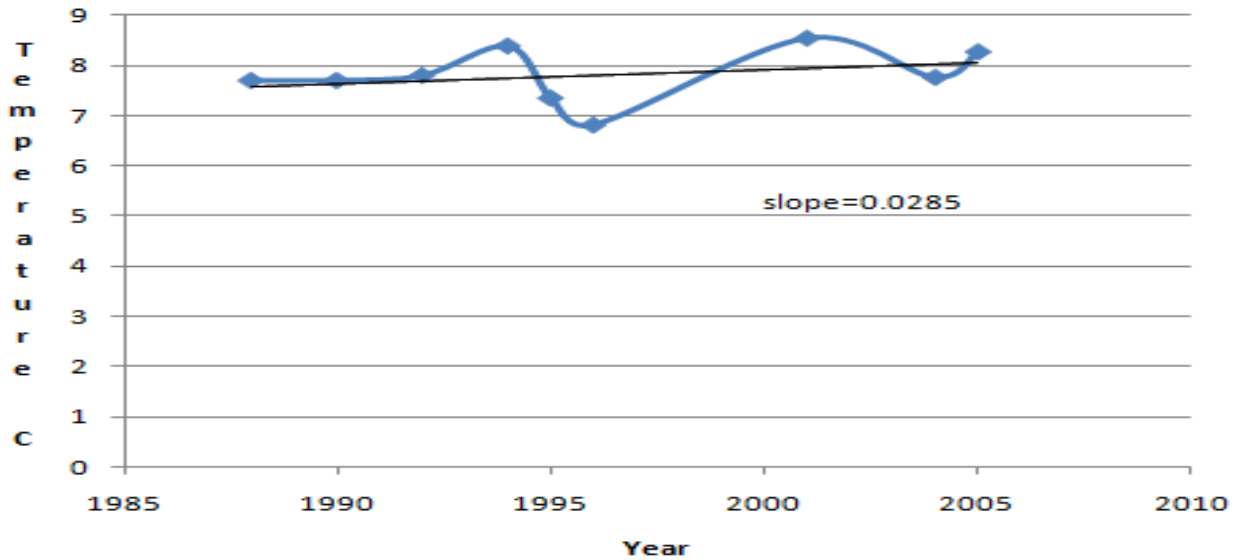


Figure 7: A-1 elevation 2195m above sea level

Niwot Ridge B-1 Average Yearly Temperature

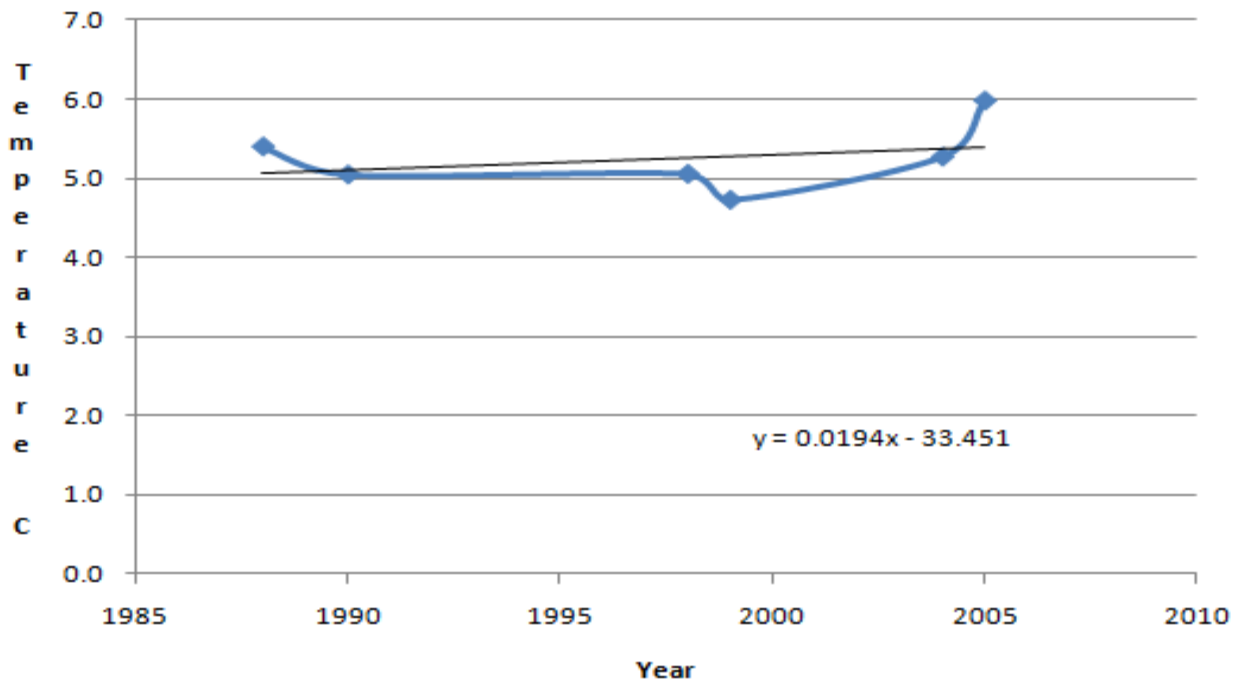


Figure 8: Site B-1 elevation 2591m above sea level

Niwot Ridge C-1 Yearly Average Temperatures

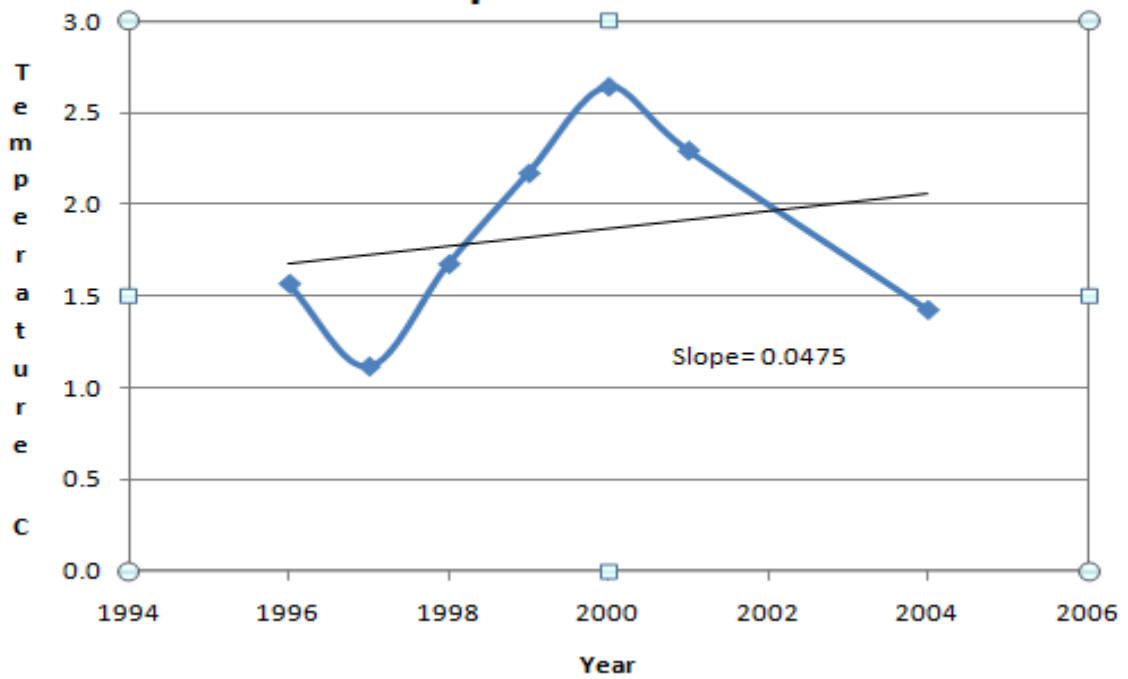


Figure 9: Site C-1 Elevation 3022m above sea level

Niwot Ridge D-1 Yearly Average Temperatures

