Joint Polar Satellite System
Understanding Infrared Light

This activity educates students about the electromagnetic spectrum, or different forms of light detected by Earth observing satellites. The Joint Polar Satellite System (JPSS), a collaborative effort between NOAA and NASA, detects various wavelengths of the electromagnetic spectrum including infrared light to measure the temperature of Earth's surface, oceans, and atmosphere. The data from these measurements provide the nation with accurate weather forecasts, hurricane warnings, wildfire locations, and much more! Provided is a list of materials that can be purchased to complete several learning activities, including simulating infrared light by constructing homemade infrared goggles.

Learning Objectives

Next Generation Science Standards (Grades 5–8)

Performance Expectation	*Disciplinary Core Ideas*	*Description*
4-PS4-1 Waves and Their Applications in Technologies for Information Transfer	PS4.A: Wave Properties	• Waves, which are regular patterns of motion, can be made in water by disturbing the surface. When waves move across the surface of deep water, the water goes up and down in place; there is no net motion in the direction of the wave except when the water meets a beach. (Note: This grade band endpoint was moved from K–2.) • Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks).
4-PS4-2 Waves and Their Applications in Technologies for Information Transfer	PS4.B: Electromagnetic Radiation	An object can be seen when light reflected from its surface enters the eyes.
4-PS3-2 Energy	PS3.B: Conservation of Energy and Energy Transfer	Light also transfers energy from place to place.
MS-PS1 Matter and its Interactions	PS3.A: Definitions of Energy	The term "heat" is used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. (secondary to MS-PS1-4)

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Performance Expectation	*Disciplinary Core Ideas*	*Description*
5-ESS2-1 Earth's Systems	ESS2.A: Earth Materials and Systems	Earth's major systems are the geosphere (solid and molten rock, soil, and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere (living things, including humans). These systems interact in multiple ways to affect Earth's surface materials and processes. The ocean supports a variety of ecosystems and organisms, shapes landforms, and influences climate. Winds and clouds in the atmosphere interact with the landforms to determine patterns of weather.
MS-ESS2-5 Earth's Systems	ESS2.C: The Roles of Water in Earth's Surface Processes	The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns.
	ESS2.D: Weather and Climate	Because these patterns are so complex, weather can only be predicted probabilistically.
MS-ESS2-6 Earth's Systems	ESS2.D: Weather and Climate	• Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns. • The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents.

Materials

There are several activities and videos provided throughout this manual to enhance understanding of the electromagnetic spectrum. For the first activity, all you need is a jump rope and a partner. For the second activity, you will be making your very own goggles to simulate infrared light. Infrared goggles can be made using any type of goggles with removable lenses, theater gels, a marker, scissors, and tape. You can also use a smartphone, free-downloadable infrared apps, and a virtual reality (VR) headset as well. Instructions are provided at the end of the lesson.

Vocabulary

Light: A form of energy. Electromagnetic radiation of any wavelength.

Visible Light: The colors the human eye can perceive. Energy that humans can see.

Energy: A measure of the ability to do work, such as heating an object.

Radiation: The emission of energy as electromagnetic waves.

Wavelength: A measurement for light. The distance between two crests of a wave.

Nanometers: An extremely small unit of measurement. 1 meter = 1 billion nanometers. Nanometers are used to measure wavelengths of visible light.

Visible Light Spectrum: The segment of the electromagnetic spectrum visible to the human eye. The colors humans can see.

Electromagnetic Spectrum: The range of wavelengths of all forms of electromagnetic radiation (light).

Light Speed: The universal speed limit. Approximately 186,000 miles (300,000 kilometers) per second.

Infrared Light: The form of light just “below” (or to the left of) the red end of the visible light spectrum. Light humans feel as heat.

Thermal Energy: Energy that comes from any heated object. Heat energy.

Absolute Zero: The lowest temperature theoretically possible (-459.67°F).

Micrometer: An extremely small unit of measurement. 1 micrometer = 1,000 nanometers. Micrometers are used to measure wavelengths of infrared light.

Polar Orbit: An orbit in which a satellite circles Earth by passing above the North and South Poles.

Water Cycle: The natural process through which water moves throughout Earth’s surface, oceans, and atmosphere.

Evaporation: Water changing from liquid to gas, rising from the surface to the atmosphere.

Condensation: Water changing from a gas to liquid. The process forming clouds.

Precipitation: Water falling to Earth’s surface as rain, snow, hail, etc.

Water Vapor: Water in gas form.

Atmospheric Moisture: The amount of water vapor in the atmosphere. Humidity.

Cryosphere: The frozen water within Earth’s water cycle.

Lesson

» What is Light?

» What are Light Waves?

Every day we interact with light. For example, we walk outside, see the bright yellow sun, and feel its heat. Visible light, or colors we see, are a form of energy that can be perceived by the human eye.

Scientists have discovered that light can travel in the form of particles and waves. You can imagine light waves as looking similar to ocean waves, with repeating peaks and valleys, or crests and troughs.

The Sun emits and transmits energy to Earth in the form of light waves through a process called radiation. Light waves can travel through the vacuum of space, air, solid materials, and even your body!

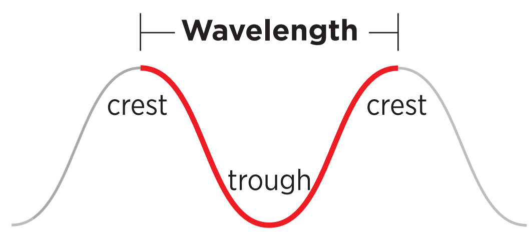
The Sun emits and transmits energy to Earth in the form of light waves through a process called radiation. Humans can see this energy and feel it as heat.

