CHICAGO BOTANIC GARDEN

Activity 1.1: Understanding the Greenhouse Effect

Grades 7 – 9

Description: In Part 1: Modeling the Greenhouse Effect, students will do a lab that demonstrates the greenhouse effect, and will discuss the results of the lab. In Part 2: The Earth's Energy Balance, students will color in a diagram, answer opinion questions, and perform a skit to understand Earth's energy balance. Students will learn that most of the energy on Earth originates from the sun. The students will also learn what happens to the energy once it reaches the Earth's atmosphere. Students will be introduced to the concept of greenhouse gases. The activity will close with a discussion of natural vs. human-induced changes in greenhouse gas concentrations.

Total Time: Two 45-minute class periods

Prior Knowledge

It is helpful for students to have covered the different types of energy, and energy transformation, particularly from light to heat, as this transformation is an important process in understanding how greenhouse gases retain heat in the atmosphere.

Materials:

Part 1

Per group

- 2 thermometers
- 2 cans
- Water
- Plastic bag
- Modeling the Greenhouse Effect lab handout
- Pens or pencils

Part 2

- Student handout
- Earth's Energy Balance diagram
- Colored pencils
- "Character" cards
- 100 dry lima beans, in groups of 10 (using food is a nice analogy because it represents another form of energy)

National Science Education Standards

B.3.f The sun is a major source of energy for the changes on the Earth's surface.

D.1.h The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor.

AAAS Benchmarks

8C/H8 Sunlight is the ultimate source of most of the energy we use. The energy in fossil fuels such as oil and coal comes from energy that plants captured from the sun long ago.

4B/H4 Greenhouse gases in the atmosphere, such as carbon dioxide and water vapor, are transparent to much of the incoming sunlight but not to the infrared light from the warmed surface of the earth. When greenhouse gases increase, more thermal energy is trapped in the atmosphere, and the temperature of the earth increases.

Guiding Questions

- What are greenhouse gases?
- What are the effects of greenhouse gases in the atmosphere?
- Where does most of the energy on earth originate?
- What happens to the energy once it reaches earth?
- What is the greenhouse effect?

Assessment(s)

- Modeling the Greenhouse Effect lab handout
- Earth's Energy Balance Diagram
- Journal entry describing what happens to the energy that comes from the sun

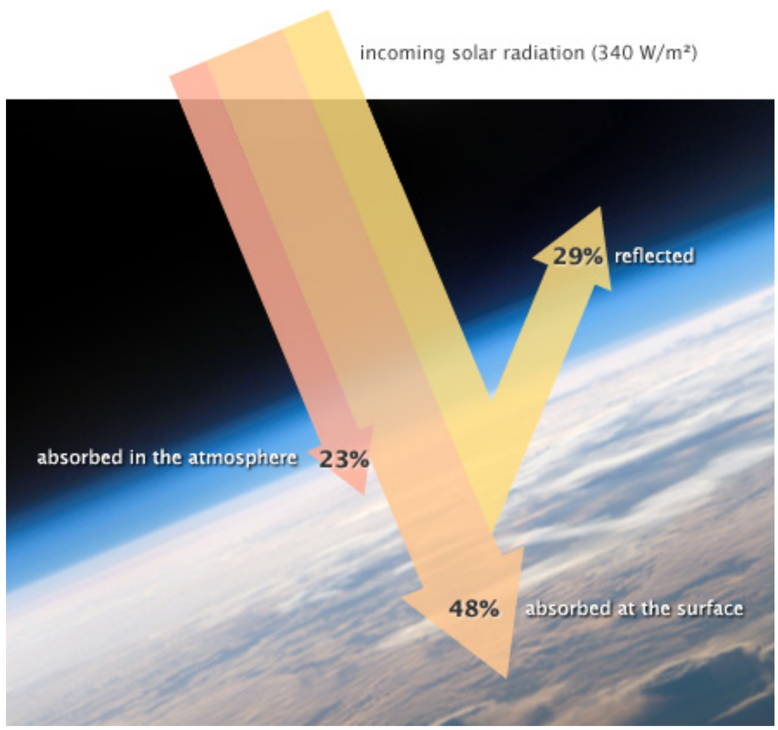
Background Information: Climate and Earth's Energy Budget

Adapted from "Climate and the Earth's Energy Budget" by Rebecca Lindsey, January 14, 2009
Full article can be found at: http://earthobservatory.nasa.gov/Features/EnergyBalance/page1.php

The Earth's climate is a solar-powered system. Globally, over the course of the year, the Earth system—land surfaces, oceans, and atmosphere—absorbs an average of about 240 watts of solar power per square meter (one watt is one joule of energy every second). The absorbed sunlight drives photosynthesis, fuels evaporation, melts snow and ice, and warms the Earth system.

The Sun doesn't heat the Earth evenly. Because the Earth is a sphere, the Sun heats equatorial regions more than polar regions (the Sun's light hits there more directly, and so is more intense in those regions). The atmosphere and ocean work nonstop to even out solar heating imbalances through evaporation of surface water, convection, rainfall, winds, and ocean circulation. Together, atmosphere and ocean circulation are known as Earth's heat engine.

Earth's heat engine does more than simply move heat from one part of the surface to another; it also moves heat from the Earth's surface and lower atmosphere back to space. This flow of incoming and outgoing energy is Earth's energy budget. For Earth's temperature to be stable over long periods of time, incoming energy and outgoing energy have to be equal. In other words, the energy budget at the top of the atmosphere must balance. This state of balance is called radiative equilibrium.



About 29 percent of the solar energy that arrives at the top of the atmosphere is reflected back to space by clouds, atmospheric particles, or bright ground surfaces like sea ice and snow. This energy plays no role in Earth's climate system. About 23 percent of incoming solar energy is absorbed in the atmosphere by water vapor, dust, and ozone, and 48 percent passes through the atmosphere and is absorbed by the surface. Thus, about 71 percent of the total incoming solar energy is absorbed by the Earth system.

