

AEROSPACE MICRO-LESSON

Easily digestible Aerospace Principles revealed for K-12 Students and Educators. These lessons will be sent on a bi-weekly basis and allow grade-level focused learning. - AIAA STEM K-12 Committee.

SENSING WEATHER FROM A DISTANCE

The Space Age revolutionized the science of weather forecasting. Before satellites started orbiting the Earth and sending photographs back, meteorologists had to rely on reports from individual weather stations spread irregularly across the continents, supplemented by ship and buoy reports from the oceans. With the Space Age, though, meteorologists are able to see wide swaths of the Earth all at once, giving them a much broader view. Satellites can also gather weather data over the open ocean, removing what was once a major blind spot in weather science.

Next Generation Science Standards (NGSS):

- * Discipline: Physical Science.
- * Crosscutting Concept: Energy and matter: Flows, cycles, and conservation.
- * Science & Engineering Practice: Constructing explanations.

GRADES K-2

NGSS: Earth's Systems: [Use and share observations of local weather conditions to describe patterns over time.](#)

The weather is the state of Earth's atmosphere (the air and clouds on our planet) at any given time and place. It may be hot or cold, clear or cloudy, wet or dry, calm or windy. Knowing what the weather is going to be like later in the day or later in the week is really important; not only does bad weather keep us indoors, it can stop airplanes from flying, it can make it hard for cars to drive, and many other things as well. So how do we predict what the weather is going to do?

Scientists called *meteorologists* use a variety of instruments to measure the different aspects of the weather. An anemometer measures the speed of the wind; a weather vane shows the wind direction. A barometer measures the air pressure, a thermometer measures the air temperature, and a hygrometer measures the amount of water vapor present in the air. Finally, a rain gauge measures how much rain has fallen recently. [We call a group of all these instruments in one place a "weather station."](#) A weather station is great for studying weather nearby, but a lot of weather – like storms, clouds, or wind – is spread out over many towns or states. How can we study big storms and other weather patterns that are far away from our weather station?

GRADES K-2 (CONTINUED)

Before people launched satellites into space, weather forecasters had to rely on reports from a network of weather stations scattered around the country. This network had large gaps, especially in desert or mountainous areas where not many people lived and over oceans. Weather forecasters filled in the gaps with estimates and did the best they could.

Starting around sixty years ago, scientists started launching satellites into space. These satellites carried cameras and other scientific instruments which let them study the Earth. With these satellites, weather forecasters and meteorologists could see the whole world at once. While these photographs did not capture all the details of what was happening on Earth, they did show how clouds were moving, which told scientists how winds were blowing and made weather forecasts much more accurate.

Suggested Activity: To illustrate the advantage that a satellite has over a set of local weather stations, find a good-sized picture of something (say, two feet by three feet) and cover it completely with blank sticky notes. (The picture should not be too big; a two-foot-by-three-foot picture will take almost 150 two-and-a-half-inch-square sticky notes to cover it.) Ask the children if they know what the picture is. Have the students remove sticky notes one at a time (randomly from different parts of the picture, if you can), and have each student describe what he or she sees in the square which has just been uncovered. Trying to guess what the picture shows from a small observable square is like predicting large weather systems using data from weather stations. After this point has been made, remove a large block of the sticky notes to simulate a satellite taking a picture, and demonstrate how much easier to see what is in a picture when you can see big swaths of it at once rather than just selected bits of it.

GRADES 3-5

NGSS: Waves and Their Applications in Technologies for Information Transfer: [Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.](#)

Weather satellites make their measurements by taking pictures of parts of the earth in many different colors. The term “color” means more here than the usual definition; “color” is just a way of describing what kind of light an object is emitting. We are most familiar with the colors of the rainbow, since those are the ones which we can see with our eyes, but

GRADES 3-5 (CONTINUED)

there are “colors” (types of light) that the human eye cannot see. You might be familiar with at least one of them: ultraviolet (UV) light. UV light is invisible to the human eye but we can see its effects on things around us, such as sunburn on our skin. Ultraviolet light is just that – “ultra violet,” i.e. it is light that lies past the end of the rainbow, beyond the indigo and violet colors you are familiar with. Scientists call the rainbow of colors the *electromagnetic spectrum*. It includes not only the visible colors, but invisible colors like ultraviolet light as well. The electromagnetic spectrum organizes light by how much energy it carries (i.e. how “powerful” it is). Violet light is the most energetic form of visible light, so ultraviolet light has more energy than any of the light we can see.

If violet is the most energetic color on the spectrum, what is the least energetic? If you think of the colors of the rainbow, the answer should be red. However, beyond red is another type of “invisible” light called *infrared*.

The first person to discover infrared light was a famous scientist named [William Herschel, who measured the temperatures in the different colors of the rainbow](#). He found that as he moved his thermometer from violet down to red it got warmer, and below the red band it got warmer still – this was the first recorded observation of infrared light! It may seem strange that the lower-energy red and infrared light were warmer, but this has to do with the physics of the prism Herschel used to create his rainbow, which concentrated these colors more. A year later, ultraviolet light was discovered by another scientist (named Johann Ritter).

Today, weather scientists use different kinds of light to study our planet. Different substances absorb and reflect light of different colors; in particular, water vapor absorbs most infrared light, but allows other “colors” to pass through. Other substances absorb other colors of light. Weather satellites measure the visible, infrared, and ultraviolet light [coming from different parts of the Earth](#). Scientists can then figure out how hot an area of the Earth is by comparing how much of each type of light they see; if a part of the Earth looks dark, scientists conclude that it is not reflecting much light, so it must be absorbing it instead, making it warmer. In this way, scientists can figure out what the temperature is in that area and how much water vapor is in the air there.