» How Do We Measure Light?

» What is Wavelength?

Light is measured using frequency, energy, or wavelength.

In any kind of wave, the distance between two crests is a wavelength. Different wavelengths help scientists identify different colors and forms of light.

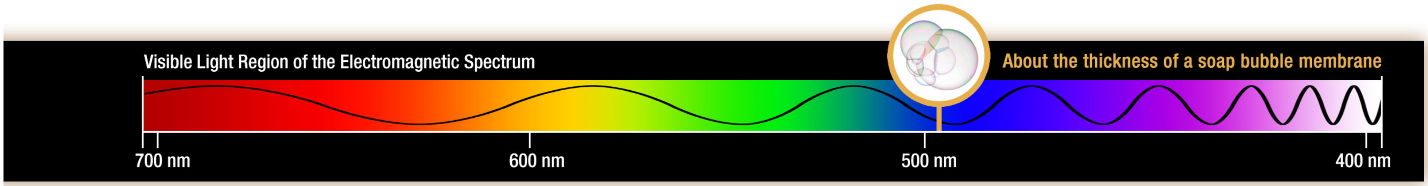


Above is an image representing a light wave of the color red. The distance between two crests is a wavelength. Visible light waves are measured using nanometers (nm). Nanometers are an extremely small unit of measurement. In fact, 1 meter = 1 billion nanometers! Red light waves range from 700–635 nanometers.

» What is the Visible Light Spectrum?

The visible light spectrum is the range of colors the human eye can perceive.

The colors in the visible light spectrum range from red to violet, or 700–380 nanometers. Similar to a car radio, the human eye is "tuned" to a specific "channel," or wavelength. The human eye is tuned to wavelengths between 700 and 380 nanometers, explaining why we can only see colors red through violet.



The colors in the visible light spectrum are organized by wavelength. For example, as we move from left to right (red to violet), wavelength gets shorter. As wavelength gets shorter, the energy the light wave carries increases.

Out of all the colors, red has the longest wavelength and the lowest energy on the visible light spectrum. In contrast, violet has the shortest wavelength and the highest energy on the visible light spectrum.

Diagram of the visible light spectrum.

Image: www.science.nasa.gov/ems/09_visiblelight

Try this with a friend

(1) Grab a jump rope.
(2) Have each person grab one end of the jump rope.
(3) Have one person slowly pull up and down on their end of the rope to form a wave similar to the bottom picture.
(4) Repeat step (3) but faster.
(5) Repeat steps (3) – (4) with the other person.

What did you notice?
It requires more energy to make a shorter wavelength. This applies to light waves. Light with a short wavelength contains more energy than a long wavelength.

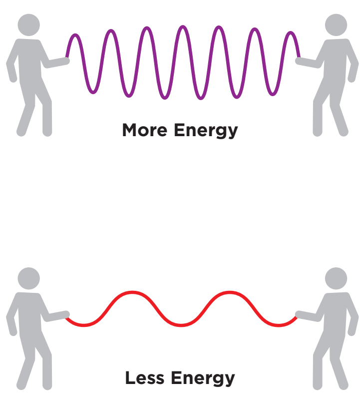


Image: www.science.nasa.gov/ems/02_anatomy

Learn more about light waves
www.science.nasa.gov/ems/02_anatomy

» What is the Electromagnetic Spectrum?

Scientists describe all forms of light as electromagnetic radiation. In fact, all light waves are electric fields and magnetic fields coupled together.

Therefore, the electromagnetic spectrum is the range of wavelengths of all forms of light, visible and invisible.