The Earth's temperature doesn't infinitely rise, however, because atoms and molecules on Earth do not just absorb sunlight, they also radiate back out heat energy. The amount of heat a surface radiates is proportional to the fourth power of its temperature (if the temperature doubles, radiated heat energy increases by 16 times!). This large increase in heat loss in response to a relatively smaller increase in temperature—referred to as radiative cooling—is the primary mechanism that prevents runaway heating on Earth.

The atmosphere and the surface of the Earth together absorb 71 percent of incoming solar radiation, so they must radiate that much energy back to space for the planet's average temperature to remain stable. However, the atmosphere and the surface absorb sunlight and radiate heat at different rates. The atmosphere absorbs 23 percent of incoming sunlight while the surface absorbs 48 percent. The atmosphere radiates heat equivalent to 59 percent of incoming sunlight; the surface radiates only 12 percent. In other words, most solar heating happens at the surface, while most radiative cooling happens in the atmosphere. How does this reshuffling of energy between the surface and atmosphere happen?

Surface Energy Budget

To understand how the Earth's climate system balances the energy budget, we have to consider processes occurring at the three levels: 1) the surface of the Earth, where most solar heating takes place; 2) the edge of Earth's atmosphere, where sunlight enters the system; and 3) the atmosphere in between. At each level, the amount of incoming and outgoing energy, or net flux, must be equal.

Remember that about 29 percent of incoming sunlight is reflected back to space by bright particles in the atmosphere or bright ground surfaces, which leaves about 71 percent to be absorbed by the atmosphere (23 percent) and the land (48 percent). For the energy budget at Earth's surface to balance, processes on the ground must get rid of the 48 percent of incoming solar energy that the ocean and land surfaces absorb. Energy leaves the surface through three processes: evaporation, convection, and emission of thermal infrared energy.

About 25 percent of incoming solar energy leaves the surface through evaporation. Liquid water molecules absorb incoming solar energy, and they change phase from liquid to gas. The heat energy that it took to evaporate the water is latent in the random motions of the water vapor molecules as they spread through the atmosphere. When the water vapor molecules condense back into rain, the latent heat is released to the surrounding atmosphere. Evaporation from tropical oceans and the subsequent release of latent heat are the primary drivers of the atmospheric heat engine

An additional 5 percent of incoming solar energy leaves the surface through convection. Air in direct contact with the sun-warmed ground becomes warm and buoyant. In general, the atmosphere is warmer near the surface and colder at higher altitudes, and under these conditions, warm air rises, shuttling heat away from the surface.

Finally, a net of about 17 percent of incoming solar energy leaves the surface as thermal infrared energy (heat) radiated by atoms and molecules on the surface. This net upward flux results from two large but opposing fluxes: heat flowing upward from the surface to the atmosphere (117 percent) and heat flowing downward from the atmosphere to the ground (100 percent). (These competing fluxes are part of the greenhouse effect, described below.)

The Atmosphere's Energy Budget

Just as the incoming and outgoing energy at the Earth's surface must balance, the flow of energy into the atmosphere must be balanced by an equal flow of energy out of the atmosphere and back to space. Satellite measurements indicate that the atmosphere radiates thermal infrared energy equivalent to 59 percent of the incoming solar energy. If the atmosphere is radiating this much, it must be absorbing that much. Where does that energy come from?

Clouds, aerosols, water vapor, and ozone directly absorb 23 percent of incoming solar energy. Evaporation and convection transfer 25 and 5 percent of incoming solar energy from the surface to the atmosphere. These three processes transfer the equivalent of 53 percent of the incoming solar energy to the atmosphere. The remaining fraction (about 5-6 percent) comes from the Earth's surface.

The Natural Greenhouse Effect

Just as the major atmospheric gases (oxygen and nitrogen) are transparent to incoming sunlight, they are also transparent to outgoing heat energy. However, water vapor, carbon dioxide, methane, and other trace gases are "opaque" to many wavelengths of heat energy, and so trap that heat in the atmosphere. Remember that the surface radiates the net equivalent of 17 percent of incoming solar energy as thermal infrared. However, the amount that directly escapes to space is only about 12 percent of incoming solar energy. The remaining fraction—a net 5-6 percent of incoming solar energy—is transferred to the atmosphere when greenhouse gas molecules absorb thermal infrared energy radiated by the surface.

When greenhouse gas molecules absorb thermal infrared energy, their temperature rises, and then they radiate an increased amount of heat in all directions. Heat radiated upward continues to encounter greenhouse gas molecules; those molecules absorb the heat, their temperature rises, and the amount of heat they radiate increases. Heat radiated downward ultimately comes back into contact with the Earth's surface, where it is absorbed. The temperature of the surface becomes warmer than it would be if it were heated only by direct sunlight. This additional heating of the Earth's surface by the atmosphere is the natural greenhouse effect.

Effect on Surface Temperature

The natural greenhouse effect raises the Earth's surface temperature to about 15 degrees Celsius on average—more than 30 degrees warmer than it would be if it didn't have an atmosphere. The amount of heat radiated from the atmosphere back to the surface (sometimes called "back radiation") is equivalent to 100 percent of the incoming solar energy. The Earth's surface responds to the "extra" (on top of direct solar heating) energy by raising its temperature.

Why doesn't the natural greenhouse effect cause a runaway increase in surface temperature? Remember that the amount of energy a surface radiates always increases faster than its temperature rises—outgoing energy increases with the fourth power of temperature. As solar heating and “back radiation” from the atmosphere raise the surface temperature, the surface simultaneously releases an increasing amount of heat—equivalent to about 117 percent of incoming solar energy. The net upward heat flow, then, is equivalent to 17 percent of incoming sunlight (117 percent up minus 100 percent down).