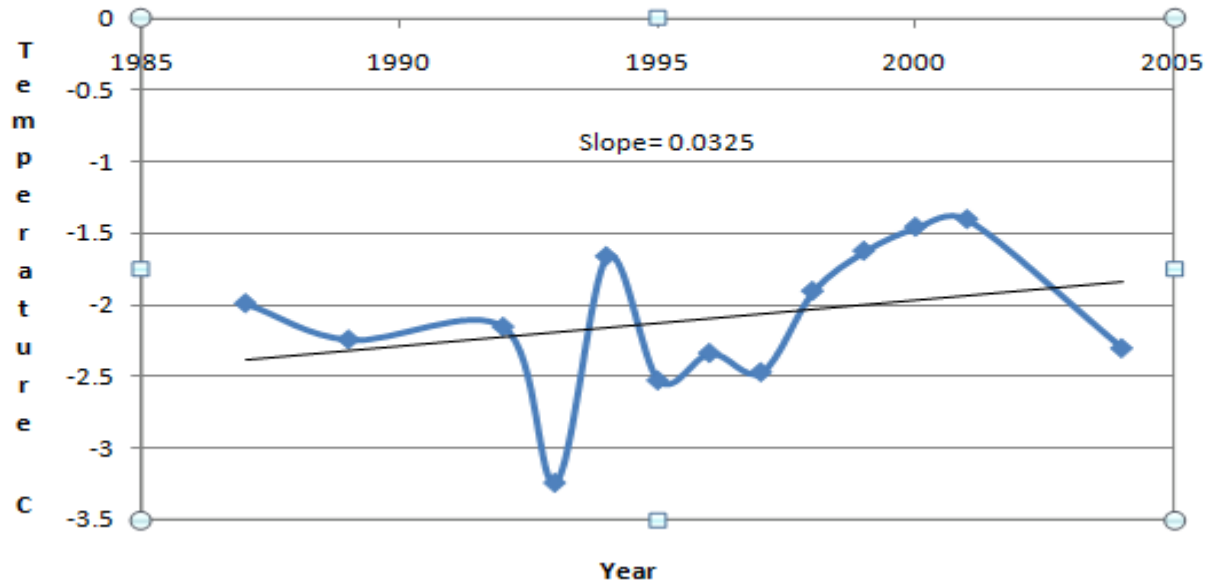


Figure 10: Site D-1 3739m above sea level

Niwot Ridge Arikaree Average Yearly Temperature

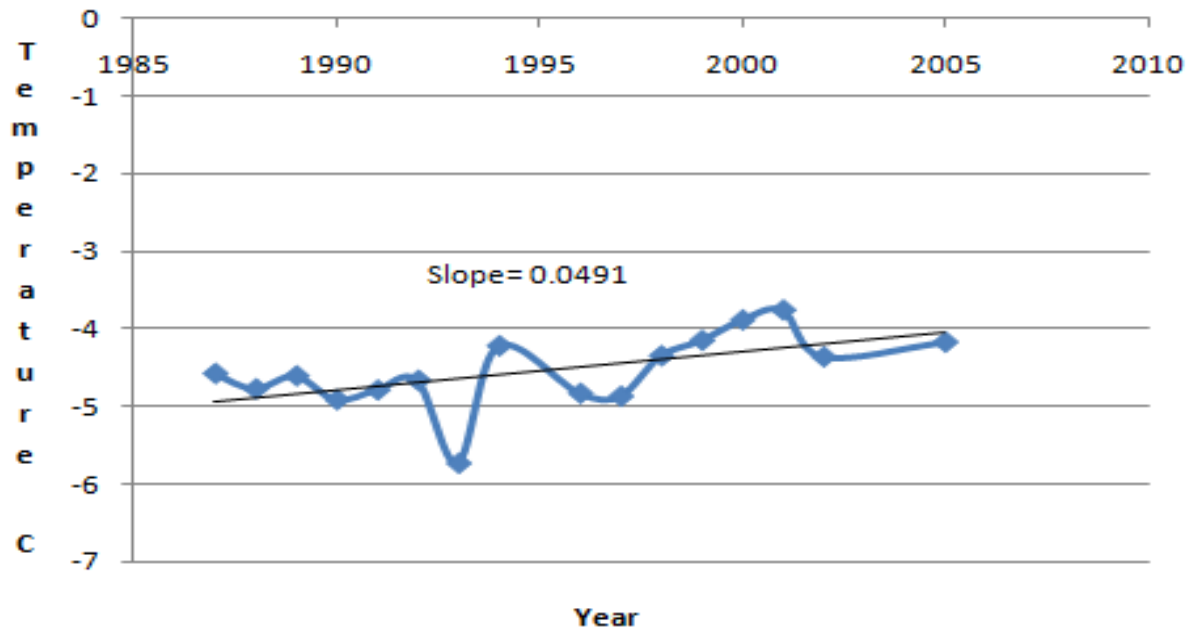


Figure 11: Arikaree Elevation 3814m above sea level

Niwot Ridge Saddle Yearly Average Temperatures

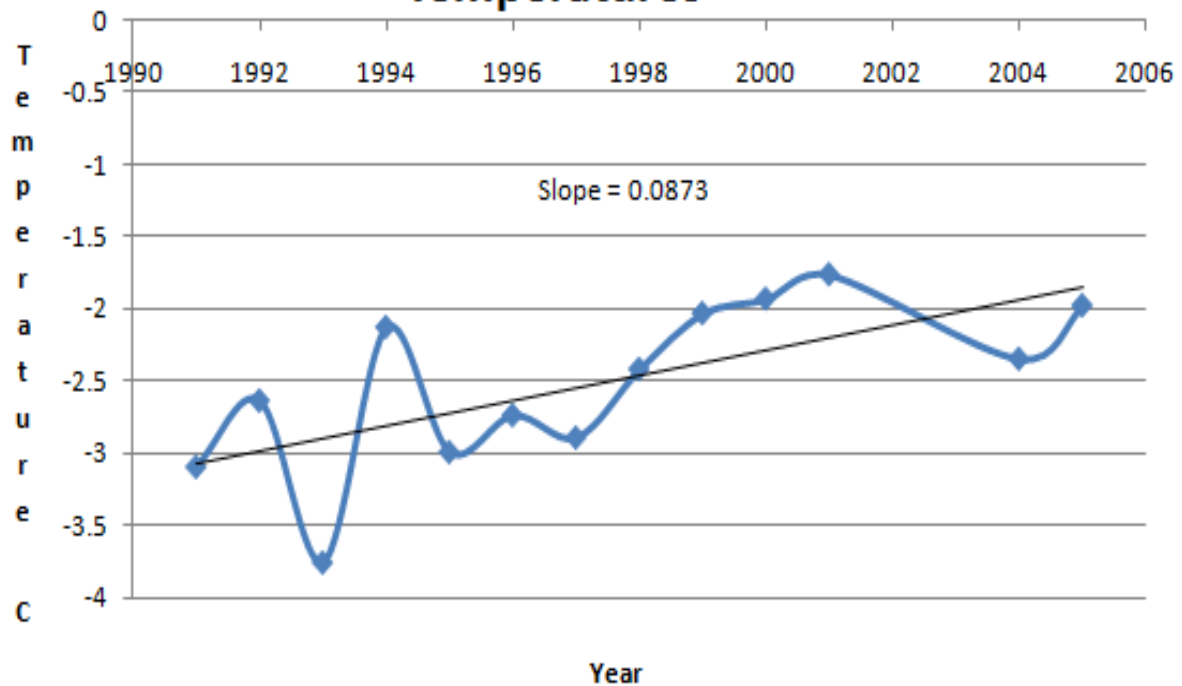


Figure 12: Niwot Ridge Saddle elevation 3528m above sea level