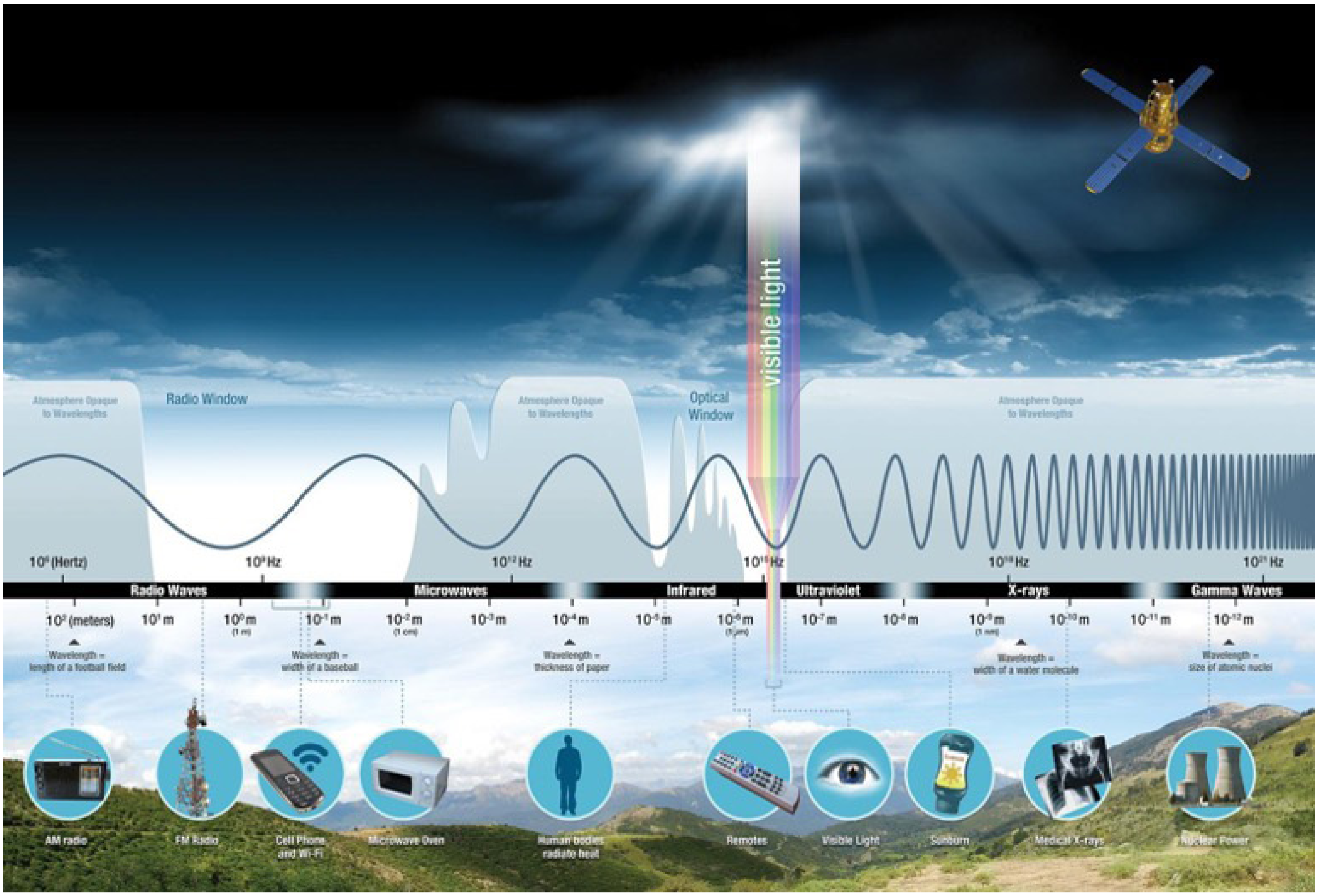


Diagram of the entire electromagnetic spectrum.

Image: www.science.nasa.gov/ems/01_intro

» What is the Electromagnetic Spectrum? *(Continued)*

Question:

Can you name any of the other forms of invisible light on the electromagnetic spectrum?

Answer:

Including visible light, there are a total of seven forms of light on the electromagnetic spectrum. From left to right, the invisible forms of light include radio waves, microwaves, infrared, ultraviolet, x-rays, and gamma waves. Some of these invisible forms of light may be familiar, as we use them on a daily basis.

- Radio waves are used to communicate with radio, TV, and cell phones.
- Microwaves are used to heat up food.
- Infrared light waves are used by remote controls to change the channel on your TV.
- Ultraviolet light can give you a summer tan, or sunburn.
- X-rays are used by doctors to take pictures of your bones.
- Gamma waves are emitted from high energy lightning strikes.
- The electromagnetic spectrum is also organized by wavelength. Radio waves have the longest wavelength and lowest energy. Radio waves can be larger than the diameter of Earth!
- Gamma waves have the shortest wavelength and highest energy. Gamma waves are smaller than an atomic nucleus! Gamma waves are so small that scientists measure them by the energy they produce instead of wavelength.

Question:

How fast does light travel? What is "light speed?"

Answer:

The speed of light in a vacuum travels at approximately 186,000 miles (300,000 kilometers) per second. Light travels fast enough to circumnavigate the Earth's equator approximately 7.5 times in one second!

Light speed is like a universal speed limit. Nothing can travel faster than light.

Learn more about the electromagnetic spectrum
www.science.nasa.gov/ems/01_intro

» What is Infrared Radiation / Infrared Light?

"Infra" means "below," so infrared is the form of light just "below" (or to the left of) the red end of the visible light spectrum.

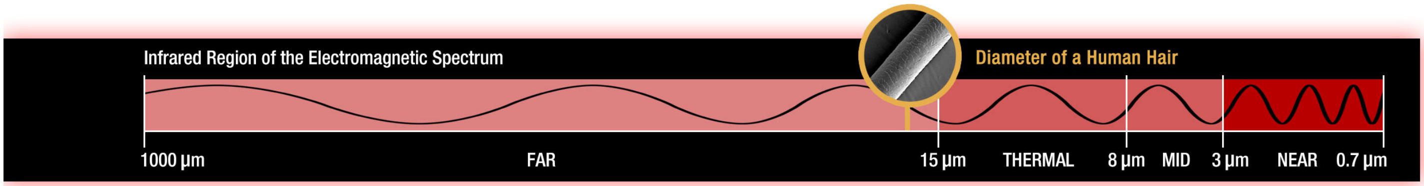


Image of the infrared region of the electromagnetic spectrum. Infrared waves are longer than visible light waves, meaning they have less energy. Infrared waves range from 1000 – 0.7 micrometers (µm).
1 micrometer = 1,000 nanometers.

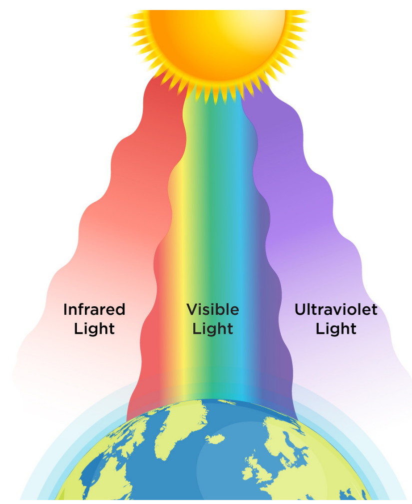
Image: www.science.nasa.gov/ems/07_infraredwaves

We cannot see infrared light, but we interact with this form of energy when we feel it as heat.