Some of the heat escapes directly to space, and the rest is transferred to higher and higher levels of the atmosphere, until the energy leaving the top of the atmosphere matches the amount of incoming solar energy. Because the maximum possible amount of incoming sunlight is fixed by the solar constant (which depends only on Earth’s distance from the Sun and very small variations during the solar cycle), the natural greenhouse effect does not cause a runaway increase in surface temperature on Earth.

Climate Forcings and Global Warming

Any changes to the Earth’s climate system that affect how much energy enters or leaves the system alters Earth’s radiative equilibrium and can force temperatures to rise or fall. These destabilizing influences are called climate forcings. Natural climate forcings include changes 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), and large volcanic eruptions that inject light-reflecting particles as high as the stratosphere. Man-made forcings include particle pollution (aerosols), which absorb and reflect incoming sunlight; deforestation, which changes how the surface reflects and absorbs sunlight; and the rising concentration of atmospheric carbon dioxide and other greenhouse gases, which decrease heat radiated to space. A forcing can trigger feedbacks that intensify or weaken the original forcing. The loss of ice at the poles, which makes them less reflective, and results in increased heat absorption, is an example of a feedback.

Increasing carbon dioxide forces the Earth’s energy budget out of balance by absorbing heat radiated by the surface. It absorbs heat energy with wavelengths in a part of the energy spectrum that other gases, such as water vapor, do not. Although water vapor is a powerful absorber of many wavelengths of thermal infrared energy, it is almost transparent to others. The transparency at those wavelengths is like a window the atmosphere leaves open for radiative cooling of the Earth’s surface.

Carbon dioxide is a very strong absorber of thermal infrared energy with wavelengths longer than those absorbed by water, which means that increasing concentrations of carbon dioxide partially “close” the atmospheric window. In other words, wavelengths of outgoing thermal infrared energy that our atmosphere’s most abundant greenhouse gas—water vapor—would have let escape to space are instead absorbed by carbon dioxide.

The absorption of outgoing thermal infrared by carbon dioxide means that Earth still absorbs about 70 percent of the incoming solar energy, but an equivalent amount of heat is no longer leaving. The exact amount of the energy imbalance is very hard to measure, but it appears to be a little more than 0.8 watts per square meter. The imbalance is inferred from a combination of measurements, including satellite and ocean-based observations of sea level rise and warming.

When a forcing like increasing greenhouse gas concentrations bumps the energy budget out of balance, it doesn't change the global average surface temperature instantaneously. It may take years or even decades for the full impact of a forcing to be felt. This lag between when an imbalance occurs and when the impact on surface temperature becomes fully apparent is mostly because of the immense heat capacity of the oceans. The heat capacity of the oceans gives the climate a thermal inertia that can make surface warming or cooling more gradual, but it can't stop a change from occurring.

The changes we have seen in the climate so far are only part of the full response we can expect from the current energy imbalance, caused only by the greenhouse gases we have released so far. Global average surface temperature has risen between 0.6 and 0.9 degrees Celsius in the past century, and it will likely rise at least 0.6 degrees in response to the existing energy imbalance.

As the surface temperature rises, the amount of heat the surface radiates will increase rapidly. If the concentration of greenhouse gases stabilizes, then Earth's climate will once again come into equilibrium, albeit with the "thermostat"—global average surface temperature—set at a higher temperature than it was before the Industrial Revolution.

However, as long as greenhouse gas concentrations continue to rise, the amount of absorbed solar energy will continue to exceed the amount of thermal infrared energy that can escape to space. The energy imbalance will continue to grow, and surface temperatures will continue to rise.

Vocabulary

- **Earth's Atmosphere**: The layer of gases surrounding the Earth. The sun's energy passes (is transmitted) through the atmosphere. Infrared radiation emitted from Earth's surface is absorbed by Earth's atmosphere thereby heating the atmosphere. Air is mainly composed of nitrogen, oxygen, and argon. These gases make up most of the atmosphere. Other gases are in the atmosphere in lower quantities. These gases include greenhouse gases like carbon dioxide and methane
- **Greenhouse Gas**: A gas in an atmosphere that lets in sunlight and traps heat energy. This process is the fundamental cause of the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are carbon dioxide, methane, water vapor, and nitrous oxide.
- **Greenhouse Effect**: The ability of gases in the atmosphere to absorb heat from the Earth is called the greenhouse effect.
- **Earth's Reflectivity**: The percentage of sunlight reflected by the Earth's surface features (water, ice, snow, plants) and atmosphere. Ice, especially with snow on top of it, has a high reflectivity. This means that most sunlight hitting the surface bounces back towards space. Water is much more absorbent and less reflective. So, if there is a lot of water, more solar radiation is absorbed by the ocean than when ice dominates. Clouds also play a significant role in the Earth's reflectivity, as they reflect incoming sunlight back into space.
- **Earth's Albedo**: The percentage of solar energy reflected from the Earth back into space. It is a measure of the reflectivity of the earth's surface.
- **Luminosity**: The total amount of light energy given off of by an object, for example a light bulb or the sun.
- **Earth's Energy Absorption**: The amount of the Sun's energy absorbed by the surface features of the Earth (plants, earth, water) and its atmosphere. The energy that is not absorbed is reflected back out into the atmosphere.
- **Solar Energy**: Energy from the sun. The Sun emits energy in all wavelengths, peaking in the visible wavelengths. Energy from the Earth peaks in the infrared wavelengths.
- **Surface Features of the Earth**: topography (land forms), bodies of water, and ground cover that cover the Earth's surface.
- **Earth's Energy Cycle/Earth's Energy Balance**: The Earth can be considered a physical system with an energy cycle that includes all incoming energy (primarily from the sun) and all losses of outgoing energy (through reflectivity). Outgoing energy is a predominantly a combination of reflected solar energy and transmitted infrared energy. The planet is approximately in balance, so the amount of energy coming in is approximately equal to the amount going out. The Earth's energy balance is what keeps the Earth at its current temperature.