Niwot Ridge Green Lake 4 Average Yearly Temperatures

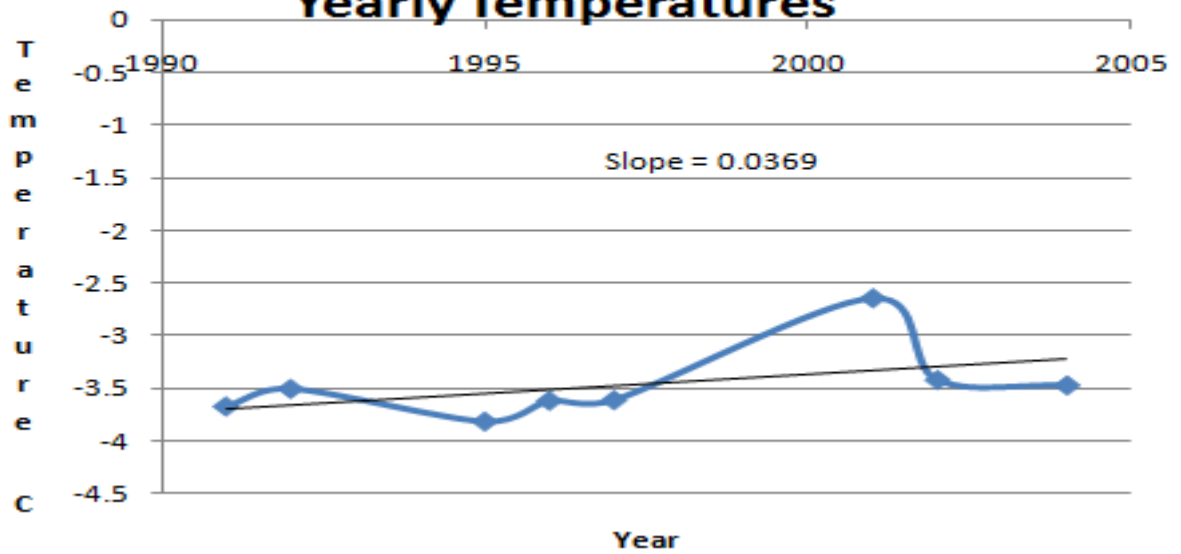


Figure 13: Green Lake 4 elevation 3570m above sea level

Discussion

In each of the graphs above there is a definite increase in average temperature as shown by the positive slope in each best fit line. With this information one can definitively state that the alpine tundra region is reacting to the carbon dioxide in the environment and the carbon dioxide is causing the region to increase in temperature. Because of this many scientists have been examining the impacts of global climate change on the plant and animal life within this biome. In this section I will discuss impacts of this change on the animal life in the region, while delving into more specifically the impacts on the North American Pika, the Edith's Checkerspot Butterfly, and the Pine Bark Beetles of the region.

In all of these species except one, there have been negative affects associated with global climate change. The pine bark beetle is the only species that seems to have not been harmed by this change. It would be a stretch to say that this change has ultimately helped the species as a whole, but the changing environment has not hurt its chances for survival.

