Science Unit:	***Climate Change***
Lesson 2:	***Greenhouse Effect: A Computer Simulation***

School year:	2008/2009
Developed for:	Shaughnessy Elementary School, Vancouver School District
Developed by:	Tom-Pierre Frappé(scientist), Carol Church and Sharlene Steele (teachers)
Grade level:	Presented to grades 5 - 7; appropriate for grades 4 to 7 with age appropriate modifications.
Duration of lesson:	1 hour and 10 minutes
Notes:	This is lesson 2 of a 4 part series

Objectives

1. Describe the basic energy budget of the Earth: sunlight energy flows in, infrared energy flows out. Describe the typical trajectory of a sunlight photon or an infrared photon.
2. Explain how greenhouse gases affect these trajectories, and what the cumulative effect is on the temperature of the planet.
3. Describe the role of clouds and ground albedo in the enery budget of the Earth.
4. Discuss the importance of computer models in science.

Background Information

“The earth's atmospheric "greenhouse effect" is much more complex than the simple greenhouse experiment described in [lesson 1]. While the earth's temperature is dependent upon the greenhouse-like action of the atmosphere, the amount of heating and cooling are strongly influenced by several factors.

The type of surface that sunlight first encounters is the most important factor. Forests, grasslands, ocean surfaces, ice caps, deserts, and cities all absorb, reflect, and radiate radiation differently. Sunlight falling on a white glacier surface strongly reflects back into space, resulting in minimal heating of the surface and lower atmosphere. Sunlight falling on a dark desert soil is strongly absorbed, on the other hand, and contributes to significant heating of the surface and lower atmosphere. Cloud cover also affects greenhouse warming by both reducing the amount of solar radiation reaching the earth's surface and by reducing the amount of radiation energy emitted into space.

*Scientists use the term **albedo** to define the percentage of solar energy reflected back by a surface. Understanding local, regional, and global albedo effects is critical to predicting global climate change.* [1]*”*

The following are some of the factors that influence the earth's [energy budget].

- ***Clouds:*** *On a hot, sunny day, we usually welcome a big fluffy cumulus cloud passing overhead because we feel cooler immediately. That's because the top of the cloud reflects sunlight back into space before it ever reaches earth. Depending on their altitude and optical properties, clouds either cool or warm the earth. Large, thick, relatively low-altitude clouds, such as cumulus and cumulonimbus, reflect incoming solar radiation and thereby reduce warming of the surface. The whitewash on plant greenhouses has the same effect on a smaller scale. High-altitude, thinner clouds, such as cirrus clouds, absorb longwave radiation reflected from the earth's surface, causing increased warming.*

Cirrus

Cumulus

Nimbus

- ***Surface albedo:*** *Just as some clouds reflect solar energy into space, so do light-colored land surfaces. This surface albedo effect strongly influences the absorption of sunlight. Snow and ice cover are highly reflective, as are light-colored deserts. Large expanses of reflective surfaces can significantly reduce solar warming. Dark-colored land surfaces, in contrast, are strongly absorptive and contribute to warming. If global temperatures increase, snow and ice cover may shrink. The exposed darker surfaces underneath may absorb more solar radiation, causing further warming. The magnitude of the effect is currently a matter of serious scientific study and debate.*[1]"

Vocabulary

Word: See worksheet.

Materials

- A computer for each student
- The worksheet (attached)

In the Classroom

Introductory Discussion

1. In last lesson, we used pop-bottle as an analogous model of the greenhouse effect. Now, we would like to know more in details what actually happens in the Earth's atmosphere. Is it the same as what happened in our bottles? In what ways is it different? To answer this question, we can't easily just "go in the atmosphere" and look at what happens. First, how would we get there? Second, what would we look at? Scientists uses instruments, and remote sensing to discover what happens in the atmosphere. Then they make computer models that represents this information. Today, we will use

such a computer model. It is simplified in some ways, but it is based on the real physics equation that describe the greenhouse effect. It also offers a nice visualization to help us conceptualize how greenhouse gases trap solar energy.

