National Aeronautics and
Space Administration

Goddard Space Flight Center
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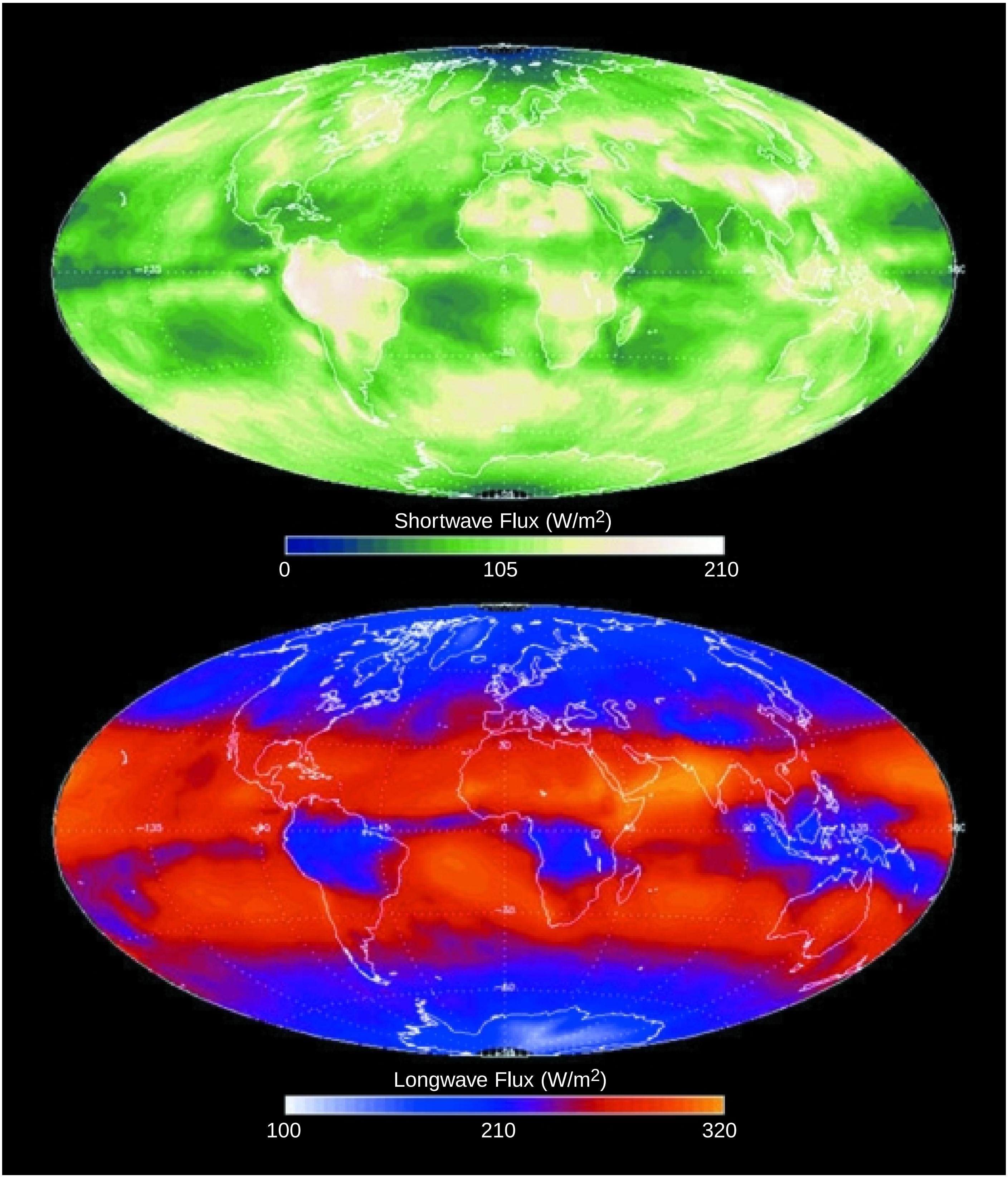
Clouds and the Earth's Radiant Energy System (CERES)