Part 1: Modeling the Greenhouse Effect

Description: Students will do a lab demonstration to learn about the greenhouse effect and then discuss the natural vs. human-induced changes in greenhouse gas concentrations.

Time: Approximately 30 minutes of active time. The lab needs to sit for at least 1 hour.

Materials:
Part 1
Per group
- 2 thermometers
- 2 empty soda cans
- 100 ml. water
- 1 large plastic ziplock bag.
- Modeling the Greenhouse Effect lab handout
- Pens or pencils

Procedure

1. Before students come into the classroom, write the following discussion question on the board: *"Animals, people, and many of the things that we use in our daily lives, such as automobiles and electricity, make gases such as carbon dioxide. These gases form a blanket around the Earth that acts something like the glass in a greenhouse. How do you think this layer of "greenhouse gases" might affect the Earth's temperature?"*

2. Have a student read the introduction question aloud, then have students brainstorm their answers and record their answers on the board. At this point you may choose to give students simple definitions of atmosphere and greenhouse gas, or wait and introduce them in part 2 of this activity, when students discuss the role of greenhouse gases in the Earth's energy balance.
   - **Earth's Atmosphere**: The layer of gases surrounding the Earth. The atmosphere protects life on Earth by absorbing light energy from the sun. The light from the sun warms the Earth, and this warmth is trapped by the Earth's atmosphere. Air is mainly composed of nitrogen, oxygen, and argon. These gases make up most of the atmosphere. Other gases are in the atmosphere in lower quantities. These gases include greenhouse gases like carbon dioxide and methane.
   - **Greenhouse Gas**: a gas in an atmosphere that lets in sunlight and traps heat energy. This trapping of heat energy is called the greenhouse effect. The primary greenhouse gases in the Earth's atmosphere are carbon dioxide, methane, water vapor, and nitrous oxide. Carbon dioxide is the most common greenhouse gas.

3. Explain that they are going to do an experiment that models this layer of "greenhouse gases" to see what effects it has on temperature.

4. Guide students through the handout before beginning the lab. Depending on the amount of time you have and the level of your students, you can either have students brainstorm how you might set up the experiment before handing out the handout, or you can hand out the handout, read through it, and ask them to think about how the setup of the experiment models the role of greenhouse gases around the Earth. Through discussion or

explanation, students should understand that the cans of water represent the Earth and that the bag around one represents greenhouse gases (or the Earth's atmosphere).

5. Have students follow the directions on the lab sheets, and place cans in a sunny spot. The cans will stay in the sunny spot for at least 1 hour. During this wait time, you may begin part 2: The Earth's Energy Balance.

6. After 1 hour have students take the final temperatures, record their data and answer the post-lab questions. You can collect the labs for a grade, or go over the answers in class.

7. As you discuss the lab, key points to communicate are that
   - the bag represents the layer of greenhouse gases (including carbon dioxide, methane, water vapor, and other trace gases) surrounding the Earth
   - greenhouse gases trap heat and keep the planet warm
   - greenhouse gases are necessary for life on our planet to exist, otherwise the planet would freeze
   - adding more greenhouse gases to the planet is like making a thicker bag, trapping more heat, and increasing the Earth's temperature.

8. Lab sheets should be placed in student portfolios.

Name:__________________________________ **Date:**___________ **Room:**__________

Modeling the Greenhouse Effect

Introduction:
Animals and plants release gases such as carbon dioxide and oxygen into the atmosphere. These gases form a blanket around the Earth similar to putting a plastic bag around a can. How do you think this might affect the Earth's temperature? Think about what happens when you wrap up in a blanket on a cold night.

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Materials:
- 2 thermometers
- 1 plastic ziplock bag
- 2 empty soda cans
- 100 ml of water

Procedure:
Part 1
1. Fill each can with 50 ml of water.
2. Put a thermometer in each can, and wait 2 minutes (make sure the thermometer is in the water). Record the temperature of the water in each can on your data table. This is the initial temperature.
3. Put the thermometers back into the cans.
4. Place one can with the thermometer, in a ziplock bag and seal the bag.
5. Put both cans next to each other in a sunny spot and leave them there for at least an hour. Your teacher will tell you when it is time to start part 2 of the experiment.

Part 2
6. Record the temperature on the thermometer in each can on your data table. This is the final temperature.
7. Subtract the final temperature from the initial temperature to find the change in temperature. Record this in your data table.

Data table:

Can	**Initial temperature**	**Final temperature**	**Change in temperature**
With bag			
Without bag			

Name:__________________________________ Date:__________ Room:__________

Questions:

1. Was there a difference in final temperature between the can with the bag around it and the can with no bag? What do you think caused the difference?

2. What do you think would happen to the final temperature if you used a thicker bag, or two bags, around the can?

3. What does the bag represent? Explain.

4. Explain why the greenhouse effect is necessary for life on earth, but why it may be a problem if the concentration of greenhouse gases increases?

5. What additional questions do you have after performing this lab? How could you design an experiment to answer those questions?

Part 2: The Earth's Energy Balance

Description: Students color in a diagram, answer opinion questions and perform a skit enacting energy movement through the atmosphere. Students will learn that most energy on earth originates from the sun and what happens to that energy once it reaches the Earth's atmosphere. Students are introduced to the concept of greenhouse gases. The activity will close with a discussion of natural vs. human-induced changes in greenhouse gas concentrations.

Time: 1 class period

Materials:
Part 2
- Desk lamp
- Earth's Energy Balance Diagram handout
- Colored pencils
- "Character" cards
- 100 dry lima beans divided into groups of 10. These groups will be broken up, but beginning the activity with 10 bean groups makes it easier to manage. (Using food is a nice analogy because it represents another form of energy.)

