Factors That Affect Global Temperature: How Do Cloud Cover and Greenhouse Gas Concentration in the Atmosphere Affect the Surface Temperature of Earth?

Introduction
All matter in the universe radiates energy across a range of wavelengths in the electromagnetic spectrum. Hotter objects tend to emit radiation with shorter wavelengths than cooler objects. The hottest objects in the universe, as a result, mostly emit gamma rays and x-rays. Cooler objects, in contrast, emit mostly longer-wavelength radiation, including visible light, infrared (IR), microwaves, and radio waves. The surface of the Sun has a temperature of about 5500°C or about 10000°F. At that temperature, most of the energy the Sun radiates is visible and near-IR light.

When sunlight first reaches Earth, some of it is reflected back out into space and some is absorbed by the atmosphere. The rest of the sunlight travels through the atmosphere and then hits the surface of Earth. The energy from the sunlight is absorbed by the surface and warms it. All objects, including Earth’s surface, emit (or give off) IR radiation. The hotter an object is, the more IR radiation it emits. The amount of IR radiation emitted by Earth’s surface therefore increases as it warms. The atmosphere traps some of this IR radiation before it can escape into space. The trapped IR radiation in the atmosphere helps keep the temperature of Earth warmer than it would be without the atmosphere. Scientists call the warming of the atmosphere that is caused by trapped IR radiation the greenhouse effect (see figure below). Many gases that are found naturally in Earth’s atmosphere, including water vapor, carbon dioxide, methane, nitrous oxide, and ozone, are called greenhouse gases because these gases are able to trap IR energy in the atmosphere.

The greenhouse effect
The amount of energy that enters and leaves the Earth system is directly related to the average global temperature of the Earth. The Earth system, which includes the surface and the atmosphere, currently absorbs an average of about 340 watts of solar power per square meter over the course of the year (NASA n.d.). The Earth system also emits about the same amount of IR energy into space. The average global surface temperature, as a result, tends to be stable over time. However, if something were to change the amount of energy that enters or leaves this system, then the flow of energy would be unbalanced and the average global temperature would change in response. Therefore, any change to the Earth system that affects how much energy enters or leaves the system can cause a significant change in Earth’s average global temperature.

The average global surface temperature of Earth has increased approximately 0.8°C (1.4°F) over the last 100 years (NASA Goddard Institute for Space Studies 2016). There are at least two potential explanations for this observation. One explanation is that the average global surface temperature of Earth normally increases and decreases over time and the current increase in temperature is just a normal part of this cycle. These changes could be due to differences in the Sun’s brightness, Milankovitch cycles (small variations in the shape of Earth’s orbit and its axis of rotation that occur over thousands of years), or an increase or decrease in cloud cover (clouds form when water vapor in the air condenses into water droplets or ice). This explanation, however, does not account for the rapid increase in the average global surface temperature. An alternative explanation, which is the consensus view of the scientific community, is that humans have caused the rapid increase in the average global surface temperature of Earth by adding large amounts of greenhouse gases to the atmosphere. The addition of greenhouse gases magnifies the greenhouse effect. The atmosphere, as a result, traps more IR radiation and emits less IR energy out into space.

Before you can evaluate the merits of these two explanations for the observed change in average global surface temperature, it is important for you to understand how energy from the Sun interacts with the surface of the Earth and the various components of the atmosphere, such as clouds. You will therefore need to learn more about the relationships between surface temperature, cloud cover, and greenhouse gas levels in the atmosphere.

**Your Task**

Use a computer simulation and what you know about stability and change and the importance of tracking how energy flows into, within, and out of systems to determine how the temperature of Earth responds to changes in the amount of cloud cover and the concentration of carbon dioxide in the atmosphere.

The guiding question of this investigation is: **How do cloud cover and greenhouse gas concentration in the atmosphere affect the surface temperature of Earth?**

**Materials**

You will use an online simulation called *The Greenhouse Effect* to conduct your investigation; the simulation is available at [https://phet.colorado.edu/en/simulation/legacy/greenhouse](https://phet.colorado.edu/en/simulation/legacy/greenhouse).

**Getting Started**

The *Greenhouse Effect* computer simulation models how energy flows into, within, and out of the Earth system and records changes in average global temperature over time (see figure on next page). It shows the surface of Earth as a green strip. Above the green strip there is a blue atmosphere and black space at the top. Yellow dots stream downward representing photons of sunlight. Red dots represent photons of IR light that are emitted by the surface of Earth and travel toward space. The greenhouse gas concentration in the atmosphere, including amounts of water vapor (H2O), carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), can be changed so
it reflects the current level of these gases, the level in 1750, the level during the last ice age, or a level of your choice. Clouds can also be added or removed from the atmosphere. Greenhouse gases block IR light (energy) that is emitted by Earth’s surface. Clouds can block sunlight and IR photons.

A screenshot from The Greenhouse Effect simulation

To answer the research question, you must determine what type of data you need to collect, how you will collect it, and how will you analyze it.

To determine what type of data you need to collect, think about the following questions:

- What are the boundaries and components of the system you are studying?
- How do the components of the system interact with each other?
- When is this system stable, and under which conditions does it change?
- Which factor(s) might control the rate of change in this system?
- How can you describe the components of the system quantitatively?
- How could you keep track of changes in this system quantitatively?
- How can you track how energy flows into, out of, or within this system?

To determine how you will collect your data, think about the following questions:

- What type of measurements or observations will you need to record during your investigation?
- How often will you need to make these measurements or observations? What will serve as your dependent variable?
- What will serve as a control condition?
- What types of treatment conditions will you need to set up?
- How many trials will you need to run in each condition?
- How long will you let the simulation run before you collect data?
- How will you keep track of and organize the data you collect?

To determine how you will analyze the data, think about the following questions:

- What types of patterns might you look for as you analyze your data?
- How could you use mathematics to describe a change over time?
- How could you use mathematics to document a difference between treatment and control conditions?
- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?
Report
Once you have completed your research, you will need to prepare an investigation report that consists of four sections (be sure to have section headings):

1. **Introduction:** Give some background information on the topic. Explain what question you were trying to answer and include a hypothesis. (Background info, research question and hypothesis)

2. **Procedure:** What did you do during your investigation and why did you conduct your investigation in this way? (How you collected and analyzed data)

3. **Data:** Include a data table and/or graph to show your results. Be sure to include a title for your table or graph with labels for the variables.

4. **Conclusion:** What is your argument? (Claim - Evidence - Reasoning)

Your report should answer these questions in two pages or less. The report must be typed, and any diagrams, figures, or tables should be embedded into the document. Type your report on Google Docs (12 point font, double-spaced) and share it with your teacher. Your report will be graded based on the rubric in the class syllabus.