For example, the total light reaching Earth's surface from the Sun is 49.4% infrared light, 42.3% visible light, and 8% ultraviolet light. We can see the Sun is yellow or orange in the sky as visible light and feel the Sun's warmth as infrared light.

The warmth we feel from the Sun's infrared light is called thermal energy. Thermal energy (or heat energy) is the energy that comes from any heated object.

All objects in the universe with a temperature above absolute zero radiate thermal energy, even an ice cube. Thermal energy radiates in the form of infrared energy.

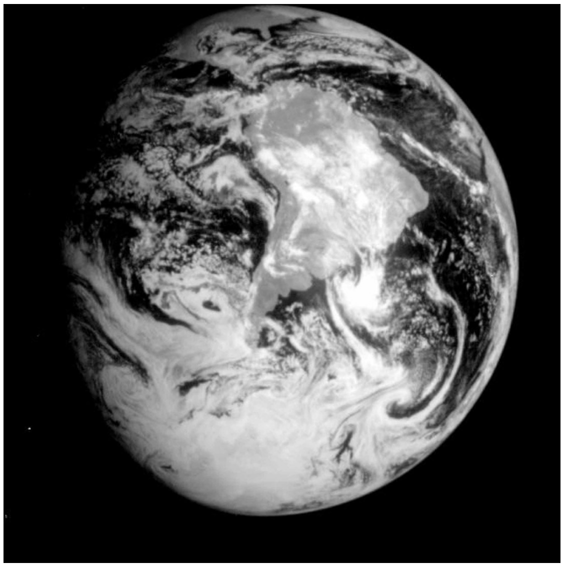


The Sun emits all forms of electromagnetic energy, but only infrared light, visible light, and ultraviolet light reach Earth's surface.

The Joint Polar Satellite System

Even the Earth radiates thermal energy. The temperature, or thermal energy radiating from Earth's surface, oceans, and atmosphere is constantly changing. These temperature changes influence Earth's weather and climate.

Scientists use infrared sensors on Earth observing satellites such as the Joint Polar Satellite System (JPSS) to understand where, when, and why Earth's temperature changes and how it affects the weather.



The Earth also radiates thermal energy as infrared light. This near-infrared photograph of the Earth was taken by the Galileo spacecraft at 6:07 a.m. PST on Dec. 11, 1990, at a range of about 1.32 million miles. The camera used light with a wavelength of 1 micrometer, which easily penetrates atmospheric hazes and enhances the brightness of land surfaces.

Image: www.jpl.nasa.gov/spaceimages/details.php?id=PIA00226

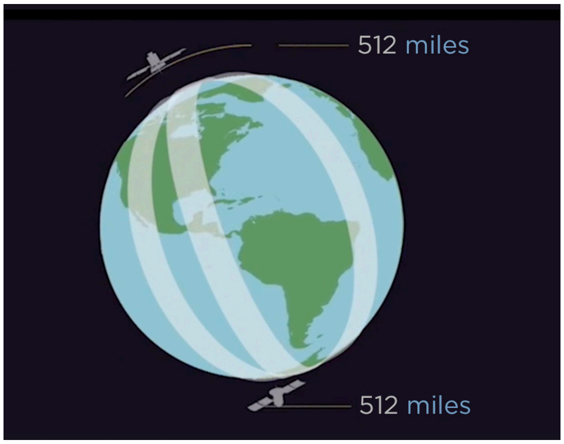
How Does JPSS Measure Earth's Temperature?

First, JPSS uses a polar orbit. In a polar orbit, a satellite circles the Earth by passing above the North and South Poles. While JPSS orbits the poles, Earth spins underneath, allowing JPSS to observe the entire Earth twice in one day.

Second, JPSS uses scientific instruments to observe Earth's thermal energy. Two of these scientific instruments detect infrared wavelengths to monitor Earth's changing temperatures.

These two instruments are the Visible Infrared Imaging and Radiometer Suite (VIIRS) and the Cross-track Infrared Sounder (CrIS).

VIIRS uses visible and infrared wavelengths from 412 nanometers to 12 micrometers. CrIS uses infrared wavelengths from 3.92 to 15.38 micrometers.



The picture above shows Suomi NPP and NOAA-20, the two satellites in the Joint Polar Satellite System in their polar orbit. Each satellite is approximately 512 miles above Earth's surface, traveling at approximately 17,000 miles per hour. At this speed, JPSS completes 14 polar orbits in one day, covering the entire Earth twice a day.

Image: www.nesdis.noaa.gov/content/jpss-joint-polar-satellite-system-overview

Learn more about infrared waves
www.science.nasa.gov/ems/07_infraredwaves

Water, Temperature, and Weather Activity

Understanding past, present, and future weather patterns is one of the primary missions of JPSS. In order to forecast the weather, scientists must understand the movement of water throughout Earth's surface, oceans, and atmosphere. Scientists call this global process the water cycle.

Depending on its temperature, water can be a solid, liquid, or gas. The infrared instruments aboard JPSS detect water in its different phases by measuring its temperature.