The Pine Bark Beetle (*Dendroctonus ponderosae*)

Because of global climate change the tree line of the alpine tundra has been able to reach record levels. Each increase of 1 degree Celsius the tree line of the tundra climbs an astounding 30.2 meters higher (Williams p.7). This fact ensures that as the Earth heats up the alpine tundra

biome will steadily decrease in size. In turn this climate change increases the viable living range of *Dendroctonus ponderosae*. In one study by the USDA Forest Service it says that an 8 degree rise in temperature will increase the population size of the Pine Beetle by 156% and that a change of no less than 2.5 degrees will change an environment from an unsuitable environment to one suitable for Pine Bark Beetle (Williams p.9). This increase in Pine Beetle population does not however affect the tree population adversely either. Even with a 156% increase in beetle population the temperature rise should also allow for an increase in forest size of over 190%. So in this specific circumstance global climate change does not have a detrimental impact on the ecosystem. This is however the minority when considering global climate change's impact on the alpine tundra.

Collared Pika (*Ochotona collaris*)

The impact of global climate change on this small rodent can be considered nothing short of a life threatening situation. Although pikas have an amazing adaptation to resist cold climates their ability to withstand warmer temperatures is non-existent. When confronted with warmer climate pikas must rely on their environment to cool them down by either burrowing underground or if the temperature is too warm to burrow underground many relocate to the snowfields that exist almost year round (Martin p. 19). However, even this tactic may not be available to these small creatures for long.

Global climate change is causing a decrease in snowpack due to an increase in the percent of precipitation falling as rain. This leads to shallower snowfields and in turn allows them to melt much more rapidly. With temperatures rising and the snowfields disappearing the pika have had no way to cool themselves in the summer months. This is shown in a multitude of documents, however none more clearly than when a research group in the Great Basin, Colorado examined twenty-five known pika populations and found that seven of the twenty-five were extirpations (Randall p.2). If temperature continues to rise in this area it can be expected that more of these populations will be extirpated and if they increase enough this could lead to the extinction of the species in the relatively near future.

This may seem as though it is an extreme circumstance, but it is not. Each mountain top in this region is almost completely isolated from every other mountain top. Because the elevation of the mountains and with it the temperature difference at different elevations animals that cannot fly are unable to descend one mountain top and ascend an adjacent one. This leads to an interesting circumstance where each of the mountain peaks can be compared to an island where creatures inhabiting one mountain top are isolated completely from another. With this mechanism in place many species are forced to interbreed with closely related relatives, disease affects entire populations, and changing climate can be a death sentence to the entire species located on an

individual mountain top. It is for this reason that these animals face extinction. They simply have nowhere else they can travel.

Edith's Checkerspot Butterflies (*Euphydryas chalcedona*)

The Checkerspot Butterfly is in a situation very similar to that of the collard pika. Both the changes in temperature and precipitation have caused this species to be declared endangered as of 1987. Although an exact model for how the population fluctuates with climatic shifts has not been found scientists have found a climate dependent non-linear model which tends to approximately track the butterfly's actual population (McLaughlin p.1). The model predicts that as greater variability in climatic conditions occur that the butterfly will become extinct. This was also confirmed in the other prevalent model which is given the name the JRC model (McLaughlin p.2). Based on this information one can infer that if global climate change continues to function according to its current trend that at least two species of animals will no longer exist on the planet.

Conclusions

If the current trend of climatic change continues, one can expect irreparable damage to be done to the alpine tundra region. Many species that once lived in the region will become extinct and the overall appearance of the region will be altered for an undetermined amount of time. Assuming that these trends will continue at their current rate or faster, due to the levels of greenhouse gasses in the atmosphere, these affects will be seen within the next 50-100 years.

Within this time, when one uses the data from the graphs found in the results section of this paper, the average temperature of the area should have raised by over 5 degrees Fahrenheit, enough to destroy the entire pika population. The Edith's Checkerspot butterfly will suffer a similar fate. This change in temperature will also facilitate an environment more suitable to the pine bark beetle an astounding 150 feet above their current level. The effects of these beetles spreading would not influence the environment in any detrimental way according to each of the studies done. With the data currently available pertaining to the alpine tundra region the only conclusive prediction that can be made is that the Niwot Ridge's alpine tundra ecosystem is in jeopardy of facing extinction.

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