First Monthly CERES Global Longwave and Shortwave Radiation

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About This image

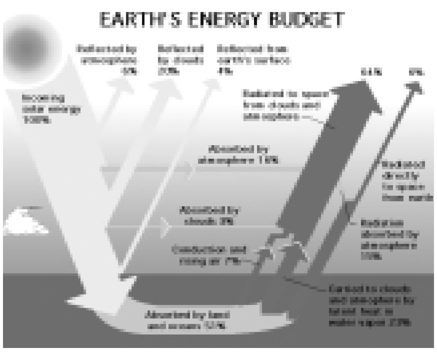
These are the Terra mission's first global snapshots of the Earth's climate system composited over a one-month period. These measurements were acquired by NASA's Clouds and the Earth's Radiant Energy System (CERES) sensors during March 2000.

CERES measures the balance of solar energy received by the Earth and the energy reflected and emitted back into space. Understanding the energy coming into and out of the Earth system is critical for assessing whether scientists' models of global climate change are making accurate predictions. This pair of images is the Terra mission's first in what will be an ongoing series of such measurements of our planet's changing climate system.

The top image shows shortwave radiation (sunlight) that is reflected back into space by our planet, averaged over the entire month. The white and tan pixels show where the Earth reflected more sunlight back into space during that month, either due to reflection by bright land surfaces such as deserts, or because of the presence of clouds. Green and bluish pixels show where less sunlight was reflected. The bottom image shows longwave radiation (heat) that is emitted by the Earth back into space. Orange and red pixels show where more heat was emitted back into space, while blue and whitish pixels show where less heat is escaping. The blue, cold, regions over Brazil, south central Africa, and the Indonesian subcontinent, are due to the presence of high thick clouds in the tropical atmosphere. These same regions have enhanced shortwave reflection as a result of thick clouds, as seen in the upper image.

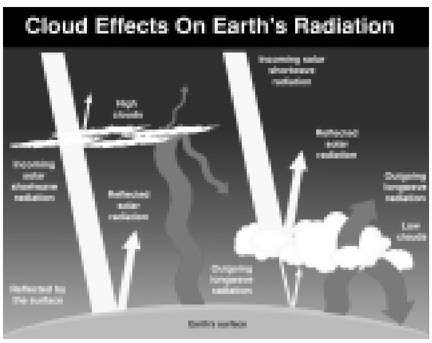
Earth's Radiation Components

The only way the Earth receives the energy that keeps the surface warm is through sunlight. Some of the incoming sunlight is reflected back up into space by the Earth's surface, atmosphere, and clouds, and some of it is absorbed and stored as heat. When the surface and atmosphere warm, they emit heat, or thermal energy, to space. The "radiation budget" is an accounting of these energy flows. If the radiation budget is in balance, then the surface of the Earth should be neither warming nor cooling, on average.



Clouds Effects on Earth's Radiation

As we all know from days at the beach, clouds block much of the solar energy and reflect it back to space before it can be absorbed by the Earth, the atmosphere, or the sunbather! The more plentiful and thicker the clouds are, the cooler the Earth. At the same time, clouds also act like greenhouse gases—they block the emission of heat to space and inhibit the ability of the planet to release its absorbed solar energy. To complicate matters further, the altitude of clouds changes the amount of thermal infrared blocking. This effect is the result of the decrease in temperature with altitude—high clouds are colder and more effective at absorbing the surface-emitted heat in the atmosphere, while they emit very little to space because of their cold temperatures! So it turns out that clouds can either act to cool or warm the planet depending on how much of the Earth they cover, how thick they are, and how high they are. Low clouds made of spherical water droplets reflect much of the sunlight that falls on them, but have little effect on the emitted energy. Thus, low clouds act to cool the current climate. High clouds made up of ice crystals reflect less energy, but trap more of the energy emitted by the surface, and thus act to warm the current climate.



About CERES

The CERES instruments, provided and managed by NASA's Langley Research Center, Hampton, Virginia, and built by TRW, Redondo Beach, California, perform measurements of the Earth's "radiation budget," the process that maintains a balance between the energy that reaches the Earth from the sun and the energy that goes from Earth back out to space. The critical components that affect the Earth's energy balance are the planet's surface, atmospheric gases, aerosols, and clouds.

