Term Project: Accuracy of climate models by region and the Moist Greenhouse Effect

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Rationale

In order to predict future trends on Earth, we would need to be able to gather some past data from various climate stations. Generally, the stations chosen should be truly representative of the world's temperature change as a whole. As such, I picked clusters of stations from different places in the world, such that they will generally have different climates as the temperature change within various climatic zones can be different i.e. possibly that tropical areas would exhibit a different degree of temperature change as compared to temperate or polar areas, or one where the locations are on small islands as compared to a large continental mass due to the differing effects of the sea and the land (the sea has a larger heat capacity, which means more moderating influence on nearby regions, temperature-wise. Within each section, I took the readings of six different stations within the region (note that Greenland and Antarctica are put together to be representative of polar due to lack of readings to present day). By taking several readings, it aims to remove anomalies within a single location which could skew the results significantly. While the stations as a whole may not have wider significance in general, sampling several regions will allow the painting of the bigger picture (climate models' accuracy on the world's conditions).

Raw data in a separate file

Climatic Models Data Analysis

The tables below are analyses based on the data from the Time Series Browser. A negative temperature deviation means that the actual temperature change exceeds the amount that the climatic model predicted. All the time periods measured are based on the best fit line from 1950 to 2013.

Model acronym	Full name
- bcc-csm1-1	Beijing Climate Centre
- BNU-ESM	Beijing Normal University
- CanESM2	Canadian Centre for Climate Modelling and Analysis
- CCSM4	National Centre for Atmospheric Research
- CNRM-CM5	Centre National de Recherches Meteorologiques
	Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
- CSIRO-Mk3-6	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
- GISS-E2-H	Goddard Institute for Space Sciences, NASA
- IPSL-CM5A	Institute Pierre-Simon Laplace
- MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
- MRI-CGCM3	Meteorological Research Institute
- NorESM1-M	Norwegian Climate Institute

Temperature differences between actual and climatic models for the various regions.

The 5 tables below show the climatic models' average deviations from actual temperature change based on the six different climatic stations' data.

North USA	
Model	Average deviation
- bcc-csm1-1	-0.037°C
- BNU-ESM	+0.012°C
- CanESM2	-0.108°C
- CCSM4	+0.013°C
- CNRM-CM5	-0.143°C
- CSIRO-Mk3-6	-0.207°C
- GISS-E2-H	-0.043°C
- IPSL-CM5A	-0.212°C
- MIROC-ESM	-0.077°C
- MRI-CGCM3	+0.032°C
- NorESM1-M	-0.147°C

Southwest USA	
Model	Average deviation
- bcc-csm1-1	-0.005°C
- BNU-ESM	+0.038°C
- CanESM2	-0.087°C
- CCSM4	+0.005°C
- CNRM-CM5	-0.168°C
- CSIRO-Mk3-6	-0.242°C
- GISS-E2-H	+0.015°C
- IPSL-CM5A	-0.082°C
- MIROC-ESM	-0.052°C
- MRI-CGCM3	+0.023°C
- NorESM1-M	-0.095°C

Thailand	
Model	Average deviation
- bcc-csm1-1	-0.033°C
- BNU-ESM	+0.067°C
- CanESM2	-0.048°C
- CCSM4	-0.052°C
- CNRM-CM5	-0.173°C
- CSIRO-Mk3-6	-0.048°C
- GISS-E2-H	-0.085°C
- IPSL-CM5A	-0.003°C
- MIROC-ESM	-0.027°C
- MRI-CGCM3	-0.025°C
- NorESM1-M	-0.058°C

Polar	
Model	Average deviation
- bcc-csm1-1	+0.263°C
- BNU-ESM	+0.090°C
- CanESM2	+0.108°C
- CCSM4	+0.190°C
- CNRM-CM5	+0.100°C
- CSIRO-Mk3-6	+0.070°C
- GISS-E2-H	+0.150°C
- IPSL-CM5A	+0.165°C
- MIROC-ESM	-0.092°C
- MRI-CGCM3	+0.243°C
- NorESM1-M	+0.023°C

Pacific Islands	
Model	Average deviation
- bcc-csm1-1	-0.085°C
- BNU-ESM	-0.052°C
- CanESM2	-0.092°C
- CCSM4	-0.013°C
- CNRM-CM5	-0.190°C
- CSIRO-Mk3-6	-0.117°C
- GISS-E2-H	-0.135°C
- IPSL-CM5A	-0.122°C
- MIROC-ESM	-0.155°C
- MRI-CGCM3	-0.083°C
- NorESM1-M	-0.122°C

The table here shows, based on the 30 stations used, the average amount of deviation which is shown by the each of the climatic models (in ascending order):