2. Briefly describe science experiment/activity.

- Before students start playing with the simulation, the teacher will describe the simulation interface.
- Then students are left to themselves. They will use the simulation to do four experiments guided by the worksheet. The teacher circulates and answers question, pausing the group when need be.

Science Activity

Activity Title: Greenhouse gases computer simulation

Purpose of Activity: exploration of the energy budget of the Earth, strengthening of conceptual understanding through interaction with an interactive and scientifically grounded visualization tool.

Experimental Observations: The effects of greenhouse gases concentration, cloud coverage, and surface albedo will be observed separately. This is not an experiment with controls and treatments.

First experiment: What if we didn't have any greenhouse gases?
Second experiment: How have humans changed the energy balance of the Earth since the industrial revolution?
Third experiment: How do clouds affect the energy balance of the Earth?
Fourth experiment: What is the effect of the reflectivity of the ground?

Prediction or Hypothesis: See worksheet.

Methods and Instructions:

Set-up prior to experiment: It is best if the simulation can be loaded on the computers before the students come in. There are sometimes glitches with the simulation due to computer screen resolution, or lack of proper Java plug-in. It is difficult to solve these problems with the kids, all at once. Instructions on how to load the simulation are included in the worksheet.

It is best if each student has its own computer; interaction with the simulation is important here, and students have different rhythms. If computers must be shared, it is advisable to switch who is "in control" between each experiment.

Closure Discussion

1- How much change happened between 1750 and now?
in terms of greenhouse gases concentration?
in terms of temperature?
Are you surprised at how small the temperature difference was?
In reality, the global average air temperature near the Earth's surface rose 0.74 ± 0.18 °C (1.33 ± 0.32 °F) during the hundred years ending in 2005 (IPCC 2007)
Did that make a noticeable difference on Earth?

What does the future holds?
Climate model projections summarized by the IPCC indicate that average global surface temperature will

likely rise a further 1.1 to 6.4 ℃ (2.0 to 11.5 ℉) during the twenty-first century.
Will that make a noticeable difference on Earth?
[Discuss with the class how the problem is not as much “global warming” as “climate destabilization” ; the changes are small but happening very fast compared to how climate naturally changes. It’s the rapidity of the changes that worries us.]

2 – Now we’ve seen how a greenhouse works, and how the “greenhouse effect” works. What are some of the differences? [Students should go complete/correct what they had in the last two questions of the lesson 1 worksheet based on this conversation]

3 – How do we know if we can trust a computer model? How do scientists test their models? By looking at what happens in nature, or by doing experiments. So, next lesson you’ll be scientists and design an experiment to test these four factors:
CO2 concentration
H2O concentrations
albedo
Effect of clouds

You can also show the two movies included in references 3 and 4 as a wrap up summary.

References

1. University Corporation for Atmospheric Research, Project LEARN, retrieved February 2008 from <http://www.ucar.edu/learn/1_3_2_13t.htm>. See http://www.ucar.edu/learn/copyrite.htm for copyright info.

2. Physics Education Technology, Unversity of Colorado at Boulder, http://phet.colorado.edu/new/simulations/sims.php?sim=The_Greenhouse_Effect

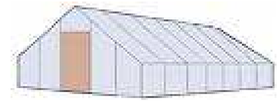
Also of interest:

3. http://www.teachersdomain.org/resources/phy03/sci/phys/matter/greenhouse2/index.html
4. http://www.teachersdomain.org/resources/phy03/sci/ess/watcyc/co2/index.html

Extension of Lesson Plan

Climate Change science unit, Lesson 3: discuss results of this lab, and data analysis in general. Brainstorms ways that this analogous model can be used to investigate other factors affecting the energy budget of the Earth, more specifically the albedo, cloud cover, atmospheric CO2 concentration, and atmospheric water vapor concentration.

Climate Change science unit, Lesson 4: Student will test the effect of one of these factors using their own experimental design.