Procedure
(You can begin this discussion while you are waiting to start Part 2 of the lab)

1. Before beginning, put the desk lamp on your desk, or in an easily accessible location.

2. Ask students what they know about energy. Take student answers and write them on the board. The depth and length of the discussion will depend on your students' background knowledge, and whether you have already covered this content.

3. Turn on the desk lamp. Ask students what kind of energy is being used to turn on the lamp (electrical). Ask students what kind of energy the lamp is giving off (light), is that all? Have one or a few students come to the front of the class and hold their hand near the lamp. What do they feel? The lamp is also giving off heat energy. Explain that the electrical energy is being transformed to light energy through the light bulb, and that the light energy is transformed to heat energy when it hits their hands.

4. Ask students how the example of the light is similar to the sun and the earth. The sun gives off light that warms the earth—if you stand in the sun, you can feel the warmth. Through this discussion, students should understand that light and heat are both different forms of energy, and that light from the sun is transformed to heat energy when it reaches the Earth's surface.

5. Have students breathe in and breathe out slowly and concentrate on how it feels to breathe. Ask students:
   - What were you breathing in? (Oxygen, air)
   - What is the "air" made up of? (Oxygen, CO_2, water vapor, nitrogen, other gases)

   Air is mainly composed of nitrogen, oxygen, and argon, which together constitute the major gases of the atmosphere. We breathe in oxygen and breathe out CO_2, plants take in CO_2 and produce oxygen. The remaining gases are often referred to as trace gases, among which along with CO_2 are many of the greenhouse gases.

   Explain that the air, or atmosphere, is not only important because we breathe it, but that it supports life on Earth in other ways—by helping to maintain the temperature of the Earth.

Explain that the atmosphere is a layer of gases surrounding the Earth. As many of these gases (oxygen and nitrogen) are transparent to incoming sunlight, they are also transparent to outgoing heat energy, so they let the heat escape back into outer space. However, a few of these gases, such as water vapor, carbon dioxide, methane, and other trace gases are “opaque” to many wavelengths of heat energy, and so they trap that heat in the atmosphere, warming the surface through heat retention (greenhouse effect), and reducing temperature extremes between day and night. To make it a little more concrete for the students, you may want to add that the gases act much like the glass on a greenhouse, trapping heat in – and ask students what happens to the interior of a car left out in the sun on a summer day.

Students should understand that this is the natural greenhouse effect, and that it is important for the survival of plants and animals, including humans, on Earth.

This is a good stopping point to go back and complete Part 2 of the lab activity.

Day 2

1. Next, students will work through the diagram. This can be done in several ways. You can pass out the handout, which will guide them through the diagram and have them work through the handout and diagram alone or in groups. Or, you can lead the class and have the all the students work through the handout and diagram step by step. In either case, it is worthwhile to discuss the italicized questions. Below are the italicized questions with possible student answers/discussion points.

   Based on the name, what do you think is the effect of the greenhouse gases?

2. Students may recognize that a greenhouse is hot, or that a greenhouse is designed to protect plants, so they may make the connection that greenhouse gases keep the Earth warm, or protect the earth. If students have already completed part 2 of the lab, this should inform their response.

   You have already colored arrow 2 orange.
   Why do you think arrow 6 is also colored orange?

3. Arrow 2 and arrow 6 both represent energy that comes directly from the sun, so both are orange.

   Why do you think arrow 6 is thinner than arrow 2?

4. Arrow 6 is thinner than arrow 2 because some of the energy from the sun was lost into space after being reflected by the atmosphere or by clouds.

   Why do you think you colored the Earth’s surface green?

5. The Earth’s surface is green and half blue because the Earth is covered by plants and water. Plants are green and they use the sun’s energy to grow. Water is dark and absorbs heat energy, but it also evaporates, which helps cool the earth.

   Explain how the energy from the sun that reaches Earth may be used on Earth.

6. The energy is used for plants to grow. When animals eat plants, they get energy as well.

7. Select six students to "act out" Earth's energy balance. Assign roles to the students using the cards below. One student each will play the sun, cloud, Earth's atmosphere/greenhouse gases, Earth's surface, plant, and space.

8. Before performing the activity, you can hang the cards on yarn to make necklaces, or simply have the students tape the cards to their shirts. You will narrate the scene, as students act it out. Explain to the students that candy will represent energy.

9. Ask them why it makes sense that food is used to represent energy (the students may answer that they get energy from food, so it makes sense to have beans represent energy). Give 100 dry lima beans to the student playing the sun.

10. As students watch the play, have them note the percentages and details on their energy balance diagrams.

11. Read through the following narration, and have the students act:

   - **The sun radiates energy in all directions. Some of the energy from the sun reaches the Earth's atmosphere. Most of the energy on Earth originates from the sun.**
     - **The sun will now give 100 beans to the Earth's atmosphere.**

   - **About 29 percent of the solar energy that arrives at the top of the atmosphere is reflected back to space by clouds, atmospheric particles, or bright ground surfaces like sea ice and snow.**
     - **The atmosphere gives 10 beans to the clouds, 10 beans to the Earth, and keeps 9 beans for itself.**

   - **This energy is reflected back into space and plays no role in Earth's climate system.**
     - **The clouds, Earth, and atmosphere then give their beans to space.**

   - **About 23 percent of incoming solar energy is absorbed in the atmosphere by water vapor, dust, and ozone.**
     - **The atmosphere gives another 10 beans to the clouds, representing heat energy trapped by water vapor.**

   - **About and 48 percent passes through the atmosphere and is absorbed by the surface.**
     - **The atmosphere will now give and the rest of the beans (48) to the Earth's surface.**

   - **For the energy budget at Earth's surface to balance, processes on the ground must get rid of the 48 percent of incoming solar energy that the ocean and land surfaces**

absorb. Energy leaves the surface through three processes: evaporation, convection, and emission of thermal infrared energy.