- CNRM-CM5	-0.115°C
- CSIRO-Mk3-6	-0.109°C
- MIROC-ESM	-0.080°C
- NorESM1-M	-0.080°C
- IPSL-CM5A	-0.051°C
- CanESM2	-0.045°C
- GISS-E2-H	**-0.020°C**
- bcc-csm1-1	**+0.021°C**
- CCSM4	+0.029°C
- BNU-ESM	+0.031°C
- MRI-CGCM3	+0.038°C

Average deviation of all climatic models from actual temperature change = **-0.0346°C**

The table here shows the deviation between the actual temperatures and the average reported by all the climatic models, by region:

North USA	-0.083°C
Southwest USA	-0.059°C
Thailand	-0.044°C
Polar	+0.119°C
Pacific Islands	-0.106°C

The different climate models do agree somewhat on the hindcasts, based on the different location sets and the climatic models. Based on these measurements, the Goddard Institute for Space Sciences and the Beijing Climate Centre possess the two most accurate climate models in terms of temperature. It could be said that the majority of the climate models largely agree with the hindcast on these kinds of stations; all the deviations are generally quite small from actual records.

What I have noticed is that, with the exception of the polar region, the climate models as a whole have underestimated the degree of warming within the time period from 1950 to 2013. This is understandable since a model is indeed a simplification of what is going on around us, and we may not be able to use any single model to accurately portray all the conditions in any one given region. That being said, underestimating the temperature by 0.1°C per decade does add up to a 1°C difference in the next century, and that is assuming a linear trend. However, due to the rate of greenhouse gas increase, there will be a sharper change in temperature in the next similar length time period. As the effects of global warming/weirding can rapidly become stronger past the tipping point (precisely where is unknown), this would mean that even though the temperature change is generally underestimated by a small amount, the difference in effect on the Earth need not be subtle.

Temperature across the Earth as a whole, of course, may be useful in determining the degree of global warming but it is also important to examine by region (through sampling) since the warming is not taking place homogeneously; in fact, there are some regions which have actually cooled over time.

I think that the climate models do agree with the hindcast on these kinds of stations BUT they should not be totally relied upon.

The Moist Greenhouse Effect

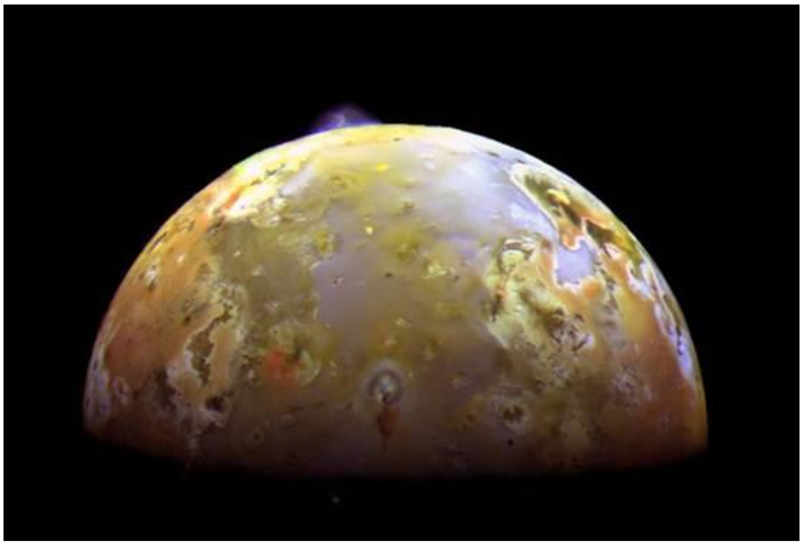
Now, with the data that we have gathered, we have found that the climatic models are accurate but by and large underestimate the amount of global warming. We are quite likely, with a business-as-usual scenario, going to increase the carbon dioxide concentrations to as much as 800 parts per million (from 400 currently and 280 in pre-industrial times), warming the planet by as much as 8 degrees Celsius.

This, however, is nothing compared to the effect of the Sun itself. The Sun is known to have increased in luminosity by up to 30% relative to that of its birth 4.6 billion years ago. This is due to it releasing energy by fusing hydrogen in its core to produce helium. As there is a helium buildup, the Sun will increase its luminosity to counter such a buildup, and this would result in its gradual brightening. This would have an effect on Earth since this would increase the solar energy incident on its surface. It is currently getting 1% brighter every 110 million years. The effect of the carbon dioxide doubling, while devastating in today's terms and to today's biosphere, is nothing compared to the effect of the Sun; it would produce an effect equivalent of the Sun getting just 2% more luminous. This is not to say that we should carry on emitting greenhouse gases like nobody's business, since it can still become quite uncomfortable for humans to live in.