Suggested Activity: Repeat William Herschel’s experiments with the spectrum and infrared light. Shine a beam of sunlight through a prism onto a piece of paper or an opposite wall and point out the colors. Hold a thermometer in each band of color and then just outside the red band. Or, set up several thermometers and compare them simultaneously.

GRADES 6-8

NGSS: Waves and their Applications in Technologies for Information Transfer: [Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.](#)

Weather satellites can be used for a variety of important purposes. As you can read in the above sections, satellites can take wide-ranging measurements of the Earth's temperature and use them to estimate what the atmosphere is made up of. However, scientists can also use satellites to pinpoint very specific things, such as forest fires, glaciers, and even objects as small (relatively speaking) as ships at sea. Maybe this seems strange – after all, weather satellites often orbit the Earth at over 700 kilometers (roughly 500 miles) away. That would be a little bit like standing in Washington, D.C. and being able to see the skyscrapers in New York City. So how do satellites see that far? Simple! They use telescopes to observe things on Earth more closely.

However, even telescopes have limits. In particular, the *resolving power* of a telescope is the smallest angle between two objects at which the telescope can distinguish that there are two objects rather than seeing just a single blur. Once a telescope has reached the limit of its resolving power, there is no use in increasing the magnification of the image; one will only see a larger blur with no more details visible. Better optics will not help; this limitation is caused by the nature of light and the size of the telescope. Given good optics, the resolving power of a telescope depends on the diameter of the objective lens (or mirror for a reflecting telescope). The larger the diameter of this lens, the closer together two objects can be before the telescope sees them as a single blur.

Satellites capable of making these detailed observations of Earth are incredibly important for scientists. The reason is that they make it possible to study huge areas of the planet at once, which would otherwise be impossible. For example, [some scientists are using satellites to study how glaciers move across the planet.](#) Most of these glaciers are in remote parts of the world (like Alaska and northern Canada), where the weather and remoteness make it very difficult to conduct scientific studies. In addition, looking at glaciers from space is one of the best ways to study them; it's a lot easier to see how they are moving by looking at the whole glacier than it is by studying them piece-by-piece on the ground.

GRADES 6-8 (CONTINUED)

Other scientists use satellites to [observe Earth's forests](#), studying how plants are growing and how forests are growing and shrinking with forest fires, droughts, and human development. Special satellites can estimate the amount of chlorophyll in a given region of the planet to measure how healthy the plants there are – all from hundreds of miles away! Data from these satellites helps predict where forest fires are likely to break out, what parts of the world are in drought, and much more besides. Even though the satellites are quite far away from our planet, scientists on the ground can use them to help make life easier, better, and safer for people on Earth by improving our understanding of the complicated planet that we live on.

GRADES 9-12

NGSS: Waves and their Applications in Technologies for Information Transfer: [Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.](#)

A body that absorbs all radiation that falls on it is called a “blackbody.” (This has no relation to a black hole, which is an extremely massive object out in space.) Although normal objects absorb some wavelengths (colors) of light and reflect others, a blackbody shows no preference for one color over another. Reflected radiation is what allows people to see objects (the wavelength of the reflected radiation gives the object its color) so in theory a blackbody would appear perfectly, absolutely black (hence the name “blackbody”).

A blackbody also radiates energy. The total amount of energy that a blackbody radiates, which is the sum of the radiated energies at all the wavelengths, depends only on the body's temperature. The variation of the amount of energy radiated by an object with the wavelength of the radiation is called its “spectrum.”

As you might imagine, actual blackbodies don't exist in the real world (although it is possible to simulate them in some ways). Real objects have color; this means that the wavelengths at which they absorb and emit radiation differs from the blackbody spectrum. The color of an object can fall within our familiar visible light spectrum (which ranges from red to violet), but it can also extend into the infrared or the ultraviolet.

GRADES 9-12 (CONTINUED)

Since everything absorbs and reflects some light, everything has a “color” – even the atmosphere around us. The absorptivity of water vapor and carbon dioxide gas in our atmosphere form the basis of the greenhouse effect, which keeps the Earth warmer than it would be without them. The two gases absorb infrared radiation but not visible light. The visible light from the hot Sun, therefore, passes through water vapor and carbon dioxide in the atmosphere and warms the surface of the Earth. The Earth, being cooler, emits most of its radiation as infrared, which the water vapor and carbon dioxide absorb and re-emit back down to the surface of the Earth. Without the atmosphere, the temperatures on the Earth would be more like [those on the Moon](#), which range from 250 degrees above zero during the day to 240 degrees below zero (Fahrenheit) at night.

Instruments on scientific satellites photograph the Earth at several different wavelengths of light. Interpolating (filling in the gaps) between the measured wavelengths, one can calculate the total energy being reflected from the sunlight and being emitted by the Earth. This total energy, with the reflected sunlight subtracted off, gives the temperature at the given position on the Earth. The variations in the amounts of energy at the different wavelengths tell scientists which colors of light are being absorbed – using a blackbody as a reference, it is possible to calculate the amount of carbon dioxide and water vapor in the atmosphere at that position.

Converting readings of radiated energy to temperature and other information involves several different estimates and assumptions. To make sure they are doing the calculations correctly, scientists must calibrate the camera. To do this, they take readings for various parts of the Earth; they then go to the places for which the readings were taken and measure the actual temperature and other quantities. If the temperature and other things calculated from the camera’s readings match the real values, the process is accurate.

Sixty Years Ago in the Space Race:

May 1, 1957: [The American Vanguard TV-1 was launched to an altitude of 121 miles and landed 451 miles downrange.](#)