- **About 25 percent of incoming solar energy leaves the surface through evaporation. Liquid water molecules absorb incoming solar energy, and they change phase from liquid to gas. The heat energy that it took to evaporate the water is latent in the random motions of the water vapor molecules as they spread through the atmosphere.**
    - **The Earth's surface should give 25 beans to the clouds**

- **When the water vapor molecules condense back into rain, the latent heat is released to the surrounding atmosphere.**
    - **The clouds give those 25 beans to the atmosphere**

- **Energy also leaves the surface through convection. Air in direct contact with the sun-warmed ground becomes warm and buoyant. In general, the atmosphere is warmer near the surface and colder at higher altitudes, and under these conditions, warm air rises, shuttling heat away from the surface.**
    - **The Earth's surface should give 6 beans to the atmosphere**

- **Many things happen to the energy that reaches the Earth. For instance, it is used to make plants grow. If an animal eats the plant, the energy will be transferred to the animal.**
    - **The Earth's surface will give 5 candies to the plant**

- **The energy that is not absorbed by plants, or other parts of Earth's surface is radiated back towards the atmosphere. The Earth will give its remaining candy back to the atmosphere.**

- **Some of the energy radiated from the Earth passes through the atmosphere and ends up in space.**
    - **The atmosphere will give 17 beans to space.**

- **However, the rest of the energy is stopped by the greenhouse gases and sent back to Earth. Now, the atmosphere will give its remaining energy back to the Earth. This energy helps to heat up the Earth to a temperature that can sustain living things.**

[end of play – everyone takes a bow]

12. Ask the students: Where did all the energy originate? Where did most of the energy end up? Was this surprising to you?

13. After students have performed the skit once, you can have new students play the "roles" and have a student or several students be the narrator to see if the students can remember or reason through the steps.

14. After the students have completed color-coding the diagram, and performing the skit, check for understanding. Have students look at the diagram. Ask them to write a paragraph in their journals explaining what happens to the energy that comes from the sun to Earth. You may collect these journal entries to determine if students understand the concepts.

Possible extensions:

- Students make a pie chart of the different gases that make up earth's atmosphere (nitrogen, oxygen, etc.)
- Students make a diagram of the different layers of the atmosphere.
- The "skit" of the Earth's energy balance could be expanded to include other animals, decomposers, etc.
- The "skit" could be expanded to include disturbances to the system – for example: increased greenhouse Gases in the atmosphere.

Journal Entry Rubric: What happens to energy from the sun?

Concept	Low	Medium	High
Correct use/definition of vocabulary.	Does not use appropriate terminology or uses it incorrectly	Uses some vocabulary, not all, and uses it correctly, to illustrate the relevant concepts	Uses all vocabulary correctly
Accurately describes the greenhouse effect	Does not describe the role of the Earth's atmosphere in maintain the Earth's temperature.	Describes the role of greenhouse gasses in absorbing and reflecting light energy from the sun.	Describes the role of greenhouse gasses in absorbing and reflecting light energy from the sun and retaining heat energy re-radiated from the Earth.
Earth's Energy balance	Describes only sunlight in/out.	Describes sunlight in/out. Describes the role of the atmosphere in maintaining the Earth's temperature. Some incomplete descriptions of the steps in the energy balance.	Describes all steps in the Earth's energy balance including the role of the atmosphere, Earth's surface, clouds and greenhouse effect.
Understands the greenhouse effect is necessary to life on Earth	Does not discuss why the greenhouse effect is important or does not explain why it is important	Understands that the greenhouse effect is responsible for maintaining the Earth's temperature, and there are both positive and negative aspects to the greenhouse effect	Understands that the greenhouse effect is responsible for maintaining the Earth's temperature, there are both positive and negative aspects to the greenhouse effect, and that by changing the makeup of the atmosphere we can have an impact on the temperature of the Earth.

Name:_________________________________ Date:____________ Class:__________

Earth's Energy Balance – Student Handout

Directions: You will color in the diagram "Earth's energy balance" to learn about what happens to energy from the sun when it reaches Earth. Follow each step below to color-code your diagram. You will need colored pencils, crayons, or markers to complete this activity.

Answer the questions as you go.

1. Locate the number 1 on the diagram. 1 represents the sun. Almost all the energy on Earth originates from the sun. Color the sun yellow.
2. Locate the number 2 on the diagram. 2 represents the energy from the sun that comes towards Earth. Color the number 2 arrow orange.
3. Locate the number 3 in the diagram. Number 3 represents the Earth's atmosphere. The atmosphere is made of gases. ome of the gases in the Earth's atmosphere are called greenhouse gases. Color the earth's atmosphere blue.

Based on the name, what do you think the greenhouse gases do to the planet? (Think about the lab you did earlier in this activity. What happened to the temperature of the water in the can in the bag?)

4. Locate the number 4 on the diagram. Some of the energy that reaches the Earth's atmosphere is radiated into space without reaching Earth. Arrow number 4 represents the energy that was radiated into space. Color this arrow red.
5. Some of the energy from the sun passes through the atmosphere. However, some of this energy is reflected to space when it hits clouds in the sky. Locate the number 5 on the diagram. Arrow number 5 represents the energy that is radiated into space from the clouds. Color this arrow blue.
6. Some of the energy from the sun passes through the Earth's atmosphere and the clouds and reaches the Earth's surface. Locate number 6 on the diagram. Arrow number 6 represents the energy from the sun that reaches the Earth's surface. Color arrow number 6 orange.

You have already colored arrow 2 orange. Why do you think arrow 6 is also colored orange? Why do you think arrow 6 is thinner than arrow 2?