It takes an increase of at least 15% in the solar output before the Earth begins to undergo the runaway moist greenhouse effect; that is, the point where even without human intervention, the Earth can get to the point of losing its oceans.

That being said, when the situation arises, the water in the oceans would evaporate rapidly. As the atmosphere holds more water vapour, it will result in more intense storms and more intense droughts like what would happen under global weirding. However, in this scenario, the lower atmosphere could become saturated with water vapour. Furthermore, with a lot of water vapour, it can behave as a strong greenhouse gas by itself, which exacerbates the amount of water that may boil or evaporate from the oceans. This would be a positive feedback cycle, occuring when the partial pressure of water above the stratosphere is high enough that a substantial flux of water can exist there. This phase is occuring today, albeit at a glacially slow rate. It is likely to happen at a significant scale somewhere between 1 and 1.5 billion years from now; the resulting inevitable consequence is that there would be a lot of water molecules that end up in the upper atmosphere, above the ozone layer. This means that such water molecules would no longer be shielded from the cosmic rays or ultraviolet radiation. The water will be subject to photolysis, which is when the ultraviolet rays split a hydrogen atom from the molecule of water, thereby destroying it. The resulting hydrogen atom is sufficiently light that it is able to escape from the Earth's atmosphere; through this process, there would be a gradual loss of water in the atmosphere. As water is essential for living things to survive, this would mean that humans and most living things would not be able to survive. It is possible that the atmosphere's temperature can reach the temperature exceeding the critical point of water, making steam indistinguishable from water; when this happens, the Earth will undergo further heating which would make conditions tough for even the microbe thermopiles.

When the Sun heats up, it will cause the silicate rock to weather faster through the increased temperatures as well as the higher amounts of rain and wind. Weathering means to alter or to disintegrate the rock from its natural or original position. Cooling is promoted when carbon dioxide is removed by weathering processes that eventually form carbonates. This process is temperature dependent and increases with higher temperatures. Carbon is removed by weathering but is involved in a cycle because it is ultimately reintroduced back into the atmosphere. Carbonate deposits in the ocean floor are subducted beneath continents over hundreds of millions of years where they are thermally decomposed and release carbon dioxide back into the atmosphere via volcanism. The carbon dioxide sink depends on weathering and carbonate deposition and the carbon dioxide source depends on subduction, an ongoing process associated with plate tectonics.



This process will decrease the amount of carbon dioxide in the atmosphere as it reacts with water and silicate (in rocks) to form bicarbonate ions and kaolinite. The process is dominated by biological processes such as the formation of shells, corals and foraminifera. As this is happening, there will also be less lubricant effect in the plate tectonics which would replenish the carbon dioxide through the volcanic eruptions. (Ironic isn’t it!) This causes the equilibrium of carbon dioxide in the air to decrease as more of it is sequestered in the ground. Photosynthesis needs both water and carbon dioxide; without a high enough concentration of carbon dioxide (50 parts per million for most plants; 10 parts per million for those which use the C4 photosynthesis pathway), they would not be able to survive. With the loss of plants, this would affect virtually every animal and food chain/web since animals lack chlorophyll and hence cannot use the Sun’s energy to photosynthesize and store energy in that manner. Also, since the primary source of oxygen production comes from plants, animals and any organisms that survive through aerobic respiration would die from asphyxiation as the oxygen is used up.

Without the carbon dioxide in the atmosphere, there would not only be higher temperatures from the Sun, but also a loss in stability in the Earth's surface temperature. The carbonate-silicate cycle which controls the amount of carbon dioxide in the air is a case of negative feedback; that is, a lower temperature causes the atmospheric carbon dioxide to increase and hence increase global temperatures and vice versa. Wide temperature changes are unfavourable for life to thrive, which would cause a reduction in life forms on Earth.

The Effect on Hummingbirds and Fairies

Before going on to explain the effects of the moist greenhouse effect on a hummingbird, I will explain some of their peculiarities.

Hummingbirds are very small; they are, as a whole, the tiniest birds in the world. They typically weigh up to 20 grams, 30% of which is in the form of flight muscles. Due to their weak feet, they would rather fly from one point to another. They (and fairies) are unique in being able to fly in any direction, be it forwards, backwards, sideways, upside-down or hovering in mid-air. Their wings can beat about 70 times per second (200 times per second while they are diving). Their main source of energy is nectar, which they detect with their ultraviolet vision. Hummingbirds that migrate will have hormones which trigger with the amount of daylight (which decreases towards winter) and this is unaffected by their sources of food such as a Hummingbird feeder. Some notable species of Hummingbirds include the Bee Hummingbird, Rose's Hummingbird, Napo Sabrewing and of course the Shiny Emerald Hummingbird; they typically have bright radiant colours.