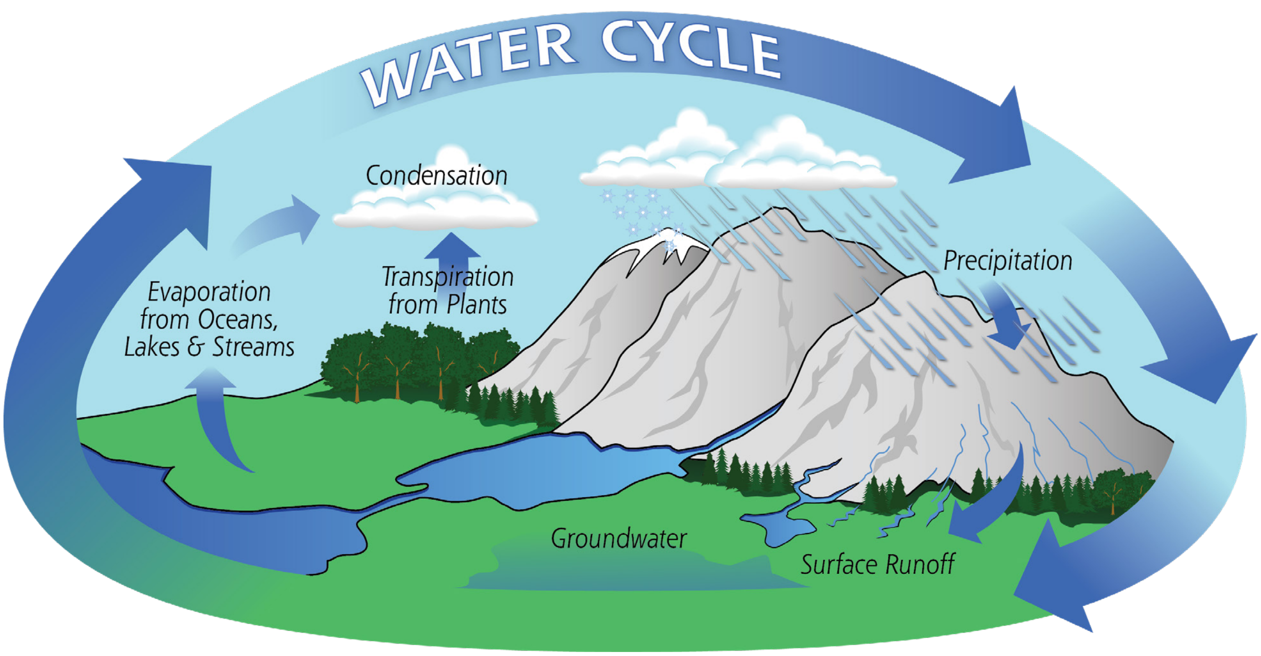
VIIRS and CrIS work together to monitor the thermal energy of water radiating as infrared energy, specifically in the oceans and atmosphere.

Forecasting a Hurricane

Hurricanes are a natural, but dangerous process of the water cycle.

In order to monitor, track and provide early storm warnings for a developing hurricane, scientists need weather data. This weather data includes temperature, water vapor (water in gas form), and atmospheric moisture (humidity).

Using multiple infrared wavelengths, VIIRS and CrIS monitor and measure all three.



The water cycle influences daily weather. For example, liquid water evaporates from the ocean, rises into the atmosphere as water vapor, condenses back into liquid water droplets to form clouds, and precipitates as rain. Water has been circulating the Earth for billions of years! By measuring the temperature of water from space, JPSS provides scientist with enough data to predict the weather 3–5 days in advance.

Image: pmm.nasa.gov/education/sites/default/files/article_images/Water-Cycle-Art2A.png

How Do VIIRS and CrIS Use Infrared to Monitor Hurricane Formation?

Sea Surface Temperature (SST): Hurricane formation begins near the equator, or tropical regions where the ocean water is at least 80°F. VIIRS measures SST and can see exactly where the ocean water is 80°F. SST measurements are also used to forecast hurricane trajectory and intensity.

As wind blows over the sea surface, the warm ocean water evaporates into water vapor and rises into the atmosphere. The hurricane that forms will use this warm, moist air as fuel.

Atmospheric Vertical Moisture Profile (AVMP): CrIS measures the water vapor and atmospheric moisture as it rises to different altitudes of Earth's atmosphere. AVMP is used to determine the stability of the atmosphere. If the atmosphere becomes unstable (such as during a thunderstorm or tropical depression), a hurricane can form.

Cloud Top Temperature: The water vapor then cools, and condenses into billions of tiny water droplets, forming a large cumulonimbus cloud (a thunderstorm cloud).