A computer simulation of the greenhouse effect

worksheet

Introduction

This simulation illustrates how the temperature of the Earth depends on the balance between the sunlight energy coming in, and the infra-red energy going out. (Just like the total amount of money in your bank account depends on the balance between how much you save and how much you spend.) This computer model allows you to make experiments that are impossible to do in real life, like: what would happen if we doubled the quantity of carbon dioxide in the atmosphere? We can't really try this in real life, but we can try it on a computer model. We will use this model to explore how greenhouse gases affect the temperature of the Earth.

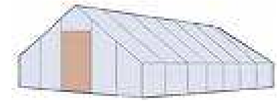
[NOTE: I do this introduction and the following "explore the simulation" section in front of the class, with the students watching the simulation on a projection screen. It could also be left for them to read and do on their own (that is why there are lines for writing answers). After this introduction, the students do the four experiments on their own, asking questions and discussing it with their teammates.)**]**

Load the simulation:

go to http://phet.colorado.edu
click on the red "simulation" button at the bottom of the page
click on the "heat and thermo" link on the left
click on the "greenhouse effect" icon
click the "run now!" button
… you're ready to start!

Explore the simulation

First, take some time to familiarize yourself with this simulation. Note that…
Each **YELLOW** dot represents one unit of sunlight energy,
Each **RED** dot represents one unit of *infrared* energy.
In science, we call a unit of light energy a **photon**; we will talk about sunlight photons and infrared photons.



The **thermometer** indicates the temperature at the Earth's surface.
(By default it uses degrees Fahrenheit. Set it to degrees Celsius by clicking the "Celsius" radio button in the option box on the right).

The **control panel** on the right allows you to adjust the concentration of greenhouse gases, and the number of clouds. We consider four greenhouses gases: water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). For now, we will leave it as is while we make our first observations.

Choose one sunlight photon and follow it with your eyes. Repeat the observation with a few other sunlight photons. Now do the same with a few infrared photons. How does the path of the infrared photons differ from that of the sunlight photons?

____

____

____

____

The simulation has been running for some time. Is the temperature still changing, or has it stabilized? ____

When the temperature stop changing, we say the system has reached **equilibrium**. The flow of energy coming in is equal to the flow of energy going out, so the temperature is stable. This is just like your bank account; if you spend as much as you earn the amount of money in your account is stable. Your budget is in equilibrium.

Let's look more closely at what happens when the Earth's energy budget is out of balance.

How long does it take to reach equilibrium?
Start the simulation over by clicking the "Reset All" button, and start your stopwatch at the same time.

What is the initial temperature? _____

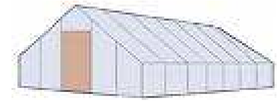
At first, is there more energy coming in or going out of the Earth?
As a result, how is the temperature changing (increasing/decreasing)?
Is the rate of sunlight energy coming in changing?
Is the rate of infrared energy going out changing?
How long does it take before the temperature stabilizes? (sometimes it keeps on varying by one degree, back and forth, that's normal and is still 'stable').

What is the equilibrium temperature?
What is the concentration of CO_2? (you can read it on the control panel)

Naturally, the Earth wants to return to a state of equilibrium. When conditions change in the atmosphere and the balance of incoming and outgoing energy is upset, the temperature changes. Eventually, the outgoing energy flow adjusts until it becomes equal with the incoming flow and the temperature stabilizes. In real life, this can take hundreds of years. Here in this simulation, it takes about 1-2 minutes. Note that because the conditions have changed, the new equilibrium temperature can be different from the previous one.

Now you will conduct a series of experiments to see how the equilibrium temperature changes when we alter the factors that control the energy budget of the Earth. We will investigate three factors:

1) The concentration of greenhouse gases
2) The presence of clouds
3) The reflectivity of the ground



First experiment: What if we didn't have any greenhouse gases?

We generally think of greenhouses gases as a bad thing. Would life on Earth be better without them? Let's try it!

Loading the simulation:

go to http://phet.colorado.edu
click on the red "simulation" button at the bottom of the page
click on the "heat and thermo" link on the left
click on the "greenhouse effect" icon
click the "run now!" button

Hypothesis: if there were no greenhouses gases, then the temperature of the Earth would be (circle one: hotter, the same, colder, much much colder) than it is today.