For the Classroom Grade Level: 9-12

Life on Earth is supported by energy from the sun. The Earth's energy budget is a balance between energy inputs and outputs. Earth's climatic system has an important role in maintaining the balance between the energy that reaches the Earth from the sun and the energy going back into space from the Earth. Shortwave radiation received from the sun is absorbed and scattered by molecules of gases, liquids, and solids in the atmosphere, by clouds, and by the Earth's surface. Radiation that is absorbed causes the planet to heat up. Earth retransmits as much energy as it absorbs from the sun via reflection and emission. However, the heat emitted by Earth is in the form of longwave radiation, rather than the shortwave radiation that it received. The air will absorb some of the radiation emitted by Earth, while some of the energy is radiated back to Earth, and some radiated into space.

The amount of solar energy that is reflected back to space is called albedo. The average albedo of the Earth is about 0.3, meaning approximately 30% of incoming solar energy is reflected back to space.

A potentially important effect in climate change is a variation in the solar irradiance reaching Earth. Scientists monitor solar variability and use mathematical representations of the Earth system—called models—to understand how changes in solar irradiance could affect climate. For example, an increase or decrease in global cloud cover could increase or decrease Earth's albedo, which would increase or decrease the amount of solar radiation reaching Earth.

Earth's energy balance is described by the following equation:

$$\frac{S}{4}(1-A) = \varepsilon\sigma T_e^4$$

S = solar "constant" = 1370 $W/m^2/K^4$
A = albedo
$\sigma = 5.67 \times 10^{-8}\ W/m^2 K^4$ (Stefan-Boltzman Constant)
T_e = Earth's temperature in Kelvins
ε = atmospheric constant (greenhouse effect)

Activity

Objective: To use knowledge of the Stefan-Boltzmann Law and constant, and the Inverse Square Law to manipulate the Energy Balance Equation.

Prerequisite Skills: Knowledge of the Stefan-Boltzmann Law, Stefan-Boltzmann constant, the Inverse Square Law, the Energy Balance Equation, Kelvin temperature scale, and the atmospheric greenhouse effect.

Materials: scientific calculator

Background: The Earth constantly receives tremendous amounts of solar energy. In spite of that fact, the Earth maintains a fairly consistent average temperature. To achieve this equilibrium, the Earth must be emitting as much energy as it receives from the sun. This heat "balance" can be described by the primitive energy balance equation: $\frac{S}{4}(1-A) = \sigma T_e^4$

Exercise 1: A key factor in the energy balance equation is missing. Prove that something is missing and how you know your proof is correct. (hint - the average temperature of Earth is 288K.)

We know that the primitive energy balance equation does have something missing. This something is the greenhouse effect. The greenhouse effect is included in the improved energy balance equation and is represented by the Greek letter ε (epsilon).

Exercise 2: Calculate the value for ε using the primitive energy balance equation. Show ALL work. The improved energy balance equation can now be written as: $\frac{S}{4}(1-A) = \varepsilon\sigma T_e^4$

Exercise 3: Use the improved energy balance equation to make a list of factors that might influence climate change including factors that will produce colder, as well as warmer climates. Describe how each of these factors could influence climate change.

Exercise 4: Use the improved energy balance equation to calculate the temperature of our planet if the following occurred:

a. the Earth-sun distance doubled (remember the inverse square law)
b. the Earth-sun distance halved (remember the inverse square law)
c. solar luminosity decreased by 1%
d. solar luminosity increased by 1%
e. the greenhouse effect was doubled (be careful with the number you choose)

Be sure to show ALL work for each of the problems.

Exercise 5: Summarize in your own words, exactly what the greenhouse effect is and how it affects the temperature of the Earth.

Resources

Terra Website: http://terra.nasa.gov

NASA's Earth Observatory – Earth's Energy Balance
http://earthobservatory.nasa.gov/Library/Oven

Note to teachers: Answers to these exercises can be found online at http://www.strategies.org/LESSON8.html

Activity courtesy of the Institute for Global Environmental Strategies http://www.strategies.org

Image Credit: CERES Instrument Team, NASA Langley Research Center, Hampton, Virginia.