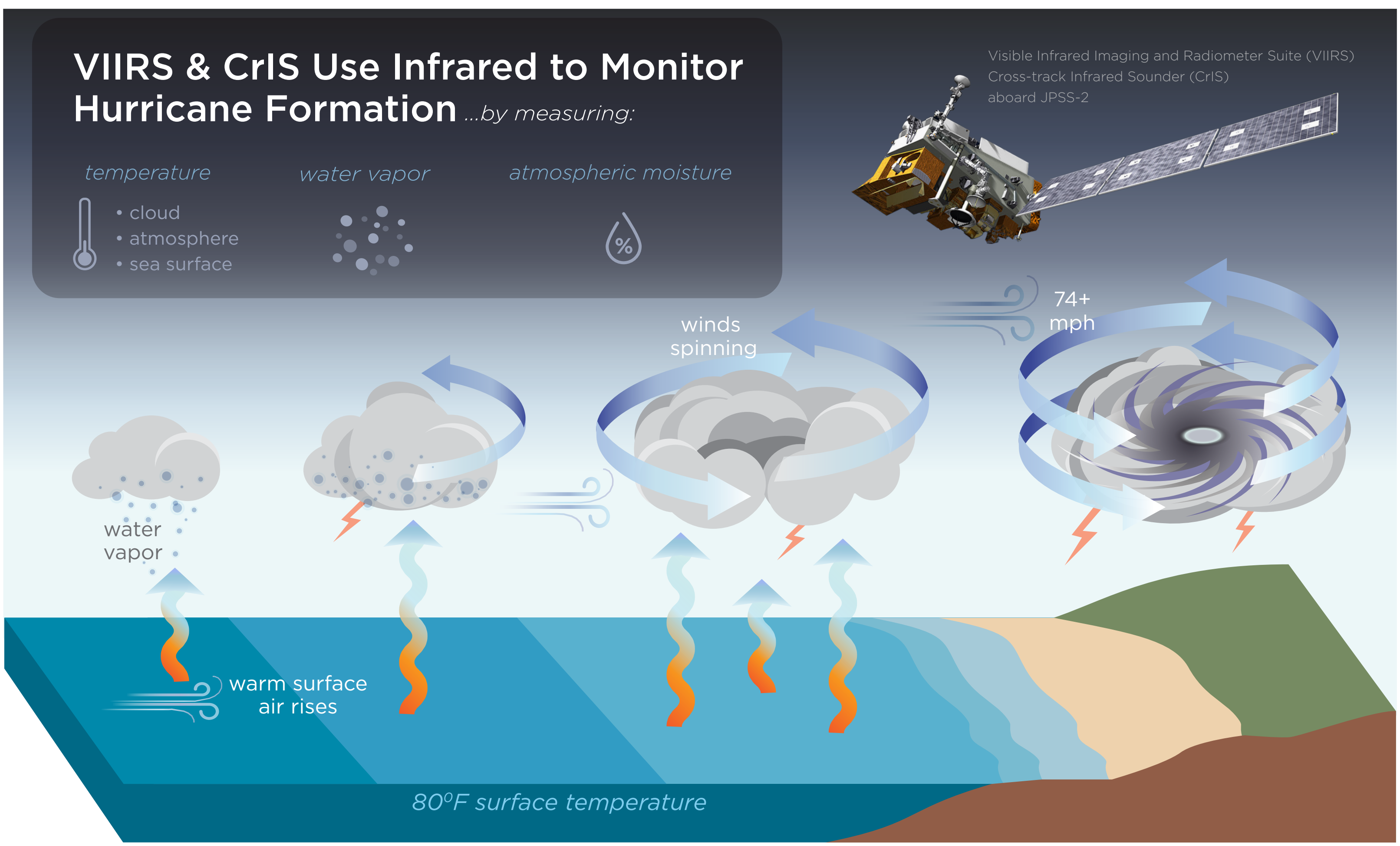
Atmospheric Vertical Temperature Profile (AVTP): CrIS calculates the temperatures at different altitudes of Earth's atmosphere. AVTP is used to predict thunderstorms, cloud cover, winds, and severe weather events.

Category 1 Hurricane: As the wind intensifies, it blows a cluster of thunderstorm clouds together, which begin circling around an eye. When the wind speeds reach 74 miles per hour (mph), the storm is officially a hurricane.

Monitoring the Hurricane: VIIRS and CrIS continue to monitor the temperature, water vapor, and atmospheric moisture as the hurricane intensifies, moves across the ocean and towards land.

Tracking and Forecasting the Hurricane: Meanwhile, JPSS sends this data to a ground station as it completes each polar orbit. Scientists use the infrared data from VIIRS and CrIS to track the hurricane and forecast where it will make landfall. This forecast provides citizens in the hurricane's path with an early storm warning so they can safely evacuate the area.

i Learn more about hurricane formation
www.scijinks.gov/hurricane/



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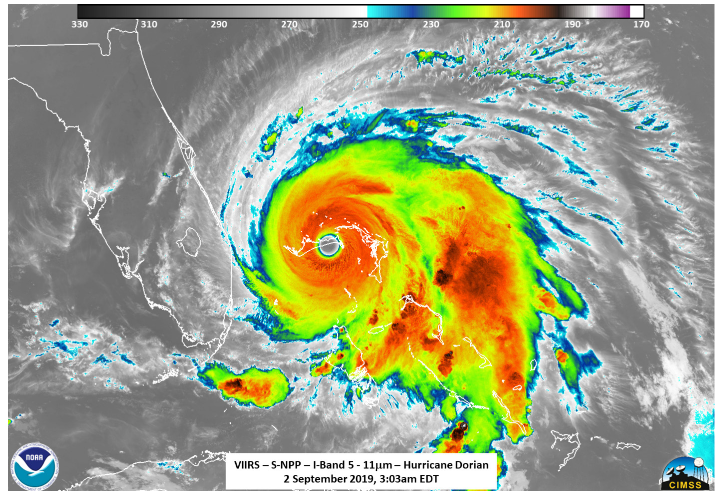
How Do We Visualize Invisible Light from JPSS? What is a False Color Image?

The human eye cannot perceive the infrared light detected by VIIRS and CrIS.

In order to visualize data in wavelengths beyond the visible light spectrum, scientists use false color images. A false color image can reveal data or patterns in Earth's weather systems that would normally be invisible, such as temperature, cloud intensity, air pressure, and wind speeds.

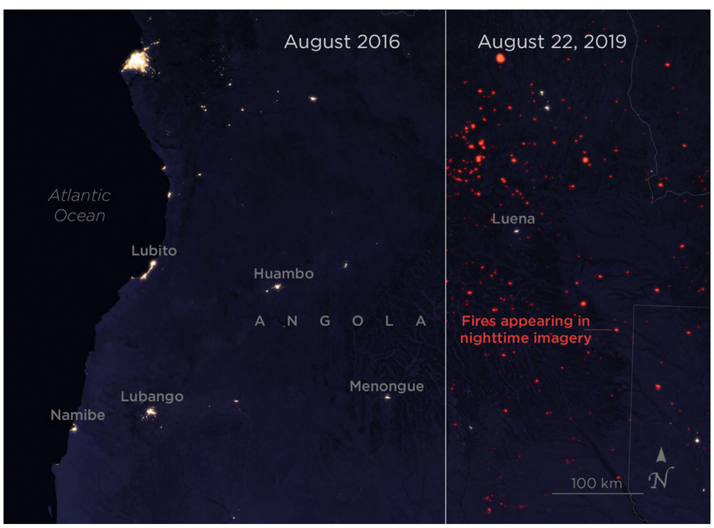
The false color images below show the other scientific uses of the infrared instruments aboard JPSS.