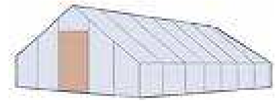
Experiment: Start from the equilibrium state representing today's atmosphere. Then take away the greenhouse gases by moving the "greenhouse gas concentration" slider to "none."

What do you observe? What changed? ___________________________________
____
____

The flow of energy leaving the Earth is now (circle one: greater than / smaller than / equal to) the flow of energy coming from the Sun, and therefore the temperature is (increasing / decreasing).

Wait a minute or two until the temperature stabilizes. According to this model, what would be the equilibrium temperature if there were no greenhouse gases in our atmosphere? ________

How do you think that would affect life on Earth? _____________________________
____
____
____



Second experiment: How have humans changed the energy balance of the Earth since the industrial revolution?

Around the year 1750, Europeans realized that they could produce lots of goods in big factories if they used coal and gas as sources of energy. This brought a period of rapid change in Western society, which we call the industrial revolution. But, as you know, burning coal and gas also emits greenhouse gases. What was the effect of this increased emission of greenhouse gases? Let's find out!

Hypothesis: The increase in emission of greenhouses gases since 1750 has (increased /decreased /not affected) the temperature of the Earth.

Experiment:

1 – Let's go back in time and seen the Earth before the industrial revolution.

Set the "Atmosphere during…" radio-buttons to "1750".

What was different back then? ____

____

Note the concentration of the various greenhouse gases:

Water vapor (H20) ___________

Carbon Dioxide (CO2) ___________

Methane (CH4) ___________

Nitrous oxide (N2O) ___________

Wait for the temperature to stabilize. What is the equilibrium temperature?___

2- Now let's add the effect of all the greenhouse gases that we have emitted since the industrial revolution.

Set the "Atmosphere during…" radio-buttons to "today".

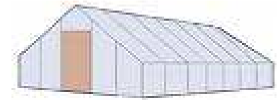
How has the composition of the atmosphere changed?

Water vapor (H20) ___________

Carbon Dioxide (CO2) ___________

Methane (CH4) ___________

Nitrous oxide (N2O) ___________



Wait for the temperature to stabilize.
What is the new equilibrium temperature? ____
By how many degrees has it changed since 1750? ____

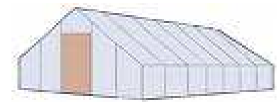
3 – What is going to happen in the future? Will the temperature keep increasing?
Well, it depends how much greenhouse gas we emit. Since the 1990s the concentration of CO_2 in the atmosphere has increased by ~2 ppm every year. Emission of greenhouse gases is increasing all over the world, at a faster and faster pace. So unless we change our ways significantly, the concentration of greenhouse gases in the atmosphere will increase, faster and faster. How will that affect our climate? We don’t exactly know. But because we have computer models, we can calculate what it could look like.

Using our model, you can simulate this increased concentration of greenhouse gases by moving the “greenhouse gas concentration” slider to “lots”.

What is the equilibrium temperature that is reached? ______
How different is it from the pre-industrial temperature? ______

Do you think this increase in temperature would change the Earth a lot?

____
____
____
____
____
____
____
____



Third experiment: How do clouds affect the energy balance of the Earth?

Greenhouse gases are not the only factors affecting the energy balance of the Earth. We will investigate two other factors: the presence of clouds, and the reflectivity of the ground.

Hypothesis: if more clouds are formed in the sky then the temperature of the Earth will (circle one: increase/decrease/stay the same).

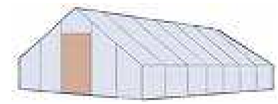
Experiment:
Set the “atmosphere during…” button back to “today.”
Click on “Reset All” to start afresh. Wait until the temperature stabilizes again, and then add clouds using the “Number of clouds” option (at the bottom right). You might have to deselect ‘view all photons’ to see better.

Observation:
What happens to sunlight photons when they encounter a cloud? _______________
____
Would that tend to increase or decrease the temperature of the Earth? ___________

What happens to infrared photons when they encounter a cloud? _______________
____
Would that tend to increase or decrease the temperature of the Earth? ___________

Wait for the temperature to stabilize.