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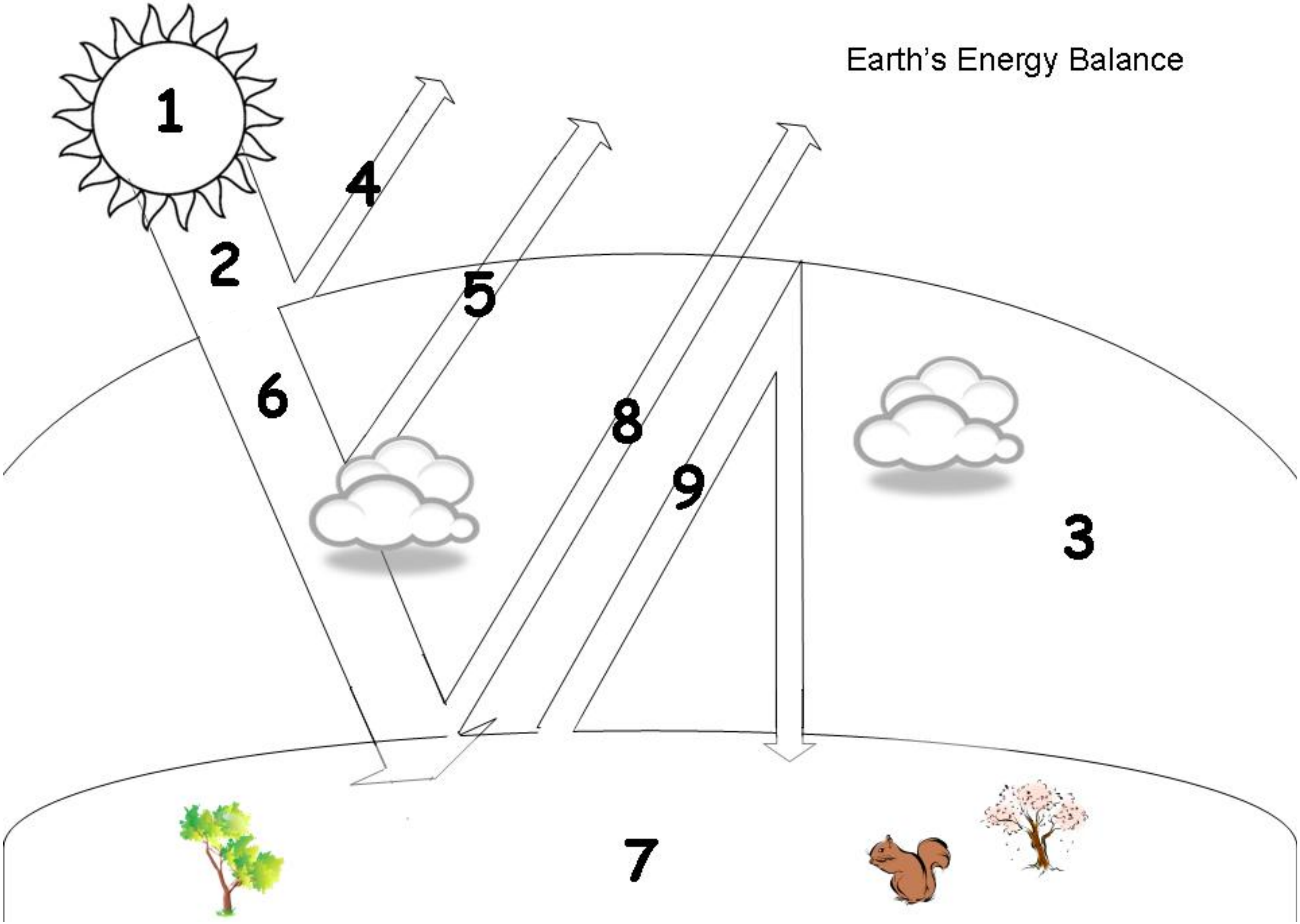
7. Locate number 7 on the diagram. Number 7 represents the Earth's surface. Color half of the Earth's surface green and the other half blue. Some of the energy that reaches the Earth's surface is used by organisms on earth.

Why do you think you colored the earth's surface green and blue?

Explain how the energy that reaches Earth may be used on Earth.

8. The energy that is not absorbed on Earth is radiated back towards space. Locate number 8 on the diagram. Number 8 represents the energy that is radiated away from Earth and goes into space. Color arrow number 8 brown.

9. Some of the energy that is not absorbed by the Earth is radiated back to space, but does not reach space. Instead, the greenhouse gases radiate the energy back towards Earth! Locate number 9 on the diagram. The two arrows of number 9 represent energy that is re-radiated back to Earth. This additional energy helps keep the Earth at a temperature that is appropriate for living things. Color the arrows of number 9 pink.