The VIIRS instrument aboard Suomi NPP shows a detailed view of Hurricane Dorian as it moves over the Bahamas on September 2, 2019. Scientists add "false color" to represent the different temperatures at the very top of the clouds. The key on top of this image shows blue is warmest, red is cooler, and black is the coldest. Colder clouds are deeper and have a greater intensity. The key on the bottom of this image shows it was taken at wavelength of 11 micrometers in the infrared spectrum.

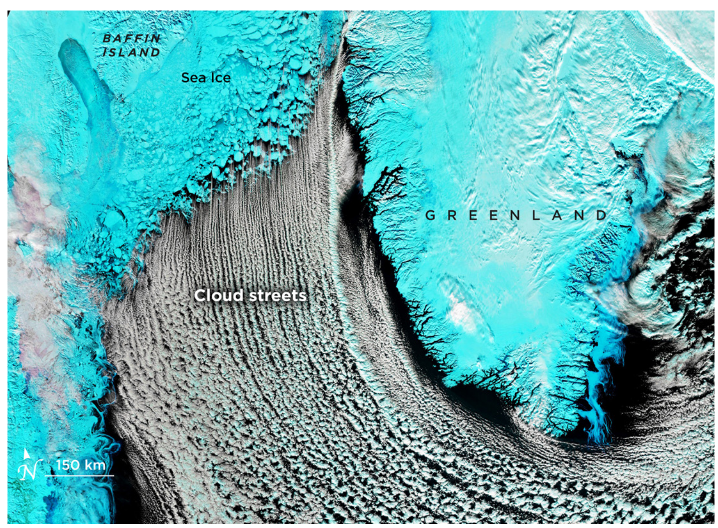
Image: www.nesdis.noaa.gov/content/guide-understanding-satellite-images-hurricanes

William Straka – Space Science and Engineering Center – University of Wisconsin, Madison



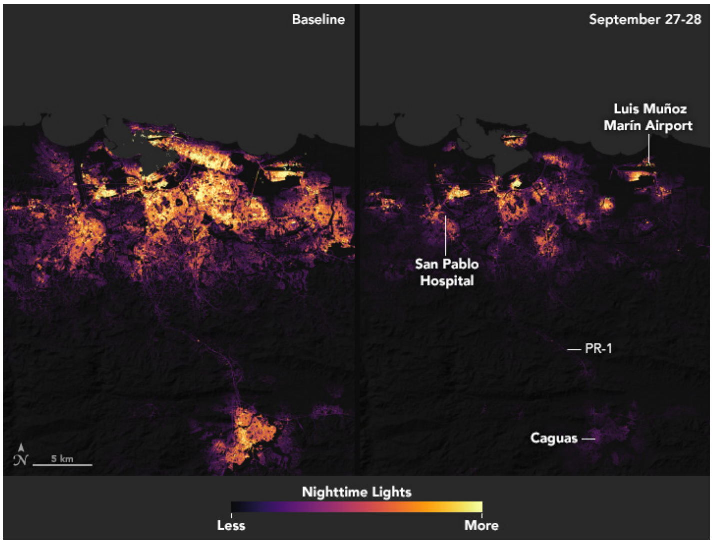
Smoke & Wildfires: VIIRS can detect the infrared radiation (heat released) from wildfires on Earth's surface. The VIIRS "day-night band" captured this image of fire detections over Angola on August 22, 2019. The "day-night band" detects light signals in a range of wavelengths from green to near-infrared, and uses filtering techniques to observe signals such as city lights, auroras, wildfires, and reflected moonlight. On this map, fires appear in red, while white light are from cities and towns. JPSS can detect smoke and wildfires too remote for fire detection planes.
See current surface smoke and fire detections across the United States: https://hwp-viz.gsd.esrl.noaa.gov/smoke/

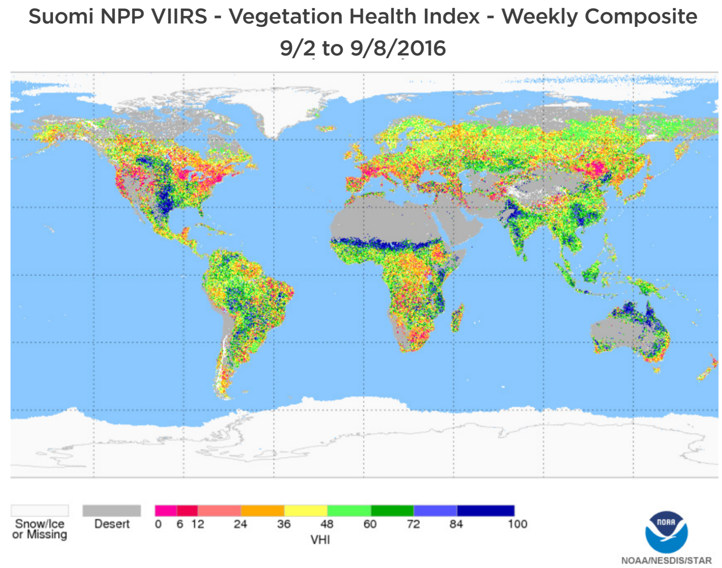
Image: www.earthobservatory.nasa.gov/images/145530/seasonal-fires-are-burning-in-angola?src=ve



Cryosphere: VIIRS can also measure the thermal energy of cold objects in Earth's cryosphere. The cryosphere is the frozen water within Earth's water cycle, such as ice and snow at temperatures below 32°F. VIIRS on the Suomi NPP satellite acquired this false color image of the Labrador Sea on March 2, 2020. With this combination of visible and infrared light, snow and ice appear light blue, and clouds are white. Scientists use images like this to study how weather is different in colder parts of the world.