What is the new equilibrium temperature? ________
According to this model, are clouds warming or cooling the Earth? _________



Fourth experiment: What is the effect of the reflectivity of the ground?

As I told you in class, 30% of the energy of the Sun is reflected by clouds and by the ground and returns directly to space, without contributing to the Earth's energy budget. This is what we call the **albedo** of the Earth: albedo is defined as the fraction of solar energy reflected back to space by the Earth. If the Earth's albedo were to change, would it affect the equilibrium temperature? Let's find out!

Hypothesis: if the albedo (reflectivity) of the Earth decreases, then the temperature of the Earth will (circle one: increase/decrease/stay the same).

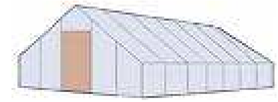
Experiment: Click on "Reset All" to start afresh.
Now, set the "atmosphere during…" button to "ice age." You are now back during the last ice age, when most of North America was covered in ice.

Observation: Pay close attention to the incoming sunlight photons. What is different from the previous simulations? ____
____

Which has a higher albedo, ice or dirt? ______________________________________
____

What is the equilibrium temperature? _____

Why do you think it is so low? (hint: also consider the greenhouse gases…) ________
____
____



VOCABULARY:

photon: a particle of light.

sunlight photons: visible light coming from the Sun.

Infrared photons: invisible light emitted by hot bodies, like the Earth, a rock, animals, humans, etc. We can't see them, but we can feel them as heat, so we sometimes call it heat radiation.

Carbon dioxide (CO2): greenhouse gas emitted when animals breathe, when matter decomposes, and when coal and gasoline are burned.

ppm: stands for "parts per million" (ppm). It is similar to "%" which as you know means percent (or "part per hundred"). We can use either one to describe the concentration of gases in the atmosphere. For gases that are in high concentration we use %. For example, our atmosphere has 78% nitrogen: for every 100 molecules in the atmosphere, 78 are nitrogen molecules. For gases that are in very low concentrations, we use ppm. For example, there is now 381 ppm of CO2 in the atmosphere (or 0.0381%): for every million molecules in the atmosphere, 381 are CO2 molecules.

Albedo: the fraction of solar energy reflected back to space by the Earth.

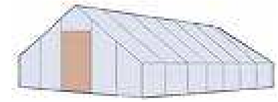
Greenhouse effect: some of the infrared photons emitted by Earth return towards the Earth because they are absorbed and re-emitted randomly by greenhouse gases in the atmosphere. This increases the equilibrium temperature of the Earth.

Earth's energy budget: the balance between the energy coming into the Earth and the energy leaving the Earth.

incoming flow of energy = energy received from the Sun MINUS *albedo effect*.

outgoing flow of energy = infrared energy emitted by the Earth MINUS *greenhouse effect*.

Equilibrium temperature: stable temperature reached when the Earth's energy budget is in balance, that is, when the incoming flow of energy is equal to the outgoing flow of energy.



Discussion points: (do not distribute to students)

1- How much change happened between 1750 and now?

in terms of greenhouse gases concentration?

in terms of temperature?

Surprised at how small the temperature difference was?

In reality The global average air temperature near the Earth's surface rose 0.74 ± 0.18 °C (1.33 ± 0.32 °F) during the hundred years ending in 2005 (IPCC 2007)

Did that make a noticeable difference on Earth?

What does the future holds?

Climate model projections summarized by the IPCC indicate that average global surface temperature will likely rise a further 1.1 to 6.4 °C (2.0 to 11.5 °F) during the twenty-first century.

Will that make a noticeable difference on Earth?

2 – Now we've seen how a greenhouse works, and how the "greenhouse effect" works. What are some of the differences?

3 – How do we know if we can trust a computer model? How do scientists test their models? By looking at what happens in nature, or by doing experiments. So you'll be scientist and design an experiment to test these four factors:

CO_2 is a greenhouse gas

H_2O is a greenhouse gas

albedo

Effect of clouds