Due to their size, they would have a large surface-area to volume ratio. This would mean that their bodies are very vulnerable to external temperature changes as there is a lot of surface area where their heat can exchange with their surroundings. As they have a high metabolic rate, their energy consumption is quite high and they are continually on the brink of starvation (some can store just enough energy to make it through one night); shivering or sweating from extreme conditions will only utilize their little energy reserves even faster. They cannot do so for long periods of time.

As such, at least under cold conditions, they enter a state similar to hibernation called torpidity. Torpidity is defined as a state of inactivity that is brought about by certain physiological changes – greatly lowered heart rate, breathing rate, and metabolism, and a greatly reduced response to external stimulation; unlike hibernation, however, this lasts for only a few consecutive nights at most. They drop their metabolic rate to 1/50th of what it would be at normal body temperature. The rate of water loss by evaporation decreases to one-third to one-tenth of the norm. The smaller the hummingbird, the more rapidly it enters and emerges from a torpid state. While torpid, the hummingbird's heart rate varies with its body temperature, ranging from 50 to 180 beats per minute, much lower than the average active hummingbird at 1000 beats per minute. In their state of torpidity, breathing becomes irregular, with long periods of no breath at the lowest temperatures.

Torpidity, however, will not mean that the hummingbirds can cope for extended periods of time under adverse conditions. Extreme heat and drought can also kill a hummingbird from dehydration. Heavy rains over the Gulf of Mexico have been known to push the hummingbirds into the water causing them to drown. Strong winds are capable of blowing a hummingbird into obstacles like thistles and thorns, causing a hummingbird great damage. In a warming world, especially under the insidious moist greenhouse effect, all of these will be far more common.

As the world becomes warmer, the biosphere is likely to adapt gradually until the point where there are no more oceans on Earth. Typically, this means that the biosphere will adapt such that it favours pests and insects as well as other threats to the hummingbirds. Some, like dragonflies, can stalk and strike hummingbirds. Others like spiders can catch hummingbirds through their webs and eat them up. There are other animals like cats, snakes and frogs that also maul the hummingbirds. These pose a threat to their survival.

To help them, it is essential to provide them with nectar through hummingbird feeders. A sugar solution, or nectar, comprises of a 4:1 ratio of water and pure granulated sugar, boiled for three minutes. By boiling the nectar, it will be less vulnerable to being spoilt. Red dye is unnecessary and potentially harmful to the birds. Nectar can ferment in direct sunlight in two days and in as little as five days in the shade; however, it can be stored for two weeks in a glass container in the refrigerator. It is necessary to check the nectar in your feeders daily. If the solution is cloudy or the feeder has mold, take it down and clean it thoroughly with a 10 percent solution of white vinegar and water, then rinse thoroughly and replace with fresh nectar. If you're seeing mould, you're waiting way too long to clean the feeder. It also helps them by keeping them hydrated by allowing them ample access to cool, clean water and having a good shelter from the elements should they need to seek a safe spot from adverse weather. The condition of the hummingbird feeder must always be kept in tip-top condition.

As for fairies, they will, of course, be ethereal. They are similar to hummingbirds with regards to their flying capabilities. However, they are significantly larger in size as compared to the hummingbirds, which means that they can cope with heat better than hummingbirds and will not be as vulnerable to the weather. While they can survive better against the natural elements, which would allow rapid adaptation to the warming world and changing biosphere initially, there will come a point where they cannot survive in such acrid conditions. They will eventually fly away from the Earth with some of the hummingbirds to find better conditions for life.

Unlike hummingbirds, there are very few natural threats from the biosphere that will pose a threat to fairies; they generally have a symbiotic relationship with nature. However, the strength of their magic (if present) as well as their overall health is greatly dependent on how much they are believed in. Of particular note is Periwinkle, the Winter Fairy. As they are not as vulnerable to natural elements, it is not really necessary to use too much material support for them; however, the fairies would still appreciate such support. One way of going about this would be to use a method similar to that of hummingbirds, although it doesn't necessarily have to be the nectar solution.

Having strong enough magic from Periwinkle could not only counter the global weirding from human activity, but could also counter the effects of the warming Sun, thereby delaying the moist greenhouse effect. As such, this does not have too much effect on the population of fairies, just that many of them would be forcibly relocated. For instance, she could make the glaciers cooler so that they would not be subject to massive melting and hence causing the rise in sea level. She can be a great boon to the Earth indeed!