Earth's Energy Balance
1
4
2
5
6
8
9
3
7

CHICAGO BOTANIC GARDEN

Earth's Atmosphere

Image courtesy of NASA

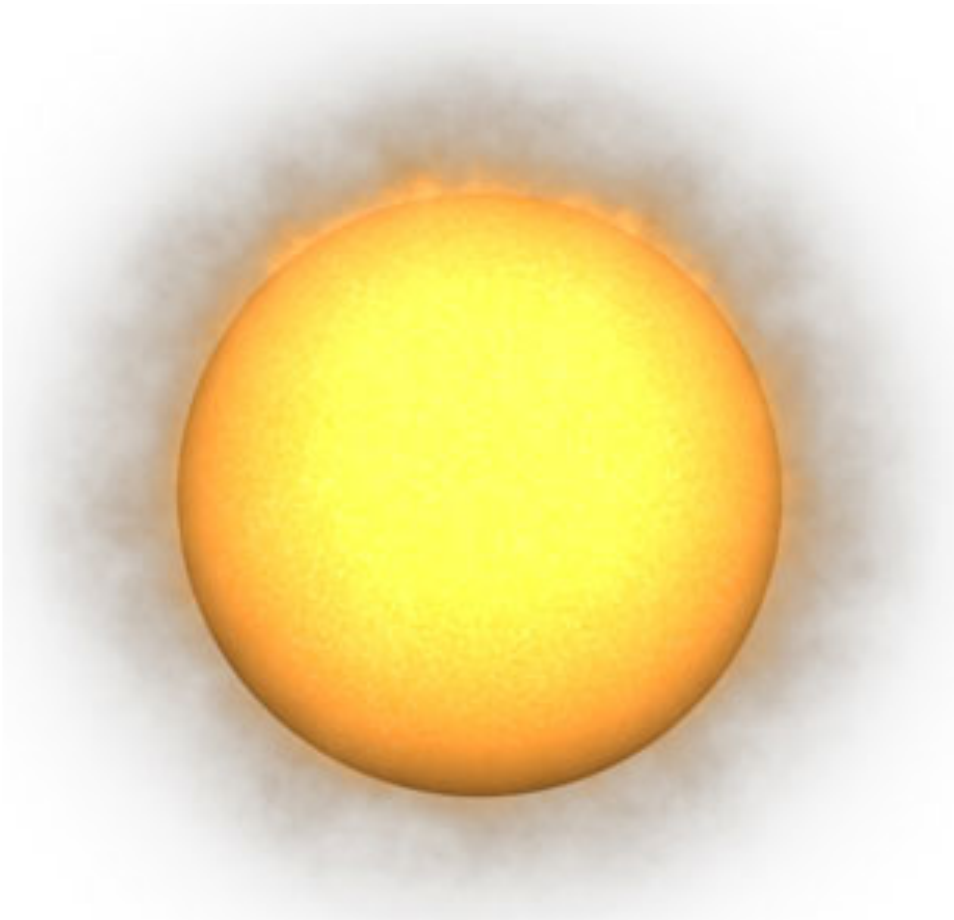
Clouds

http://earthobservatory.nasa.gov/Features/SmokeClouds/

Earth's Surface

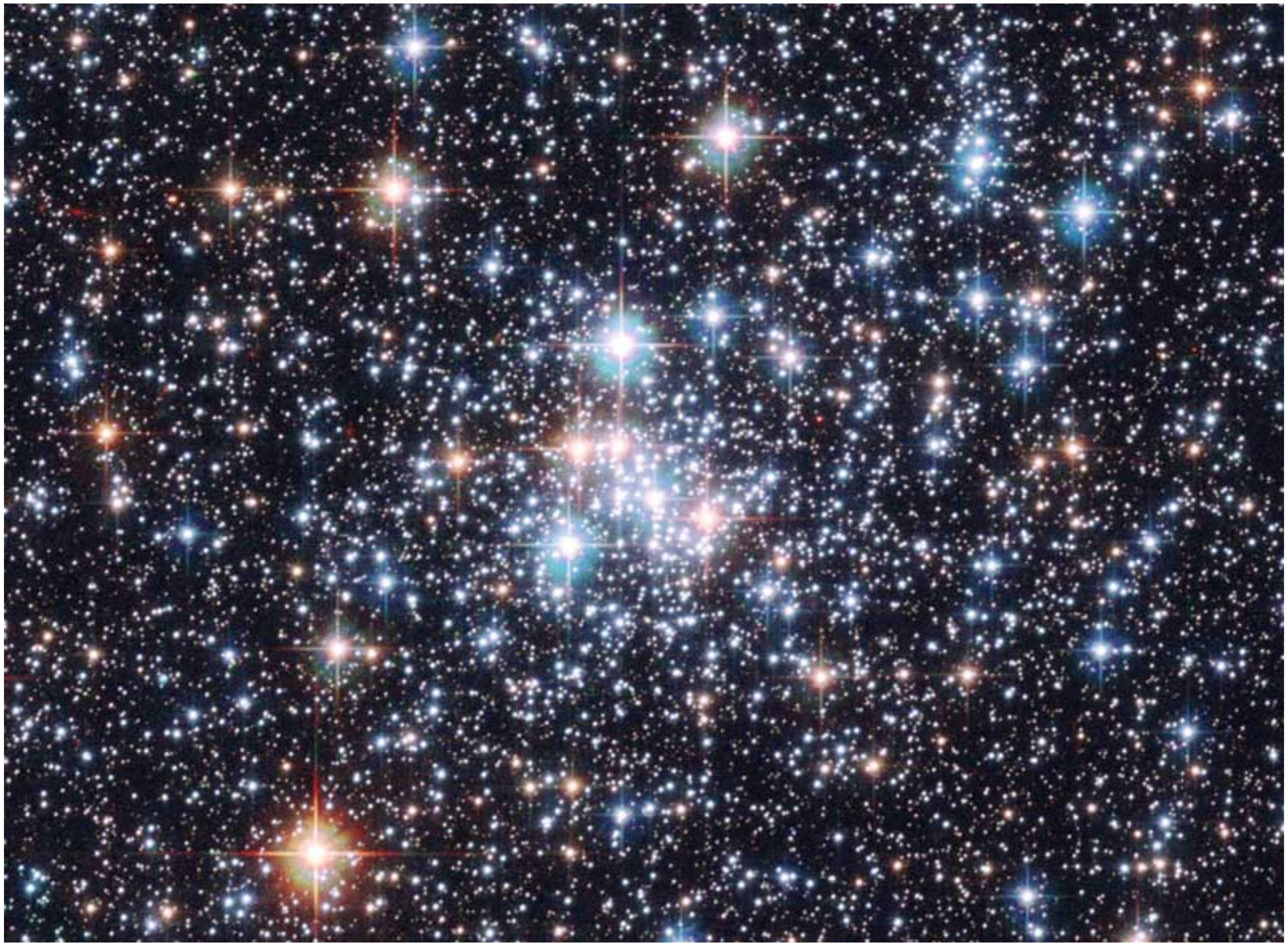
http://climate.nasa.gov/imagesVideo/earthWallpaper/index.cfm

Sun



http://sciencedude.ocregister.com/2012/01/31/nasa-warming-driven-by-humans-not-sun/167369/

Space



http://hubblesite.org/gallery/album/star/pr2006017c/

Plants

Chicago Botanic Garden