

# How do clouds keep the earth warmer?



## Overview

You know it's true: If there isn't a cloud in the sky, the air temperature will drop much more over night than if you can't make out the stars.

Why? It's all about radiation...

## Theory

All objects radiate electromagnetic waves. And increasing an object's temperature increases the total amount of energy radiated; hot objects "glow" more brightly.

Increasing the temperature also decreases the peak wavelength of the emitted radiation. The sun gives off visible light. You are cooler than the sun, so although you do emit electromagnetic energy as well, you do so at a longer wavelength, in the far infrared region of the spectrum.

The sun, of course, glows much more brightly than you. But you are still pretty bright! The amount of energy you emit might come as a bit of a surprise. Here's a remarkable fact: An unclothed human will *emit* a significant amount of electromagnetic energy — about 850 W. Your body's basal metabolic rate is only about 150 W, so something else must be going on. If this was all there was to the story, you'd be losing 700 W more than you generate, so you'd cool off and die.

But there is a piece we left out: The radiated energy that your body absorbs from the environment. An unclothed human in a room at about 20°C will *absorb* about 750 W of thermal energy that is emitted by the walls, floor and ceiling of the room. The net loss of energy is only 100 W—enough that you will feel chilly, but not so much that you will develop hypothermia.

If the walls of the room you are in are cold, you will radiate just as much, but you will get less back. If the walls are warm, you will get more back. The temperature of the walls, ceiling and floor in a room are every bit as important to your comfort as the temperature of the air.

Now, let's look at the earth. The only way the earth can gain or lose energy is by radiation. During the day, sunlight warms the earth. At night, the earth radiates far infrared electromagnetic radiation — a lot of it — to space, thereby cooling itself. Think about this: The earth, as a whole, stays at about the same temperature from day to day. This means it must be radiating as much energy to space as it receives from the sun. If your eyes were tuned to far infrared wavelengths and you looked at the earth from space, it would be really bright!

This emitted infrared carries away energy. But the earth's atmosphere isn't particularly transparent to infrared radiation, so the earth doesn't cool off so much; it ends up being a bit warmer than it would be with no atmosphere. If the earth had no atmosphere, the it would radiate enough energy to cool off to an average temperature of -18°C. But we do have an atmosphere — critically, one that blocks infrared radiation. This keeps the earth's temperature at (on average) a much more pleasant 15°C.

This warming is called the greenhouse effect, and it is, undoubtedly, A Good Thing. But as human activities, particularly combustion of fossil fuels, continue to increase the proportion of infrared-blocking gases in the atmosphere, the earth is

warming up further. This change could prove quite catastrophic for life as we know it — it is most definitely Not A Good Thing.

On a small scale, clouds behave similarly to these gases. Clouds (since they are made of water vapor) absorb thermal radiation quite strongly, so they will intercept some of the energy radiating to space from the earth. The cloud will eventually re-radiate this energy. The emitted thermal radiation could be directed up to space, or it could be directed back down to earth; the direction of emission is random. Clouds thus do not act like a blanket “trapping” thermal radiation, but they do decrease the net emission of thermal energy to space by the earth. In terms of our earlier discussion, adding clouds to the sky is effectively like increasing the temperature of the walls — the earth radiates the same amount of energy on cloudy nights as on clear, but it gets more back on cloudy nights. You perhaps have noticed that, in a given season, cloudy nights are typically warmer than clear ones — this is why!

## Doing the experiment

Before we begin, an important note: When you point a thermal radiation sensor (“infrared thermometer”) at an object, the device measures the amount of thermal radiation emitted by the object, and makes an assumption about how effectively the object emits thermal radiation to compute a temperature based on the measured thermal radiation. Most things emit thermal radiation quite well, but some things don’t. Because better emitters are much more common than worse ones, the thermal radiation sensor always assumes that it’s receiving thermal radiation from a good emitter when it calculates a temperature. However, this means that the temperature the sensor reports isn’t always accurate... (This is why we prefer the term “thermal radiation sensor” to “infrared thermometer.”)

★ **SAFETY NOTE: The thermal radiation sensors we use have lasers on them. The usual precautions regarding lasers in the eyes should be followed.**

★ **EQUIPMENT SAFETY NOTE: The instruments should not be pointed at the sun! This will destroy them.**

Here are some things you can try:

- Point the thermal radiation sensor at your hand and pull the trigger. You will measure your hand’s temperature as calculated based on the thermal radiation it emits. Try measuring the temperatures of other things.
- Now, put a piece of glass between your hand and the thermal radiation sensor. Can the sensor measure your hand’s temperature through the glass? Nope. Glass is opaque to thermal radiation.
- Try other things between your hand and the sensor. What things absorb thermal radiation? What things transmit it?
- Can you find surfaces from which thermal radiation reflects? How would you measure this?
- Now, go outside and point the sensor at the sky. The sensor will dutifully report a temperature, and it will be a temperature that is much lower than the air temperature. Nitrogen and oxygen are very poor emitters of thermal radiation; the thermal radiation that the sensor detects was emitted by the greenhouse gases present in the atmosphere, mostly water and carbon dioxide. These are a small percentage of the overall atmosphere, so the total radiated thermal energy is very small, which the sensor interprets as a low temperature. It’s not that the air above you is this cold, it’s that it’s a poor radiator (and absorber) of thermal energy.
- Now, point the sensor at a cloud. You will see a much higher temperature, *even though the cloud is actually at almost precisely the same temperature as the sky around it.* The cloud is a much better emitter of thermal radiation than the

### Necessary materials:

- thermal radiation sensor (“infrared thermometer”)
- sheets of plastic, glass, etc.

The crucial piece is the thermal radiation sensor. You need one that can measure very cold temperatures, and which has a reasonably narrow field of view. Such devices can be found at [www.harborfreight.com](http://www.harborfreight.com) under “non-contact pocket thermometer.”

sky. In fact, the cloud is rather close to matching the sensor's assumption, while the sky is a far worse emitter than the sensor assumes. If you are underneath a cloud at night, you will get more thermal radiation back, and cool down less.

After some experimenting, your students should be ready to answer the central question of this exercise:

*How do the observations show us that clouds keep the earth cooler during the day and warmer at night?*

## **Summing up**

When the night sky is cloudy, it's emitting a good deal of thermal radiation. When the night sky is clear, it's not. The radiation from the clouds — let's call it cloudshine, what say — will keep the earth warmer. It's not that the clouds insulate the earth, it's that they radiate energy to keep it warm. That's why it gets colder on clear nights than cloudy — no cloudshine!

Now, consider: What will happen as we add more carbon dioxide to the atmosphere? Carbon dioxide is an effective radiator, so we'll get more energy radiated from the sky — let's call it skyshine. More skyshine means more warming during the day and less cooling at night. That's the crux of the climate change biscuit!

## **For more information**

Colorado State University College of Natural Sciences: <http://www.natsci.colostate.edu>

Little Shop of Physics: <http://littleshop.physics.colostate.edu>