Image: www.earthobservatory.nasa.gov/images/146387/cloud-streets-over-the-labrador-sea





Cities: VIIRS can view the thermal energy coming from cities. After Hurricane Maria hit Puerto Rico in September 2017, the VIIRS "day-night band" captured these before-and-after images of San Juan's nighttime lights. The thermal energy data from VIIRS allowed first responders to better deploy rescue and repair crews to distribute life-saving supplies. The "day-night band" uses near-infrared to see emissions from cities and other human activity.

Image: www.earthobservatory.nasa.gov/images/91044/pinpointing-where-the-lights-went-out-in-puerto-rico

Vegetation Health: Plants reflect near-infrared radiation, which can be sensed by satellites, allowing scientists to study vegetation from space. A healthier plant will reflect more near-infrared energy than an unhealthy plant. VIIRS uses visible and infrared wavelengths to measure the greenness, moisture, and temperature of vegetation health across Earth's surface. The Vegetation Health Index (VHI) and weather forecasts provided by JPSS helps farmers grow more crops. See the current Global Vegetation Health: www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_browse.php

Image: www.star.nesdis.noaa.gov/jpss/vh.php

What Other Wavelengths Does JPSS Use?

JPSS uses wavelengths ranging from radio waves to ultraviolet.

Microwaves can measure the amount of water inside clouds by passing through them. Microwaves significantly improve weather forecasts by monitoring the water cycle.

VIIRS uses visible wavelengths to watch atmospheric events and weather formation from space.

Ultraviolet waves are used to measure the health of Earth's ozone layer, the part of Earth's atmosphere protecting life from the Sun's harmful ultraviolet radiation. Scientists have been monitoring the ozone layer for over 30 years.

Radio waves are used by JPSS to transmit the weather and climate data to a ground station near the North and South Poles.

We interact with light every day, but there is a lot more to the electromagnetic spectrum than what humans can see.

The broad spectrum of wavelengths used by JPSS provides scientists with more data to study Earth's unique and dynamic weather and climate systems.

By constantly monitoring Earth in microwave, infrared, visible, and ultraviolet wavelengths, scientists can forecast severe weather events such as hurricanes, tornadoes and blizzards days in advance, and assess environmental hazards such as droughts, forest fires, poor air quality, harmful coastal waters and much more!

NOAA-20, one of two satellites in the Joint Polar Satellite System. NOAA-20 was launched on Nov. 18, 2017 from Vandenberg Air Force Base in Lompoc, California. The third satellite of the Joint Polar Satellite System, JPSS-2 is scheduled to launch in the first quarter of 2022 from Vandenberg Air Force Base.

Image: www.nasa.gov/sites/default/files/thumbnails/image/gallery-satellite_68-2.jpg

Activity Instructions

Humans cannot see infrared light. However, there are several ways to visualize or simulate infrared light. False color images are a way to visualize data from wavelengths beyond the visible light spectrum. Infrared and thermal video cameras are used to see infrared radiation or temperature in the visible light spectrum. In the activity below, we show you how to create your own infrared goggles! You can find most of the materials and instructions from a quick online search.

Create your own goggles to simulate infrared

MATERIALS

- A pair of goggles with removable lenses (plastic welding goggles works best)
- "Congo Blue" theater gel
- "Primary Red" theater gel
- Pen or Markers
- Scissors
- Tape

INSTRUCTIONS

1. **Gather all your materials**: Some materials may need to be purchased from a hardware store or online.
2. **Create your infrared lenses**: Remove the lenses from your pair of goggles. Keep the clear lens for later. Using one of the removed lenses as a template and a marker, trace and cut 8 blue theater gels and 4 red theater gels. These will be your infrared lenses.
3. **Customize your infrared lenses**: There are several ways to insert your theater gels into your infrared goggles; each simulates different view of the infrared spectrum.
   a. Use 4 blue theater gels in each eyepiece.
   b. Use 4 blue theater gels and 1 red theater gel in each eyepiece.
   c. Or you can experiment with any combination of gels.
4. **Complete you infrared goggles:** Insert the original clear gel from your goggles followed by your customized infrared lenses. You may need tape for this step.
5. **Try out your simulated infrared goggles!** The infrared goggles work best on a sunny day. WARNING: Never look at the Sun. Looking at the Sun can cause damage to your eyes.

   Look at the color of different objects around you such as vegetation and the sky. The blue and red colors look similar to a false-color image.

Simulate infrared light with a virtual reality (VR) headset

This is the quickest option. Directions for crafting your own VR headset are below if you do not have one.

MATERIALS
(With VR Headset)

- A smartphone
- Free-downloadable infrared apps
- A VR headset

MATERIALS
(Make your own VR headset)

There are plenty of ways to make your own VR headset from common household items. Google Cardboard provides "Build It Yourself" instructions and materials here: www.arvr.google.com/cardboard/get-cardboard/

Try out your VR simulated infrared goggles! Try looking at hot and cold objects such as a candle or an ice cube.

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